Pipe-deployed sampling system designed for cased-hole applications with extended HP/HT exposure is an ideal sampling option where wire in the hole is problematic or unacceptable.

The preferred method for obtaining a representative reservoir fluid is to collect the sample downhole. Maintaining it in a truly representative state requires preserving the original temperature and pressure during recovery. Attempts at temperature control during sample recovery have not been very successful, and consequently, the present approach is to try and maintain the pressure of the sample as high as possible during recovery to the surface. The presence of asphaltenes in the sample is a significant problem. Asphaltenes are complex molecules that remain in solution in the reservoir fluid through interactions with the continuous oil phase. However, as pressure on a sample decreases, asphaltenes will come out of solution, usually at pressures above the saturation pressure. When that happens, the sample no longer represents the true nature of the reservoir fluids, and costly and time-consuming reconstitutions are needed.

A new, tubing-conveyed sampler designed by Halliburton addresses these limitations. The design eliminates the need for wire in the hole and creates operational efficiencies around handling the carrier on location. The system can be fully assembled at the shore base, eliminating any delays in running it in the hole. The only requirement on location is to charge the common nitrogen section, so that within a few hours of the system arrival it is ready to run in the hole. Other improvements center on the nitrogen (N₂) source delivery system, which is crucial to guaranteeing a monophasic sample.

The pressure challenge
The primary cause for a drop in sample pressure is sample shrinkage during recovery due to temperature drop from the collection point to surface. This must be compensated for if the retrieved sample is to be truly representative. Additionally, the sample pressure after retrieval should be at least as high as the reservoir pressure. A simple and reliable method for pressure maintenance is the use of high-pressure nitrogen (N₂). In conventional practice, pressurized nitrogen is carried in a separate section integral to each individual sampler and is released only when the sample has been collected. The N₂ is then released directly under the sample piston to maximize its contribution to pressure maintenance.

To illustrate the challenge posed by pressure maintenance in a high-pressure/high-temperature (HP/HT) environment, consider a generic sampler designed to capture a 600-cc sample from a reservoir at 400°F (204.4°C) and 20,000 psi. Let us also presume that this sampler has a nitrogen compensation section of 450 cc and can be charged at the surface to a maximum pressure of 15,000 psi. When so charged at a surface temperature of 80°F (26.6°C), at a reservoir temperature of 400°F, the sampler internals will face pressure loads of 27,300 psi. If the captured sample is a generic black oil with a thermal expansion coefficient of 4.5 by 10⁻⁴, then shrinkage during recovery would expand the nitrogen volume to 536.4 cc.

Consequently, the maximum pressure of the sample at recovery due to nitrogen maintenance would be 9,946 psi.

Whereas this recovery pressure might exceed the saturation pressure of the sample, it certainly does not approach the reservoir pressure requirement occasionally imposed. Additionally, there are situations where the saturation pressure exceeds 10,000 psi, and this recovery pressure would be unacceptable. Furthermore, during transition through the mud line, the opportunity exists for the sample pressure to fall as low as 8,596 psi. Other factors like condensates with higher coefficients of thermal expansion also impact recovery pressure.

Certain field practices also result in lower recovery pressures. For instance, in the example cited above, it is not unusual to charge the nitrogen to only

Figure 1. The Armada sampling system is a full bore sampler with an OD of 5.38 in. Each of the nine Inconel samplers is rated to 400°F (204.4°C) and 20,000 psi and will collect a 400 cc sample. (All images courtesy of Halliburton)
7,500 psi, and then to inject some power fluid to bring the final pressure to 15,000 psi. The resulting loss in volume of pressurized nitrogen (from 450 cc to 311 cc) would drop recovery pressure from 9,946 psi to 8,633 psi.

Meeting the challenge
In order for traditional samplers to meet the challenge of HP/HT single-phase sampling, it is necessary for the starting nitrogen pressure or volume to be significantly raised. Increasing the nitrogen pressure has mechanical and safety risks, and with the traditional sampler design increasing nitrogen volume is not always practical.

The Armada sampling system is a new sampling system designed for HP/HT environments. Instead of a separate nitrogen source integral to each sampler, the Armada system uses a single nitrogen source common to all the samplers. This provides considerable flexibility. For example, in any specific situation, the system can be run with a complete suite of nine samplers for a certain recovery pressure, or only three to six samplers for even higher recovery pressures (Table 1). In most applications, the system recovery pressures can be expected to outperform the generic sampler.

Additionally, a stand-alone nitrogen option allows for much larger gas volumes, which in turn allows additional options in the sampler’s design. The traditional sampler, with its limited nitrogen charge, must bypass the displacement fluid chamber so that only sample shrinkage is addressed. This leads to more complex samplers. The significantly larger nitrogen volume available in the new system meets the shrinkage demands of the sample and the displacement fluid. This results in much simpler samplers that are easier and faster to redress. These nitrogen sections are identical to the nitrogen sections that have been used with most drillstem test tools for many decades and have a long history of reliable operation.

With only minor modifications, the system can be adapted to run six samplers and the remaining three sampler slots converted to take gauges. In this configuration, the system can double as both a sample and gauge carrier, thus eliminating a significant leak path between annulus and tubing.

Field history
Prior to commercialization, the system was repeatedly tested at its rated capacity of 400°F and 20,000 psi. It also passed HP/HT pre-qualification testing, which required subjecting it to a multiday test at 383°F (195°C) and 12,000 psi for an international oil company.

In early 2007 the system was used to capture bottomhole samples of reservoir fluid for Oilexco North Sea Limited. The pipe-conveyed system was loaded with nine samplers to run a drillstem test at 228°F (108.9°C) and 3,500 psi well conditions. All nine samples were collected and were transferred in a controlled environment on location. A second well was also successfully sampled at bottomhole temperature of 260°F (126.6°C) and 10,170 psi bottomhole static pressure. During both applications operational requirements outside the scope of the system required that the bottomhole assembly be run into and out of the hole three times to 13,000 ft (3,963.4 m). The system retained its integrity between trips and required no redress. The goal was to optimize the reliability of reservoir evaluation by gathering samples uncontaminated by drilling fluids while expediting turnaround time and dramatically enhancing safety by eliminating the use of wireline.

Table 1. Armada 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>
<th>GENERIC</th>
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</thead>
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<tr>
<td>Black Oil (psi)</td>
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<td>10417</td>
<td>10929</td>
<td>9946</td>
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<tr>
<td>Condensate (psi)</td>
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<td>8644</td>
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<td>6</td>
<td>3</td>
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*Theoretical estimates.