OTC 19623

New Reservoir Testing and Sampling System Reduces Costs and Provides Improved Real-Time Data Acquisition in Deep Water and Environmentally Sensitive Wells — Gulf of Mexico and Brazil Case Histories

Alejandro Salguero, Edgar Almanza, and Henk Kool, Halliburton

This paper was prepared for presentation at the 2008 Offshore Technology Conference held in Houston, Texas, U.S.A., 5–8 May 2008.

Abstract

The use of drill-stem testing (DST), particularly in offshore environments, has seen a marked decline in recent years. Several factors such as escalating rig rates, environmental concerns, personnel safety, and drilling-rig deck-space requirements have been responsible, but other factors have also contributed to this decline. Other testing methods have been developed that have been capable of providing certain types of reservoir information more cost efficiently and during a shorter period of time. This paper discusses a new type of system that allows a prospect to be sampled and tested without the necessity of a comprehensive and extended well test, or the testing process can be used as a first testing phase to be followed by a complete DST or production test, if necessary.

Since closed-chamber tests were introduced in 1977, variations of this testing technique have been used to provide good flow estimations and basic reservoir parameters, although build-up data with short producing times were difficult to analyze. Combining this method with back surge proved to be very useful for perforation cleaning. However, some conventional sampling and data-collection systems in heavy oil and unconsolidated reservoirs have had limited success, resulting in decisions concerning assets to be made with limited information.

The development of new bottomhole tools, either for testing or sampling, as well as real-time data acquisition systems and bottomhole data analytical methods are now available for short-time tests and offer an alternative for reservoir testing that can be completed in shorter testing times and are environmentally acceptable. They are also more effective in a broader scope of environments.

The focus of this paper is one of these techniques that can be used in prospects where:

- Expected production does not support the implementation of full-scale well-test evaluation and the data provided can be used to properly design an operation for full evaluation.
- Environmental issues limit the oil and gas flaring as in some offshore wells or rain-forest locations.
- Remote locations are not conducive to equipment transportation or have limited footprint.

This document describes the first jobs performed with this limited-emission system in deepwater Gulf of Mexico in heavy-oil unconsolidated sandstone and in high-viscosity oil environments in Brazil. No safety incidents and no environmental incidents occurred. The system successfully captured bottomhole samples with pressure-volume-temperature (PVT) quality and sufficient reservoir information to calculate reservoir pressure, relative permeability, and radius of investigation on both cases presented. Both examples met all test objectives and demonstrated the advantages of the system.

Introduction

Traditionally, fully blended DSTs have been used to acquire bottomhole pressure and temperature and perform sampling operations. The system described in this document minimizes the potential environmental impact from surface fluid handling during these operations, making the work more environmentally friendly, reducing risk, and increasing safety. In addition, the use of the advanced sampling and data-collection systems now available for heavy oil and unconsolidated reservoirs has increased the performance of data acquisition and characterization information.

Candidates for the system discussed here include deep water, environmentally sensitive, HP/HT, remote locations, and heavy-oil wells where reservoir permeability, reservoir pressure, radius of investigation, single phase or bulk oil sampling is required. Other system benefits include:

- safer operation from eliminating pressurized well effluents at surface
- reduced testing costs
- less contaminated reservoir fluid samples
- capability to obtain data concerning near wellbore reservoir parameters, productivity potential, fluids and solids identification, and assessment of sanding potential.

Two operators in North America and South America wanted to test wells, and both were reviewing the different alternatives available to perform these evaluations. The two wells were in offshore environments. The primary needs for the first well were to collect a representative heavy-oil sample with PVT characteristics, and in addition, collect representative reservoir information for reservoir analysis. In the other prospect, the objective was to perform a limited emissions test.

The first application called for the use of the system in a well with a TD of about 6000 ft and a perforated interval of approximately 10 ft. The permeability of the well was estimated to be between 400 - 500 md. The second case history well also had a TD of about 6000 ft. Several testing methods were reviewed, and the limited-emission short-term pressure-transient test method was chosen by both operators for the jobs.

Main Concepts

Before discussing the applications for this method, it is necessary to understand the focus of its usage. It can be used for:

- Back surge and slug tests
- Closed chamber tests
- Sampling and real-time data-acquisition systems.[3]

Surge Tests

Originally used as a backsurge perforation washing and underbalanced perforating technique, it is used in this capacity to assist in well clean up that will allow a higher-productivity well completion. The analysis techniques now allow surge pressure data to be analyzed.

This application is performed in a shorter period of time than a DST, but it provides a quick method for initial assessment of a zone of interest, requiring a relatively small amount of production. This technique also enables estimates of reservoir permeability and better estimation of initial pressure values. Also, fluid samples can be collected. **Fig. 1** shows a pressure/time surge behavior analysis developed with the system.

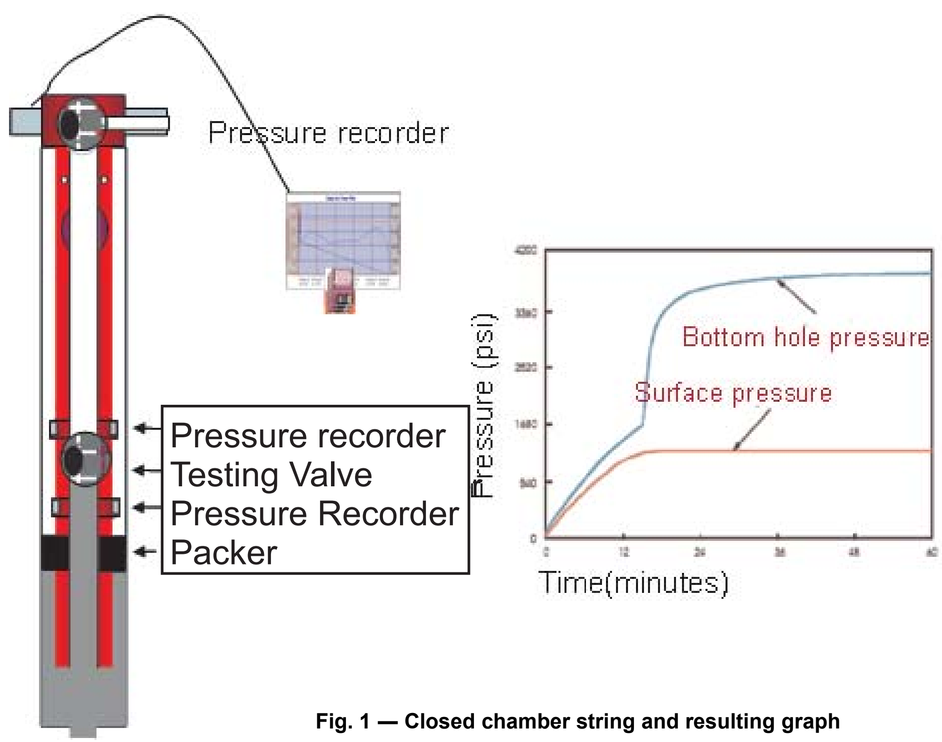


Fig. 1 — Closed chamber string and resulting graph

Slug Tests

This technique allows the reservoir to produce liquid into a pipe open at the surface. When the hydrocarbons flow into the pipe, the backpressure generated against the formation results in an increase in the pressure, which in turn reduces the flow rate. This is somewhat similar to the behavior of a DST job during its flow period; however in the DST situation, the flow period is an extended period. This is similar to what happens during the period of the DST when the fluids reach surface. The slug no longer exists, and the true pressure drawdown starts.

The difference between slug and surge tests depends on whether the test uses a closed surface valve or a closed chamber. In both cases, the performed tests are backpressure tests, but due to the fact that in a surge test, a closed chamber and air compression are present, the surge tests builds back up to static reservoir pressure faster than slug tests.

