A State-of-the-art Cased-Hole Tubing Conveyed Reservoir Fluid Sampling System for HPHT Applications.

The capture and analysis of a representative reservoir fluid sample is a crucial part of any exploratory program. A detailed analysis of the collected sample provides invaluable information to reservoir and facility engineers with regards to field and platform development. The growing global need for hydrocarbons coupled with maturing of existing reserves is forcing the industry to move into more difficult offshore frontier areas. Associated with the increasing water and reservoir depths is the greater likelihood of encountering high pressure and high temperature (HPHT) reservoirs from which hydrocarbons will be recovered. These HPHT environments impose harsh requirements on equipment traditionally used to evaluate a prospect, including fluid sample collection.

The reason for obtaining representative fluid samples is to maintain the reservoir fluid so that it represents the natural condition of the reservoir to be produced. Attempts to maintain the sample at reservoir temperature have not been very successful so that leaves us to focus on pressure. The present approach is to try and maintain pressure of the sample as high as possible during recovery to surface. Fluid samples shrink from collection point to surface simply because of temperature drops between bottom hole and surface. As the sample shrinks, pressure drops and has to be compensated by applying high-pressure nitrogen. The pressurized nitrogen is carried in a separate carrier section integral to each individual sampler. When the sample has been collected, nitrogen is released directly under the sample piston to maximize its contribution to pressure maintenance. The ramification of not maintaining the sample at representative pressures can be highlighted by the potential presence of asphaltenes in the sample. Asphaltenes are complex molecules and can remain suspended in reservoir fluid if pressure is maintained. But, as pressure on the sample is lowered, asphaltenes – if present – will fall out of solution. If that happens, the sample no longer represents the true nature of the reservoir fluids. Getting the sample to resemble reservoir fluid requires costly and time consuming reconstitution.
A number of methods are available for undertaking a detailed reservoir evaluation. The traditional method has been to undertake a drill stem test (DST) which involves testing the surrounding geological formation through drill pipe (or tubing) in a cased hole environment. During normal drilling, fluid is pumped through the drill stem and out the drill bit, returning to the surface via the annular space between the drill stem and formation. However, in a DST, the procedure is reversed, and fluids from the formation are recovered through the drill stem and collected at a surface separator under controlled conditions. Recombining of the surface separator oil and gas samples in the correct ratio results in the generation of a representative reservoir sample. More recently, the emphasis has shifted to also collecting single phase bottomhole samples during a DST, and Halliburton’s Armada™ sampling system has been designed specifically for this service. Because a DST can contact a significantly larger volume of reservoir, DST’s have retained their significance, and in some instances are considered more relevant than other testing methods.

Another method for reservoir evaluation in open hole environments is wireline formation testing (WFT). In this approach, a bottomhole tester is sent downhole via a wireline and located alongside a formation of interest. The WFT tool is designed so that a probe can be brought in firm contact with the reservoir, allowing the reservoir fluids to flow through the tool and past appropriate sensors that can define when the flowing sample is fit to be captured. Because a WFT can work in an open hole environment, it has been a very popular tool for reservoir description. Continuous improvements in downhole sensors for measuring reservoir parameters have helped WFT to retain its popularity. A disadvantage of a WFT is the limited volume of reservoir it can access.

Halliburton has an active presence in all aspects of sampling. The MRILab® service coupled with the RDT™ samplers is a very versatile offering by the Wireline and Perforating Services group for WFT. Other aspects of sampling fall within Halliburton’s T-FAS® service offering, and include surface sampling, bottomhole sampling on slick/wire line, bottomhole sampling on pipe (Simba® carrier and Armada system), surface field transfers and long term storage bottles.

The Armada™ Sampling System
The Armada™ sampling system (Figure 1) is Halliburton’s new state-of-the-art tubing conveyed cased hole sampling offering. It was specifically designed to consistently and reliably deliver large volumes of monophasic samples even after extended exposure to significant temperatures and pressures. As such it is the ideal sampling option for the growing number of instances where wire in the hole can be problematic or is unacceptable. The nine Inconel® samplers are rated to 400°F and 20,000 psi, and each sampler can collect a 400 cc monophasic sample. The samplers are located on the outside of the sample carrier as shown in Figure 2, thus presenting a smooth bore in the tubing string through which wireline or coiled tubing can pass with unrestricted access and without damaging the samplers. This is an important feature in the tool’s performance and reliability.

