Innovative Work Scheme:
Real Time Analysis During Well Test Operations
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ABSTRACT

In 2007, a new Independent Brazilian Oil and Gas company acquired 21 exploration offshore blocks, increasing its portfolio up to 29 blocks by March 2009. Ambitious exploration and production goals were set, such as Drilling Commencement by Q3 2009, Minimum Well Drilling Commitments in four Basins by 2010/11, Initial Development in the Campos Basin and First Oil by 2012. The first three initial goals have already been met and the fourth one is well online to be met as expected with the FPSO already in the Brazilian coast.

One of the key elements to reach these objectives is recognized to be the implementation of a focused innovative decision workflow, supported by a real time monitoring process from a cross-disciplinary Operations Support Center (OSC). This paper presents this innovative work scheme, based on a collaborative working environment between the operating and service companies during the well testing operations, with the most advanced monitoring and interpretation tools.

It includes a concrete field case which resulted not only in improved risk identification, prevention and mitigation, but also in operational performance optimization. This case was a horizontal open hole test of 1080 mts with 90 deg deviation. The real-time collaboration resulted in significant rig time savings, mitigation of unexpected events consequences, and delivery of higher productivity comparing similar wells results in the area.

This innovative decision workflow implemented in Brazil is considered as a high-technological reference model for operating companies, locally in Brazil and others around the world, to achieve success during challenging Well Testing operations.

INTRODUCTION

In order to get information from exploratory wells and unknown reservoirs, operators usually need to perform a carefully planned set of well tests. Conventional well tests were performed using surface (wellhead pressure control equipment, choke manifold, heaters, separators, multiphase flow meters and storage tanks) and downhole equipment (efficient guns systems, remote circulating valves, sample taker and pressure and temperature gauges) taken to the field location. After all the equipment is installed, the well is put on production for the first time.
The main objective of this operation is to collect a significant amount of information such as pressure, temperature, flowrates and fluid samples. The analysis and interpretation of these parameters are aimed to determine reservoir and fluid properties such as: permeability, productivity index, storativity, absolute open flow, fluid composition, API, specific gravity and viscosity. In the past, with that work scheme, the operators used to receive the information collected only after the operation was completed and the equipment was rigged down. The delivery of the information from the rig to the office was subjected to delays until the field crew returned to the office, and with the rig offshore this delay was even more significant. Hence, it is not surprising that, for years, testing was perceived as a low technology segment, not yielding full value.

**THE CHALLENGE**

With the increased field activity in exploratory wells, and the reduced amount of equipment available, there is a common concern about the efficient use of the equipment and the results of a well test. Hence, there is a significant increase in the need to improve the current test workflow, by monitoring and support testing operations in real time, in order to be able to monitor all the wells that operators want to test, providing support for such testing operations, maintaining data quality and minimizing Health Safety and Environment risks.

**HISTORY**

Until now, operators all around the world were able to perform well tests, but generally were only able to fully review and interpret the data gathered (surface and downhole) after the operation was completed, and the production string was retrieved. At that point, the service companies performing the Well Test would have spent several hours or even days on operations, and rig time, not knowing if the information they collected during the test was useful or sufficient. As a consequence, flow and static periods are often extended more than needed. Thus, it was difficult to make decisions during the operations, and quality control of the data was also a concern for everybody involved in the measurement and interpretation process, affecting significantly the real value of such testing operations. For Operators, the benefit of having the data in real time allowed them to make fast operational decisions and test the well within the limits of production facilities.

The technological advances, the ability to have resources such as internet on the rigs, and the use of an interactive real-time data management system that streams data from a remote data hosting server to an interpretation software, enables the reservoir engineers in their office to access complete and up-to-date information. They are able to make decisions on the spot that could eventually change the lifecycle of a well. On the other hand, these resources also allow managers and quality control engineers of the service companies to monitor in real time the performance of the field equipment, as well as the consistency of the collected data. Some of the real time applications features are aimed at cost optimization and maximization of the data value in the referred testing programs.

The development, testing and improvement of such tools (hardware and software), allows support companies to deliver the highest service quality to Operators, and also decreases the risk of failure of the operation and improves the total cost (time, money and resources) of the testing program. This is the result of taking immediate remedial actions which may be required during the course of operations.
**METHODOLOGY**

- **Planning an RT Testing Job**

When a job is requested, the engineering team should start to gather the basic information from the Operator’s team, including open hole logs, formation tester, core data and fluid sample analysis from the laboratory or from downhole fluid analysis executed with the proper tools as shown in Figure 1. The information collected generally includes: permeability, porosity, lithological and fluid distribution logs, pay zone definition, reservoir pressure, temperature, formation mobility, saturation pressures, fluid’s properties (GOR, API, viscosity, density), rock mechanical properties and others.

