Well Testing

Over 85 years ago, Halliburton introduced drillstem testing (DST) to our industry, establishing the initial standard for well testing. These early well tests provided a basic understanding of a reservoir’s characteristics.

Although the discipline of well testing has evolved dramatically since then to provide more extensive and accurate reservoir information, the ultimate goal remains the same: to empower you with the ability to not just optimize a well’s performance, but to also optimize your financial investment.
Accurate Fluid Sampling

Accurate fluid sampling and analysis are keys to optimizing the profitability of an oil or gas field. Halliburton specializes in reservoir fluids sampling, using state-of-the-art tools and techniques to deliver safe, reliable, and accurate sampling and analysis results. Both internally and in conjunction with alliance partners, Halliburton is also positioned to provide detailed onsite and laboratory-based pressure, volume, and temperature (PVT) studies. Collection, analysis, and proper interpretation of representative samples are crucial to developing the needed understanding of a hydrocarbon reserve and determining its economic viability.

Physical properties and chemical composition of reservoir fluids play a crucial role in all aspects of petroleum and reservoir engineering. Accurate sampling and analysis techniques provide critical input to reservoir simulation models and help to optimize processing facility designs while boosting the profitability of an oil or gas field. A physical sample of the reservoir fluid is also crucial to undertaking an assay. An assay is imperative for defining the monetary value of a hydrocarbon reserve, as it helps to define how the reserve will be produced, processed, and transported.

Our integrated approach to reservoir fluids sampling and analysis provides a comprehensive solution for reservoir characterization. Moreover, it gives the insight needed to maximize the value of your assets.

OFFERED SERVICES
Halliburton provides a full suite of sampling services suitable for all environments, including:
» Armada® tubing conveyed single-phase sampling systems
» Armada slickline, electric-line, and coiled-tubing-conveyed systems
» Acoustic control of downhole sampling systems with the RezConnect® well testing system
» Fluid transfer service
» Wellhead and separator PVT sampling
» Sample cylinder rental, including single-phase, dual-phase, and atmospheric-type bottles
» Coated sample cylinder rentals for analysis of trace components
» Basic onsite analysis
» Full lab PVT analysis

Reservoir Fluid Sampling

Representative reservoir fluid samples are essential prerequisites for providing quality data. Therefore, accurate and representative sampling is of the utmost importance. Special sampling equipment and procedures have been developed to secure the highest-quality samples possible.

BOTTOMHOLE SAMPLING
Bottomhole samples collected during a drillstem test (DST) offer the greatest probability of delivering contamination-free representative samples of the reservoir fluid. Sample contamination is primarily from the use of oil-based drilling fluids that infiltrate the near-wellbore region of the reservoir to be investigated. When subsequently produced, the first fluids recovered tend to have this oil-based drilling mud as a contamination that will adversely affect PVT studies and
asphaltene analysis. Because a DST allows for large volumes of reservoir fluids to be recovered to the surface, there is a greater probability, with proper job planning, that contaminant-free fluid will be collected during the sampling program. Halliburton has developed state-of-the-art sampling technologies that deliver samples to the surface at pressures that are usually significantly higher than the reservoir’s pressure.

These high recovery pressures ensure that the sample will stay securely in the single-phase region during recovery to the surface. Consequently, the likelihood is greatly reduced that asphaltenes will drop out of solution to create a nonrepresentative sample. When analyzed in the laboratory, these representative samples will deliver an accurate picture of whether the hydrocarbon of interest has asphaltenes present, and under what conditions of temperature and pressure they might pose a problem during the life of the reservoir.

The most important success factor for obtaining representative reservoir fluid samples is to maintain the reservoir fluid in single-phase prior to sampling. This can be best accomplished by effectively controlling the reservoir drawdown pressure during the actual sampling phase. Although downhole sampling is generally associated with oil reservoirs, it also offers some advantages in lean gas condensate wells where produced liquid volumes at surface may result in uncertainties in the gas/oil ratio (GOR) and in subsequent recombination ratios for separator samples. By sampling close to the perforations with minimum reservoir drawdown, downhole sampling provides samples containing representatives GORs.

Halliburton offers a complete suite of sampling systems that cover all aspects of sampling operations. The Armada sampling system is a premium, state-of-the-art sampler for cased-hole sampling. In terms of volume of sample collected, HPHT operability, and innovative safety and performance features, the Armada system is unmatched in the oil and gas industry.

The Armada sampling system starts with a uniquely designed sampler, the Armada SPS-A, that is able to collect 400 cc of sample fluid. These samplers are smaller in diameter than the average sampler, and rely on a nitrogen source provided by the conveyance system to provide the overpressure of the sample to keep it in single phase. This provides Halliburton with some unique competitive advantages in conveyance size, flexibility, and capability.