Sometimes slug tests happen by accident rather than from direct planning. Thus, although slug tests can collect information such as fluid samples, permeability, skin, and initial pressure, some test designers do not consider the information obtained concerning initial pressure or skin accurate.

Closed-Chamber Testing Techniques

Initially, the closed chamber method was introduced by Alexander[1] as a qualitative method for designing drill-stem tests, determining fluid properties, and expected flow rates. While similar to the conventional DST, the closed-chamber DST uses a closed surface valve during the flow periods. Rigorous use of surface pressure changes (dp/dt) and liquid influx data allow calculation of gas and liquid rates. Normal analysis of pressure buildup data taken during the closed-in periods may proceed with the known rates. According to Alexander, closed-chamber drill-stem tests (CCDSTs) offer greater security and safety over standard DSTs, and the rates can be used to estimate flow times needed for fluid recovery in order to design surface equipment for future conventional testing.

Closed-chamber DSTs are well suited to testing of low-permeability gas wells. The test provides permeability, reservoir pressure, skin, and a fluid sample. An attractive feature of CCDST is that the test may be switched to conventional DST; i.e., the surface valve may be opened at any point during flow periods. The behavior of pressure/time during a Closed Chamber Test can be modified from a DST as shown in **Fig. 2**.

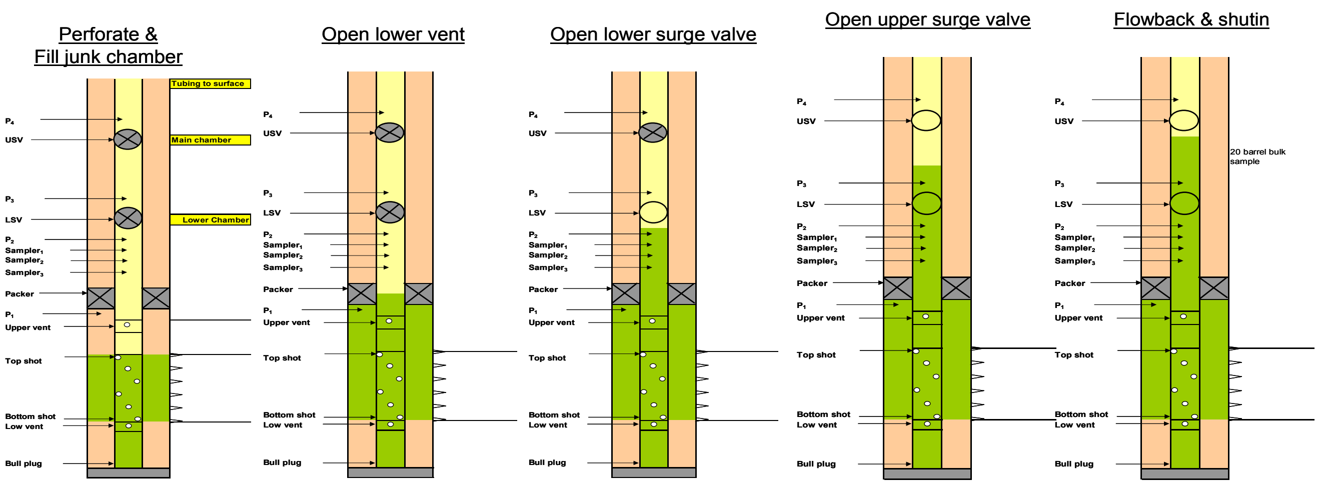


Fig. 2 - String used to start with short-term pressure-transient test and follow with a DST if necessary

Interpretation Techniques for Short-Term Pressure-Transient Test

Traditionally, pressure testing interpretation techniques use late-time data to estimate permeability and formation pressure. Typically, radial time, spherical time and derivative plots are used to select a portion of data to fit a straight line and to determine formation pressure and permeability. Also, convolution and superposition methods have been developed to analyze short-duration tests, but they can be complicated, since they might need iterative procedures to calculate formation properties.

Soliman[2] developed this technique for analysis of buildup tests with very short producing times. It differs from the traditional methods, because it is not based on type-curve matching techniques. Instead of using the principle of superposition to derive the solution for a buildup test, Soliman included the change in flow rate into the boundary condition and directly solved the drawdown-buildup problem:

$$p_{ws} = p_i - \frac{162.6 q \beta \mu}{kh} \log\left(\frac{t_p + \Delta t}{\Delta t}\right)$$ Superposition

$$p_i - p_{ws} = \frac{1694.4 V_{ch}\, \mu}{k\, h} \frac{1}{t}$$ Direct Solution

Basically, this method is based on the two plots shown in **Fig. 3** to graphically determine the reservoir pressure as well as the permeability. The short-term pressure-transient analysis technique was developed especially for analyzing buildup tests with very short producing periods. Instead of using the principle of superposition to derive the solution for a buildup test, the system developers included the change in flow rate into the boundary condition and directly solved the drawdown-buildup problem, which made it possible to see features of the solution that could not have been observed otherwise. Also, it was found that a plot of pressure change versus time yields a straight line whose slope is a function of flow regime, while its intercept with the y-axis is a function of formation permeability.

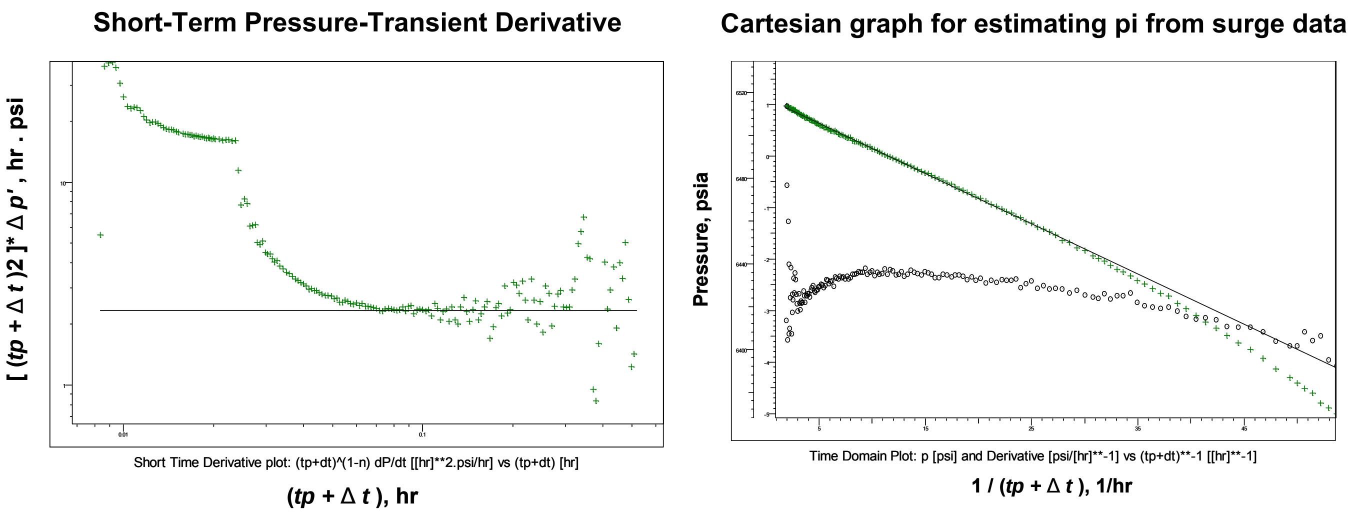


Fig. 3 — Two plots used to determine graphically the reservoir pressure

The short-term pressure-transient test method can be used to sample and test a reservoir without the need for a comprehensive well test. The data collected are not as conclusive as that obtained from a typical drill stem test or production well test, but it can be used to obtain a limited evaluation of the reservoir parameters in substantially less time than a comprehensive well test. The system and analysis technique can be used to test zones where production does not appear to merit the cost of a full well test, and the data gathered can be useful in the design of a comprehensive well test and stimulation operations.