![Data analysis workflow for well testing planning and productivity analysis](image)

The next step in the job planning is to include all the collected data in a well / reservoir productivity analysis using downhole and sub-surface modeling tools to determine parameters such as production range, optimum flow rate and pressures, to understand the reservoir performance and most critical parameters affecting its productivity. As a result of this process, the well productivity scenarios can be estimated as shown in Figure 2. The system productivity analysis allows to evaluate the possible production scenarios (worst and best included) based on the available information, and also, it helps to fine-tune the model in case the actual results fall out of the expected productivity window.

Figure 2 shows the results obtained for the simulation of the study case presented at the end of this paper. It is to be noticed that the well performance was way above the initial predictions.
With the initial reservoir characterization, well test simulations are performed to define the optimum flowing and shut in periods for proper reservoir evaluation) as shown in Figure 3. All the models and information generated in these initial steps will help the service design team to select and prepare all the required equipment for the operation. Also, the models initially generated will be updated accordingly during the course of the operation. At the end of the test, the models and simulations will be compared to establish the accuracy of the simulations.

Log-Log plot: \( p - p_0 \frac{\partial t}{\partial t} = 0 \) and derivative \([\text{kg/cm}^2]\) vs \( \text{dt [hr]} \)

Figure 3 Pressure derivative curves as results of the reservoir and well dynamic simulations for proper flow regimes characterization. Superposition with real data allows to determine when radial flow will be achieved and accuracy of simulations

All the initial preparation will provide the reservoir engineers with the proper tools to make reasoned recommendations in case of an unexpected events or contingencies. The information of all the simulations is passed on to the technical team which is responsible for the job preparation; ensuring that all the equipment is available on time for the field operations. Then, the field crew will execute the well test and the reservoir engineers will monitor the job from the Operation Support Center (OSC); the reservoir engineers will perform a well test
analysis and deliver a final interpretation. This process is continuously updated and improved, for the next coming operations to attain improved quality.

**Scope of a Testing Operation**

Well test operations are focused on identifying fluids and their properties as well as those of the reservoir, using surface and downhole samples, determining the Productivity Index as well as the potential of the reservoir (PI and IPR curves), and confirm reservoir parameters such as initial pressure, permeability, skin factor and others. It is well known that the longer the duration of the test the more information could be obtained from the reservoir. However, it is not economically feasible to extend the duration of operations for long periods; also the Brazilian Government Agency (Asociação National do Petroleo ANP) allows to flow a well during a well test for a maximum of 72 hrs, and in some other countries government agencies allow to test a well for even shorter periods or allow only limited cumulative produced volumes. Thus, it is important to optimize the duration and program of the tests. Reservoir engineers monitoring and analyzing in real time these operations can enhance the well test optimization process.

**Execution of Well test job with Real Time Support**

In the planning of well test operations some questions should come to our mind: Why use Real Time during testing? What is behind the Real Time concept for Well test operations? Is RT adding any value to the procedure? As shown in Figure 4 Real Time operations during testing allow the information to be received immediately, so that the operators’ reservoir engineers can update the reservoir models with critical information.

![Figure 4 What is behind real time concept?](Figure 4 What is behind real time concept?)

The reservoir team is able to monitor the response of the reservoir as it flows, as well as monitor the operations throughout their duration, using visualization tools such as shown in Figure 5, especially during the flowing periods. Also, the reservoir and the development teams can start to plan ahead for the production facilities.
The support of experienced personnel from the operating and service company during field operations, monitoring the progress of the well test, allows the risk of a Health Safety and Environment (HSE) eventuality to happen. The expert team is able to make recommendations, and to take immediate corrective action on potentially dangerous conditions that might occur during the operations, such as high H$_2$S content at the surface that reflects high H$_2$S downhole. In such a case, adequate actions can be taken immediately in order to protect the field crew and the integrity of the surface equipment.

Also, the ability to have real time support allows the service provider to improve the data quality for reservoir characterization. After initial comparison of production, as shown in Figure 6 and Figure 10, of the results obtained from the surface equipment, some adjustments to the equipment parameters can be requested to the field crew.
Critical Demands

The reservoir engineers in the Operations Support Center (OSC) are able to recommend and support key decisions based on actual well and reservoir performance. For instance, modifications of the choke size, aligning the flow to a multiphase separator or to the two phase separator, extend the flow period, extend a static period, suggest the proper time to lower wire-link in order to recover the downhole information, determine fluid level, and decide when to collect the downhole samples are some of the recommendations that the reservoir engineers could make. All the suggestions or recommendations are based on professional knowledge and understanding of well, reservoir and fluid principles and acquired knowledge from previous experience.

