A highly efficient and popular technique for multistage fracturing involves placing a completion string in the open hole with a series of ball-actuated stages isolated by hydraulically set or swellable packers. This practice has been instrumental to the increase of activity in hydrocarbon-bearing reservoirs, as it allows continuous operation while performing a large number of stimulation treatments.

When using this technique, sections of the reservoir can be selectively accessed by pumping actuators, or frac balls, from surface that land on correspondingly sized seats that have progressively larger diameters as operations advance from toe to heel. When all stages have been treated, the well is allowed to flow back, flushing the balls back to surface where they are caught in a ball trap.

Despite more than a quarter of a million stages that have been treated using the sliding sleeve technique, the results are not always up to expectation. Operators have experienced suboptimal production from wells in which logs and tests indicated high productivity. In searching for a root cause, it has been discovered that often not all balls are recovered. Further investigation has sometimes found that balls may have deformed and become jammed in their seats, plugging all production from beneath. The only solution is to trip into the well and mill out the seats.

Aside from the added cost and risk, the challenge is that this undesirable situation is difficult to identify because other reservoir problems that milling will not solve can present a similar production profile. This adds uncertainty to any decision to mill out the system.

Frac balls are typically made from phenolic or composite materials. The composite material is laminated and, depending upon the orientation of the laminar planes, it can fracture when it seats and is subjected to additional hydraulic pressure during fracturing operations. If the ball fractures before it has served its purpose, the entire job may be jeopardized. Both types of balls are subject to deformation, often referred to as egging, when under pressure (Fig. 1). Slight egging can cause the ball to stick in the upper seats when the well is put on production, or the ball can jam itself into the seat so tightly that the only way to remove it is by milling. A stuck or jammed frac ball acts as a permanent isolation point for all treated stages below it.

Alloy Ball Technology
Schlumberger has recently introduced a degradable alloy technology suitable for ball drop systems. The Elemental degradable alloy balls disintegrate after making contact with well fluid within a few hours of deployment. The ball does not dissolve, but rather goes through a controlled degradation (Fig. 2) in which an electrochemical reaction occurs over hours or days that slowly transforms the material into hydrate oxides and hydroxides while slowly releasing a small amount of hydrogen. All that remains is a fine powder (micron scale) that does not interfere with flowback or production.

The mechanism of this material degradation includes intra-galvanic cells and depassivation. During the first process, different crystallographic phases electrochemically interact, leading to one dissolving, while another remains and slowly generates hydrogen. The first mechanism resembles the electrochemical process that takes place in a car battery and is well understood in the oil field.

To understand the second degradation mechanism, take the analogy of stainless steel—a metal or alloy known for its self-passivating behavior in aerated conditions. Stainless steel, because it has at least 12 wt% chromium in iron, naturally forms a thin protective layer of chromium oxide, among possibly other more complex oxides. When one or several of the oxides are removed, for instance as a result of abrasive wear, they instantly re-form as long as sufficient aeration is present. In contrast to stainless steel, the degradable material is unable to form a self-protective passive
film. Instead, it has a strong chemical affinity toward disintegrating in water-containing fluids.

The frac ball does not have to degrade completely before flowing back because, once its outside diameter is reduced below the seat’s inside diameter, the ball falls through to the bottom where it continues to degrade until it disappears. With a compressive strength comparable to mild steel, the new metal alloy balls can withstand differential well pressures exceeding 10,000 psi without deforming or fracturing.

During development, more than 700 prototypes were subjected to more than 6,000 hardness tests and 300 fluid compatibility tests to validate manufacturing quality. Most importantly, degradation is more uniform and consistent with the new metallic alloy frac balls than with previous designs. Measured dimensions during degradation have a near 1:1 correlation with predicted diameters. When tested under extreme temperatures, the balls were undamaged and not desensitized by exposure to ambient heat or cold.

Since their introduction, the new metal alloy degradable frac balls have been run on 500 stimulation stages in the United States, Canada, and other countries. The balls demonstrated predictable degradation in a wide variety of well depths, temperatures, pressures, and fluids. The frac balls and the wells in which they were deployed performed as expected. One operator wanted assurance that the balls could be easily milled in case of a contingency. The balls were quickly milled with no special operational requirements.

**Field Performance**

The Elemental degradable alloy balls were run in a six-stage well scheduled to be hydraulically fractured. The pressure log showed a clear frac ball signature for all stages. Different fracturing profiles for the stages confirmed that each was fully isolated from the others. Following treatment, the well did not flow back naturally to surface. This was expected, and coiled tubing (CT) was brought in to lift the well and recover any debris or ball residue. The CT passed through all six seats, indicating that there was no ball residue impeding flow. The job was completed in 5 hours.

Another well with 16 stages was to be treated using low-temperature foam at 50°C (122°F). Following treatment, five partially degraded frac balls were caught in the ball catcher 53 hours after completion of the 16th stage. After 72 hours, the ball catcher was rechecked and found to be empty. All stages were deemed to be open by a comparison of production with a nearby offset well. The recovered balls were determined to be from the last five stages pumped—the balls from the deeper 11 stages fully disintegrated.

Other equipment improvements have also been implemented. Whereas most seats have conical geometry, it was determined that better sealing action would result from concave seats that have profiles matching the spherical surface of the ball designed for that seat. Not only was the sealing improved, but also the differential pressure rating was raised beyond 10,000 psi.

**Maximizing Production**

The advent of the degradable alloy frac balls helps to ensure that production is maximized. This assurance gives operators added confidence that each well is performing to its limit, thus enabling better management of reservoir development. By eliminating the risk of balls breaking or jamming in the seats, considerable time and money is saved because cleanout milling trips will no longer be necessary. JPT