The system perforates a limited interval and produces a relatively small volume of fluid (typically 5 to 20 bbl). Many of the downhole tool components required for a limited-emission short-term pressure-transient test are based on modifications of existing cased-hole test tools that have had a history of durability and reliability in the challenging environment of well testing.

Selection of the Limited-Emission Short-Term Pressure-Transient Test Method

Considering the requirements identified during the feasibility study for the case history wells as well as the prevailing industry testing drivers, the operators decided to use the short-term pressure-transient analytical method since they felt that a closed-chamber-type test would provide the sought-after information. To properly implement the system, it was necessary to identify the main characteristics that the chosen system should have:

- Interpretation software
- Sampling equipment
- Compartmentalized design
- Zero flaring requirements
- Real-time control and capability to transfer data.

The most critical requirements identified for collection were those concerning:

- Permeability
- Skin
- Radius of investigation
- Initial reservoir pressure
- Static and flowing temperature.

Several factors influenced the decision to use this test method. These included:

1. New bottomhole tools developed for DST and TCP strings
2. Advanced data and sample-acquisition systems
3. The short-term pressure-transient interpretation method
4. Advanced design tools.

In addition, tubing-conveyed short time tests could be used that offered limited emissions, lower rig costs, zero-produced hydrocarbon fluid sampling, and dynamic formation evaluation. The system was also compatible with a real-time acoustic telemetry system for downhole monitoring and test control, and some testing could be accomplished with memory gauges. Because of the system's real-time data acquisition capabilities, the tests would be analyzed and controlled using real-time data transmission as can be performed using wireline testers. Another important factor is that the quality of data and fluid obtained during this operation is excellent. Finally, one of the most attractive advantages to the system is that a short-term pressure-transient test can easily be converted to a conventional drill-stem test if the proper surface equipment is available.

Operating Envelope

In time duration, the technique discussed here can be positioned between DST and wireline formation tester techniques (WFT). In addition, comparison with other testing methods can be found in **Fig. 4**.

	WFT	**Short-Term Pressure Transient Test**	**DST**
Initial Reservoir Pressure	X	X	X
Permeability	(X)	X	X
Quality Single-Phase Samples	(X)	X	X
Skin Factor		X	X
Large Atmospheric Samples		X	X
Large Volume of Fluid Moved		X	X
Time-on-Depth Days			X
Reservoir Limits Test			X
Typical No. of Rig Days, 1 zone	±2	±3	±10
Typical No. of Rig Days, 2 zones	±4	±6	±15

Fig. 4 – Capability and time comparison between the different reservoir testing methods

System Operation

A typical limited-emission short-term pressure-transient system has the following components:

- A perforation system with a junk chamber that allows the initial clean-up flow period
- Annulus-pressure-operated bottomhole tools that provide the surge periods
- Data acquisition systems such as acoustic telemetry real-time surface readout systems or memory gauges
- Annulus pressure or acoustically operated bottomhole samplers that allow several samples to be taken at different times during the test.

The running procedure is similar to the procedure used for a conventional drill-stem test string.

- Set the packer after correlating depth.
- Fire TCP guns by use of annulus pressure, which will open a lower-surge chamber that is called (for practical purposes) a 'junk chamber.' That chamber allows the wellbore and some distance into the formation to be cleaned. Then, the pressure will be applied on the bottom of the lower surge/circulating valve. If the real-time data-acquisition acoustic telemetry system is available, it reads and transmits this pressure to surface.
- The lower-surge/circulating valve is opened to the flow, allowing the reservoir fluids to surge into the main chamber via a choking device. The real-time data-acquisition acoustic telemetry system and memory pressure/temperature gauges will record the data that will be used for transient analysis and flow-rate estimation.
- Open the upper surge valve to allow the system to capture the bulk sample. This operation is controlled by a surface choke.

- When the required volume has been collected, cycle the lower-surge circulating valve to the "circulating position," allowing the bulk sample to be reversed to surface for collection in a transport tank(s).

Note that single-phase bottomhole fluid sampling can be performed at any time after the filling of the main chamber by activating the samplers and applying pressure to the annulus. Finally, after the job is completed, the lower-surge/circulating valve is cycled to the "well testing" position, and the well is killed as is done in a traditional cased-hole drillstem test. Modifications to the above system operation can be accomplished with variations to the string configuration. (**Fig. 5**)

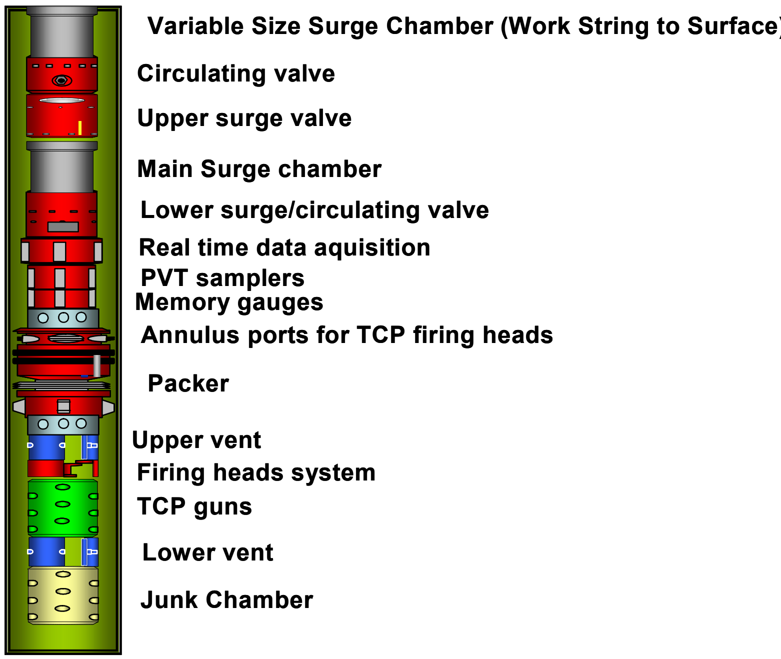


Fig. 5 — Configuration for Short-Term Pressure-Transient test string design.

Tools

The basic equipment used to run the system is very similar to that used for a DST:

1. Testing String
   a. Perforating System
   b. Sampler Carrier
   c. Lower Surge/Circulating Valve
   d. Upper-Surge Valve
   e. Venting System
   f. Downhole Choke Assembly
2. Data Acquisition
   a. Acoustic telemetry surface readout system for real-time data acquisition
   b. Memory gauges
3. Single Phase Sampling System
4. Seabed equipment (offshore cases)
5. Surface equipment.

Perforating System. A tubing-conveyed perforating technique activated by annulus pressure is used with the proper explosives for the reservoir temperature of the prospect that will be tested. Also, surge valves (TCP vents) activated with firing heads and delay systems are part of the system. Changes to the basic tool configuration, including alternative firing systems, are possible.

Single-phase Sampling System. Currently, new developments in sampling technology allow the use of 5.375-in sampler carriers with 9 slots for single-phase samplers rated for environments of up to 400º F and 20,000 psi working pressures.[4]

Lower-Surge/Circulating Valve. The lower surge circulating valve is an annulus-pressure operated, reclosable circulating valve for use in cased holes. This tool is operated by repeatedly cycling the annulus pressure up to a predetermined value, and then, releasing this pressure. This tool was designed originally for this purpose, but several variations with other tools were implemented to give more flexibility to the system.

Upper Surge Valve. Upper surge valves are annulus-operated tools that are run into the well with a closed ball that is activated to open the string to the main atmospheric chamber.