Yet another innovation is the introduction of a means to track the position of the sampling piston (Figure 3). This allows a field engineer to immediately identify on location (by piston position) how many samplers triggered successfully and the volume of sample available in each sampler. The sampler carrier is also equipped to carry a three gauge set. The gauge set can include a gauge for measuring tubing pressure, a gauge for measuring annulus pressure, and a gauge for measuring the common nitrogen pressure.
Most conventional samplers carry the nitrogen charge as a separate section associated with each individual sampler. This design limits the volume of nitrogen that is available, which requires a higher initial nitrogen pressure. The Armada system design takes the innovative approach of using a single large nitrogen section to service all nine samplers. This fundamental design change favorably impacts a number of sampler features. Because a very large nitrogen volume is available, it can be used to compensate for sample and displacement fluid shrinkage, which in turn results in a much simpler and more reliable sampler that can be quickly redressed and returned to service. Additionally, a gauge dedicated to monitoring the nitrogen pressure provides a quality control check on the performance of the samplers throughout the recovery phase.

In standard practice the carrier will be loaded with nine samplers which will be fired in sets of three using annulus pressure triggers. However, the design is completely flexible and any number of samplers from one to nine can be run. Because one common nitrogen section services all the samplers, for any given initial nitrogen charge the final return pressure is very much a function of the number of samplers run. Table 1 demonstrates a hypothetical case where the reservoir temperature and pressure are 350°F and 15,000 psi respectively. In this case, the Armada system was charged to its maximum allowable surface loading at an assumed ambient temperature of 80°F.
It's unique design has allowed the Armada system to be fully assembled and pressure tested onshore. It is shipped to location with a nominal nitrogen pressure. On location, the only requirement for operation is to complete charging the nitrogen section. Consequently, the Armada system has been run in the hole within just a few hours of arriving on location, which can translate into significant rig cost savings. The simplicity of this design also means that only one person is required during run-in-hole operations, which can be a significant safety consideration. With only minor modifications, the Armada system can be adapted to run six samplers, with the remaining three slots converted to take gauges. In this mode the Armada system module can double as both a sample and gauge carrier, thus eliminating a leak path between annulus and tubing.

**Armada Sampling System Qualification Testing and Field Trial**

Prior to commercialization, the Armada sampling system was tested repeatedly at its rated capability of 400°F and 20,000 psi in Halliburton’s deep well simulator located at the Carrolton Technology Center near Dallas, Texas. The deep well simulator is a below-ground test facility designed to accommodate long assemblies up to 60 feet in length at temperatures up to 1000°F. The simulator is a vertical pit oven where the piece being tested is uniformly heated with air. The deep well simulator proved invaluable in accelerating the development of the Armada sampling system because it facilitated the repeat testing of the tool in highly representative extreme HPHT environments. The deep well simulator was also used for specific HPHT qualification testing requested by a client in connection with an upcoming HPHT well. The qualification test was designed to closely duplicate environmental conditions the tool would experience in actual field applications. The Armada system met the client’s qualification requirements, and at present is the only one qualified to do so.

### Table 1

Armada Sampling System Recovery Pressures* for Various Hydrocarbon Fluids

<table>
<thead>
<tr>
<th>Hydrocarbon Type</th>
<th>Armada 9</th>
<th>Armada 6</th>
<th>Armada 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Oil (psi)</td>
<td>10,000</td>
<td>10,500</td>
<td>11,000</td>
</tr>
<tr>
<td>Condensate (psi)</td>
<td>9800</td>
<td>10,300</td>
<td>10,800</td>
</tr>
<tr>
<td>Number of Samples</td>
<td>9</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
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*Theoretical estimates
Simultaneous to the qualification testing in the deep well simulator, a field trial opportunity in the North Sea became available. In this opportunity the flowing bottomhole temperature and pressure were reported as 228°F and 3184 psi at a depth of 13,164 feet. The well had a number of operational issues unrelated to the Armada system that required the bottom hole assembly to be pulled in and out of the hole on three separate occasions. On each trip out, a quick check of the common nitrogen pressure and confirmation of piston location was performed. This combination of measurements was definitive in confirming the systems readiness for service. There were additional problems with the hole that eventually required the string to be over-pulled 175,000 pounds and torqued 3000 foot-pounds. In spite of these complications, the Armada system successfully collected nine out of nine monophasic samples.

**Case Histories**

Following the field trial in the North Sea, a commercial opportunity arose for the Armada system. In this instance the static bottomhole temperature and pressure were 260°F and 10,172 psi, respectively. Because of this potentially high pressure environment, the Armada system was charged at the surface to its highest pressure to improve the probability of collecting single phase samples. Once again operational issues unrelated to the Armada system required the sampling system to be run in and out of the hole, multiple times, to a depth of 13,000 feet. As previously indicated, on each return to surface a quick check on the piston position and the common nitrogen pressure confirmed that the Armada system was ready for service with no redress needed. The final flowing conditions came in at 276°F and 4618 psi. All nine samplers were fired, and eight out of nine samplers had taken a representative sample exceeding the customer’s expectations and acceptance criteria.

**Case History Fig. 1- Armada System being deployed to the rig floor**
Since its introduction early in 2007, the Armada sampling system has been successfully run on several jobs in the North Sea, Latin America and West Africa. In every instance thus far, the Armada sampling system has met or exceeded the clients expectations for volume and number of monophasic samples captured.

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