Reservoir Test Optimization in Real Time with New Wireless Telemetry System  
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Abstract

A new wireless telemetry system has been field tested in a variety of conditions in Saudi Arabia with excellent reliability. This wireless system enables bi-directional communication between the surface and downhole tools during downhole testing (Drillstem Test (DST) / tubing conveyed perforation (TCP)) operations by using an electro-magnetic signal. The wireless telemetry is used to transmit bottomhole pressure and temperature to the surface and permits control of downhole tools. This paper will describe the operating principle of the wireless system, present examples of how real-time bottom-hole data have been used to optimize the testing operations and summarize the key benefits achieved with this new technology. The real time analysis of well testing data during well flow and shut-in was effective in adjusting the test duration. The wireless telemetry eliminated the need for well intervention, which simplified the operation and eliminated the possibility of loss of data.

Introduction

Exploratory well testing to evaluate hydrocarbon bearing zones in new fields is normally performed with a drilling rig on location. The main objective of well testing operations is to capture representative data on the reservoir and its fluids in the most cost and time efficient manner possible. A technology enabler for achieving this objective is a system that can transmit data from the bottom hole to the surface instead of relying only on surface data and waiting for downhole sensor retrieval at the end of the test. A new safe, reliable and efficient realtime data transmission system based on downhole electromagnetic telemetry has been developed for this purpose. The system uses electromagnetic waves to transmit data along the casing and through the formation to the surface, enabling the retrieval of reservoir pressure and temperature in real time during the test. In addition the system allows for control of downhole equipment such as the tester valve without having to apply annulus pressure as is conventionally done. The data streams from the reservoir to the surface and then through satellite transmission to the exploration group's operations center to allow the team to make effective decisions during the well testing operations.

Equipment Description

The wireless telemetry transmission is based on low frequency electromagnetic signal. The general arrangement of the system is presented in Fig. 1. The communication is bi-directional, from the surface to the bottom of the hole and from the bottom of the hole to surface. Telemetry performance depends on formation resistivity, completion geometry and wellbore fluids. Transmission ranges achieved during field testing from the hub to the surface have been between 6,000 to 10,500 ft. Installation of repeater unit(s) enables the depth range to be extended and helps to overcome the challenges of formation resistivity as shown in Fig. 1.

The centerpiece of the downhole wireless system is the hub, which contains four pressure gauges and all electronics necessary for wireless transmission and reception. Each gauge that is mounted in the hub has independent battery and electronics for processing and recording of data. This arrangement guarantees redundancy and safeguards the data capture in case of any wireless telemetry system failure. The repeater has the same telemetry capabilities as the hub; however, with only a single
pressure measuring device ported to the annulus. If additional tubing pressure measurements are required, a hub may be run as a repeater. The hub may be run below the combined tester and circulating valve, the intelligent remote dual valve (IRDV), and when run and connected in this location, permits either valve status readout or control. It should be pointed out that the IRDV retains existing functionality and can be operated by the traditional pressure pulses. As a further option, the system can also be used with wireless activated firing heads for selective, multi-zone perforating.

At surface the system has cables connected to the wellhead and to stakes positioned approximately 300 ft from the wellhead. From these two connection points, the surface transmission and reception boxes are connected which enable signal transmission and reception at surface.

**Wireless Telemetry for Testing Optimization.**

Wireless telemetry technology was applied and used in three different wells with multiple runs in each well (see Table 1 for a summary of operations performed to date) in Saudi Arabia. For each operation data were successfully received at surface, as shown in Fig. 2 and transmitted via a realtime data transmission and storage and display system (InterACT) for viewing and analysis as required in the client office. Various examples will be taken from these operations to demonstrate how the data have been used to optimize operations by both the service company and the client.

The data displayed in Fig. 3, were obtained in real time using the wireless system during the test and show an overlay of the full memory data set. The data for real time and memory are from the same gauges mounted in the hub and in addition, each data point is transmitted with both full value and time resolution; thus, ensuring no loss of any data quality and guaranteeing the same results in realtime as from the gauges memory. Fig. 3 confirms that both the real-time and memory data are identical. This is an expected result as the wireless telemetry system transmits full resolution data from the memory of the pressure gauges.

The following examples, taken from these operations, demonstrate how the data has been used to optimize operations by both the service company and the client.

**Verification of Downhole Operations**

Pressure data transmitted to the surface can also be used to validate and verify downhole tool operations. The recent field tests in Saudi Arabia were predominantly performed across low-permeability zones. A major challenge in these zones is finding a way to confirm perforation and tester valve operation. In these wells, it may be very difficult or impossible to verify correct tool operation from the surface-pressure readings. Bottomhole data can be used to not only verify valve operation but also ensure complete pressure integrity as is shown in the Fig. 4 example. By immediately verifying the correct valve operation, any doubts can be eliminated or if there is an issue, remedial action can be taken directly. This procedure will not only save time, and guarantee data reliability, but it ensures that potentially risky operations such as wireline intervention (e.g. for drift runs) are not carried out, which saves time and simplifies the operations.

In addition to transmitting bottomhole data, the wireless telemetry system can provide status feedback from the tester valve itself. This provides an additional level of operation confirmation.