Downhole Choke Assembly. The downhole choke assembly is run into the cased hole to help control or restrict the flow of formation fluid into the workstring. The tool includes a spring-loaded bypass around the choke, which can be used to help increase flow area when fluid must be pumped back into the formation and helps prevent or reduce sand production by limiting reservoir pressure drawdown when the well is flowed / tested with high underbalance or into an atmospheric chamber (surge chamber).

This restricts the reservoir fluids from reaching the bubble/dew point by limiting reservoir pressure drawdown when the well is flowed/tested with high underbalance or into an atmospheric chamber (surge chamber).

Data Acquisition. Several data acquisition systems that transmit data from the memory gauges to real-time data acquisition equipment such as an acoustic telemetry surface readout system are used. The data can be recovered using wireline, but a wireless option is also available. This option was used for this system with good results.

Sampling system. The case history jobs used a tubing conveyed sampling system with 2 ea. of 600-cc samplers in each carrier. For future applications, a new generation of samplers that will allow collection of enough fluid samples for fluid characterization can be used.[4]

Ocean Floor Equipment Package. This can be used with offshore wells and floating vessels. The only difference would be the real-time data acquisition devices that would be appropriate for the sea bed.

Surface Test Equipment. Its use will vary according to the type of test to be performed and the job design. However, in most cases, a surface test tree and a choke manifold will be required to hook up to the rig manifold. In addition if the bulk sample is large and needs degassing before transfer to transport tanks, a small pump and a pressurized tank might be needed.

Typical Downhole and Surface Configurations. Several test-string configurations can be used, depending on the environment. In addition, variations with standard DST tools to perform the application can be used. This enables accurate results to be obtained in a variety of well scenarios. Some of the configurations are shown in **Fig. 6**.

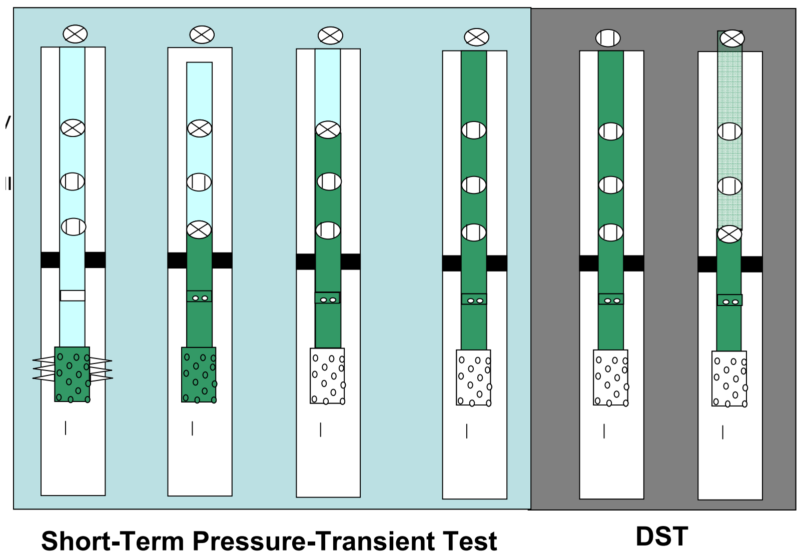


Fig. 6

Job Planning and Design. The job planning and design are the greatest challenges. With the inherent cost, information, and analysis requirements, it is of great importance that all data required be available. Failure to provide accurate information can negatively affect the final results of the test.

Mud Information. Information requirements start with collection of data concerning the mud system that was used during the drilling of the well to estimate the invasion into the formation. Later, it is important to have information about the fluid that will be used during the testing stage to evaluate its impact on the venting system used during the evaluation. Also, pressure transmissibility and solids decantation control should be run if drilling mud will be used.

Junk Chamber. The interval length to be perforated is required in order to maximize the junk-chamber length. This junk chamber will be at atmospheric conditions. At this point, it is important to evaluate the impact that could be created by the dynamic under-balance when the guns are activated and fluids enter the atmospheric chamber. It is important to mention that the interval selected must provide a good radial flow pattern around the well bore and the capability to go deeply into the formation for proper formation clean up.

Fluid and Rock properties. For proper job sizing, the following parameters are required:

- Oil Compressibility
- Total Compressibility
- Oil Viscosity

Choke Sizing. During job design, it is necessary to identify the drawdown limitation in order to avoid presence of two phases. The smallest choke size that can be used is 6/64-in.; if the work requires smaller sizes for proper control in the drawdown pressure or removal of the choke to overcome any sand plugging risk, special configuration changes should be investigated.

Other Formation Information. The following information is required also to use the developed computer software:

1. Permeability
2. Reservoir pressure
3. Perforated interval
4. Maximum drawdown
5. Flowrate target
6. Actual flow rate estimate.

Design Results. To design the test, a series of calculations and simulations using different software available to achieve the objectives of the application are required. These include:

- Proprietary short-term pressure-transient test design software
- Perforating characterization
- Nodal analysis
- Nitrogen calculations
- Pressure-transient analysis software
- Multiphase simulator software.

Sizing Results Obtained. Based on the above input, the following information is generated:

1. Gun length
2. Junk Chamber size
3. Junk Chamber length
4. Clean up distance in formation
5. Choke size
6. Main chamber size
7. Main chamber length
8. Bulk Sample size
9. Packer setting depth
10. Water Depth
11. Wiper plug stop depth
12. Ideal radius of investigation
13. Estimated main chamber fill-up time (without compression time).

In addition, the formation sampling program could be generated depending on the number of samplers allocated in the test column and might include: sample taken after filling of main chamber, sample taken after filling 50% of the bulk sample, and samples taken after filling 100% of the bulk sample. And finally, a time estimate can be made for the duration of the test.

After the job has been properly sized, a procedure should be developed with the set of tools to be used to achieve the objectives of the test. This detailed procedure details the different stages of the evaluation, how many shut-ins and drawdowns will be performed, when samples will be collected, and when reservoir information will be retrieved for analysis — all aligned with test objectives. (**Fig. 7)**

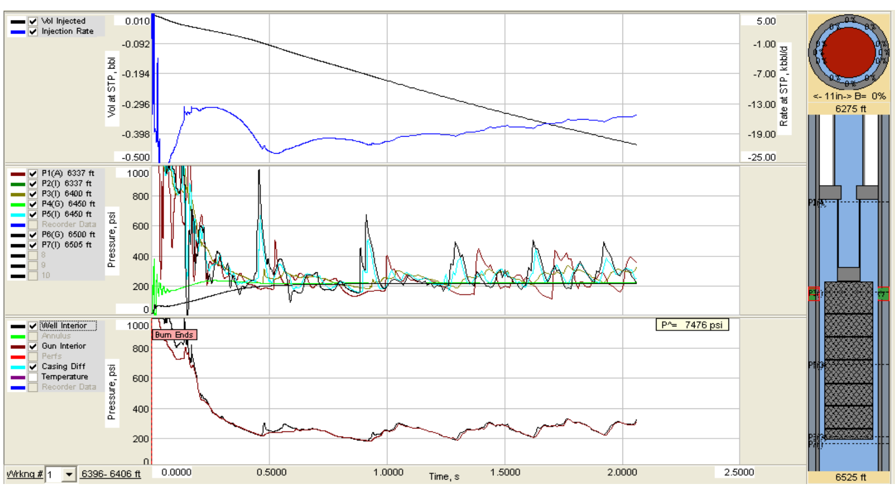


Fig. 7 — Sizing Results generated from using specially developed software

Case Histories

The limited-emission short-term pressure-transient test procedure was used in an offshore well in Brazil. The data collection was performed with a wireless acoustic telemetry surface readout system. The case history follows:

Case 1

Well Information

The well has a TD of approximately 6000 ft and 9⅝-in. casing. The interval to be perforated was 10 ft, using 12 SPF, 7-in. guns. The permeability of the well was estimated to be in the 400 - 500 md range.