The tubing conveyance method for the Armada samplers is a fullbore tubing-conveyed carrier capable of carrying up to nine samplers. Depending on the requirements, Halliburton can offer the Armada carrier system in 5-inch or 7-inch outer diameter system. Each carrier is adaptable to accept various nitrogen charging systems to achieve the required sample recovery pressure. The Armada Agile configuration provides unrivaled flexibility with unprecedented recovery pressures in one of the most distinct and compact designs offered for downhole sampling. Each Armada carrier system can activate samplers in sets of three, giving operators the ability to trigger samplers during different flow periods or different flow regimes, depending on the objects of the test. Furthermore, these systems can be triggered by annular pressure, or acoustically by using the DynaLink® telemetry system.
Activate and Monitor in Real Time
Part of the RezConnect system, Armada samplers can be activated and monitored in real time.
The exclusive Halliburton TRACE DynaGauge™ is able to monitor the pressure of the common nitrogen source on the tubing conveyance systems. It is integrated into the DynaLink telemetry system and is able to monitor and record the nitrogen pressure as samples are taken and to communicate that information to the surface in real time. Not only does this serve as a quality check for maintaining samples in single phase, but it also provides the exact moment the samples were collected downhole. When the TRACE DynaGauge is connected to the DynaLink system, it provides real-time knowledge of:

» Sample collection and retention  
» Number of samples collected  
» Basic composition of the collected samples (gas, oil, or water)

Both the acoustic activation of the Armada carrier systems and the TRACE DynaGauge are part of the RezConnect well testing system, powered by DynaLink telemetry system, providing a complete wireless well testing solution.

The Armada Slickline Sampler (SPS-ASL) system is one of the Halliburton wireline-conveyed sampling systems that utilize the Armada SPS-A sampler, the same well-proven sampler technology used in the Armada workstring-conveyed carrier systems. Each SPS-ASL slickline assembly carries two SPS-A samplers with an integral high-pressure nitrogen system. The SPS-ASL assemblies can be run in tandem, triggered by an electronic timer or acoustically when run on e-line. In ultra-high-pressure environments, the SPS-ASL-X system provides samples of unparalleled recovery pressures.

Hydrogen sulfide (H₂S) is always an area of concern when sampling, and Halliburton’s Inconel® samplers are rated for significantly higher H₂S levels than conventional 17-4PH stainless-steel samplers. At low H₂S levels, it is imperative to reduce H₂S losses to identify the correct metallurgy for subsequent completion and production equipment, and to reduce intervention costs. Halliburton has taken the leading role in ensuring that samples are H₂S representative by providing an internal ceramic coating. Also available is a transportation case, approved by the U.S. Department of Transportation, that eliminates sample transfers in the field and reduces the time-consuming sample transfers on the rigsite. When it comes to downhole sampling, Halliburton provides industry-leading solutions and is successfully carving a niche by working closely with our clients on the most challenging of projects.

SURFACE SAMPLING

Surface separator sampling is generally performed during a number of different flow rates during a DST, and, although suitable for PVT analyses, it may not provide asphaltene information, as the reservoir fluid will be below bubble point at separator conditions. Nevertheless, the samples that are collected are valuable and are relatively free of the volume restrictions that attend downhole sampling. The very nature of surface operations also allows for a number of parameters to be simultaneously monitored as a measure of stability before sampling. For example, if a steady GOR value is obtained during a flow period, the operator has a strong indicator of a stable sampling opportunity. In addition, surface samples may provide an important cross-reference for the GORs obtained from downhole samples and, thus, increase confidence in the subsequent analysis. Even though separator samples require a recombination to be undertaken in a laboratory, such a recombination can be driven by a field-measured GOR, or even a reservoir-pressure-driven saturation pressure, thus providing a remarkable measure of flexibility in defining potential alternate variations for reservoir fluid interpretation.
For surface sampling, H₂S is again an area of concern, and Halliburton has addressed this through the provision of Inconel and titanium sample bottles suitable for higher H₂S levels.

Halliburton has significant experience and the necessary equipment associated with surface sampling operations. With the global introduction of our advanced surface well testing capability, Halliburton is well positioned to provide exceptional and detailed sampling capabilities worldwide.