If the process allows and the service company has the capabilities, the reservoir Engineer at the OSC could even be in touch with global expert support in order to provide the most educated recommendations based on facts and experience. All the findings from the expert team can be sent back to the remote data hosting server, and the Operator will have an accurate analysis within hours from the beginning of the test. It is important to highlight that the support reservoir engineers in the real time assignment can make recommendations or suggestions, but that the final decision always remains in the Operator’s hands.

Real Time Testing Analysis and impact on Decision Making

With Real Time support, the service companies are able to integrate in an effective and interactive way the onshore expert team with the offshore operations, and the office expert team with field expert’s crew. The service companies are also able to address the Operator’s needs by offering accurate support during operations and offer a potential package of tools for
exploration, production and development in order to better understand the reservoir behavior and be able to develop the maximum potential of an asset, all with only one objective: the success of well tests with improved results for operators, minimizing the cost and the impact to the environment.

Decisions can be and have been made that have changed the lifecycle of a well, such as for example making an unplanned second acid injection, installation of an ESP pump in order to assist the lift of fluids, and others.

• Reservoir/completions/testing Integration during a Real Time Job

After several jobs supporting the Operator and monitoring real time jobs, a key question arises: What is Behind the Real-Time Concept? The answer is that the service company needs to convert data to meaningful information to help the Operator make the best decisions.

The reservoir engineers monitoring a reservoir test in real time will have all the resources to integrate the complete set of components that conforms a well test, in order to provide the most accurate and clear picture of the whole system. Knowing the reservoir (fluid and rock properties), the reservoir geometry (boundaries, fractures, layers), the downhole equipment position (pressure and temperature recording point, and sample point) combined with the knowledge of the surface equipment (choke, two phase and three phase separators) and the pre-job analysis, even in a situation when there is no flow at surface, the reservoir engineers can predict if the fluid level is at the downhole sampling point, or if the fluid at the sampling point is clean or contaminated. Based on all the information obtained and reviewed the reservoir engineers can perform a quick analysis and determine if the static period was enough as shown in Figure 3. From Figure 3 it was concluded that after 3 hours of static period radial flow was attained, and some initial properties could be determined. Also, with that analysis it is possible to determine initial reservoir properties such as permeability, skin factors and recommend further actions.

• Work/communication flows

It is clear that communication is the basis for the success or failure of any project. For Real Time operations it is extremely important that a well organized structure exists. During the well test it is really the first time that a well is put on production and the reservoir pressure and fluid reach the surface, therefore, generally there is pressure on the field team in particular (field and rig crew) to properly execute the job. Thus, a well structured communication organization and hierarchy work flow as the one shown in Figure 7 can be very effective and has been implemented and tested in more than 20 jobs relative to the discussed project.
From all the above it is possible to conclude that the reservoir engineers monitoring the job in real time play one of the most important roles in the communication chain, since they become the link between the service company and the operators. Reservoir engineers reviewing the information in real time can anticipate and/or react to the failure of rig pumps, leaks from downhole valves or packers and others fluids and reservoirs particularities.

**Results**

An effective way to present the typical results achieved with the real time operations for testing already undertaken is using a field study case:

The challenge in this field case was to test 8 sections in 1080 mts of open hole in a 90 deg horizontal well. This is a well located in shallow waters of the Campos Basin, see Figure 8, where initial tests on vertical wells in the same area showed a highly heterogeneous and naturally fractured carbonate reservoir. Anticipated pressures and production flow rates, as well as oil properties (API 19), led the Operator to be concerned about the cleanup efficiency and duration of the test, as well as the optimum duration of the static period in this offshore exploration well.
The solution was to propose and create a collaborative working environment with most advanced monitoring well test tools used jointly by the Operator and support service company experts, to evaluate in real time the well response and implement modifications to guaranty the success of the testing, while test was in progress.

After initial extensive reservoir numerical simulation, assessing the productivity and evaluating the uncertainties, considering the reservoir characteristics related to the impact of fractures on the horizontal well productivity, a horizontal well was drilled in a heterogeneous naturally fractured formation. An initial acid diversion completion system was selected to perform an acid stimulation instead of a high pressure acid fracture job, as shown in Figure 9. This initial stage was successfully run in this anisotropic carbonate reservoir and eight sections were stimulated using an acid plant and high pressure pumps assembled on a Supply Boat dynamically positioned. More than 1000 barrels of stimulation fluid, a mixture of hydrochloric acid and a visco-elastic agent to improve diversion were pumped, stage by stage, to the reservoir with real time monitoring from the Operator Support Center in Rio de Janeiro.