The job was to include the following steps:

1. Job design
2. Job execution
3. Job results and interpretation.

Job Design

A significant amount of time was spent in job preparation to be certain that all the details that were important to the success of the job were identified. Initially, the objectives of the test were as follows:

- Sample collection in heavy-oil environment – bulk and PVT
- Reservoir data
- Non-flaring system application

Planning

Several aspects were taken into consideration during the design stage of the work, and after careful consideration, it was decided that the limited-emission short-term pressure-transient test was preferred over a wireline formation test. There were several main constraints and critical factors identified: The main constraints involved:

- Formation consolidation – perforating length
- Applicable under-balance pressure
- Real-time bottomhole data transmission
- System flexibility

In addition, another topic requiring consideration was mud leak-off to the formation. The mud leak off to the formation was estimated considering a total mud filtrate loss of 44 bbls in the entire interval. This converts to 14 bbl lost in the 10-ft interval to be perforated. Then, in theory, the perforated interval would produce 14 bbls for a total formation clean up, assuming the worst case scenario. The above scenario would give a contaminated distance into the formation as listed in **Table 1**.

Table 1 —Mud leak-off to formation

Formation	Contamination distance into the formation (Measured from the openhole diameter)	
	Meter	Feet
Formation A	0.61	2.00

Junk Chamber Design

Based on the well information obtained a set of perforation intervals was recommended, aimed at maximizing and optimizing the Junk Chamber length (7” guns at atmospheric conditions were used for a junk chamber). Evaluation of expected dynamic under-balance created by this chamber was executed and results showed that pressures will draw down initially along the formation in the range of 300 psi. See **Table 2.**

Table 2 — Junk Chamber Design

Formation	Perforation Interval	Max Junk Chamber Length
Formation A	10 ft	81.3 ft

It should also be noted that the planned TCP interval was only 10 ft long with 12 shots per foot. This is the minimum gun length that can be shot, and at the same time, obtain a good radial flow pattern around the well bore. Perforating less than a 10-foot interval would set some limitations on how far into the formation cleaning could be performed when opening the junk chamber.

Choke Sizing

When doing the choke sizing the drawdown was assumed to be 300 psi. The drawdown limitation of 300 psi should not be exceeded, and because the smallest choke size is the 6/64th inch size, it would be necessary to use nitrogen to have proper control of the drawdown pressure. Also, the bottomhole choke would be removed to overcome any sand plugging risk during well flow.

Table 3

Formation A	
Permeability input	400 - 500 md
Reservoir pressure	3000 psi
Perforated interval	10 ft
Max. drawdown	300 psi
Flow rate target	200 bopd
Actual flow rate	200 bopd

Initial Sizing Results

Based on the all estimates and inputs obtained during the design stage, the sizing results are shown in **Table 3** and **Fig. 8**.

Gun Selection

A technical software program that allows optimization of gun selection was used. Results are shown in **Fig. 9**.

The curves included on the graphics were based on a 10 ft perforation interval. Flow rates were directly proportional to the perforation interval. Based on this information, the different job stages included in **Fig. 10** were calculated.

Information Description	
Formation A	U.S.
Gun length	10 ft
Junk Chamber size	2.84 bbls
Junk Chamber length	81.3 ft
Clean up distance in formation	0
Choke size	0
Main Chamber size	3.32 bbl
Main Chamber length	526 ft
Bulk sample size	45 bbls
Wiper plug stop depth	N/A
Ideal Radius of investigation, based on 1 hour test time.	146 ft
Estimated Main Chamber fill-up time (without compression time)	6 min.

Fig. 8 — Sizing Results

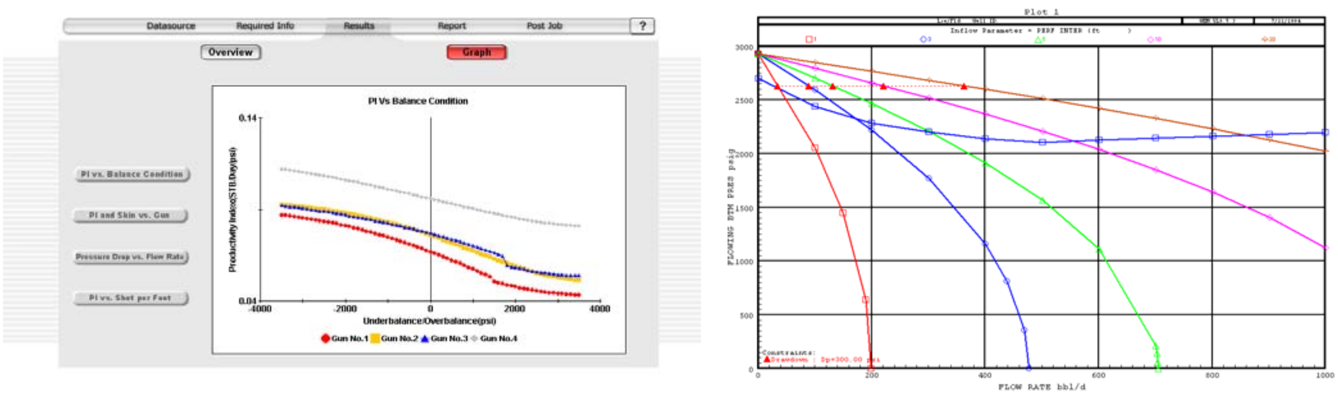
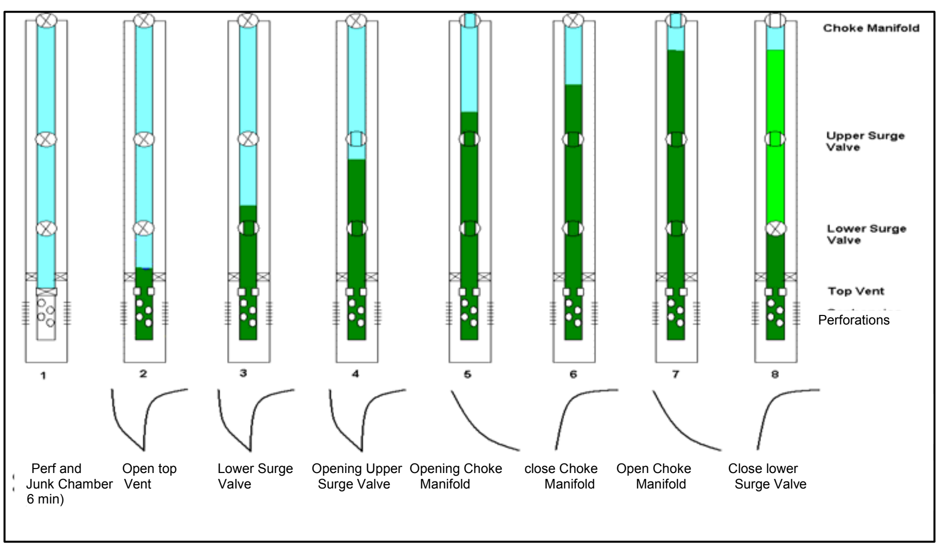


Fig. 9 – Gun Selection

Fig. 10 – Job Stages



Detailed Final Sizing Results

The detailed sizing calculations for the limited-emission short-term pressure-transient test are included in **Fig. 11**. The junk chamber was sized to 3 barrels to account for annular volume below the packer. The main chamber was sized to 12.6 barrels to allow for the oil level in the chamber to reach the lower sampler. In the event that the upper vent plugged with sand during the flow period, the lower sampler could be activated to collect PVT samples.