**Reservoir Fluid Analysis: Routine Laboratory Services and Unconventional PVT Analyses**

Halliburton delivers PVT analytical services either at our own state-of-the-art laboratory in Algeria or through well-respected alliance partners. These analytical services cover the complete range of information needed to deliver a proper understanding of hydrocarbon reserves. This complete range of equipment and services includes:

- HPHT visual cell to 15,000 psi and 600°F (316°C)
- Compositional analysis up to C70+
- Constant composition expansion with relative volumes (ranges up to 30,000 psi and 500°F/260°C)
- Viscosity measurements using capillary viscometers to 20,000 psi and temperature range from 30°F to 600°F (-1°C to 316°C) (viscosity up to 1 million cP)
- Differential liberation (black oil) or constant volume depletion (condensate or volatile oil)
- Swelling, solubility, and mixing studies
- Compressibility measurements on hydrocarbons and hydraulic fluid systems from 30°F to 600°F (-1°C to 316°C) and up to 30,000 psi
- Determining the effect of mud additives on fluid behavior for equation-of-state modeling
- Testing additives for viscosity improvement
- Handling heavy oil or sour gas systems
- Performing benchmark compositional analyses
- Performing solid deposition studies
- Drilling mud additives under reservoir conditions
- Slim tube studies to examine fluid behavior for miscible flooding and gas cycling projects
- Water analysis, salinity
- Iron isotope analysis

In addition, unconventional studies can also be undertaken to address specific problems that require a unique understanding of the tough challenges facing the modern petroleum industry. If needed, customized tests can be designed to meet specific client needs.
Armada Sampler Conveyance Systems

The Armada SPS-A sampler can be conveyed into a well by multiple conveyance systems from tubing to slickline and, further, by electric line. The tubing-conveyed system for DST is a fullbore, FULFLO® formation testing tool design that can operate in normal or hostile cased-hole environments.

**TUBING CONVEYANCE SYSTEMS**

The state-of-the-art, tubing-conveyed design allows running up to nine samplers, plus one or more pressure/temperature gauges, to monitor bottomhole conditions and nitrogen pressure. Additionally, its smooth-bore design facilitates wireline and coiled-tubing (CT) intervention work, protecting the samplers from any damage or disturbance from the intervention work. The 5-inch and 7-inch Armada carriers utilize a common nitrogen pressure compensation system to ensure that the collected samples maintain overpressure from sample collection to the point of sample transfer.

» The **5-inch Armada carrier system** is the base platform for conveying the Armada samplers on tubing. It carries nine samplers, externally mounted, that are activated or triggered in sets of three. This carrier design is unique in that all the samplers share a common nitrogen source that attaches to the end of the carrier body.

The nitrogen pressure (which is charged on the surface before running in the well) is used to overcharge the samplers to keep the collected samples in “single phase” or what is sometimes called a PVT condition. This common nitrogen source provides a much larger nitrogen (N₂) volume than all other tubing-conveyed samplers, facilitating high return pressures across a wide variety of reservoir conditions.

The 5-inch Armada carrier provides the capability of carrying a pressure gauge to document the overcharge pressure on the collected samples.

» The **5-inch Armada Agile system** is very similar to the 5-inch Armada carrier, with the same inside diameter (ID) and OD, but instead of the common nitrogen section attached to the carrier body, it uses 1-inch-diameter nitrogen tubes. These tubes are carried in the slots where the samplers are carried, thus reducing the number of samplers. However, the benefit of the Armada Agile system is that a higher return pressure can be achieved with the same tubing-conveyed tool because the small nitrogen tubes can be charged to a significantly higher pressure. The Agile system isolates the nitrogen for each of the three triggering mechanisms. Therefore, it is configured with one or two N₂ tubes to one or two samplers, and this configuration can be different between the three trigger sections.

» The **7-inch Armada carrier** is a large-bore carrier conveyance system that is configurable with 1.25-inch diameter nitrogen tubes vs. the common nitrogen chamber of the 5-inch Armada carrier. This carrier is capable of carrying up to nine samplers, and it also provides a common nitrogen section for all the samplers. It also has the ability to utilize a nitrogen gauge to record the common nitrogen pressure to document the overcharge pressure on the collected samples.

» The **TRACE DynaGauge** is a gauge that is connected to the common nitrogen section of the 5-inch and 7-inch tubing-conveyed carriers. Each of these carriers has an extra slot in which the TRACE DynaGauge can be carried. This gauge monitors the common nitrogen pressure and is able to transmit the nitrogen pressure to surface in real time using the DynaLink telemetry system. From this data, Halliburton is able to identify that samples have been collected, determine how many samples have been collected, and deduce the basic fluid composition of the collected sample. This provides real-time confirmation that proper PVT samples have been collected. It further provides a confirmation of the collected sample pressure from the time of collection until the samplers are removed from the carrier.