![Figure 9 Design of open-hole completion for multi-stage acid stimulation.](image)

Subsequently, a Drill Stem Test (DST) job was performed, lowering a downhole intelligent remote valve to minimize the storage effect, bottom hole sampling bottles in order to obtain a single phase sample representative of reservoir conditions, and memory gauges to record pressure and temperature under dynamic conditions during the well test. The well was opened to flow back with the aid of coiled tubing and nitrogen lifting, a good match is found between the flow rate measurement equipment. After the kick-off, the well started flowing naturally with oil reaching the surface within the first 8 hours of flow. The clean-up process continued for a few days, and then the well was flowed at various stabilized rates to calculate the productivity index (PI) and to sample the fluids. Finally a 48 hrs build-up period was performed to confirm reservoir parameters. A final comparison as shown in Figure 10, indicates that the adjustment of the equipment was done.
According to the program, the planned clean up time was 72 hours. After 72 hours, the reservoir team monitoring the information in real time determined that the well was not clean enough and decided to extend the cleaning period for 90 additional hours, for a total of over 162 hours. As the local agency allows testing wells only for 72 hours it was necessary to inform the local agency to avoid fines. The second flow period was planned to last for 24 hours. However, after 7 hours of flow the reservoir team found that the collected information was sufficient and decided to close the downhole valve in order to initiate a static period. Also, during the job preparation a preventive measurement was scheduled in case the well was not flowing by itself, and an ESP pump would be used in order to complete the well test. The time required for the operation of pulling out of the hole the current string and running in the hole with the ESP was estimated to be 3 days each (total of 144 hours).

Adding, the total time saved was 161 hours, considering an hourly charge of 16.000 USD for the rig, the total savings was 2.576.000 USD, as shown in Table 1

<table>
<thead>
<tr>
<th>Expected Main Flow</th>
<th>24 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual duration</td>
<td>7 hr (time reduced due to RT Int.)</td>
</tr>
<tr>
<td></td>
<td>17 hr Saved</td>
</tr>
<tr>
<td>POOH Current String</td>
<td>72 hr (Not needed due to RT Int.)</td>
</tr>
<tr>
<td>RIH With ESP</td>
<td>72 hr (Not needed due to RT Int.)</td>
</tr>
<tr>
<td>Total Saved Rig Time</td>
<td>161 hr</td>
</tr>
<tr>
<td>Rig Charge</td>
<td>16.000 USD/D</td>
</tr>
<tr>
<td>Savings (Rig time only)</td>
<td>2.576.000 USD</td>
</tr>
</tbody>
</table>

The result was an improved communication system that allowed the Operator to save rig time by delaying the use of an ESP initially planned, optimizing the nitrogen lifting time, reducing the
HSE risks, and achieving the test objectives efficiently. The total estimated savings were 161 hrs (~2.5 MMUSD).

In this case the streaming data and real time application were used. Also, the Real Time application allowed the service company to monitor and evaluate the performance of the different pieces of equipment to provide reliable measurements.

**Way forward**

After a new technology or process has been released there is always the question: what is the way forward? From the user’s point of view, the way forward is to have all the resources and tools on hand to make the decisions on a faster timeframe, in order to minimize the risks, and decrease the operation costs by improving the performance of the service company equipment. For example, on a single well or set of wells that have been tested, the reservoir model is clearly identified and the operators have equipment and technology (such as Intelligent completions, and multiphase separators) collecting information in real time that can be integrated with the real-time evaluation workflow; the information is sent to the remote data hosting server and downloaded in the Operator’s office through a real time streaming tool. The Operator could decide to do a workover job because of a low productivity that does not fit the reservoir model or to take some drastic measures such as flow or shut-in, even abandon an interval and remotely close a valve downhole in order to avoid water production.

**Conclusions and Recommendations**

As the main results, this paper presents the following:

1. A substantial well test optimization procedure including Real Time support and monitoring for testing operations has been successfully used in more than 20 well tests in Campos Basin. An innovative decision workflow has been implemented in Brazil and fully tested in Brazil and other producing countries. The aforementioned decision workflow is now considered a reference decisional model around the world, and contributes significantly as a new tool to achieve success and increased value during challenging well testing operations.

2. The savings for the test case presented in this article reached 2.5 MMUSD. The total savings relative to more than the 20 well testing jobs performed with Real Time Support sum over $5 million USD on rig time. Those savings were obtained because the correct decisions were made, at the right time and with the right available information.

3. With RT Procedures, it is now feasible to achieve full value for all measurements acquired during well testing, since interpretation and operational actions can be taken in real time, yielding immediate results by using effectively the well and reservoir information.

4. The workflow have been effectively used in over 20 wells, and the results have translated in testing success, savings and overall effective use of the acquired data to make timely decisions under complex operational scenarios. Currently no well test is done without real time support, for one of the major operators in Brazil.

5. As a frontline Operator, the experience with RT Testing is now being reported in the area as successful practice and is a typical example of added value with new technology and applications to otherwise traditional operations.
References