The corresponding pressure response during the flow into the main chamber is displayed in Fig 11 also. The expected bottomhole pressure response from the test is shown in the chart in **Fig. 12**.

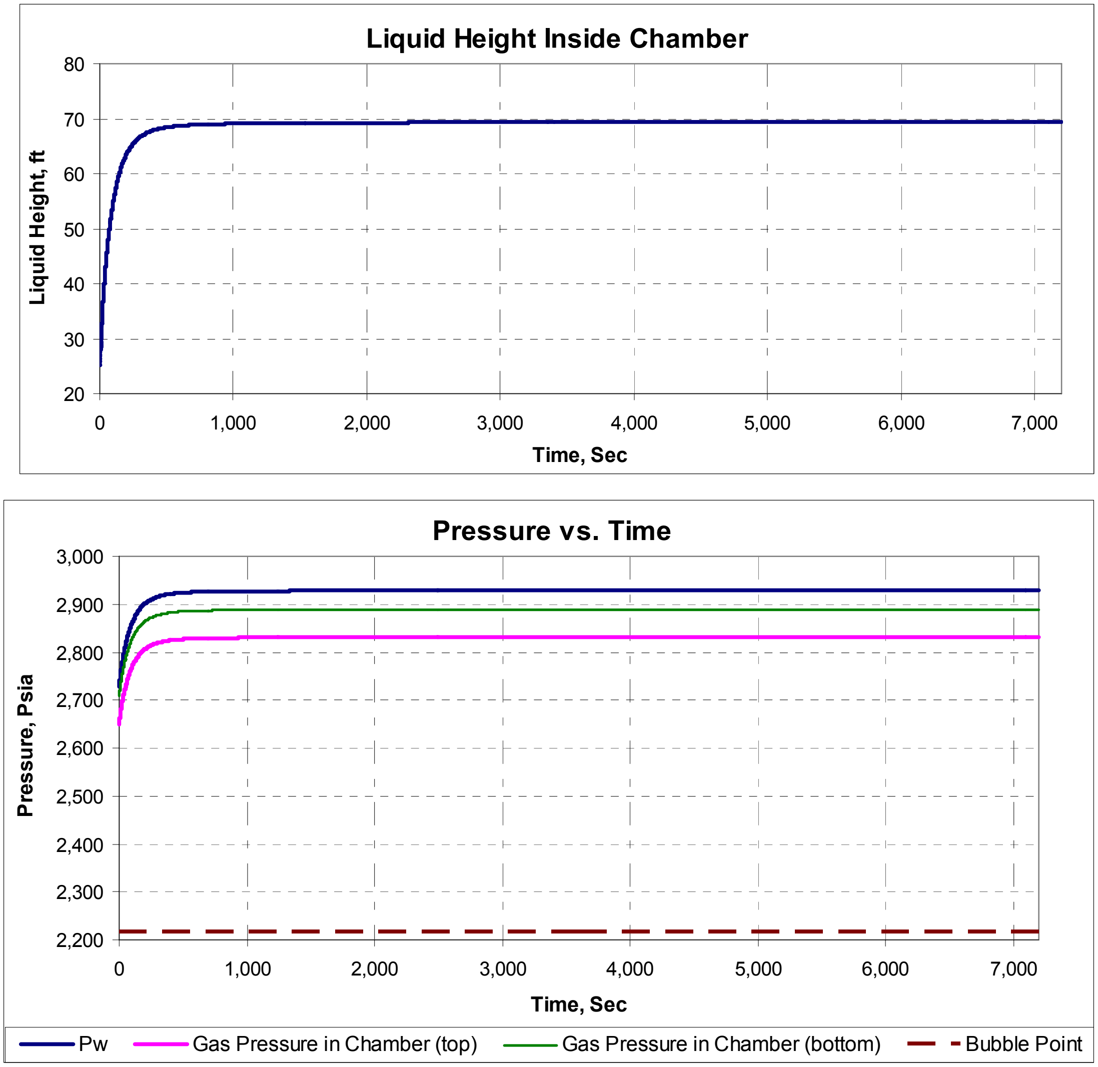


Fig. 11 – Detailed Final Sizing Results

Job Execution

The closed chamber string was rigged up in order to be run into the hole. The string included an acoustic telemetry surface readout system to allow real-time data acquisition. The lower and main chambers were pre-loaded with nitrogen in order to reduce the differential pressure in favor of the formation. The lower chamber was pre-loaded with 2,150 psi, and the main chamber with 2,120 psi. The string was run, but due to some problems experienced during the correlation, the string was retrieved. Weighted materials were placed on top of the bridge plug. The string was run again, but a nitrogen leak in one of the chambers was suspected, and the string was retrieved again. Pressure on the chambers was checked, and no leak was found. The string was re-run, correlated, the packer was set, and the surface equipment was rigged up (**Fig. 12**).