**Managing Unexpected Events**

A particularly useful application of real-time bottomhole data is when unexpected events occur. Typically, when a zone performs as expected and the tools operate correctly, management and operation of the test is successfully achieved by careful monitoring of the surface indicators, pressure, temperature, and flow. However, when an unexpected event occurs, a careful and methodical approach to troubleshooting is required to properly identify the problem and take remedial action. With real-time bottomhole data available, this process is dramatically simplified. The operation on Well 1, test #2 is a case in point.

Following displacement of the cushion and setting of the packer, pressure was being monitored by the wireless telemetry system. Prior to running a slickline in the hole to convey a drop bar to the firing head, wellhead pressure was bled down. However, the wireless telemetry system signaled and increase in downhole pressure as shown in Fig. 5. This indicated communication between the wellbore and the reservoir prior to perforating. Following initial identification of the problem and by verifying with wellhead pressure measurements, the decision was made to flow the well and establish if the existing perforations in the well were connected or not connected. While other methods may have provided the same information, it is clear the wireless telemetry system quickly identified and confirmed that the pressure increase was due to reservoir effects. Other methods would have taken much more troubleshooting and evaluation time.
Monitoring Nitrogen Lifting
During nitrogen lifting operations, it is often difficult to accurately measure the well's performance. Surface flow and pressure measurements are typically irregular and the process can be iterative and time consuming, which represents tremendous opportunities for optimization.

Fig. 6 shows both the surface pressure and bottomhole pressure acquired in real time during a nitrogen lifting operation. Whilst nitrogen injection rate and also coiled tubing depth are not displayed, it is clear that there is limited productivity from this zone, with the generation of pressure drawdown created by the gas lift not providing significant reservoir flow. Also, the electromagnetic based telemetry performed well during the nitrogen and coiled tubing operations.

Pressure Transient Analysis of Real-time Data.
A primary use of downhole pressure data captured during testing is for buildup-pressure transient analysis in determining key reservoir properties; reservoir pressure, skin, kh, boundaries etc. The capability to perform this analysis while the test is ongoing is of fundamental importance for test validation and design optimization.

Fig. 7 displays the transient analysis on the final buildup of DST-1 in Well B. The plot shows the data obtained in real time in red and compared to memory data in blue the results obtained from this analysis are almost identical. There is a slight variation between the curves in very early time and in middle time (0.1hr), that are mostly related to the pressure derivative smoothing algorithm, however these differences do not affect the results of the analysis.

The ability to fully interpret the data set prior to retrieving the DST string is invaluable in ensuring that test objectives have been achieved, and that the next phase of operations can commence.

Evaluating Acidizing Performance
The tubing pressures measured during nitrogen lifting and acidizing on Well B, DST 2 are shown in Fig. 8. The hydrostatic pressure is decreased by nitrogen lifting and when injection is halted, bottomhole pressure increased, providing a clear indication of flow from the reservoir. The real-time bottomhole pressure is the only method of detecting the fluid production in this case, which is extremely low. On completion of the acidizing operation, the liquid flow from the reservoir improved as can be seen by the improved rate of pressure increase indicating a successful treatment.

Buildup analysis following this nitrogen lifting and acidizing operation is presented in Fig. 9. As with the previous example the results between realtime and memory data are consistent.

Conclusion
A new wireless telemetry tool for testing applications has been run successfully in various conditions and configurations for Saudi Aramco. The examples presented have demonstrated various applications and benefits gained from access to the real-time bottomhole pressure, including verification of tool operation, managing unexpected events, monitoring nitrogen lifting, pressure transient analysis, and evaluation of acidizing performance. These benefits have enabled the operator to optimize the testing program and simplify the operation while ensuring complete and validated data capture.

Further operations will focus on testing interfaces to the firing heads and developing the data workflow and decision-making process.

Acknowledgements
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Abbreviations

BHA = Bottom-hole Assembly
CV = Circulating Valve
DGA = DST Gauge Adapter
DST = Drill Stem Test
InterACT = Web-based system for real-time collaboration, visualization and data delivery via a WITSML data store.
IRDV = IRIS Controlled Dual Valve
POOH = Pull out of hole
RIH = Run in hole
TCP = Tubing Conveyed Perforating
TV = Tester Valve
Table 1- OPERATIONAL SUMMARY OF JOBS PERFORMED WITH WIRELESS TELEMETRY SYSTEM IN SAUDI ARABIA

<table>
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<th>Well</th>
<th>Well A</th>
<th>Well A</th>
<th>Well B</th>
<th>Well B</th>
<th>Well C</th>
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<td>6329</td>
<td>6200</td>
<td>10499</td>
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<td>9500</td>
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Fig. 1- Diagram of wireless telemetry system deployed for land operations
Fig. 2- Wellsite setup for wireless downhole and surface data acquisition.

Fig. 3- Overall plot of bottom hole pressure data, displaying data transmitted wirelessly overlaid with recorded memory data.
Fig. 4- Surface and real-time bottomhole data at the moment of downhole tester valve shut-in.

Fig. 5- Bottomhole pressure prior to perforation operations on Well A DST 2.
Fig. 6- Bottom-hole and surface pressures during nitrogen lifting with coiled tubing on Well A DST 1.

Fig. 7- Log-log plot of pressure buildup and derivative for Well B DST 1.
Fig. 8- Bottom-hole pressures in real time and memory during nitrogen lifting and acidizing on Well B DST 2.

Fig. 9- Log-log plot of pressure buildup and derivative for Well B DST 2.