**ARMADA SPS-A SAMPLER**

A single-phase sampler is utilized in all Armada tubing-conveyed carrier, slickline, and electric-line systems.
TUBING-CONVEYED CARRIER TRIGGERING MECHANISMS

» The tubing-conveyed carrier is equipped with three annulus-pressure-operated rupture disc ports. Each rupture disc activates sample collection for three samplers. Consequently, three samples can be collected during each of three separate sampling periods in the course of a multi-flow well test. The standard method of sampler activation in the 5-inch carrier is by using applied annulus pressure to burst rupture discs, set at different burst pressures to enable multiple sampling events during a single trip in the hole. This enables up to three separate sampling periods. In certain situations, the casing pressure test limit restricts the amount of applied annulus pressure, so three distinct sampling events may not be possible. In that case, the system can be set to burst multiple rupture discs to trigger one, two, or even all three sampling events at the same time.

» The acoustic sampler trigger is an acoustic telemetry-activated trigger system for the Armada tubing-conveyed carriers. This system utilizes the proven DynaLink telemetry system. It enables an operator to query the trigger system status to ensure that it is ready to trigger samplers. The acoustic command to trigger the samplers is sent from the surface to initiate the sampling event. The system then provides feedback to the surface that the specified sampling event has begun. This enables multiple sampling events for the tubing-conveyed systems when there are restrictions because of the casing pressure test. The tubing-conveyed carriers retain the rupture disc activation, which can be used as a secondary activation method.

WIRELINE CONVEYANCE SYSTEMS

The Armada slickline single-phase samplers represents the latest in Halliburton slickline/wireline-conveyed sampling equipment. They are comprised of an electronic timer activation section and a nitrogen section, and it typically carry two Armada SPS samplers. The Armada slickline sampler arrives onsite fully assembled, requiring only the electronic timer to be programmed and the nitrogen to be charged before running in the hole. When the timer completes its countdown, sampling of the reservoir fluid begins. When a sample has been fully collected, the sampler automatically triggers the release of high-pressure nitrogen, locking in the sample and overpressurizing the collected reservoir fluid sample, thus maintaining the sample in a single-phase condition during its recovery to the surface.

» The Armada SPS-ASL sampler utilizes the same reliable samplers as used in the Armada tubing carriers and offers unparalleled recovery pressures. The SPS-ASL sampler assemblies are composed of an activation section (delay timer), two nitrogen tubes, and two SPS-A samplers. Each sampler is serviced by a single nitrogen tube. In a standard configuration, each SPS-ASL assembly holds two 400-cm³ (24.4-in.³) SPS-A samplers that return 800 cm³ (48.8 in.³) of sample with recovery pressures over 10,000 psi (689 bar) for black oil. Multiple SPS-ASL samplers can be connected in the bottomhole assembly (BHA) to increase the collected sample volume.

» The Armada SPS-ASL ERP is a derivation of the standard ASL configuration, facilitating significantly higher sample recovery pressures by using the standard ASL carrier. This is accomplished by removing one sampler and replacing it with a third nitrogen tube and a specialized manifold to connect all the nitrogen tubes to the remaining sampler. This enables samples to be returned with surface recovery pressures approaching 14,000 psi for black oil samples.
The Armada SPS-ASL-X system is a further adaptation of the slickline carrier to recover samples to the surface with extreme recovery pressures. This configuration adds a nitrogen reservoir to the slickline carrier, increasing the carrier length, but greatly increasing the volume of nitrogen available for sample overpressure and facilitating increased nitrogen surface charging pressure. This system utilizes the adaptable nitrogen housings and retains two SPS-A samplers for unprecedented sample recovery volumes at extremely high recovery pressures. Recovery pressures for this system can approach 17,000 psi for a black oil sample.

The Armada fluid sampling tool (FST) is a system that incorporates the Armada slickline carrier into a production logging tool (PLT) system’s BHA. The Armada FST can be run in combination with production logging sensors for real-time understanding of downhole conditions prior to activating electronic triggers for on-demand flexibility. This provides the ability to monitor downhole conditions prior to fluid sampling so that the best possible sample quality is collected. This system utilizes an electronic trigger that enables the surface operator to trigger sample collection on demand. The Armada FST combines two proven and reliable technologies of the SPS-A sampler with the PLT systems for ultimate operational flexibility coupled with the clearest picture of downhole conditions prior to sampling.

ELECTRIC-LINE TRIGGERING SYSTEM

If any of the Armada slickline sampler configurations are conveyed into a well via electric line instead of slickline, then an option is available to trigger the sampling event(s) by using the well-proven DynaLink wireline tool as part of the BHA. Using this system, each individual slickline sampler can be triggered when desired, without delay, through a signal from a surface computer to the DynaLink-enabled BHA. This removes the necessary time on bottom waiting for the timer to initiate the sampling event(s). It also provides real-time feedback that the sampling event has begun. Additionally, it is possible to incorporate a real-time pressure and temperature gauge as part of the BHA to provide additional downhole data.
Sales of Halliburton products and services will be in accord solely with the terms and conditions contained in the contract between Halliburton and the customer that is applicable to the sale.