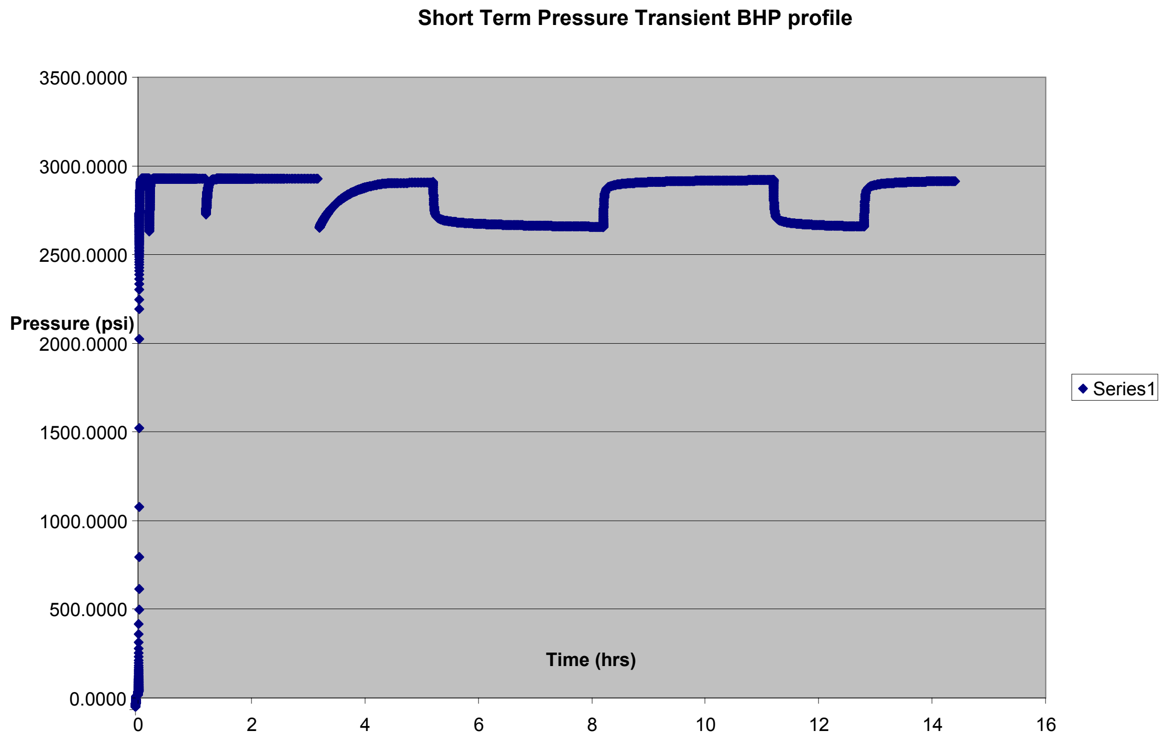


Fig. 12 — Job Profile

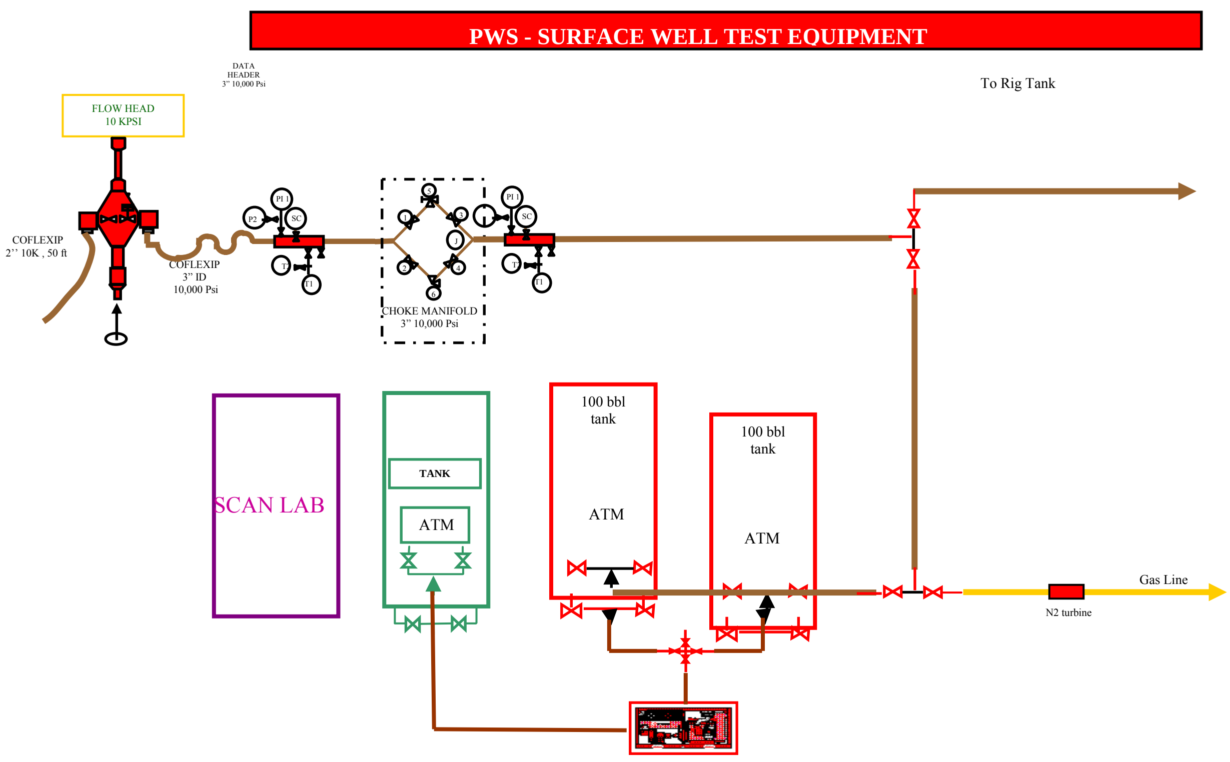


Fig. 13 — Surface Layout

The acoustic telemetry surface readout system was calibrated and the annulus was pressurized to activate the perforating guns. The guns were fired, opening the upper vent. Then, the lower surge valve was opened. The operation was monitored with the acoustic telemetry surface readout system and then the upper surge valve was opened. The well was opened and flowed through the different chokes.

A gradient job using a memory gauge was performed. After this operation was completed, the acoustic telemetry system wireline probe was re-run to acquire data. When the data was retrieved, the samplers were activated and the surge valves were cycled to close the well on bottom. Pressure was bled off and the bottomhole pressure was captured. The well was reversed while collecting surface atmospheric samples. The packer was released and the string was pulled out of the hole.

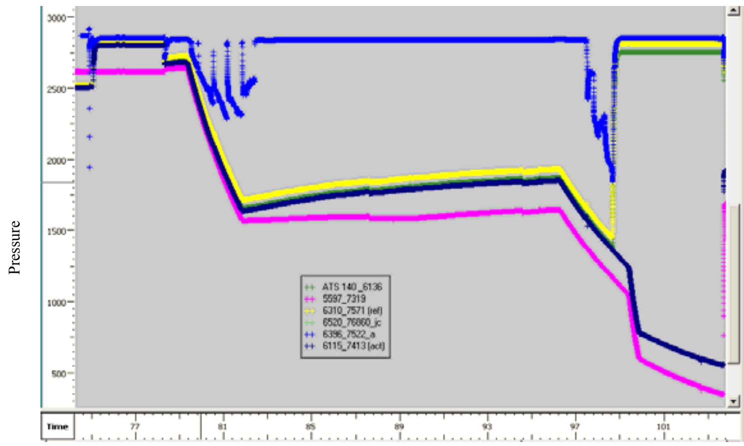


Fig. 14 — Job Results

Job Results and Interpretation

The results obtained from the data acquisition perspective and fluid collection are presented in **Fig. 14.**

Fig. 15 is a gradient plot used to determine where the nitrogen-oil interface is located in the tubing. It is also used to estimate the oil rate based on the time it takes for the oil level to rise. In this instance the nitrogen gradient is 0.8 and the oil gradient is 0.4 psi/ft. The oil starts to rise in the tubing above 6310-ft at the start of the 2nd surge. It can also be seen that the oil level continues to rise after the well is shut in for the first buildup.

The plot in **Fig. 16** was created to show the pressure drop across the vented screen compared with the tubing pressure. As can be seen, the screen starts to plug up when the upper surge valve opens (2nd surge). It can also be seen that the screen continues to plug off as the nitrogen is bled off during the first flow period. After the well is shut in for the second buildup, the pressure drop across the screen returns to its normal pressure drop caused by the gradient.

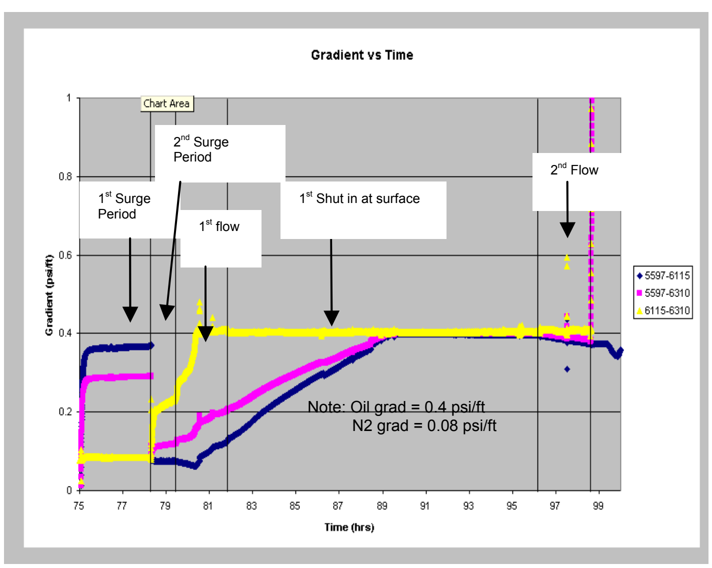


Fig. 15 — Gradient Plot

In addition, the results of the first surge, (**Fig. 17**) generated by the upper vented screen opening, had a pressure response that could be analyzed using the short-term pressure-transient analysis technique. First, a plot of delta pressure vs. delta time was created on a log-log scale to identify the flow regime. As shown by the slope of the line, the flow regime indicates a spherical flow. Therefore, a -1.5 slope was entered into the pressure-transient analysis software program. A short-term pressure-transient analysis was done using the derivative and the time-domain plots.

The samples were collected as outlined during the design stage of the job. The test process was successful in obtaining the information needed by the operator.

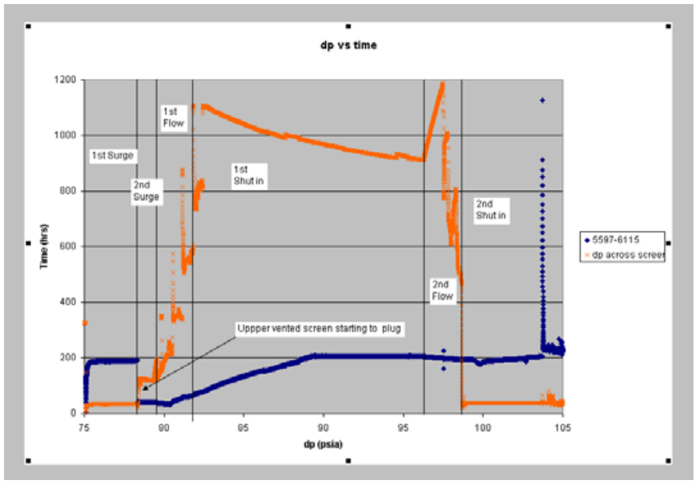


Fig. 16 — Pressure Drop

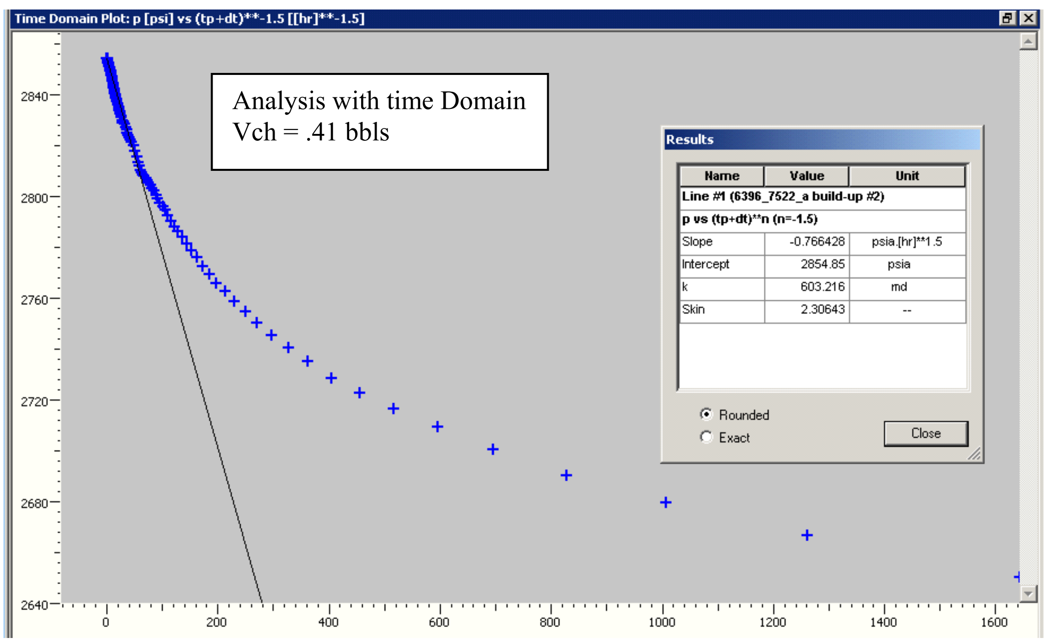


Fig. 17 — Upper Surge Valve

Case 2

Another test was run in the Gulf of Mexico in a water depth of approximately 8,000 ft. The purpose of the job was to run a limited-emissions test with the following features:

- Short-term pressure-transient test design
- Acoustic telemetry real-time surface readout data acquisition. A large bore transceiver was installed with the sea floor equipment to receive the downhole data, and send the information to surface via an umbilical line

- Premium tubing was used to improve the acoustical signal
- A special mechanical trigger was designed for the sampler carriers
- Three analysis periods were generated in order to validate results with no flow at surface
- The following fluid samples were acquired:
    1) 3 ea. 600-cc single phase samples
    2) 1- 50-bbl atmospheric bulk sample
    3) On-site dead-oil compositional analysis
- The following reservoir results were obtained:
    1) Pressure transient data
    2) Skin, permeability, and initial pressure
    3) Static and flowing temperature.

The test was successful in obtaining the required information for the operator.

General Recommendations

The following recommendations have been developed from the experience gained on these jobs:

- Increase interval length to improve formation influx
- Implement the use of screens to avoid plugging
- Increase the influx on the junk chamber to avoid plugging
- Perform an injectivity test before pulling closed-chamber tools out of the hole.

Conclusions

Advanced well-test systems such as short-term pressure-transient tests that avoid or reduce the need for flowing to surface have applications in environmentally sensitive areas or remote locations. The advantages shown by the case histories follow:

- Flow can go directly into the available tubing volume, allowing clean samples to be collected and a greater radius of investigation to be reviewed
- The system can be reseated several times to improve clean up of the formation and validation of the initial results
- The system allows collection of single-phase PVT samples in each run
- The samplers can be activated from surface at any time during the test
- The surge chamber can be sized to accommodate a range of reservoir properties
- A large-volume reservoir fluid sample can be collected at atmospheric conditions. Normally 1 to 20 barrels of samples are collected. The only limitation is the available tubing volume
- Fluid flow-rate estimates can be determined from pressure measurements obtained with the system
- System does not require flaring, burning, or disposal of large volumes of reservoir fluids
- Information can be collected and made available in real time, and data collected downhole can be transferred easily
- The system can be used for different environments and applications, including:
    1) Horizontal wells
    2) Multilateral wells
    3) Perforate and test prior to stimulation or sand control treatment
    4) Deepwater applications
    5) When wireline formation sampling does not yield the desired results
    6) When a fully blended DST cannot be performed.

The system demonstrated that it could perform a deep radius of investigation and could obtain representative formation samples for PVT analysis in a heavy oil environment. It can satisfactorily calculate reservoir parameters, productivity indices, identify fluids and solids, and can perform in heavy oil, unconsolidated sands, high permeability sands, and high viscosity fluids. Its data collection capabilities allow decisions to be made concerning performance of injectivity tests to determine reservoir geometry, and the use of nitrogen chambers can be implemented to better control formation differentials. The system demonstrated excellent flexibility on the two jobs, as it was capable of being adapted to the specific well conditions and environments of each, and allowed the use of the tools and equipment required to achieve the job objectives. In both cases, the required data and information were retrieved.

Acknowledgments

The authors wish to thank the management of Halliburton for their support and permission in writing this paper.

References

1. Alexander L.G.: "Theory and Practice of the Closed-Chamber Drillstem Test Method," JCT (Dec. 1977) 1539-44.

2. Soliman, M.Y., Azari, M., Ansah, J., Kabir, C.S.: "Design, Interpretation, and Assessment of Short-Term, Pressure-Transient Tests," paper SPE 90837 presented at the SPE Annual Technical Conference and Exhibition held in Houston, Texas, U.S.A., 26–29 September 2004.
3. Pahmiyer, R.C., Flowers, A., Almanza, E., and El Hassal, H.: "Implementation of Advanced Wellsite Data Management and Communications System Adds Value and Efficiency to Well Testing Operations," Paper SPE 71825 presented at the Offshore Europe Conference held in Aberdeen, Scotland on September 4-7, 2001.
4. Irani, Dr. C. A.: "Development of a New Carrier-Conveyed Sampler with Improved Reliability and Safety in HP/HT Environments, paper 45 presented at the Deep Offshore Technology International Conference 2008 held 12-14 February 2008, Houston, TX .

SI Metric Conversion Factors

°F	(°F - 32)/1.8	=°C
ft	× 3.048*	E-01= m
in.	× 2.54*	E+00= cm
psi	× 6.894 757	E+00= kPa
bbl	x 1.589 873	E – 01 = m^3

*Conversion factor is exact