MORE than a century of extensive drilling throughout the world has left many oil fields in advanced states of depletion. The oil is still there, in great abundance, but the pressure levels necessary to force the oil and gas to the surface are lacking. This has the potential to leave large amounts of product resting below the surface, untapped.

Regardless of the reservoir pressure, economic demand necessitates that operators continue to sink new wells to maintain their current production volumes. To keep up with that demand, new technologies are being developed that allow more efficient and effective recovery of hydrocarbons. One such technology is underbalanced drilling (UBD). Utilizing underbalanced drilling techniques allows new wells to be drilled in mature, low-pressure reservoirs.

The UBD technique is a complete 180° turn from conventional drilling theory, which calls for the dynamic hydrostatic head pressure to be higher than the formation pressure. This prevents oil and gas from exiting the well before producers are ready to pump it. UBD is used when the formation is either damaged, or there is a real danger of damage. The hydrostatic head is intentionally set at a negative pressure differential. As a result, underbalanced drilling allows a well to flow oil and/or natural gas to the surface.

This technique is typically employed when the reservoir pressure has fallen below about 8.3 pounds per gallon. Drilling is then conducted with lightweight fluids possessing a specific gravity less than 8.3 ppg.

The advantages and disadvantages of underbalanced drilling

The benefits of underbalanced drilling extend far beyond a producer’s ability to utilize previously hard-to-harvest oil and gas. Among other things, UBD helps to minimize damage to underpressurized hydrocarbon pools or formations prone to lost circulation; increased drilling rates have been observed with certain rock types; bit life may be extended; reduced chip holdown occurs, allowing the bit to continuously cut new rock which is then swept away by the drilling fluid; and, oftentimes, well stimulation can be eliminated, further protecting damage-prone formations.

It is important to realize that underbalanced drilling is not a miracle technique; as practiced most often today, it is a complicated process that, in general, increases the overall production risk. Hole instability, well control issues and detection of kick need to be considered when choosing to uti-
lize underbalanced drilling. Drillstring vibrations are often more pronounced, higher drag and torque will be experienced, and there is often a general attenuation of the conventional MWD mud pulse signal. Surface cleaning equipment must be made available and may have to accommodate a complex mixture of fluids and cuttings.

One of the most common methods of creating low-density drilling fluids is through aeration. Aeration can create additional, unique problems apart from those typically associated with underbalanced drilling. Aerated drilling fluids are compressible in nature, which gives them a complicated and demanding hydraulic profile. Compressors will need to be rented, considerably increasing the daily drilling cost. And, if air is used to aerate the drilling fluid, an explosion potential exists due to the formation of hydrocarbon/oxygen mixtures and the frictional sources of ignition downhole. In addition, air in contact with steel drillstrings is a corrosion risk.

An innovative technique for creating low density fields

Field tests have shown that the use of 3M™ Scotchlite™ Glass Bubbles—a low density additive that has been used as a polymer filler for years but is still relatively new to the oil and gas industry—can help alleviate many of the risks attendant with aeration.

3M™ Scotchlite™ Glass Bubbles are high strength, low density, hollow glass microspheres. Made from soda-lime-borosilicate glass, they are unicellular; chemically inert except in the presence of hydrofluoric acid; and have high water resistance, temperature resistance and pressure resistance.

Scotchlite glass bubbles have been successfully used as engineered fillers in many other industries, including aerospace and automotive, where their high strength-to-weight ratio is beneficial. They are also used in buoyancy modules for undersea risers. These hollow glass spheres range in average true density from 0.38 g/cc to 0.60 g/cc, with isostatic crush strengths from 4,000 psi to more than 18,000 psi.

This combination of properties—strength under pressure and low density—makes them ideal candidates for demanding downhole conditions, particularly as density-lowering additives for drilling fluids. Scotchlite glass bubbles have the ability to create a lightweight yet incompressible fluid that can overcome some of the limitations associated with aerated fluids in underbalanced drilling applications, while retaining the benefits of UBD:

• They can successfully and predictably reduce the density of drilling fluids
• They can survive demanding downhole conditions and are compatible with standard surface cleaning equipment and pumps
• In concert with calcium carbonate, they can help stem fluid filtration loss
• They will not adversely affect the rheology of a fluid
• They can help reduce formation damage
• Reducing the friction of drilling fluids, they help lubricate the drillstring and reduce the casing wear
• They are reusable

3M™ Scotchlite™ Glass Bubbles vs. Aeration

The advantages of using Scotchlite glass bubbles to reduce the density of drilling fluids begin and end with simplicity. Fluids made with hollow glass spheres are single-phase, meaning they are virtually incompressible with simple, hydraulic behavior. Aerated fluids are typically multiphasic, yielding a mixture with complex hydraulics. Also, there is no need for a compressor when using Scotchlite glass bubbles. The product is easily added to drilling fluids using only a venturi hopper.

Scotchlite glass bubbles can allow producers to use near balanced or balanced drilling when appropriate. Because drilling fluids made with Scotchlite glass bubbles have such predictable performance at depth, the hydrostatic head pressure can be tuned to a pressure just above that of the formation. This helps prevent oil or gas from flowing out of the well while also not damaging the formation. Well control or well stability is also less of a problem when using Scotchlite glass bubbles.

Reducing the density of drilling fluids

Scotchlite glass bubbles can be added to virtually any type of existing fluid system to reduce its density, including fresh water, brine, diesel or any other base. The density reduction of a drilling fluid is directly proportional to the concentration of these hollow glass spheres. Increasing the concentration of Scotchlite glass bubbles decreases the fluid’s weight. Scotchlite glass bubbles are independent of the nature of the liquid and basically extend the density window of a liquid into ranges only achieved by aeration.

There are practical limitations to the use of these materials, however. Every grade of Scotchlite glass bubble has an upper limit as to how much of a weight reduction can be attained. For the most part, these limitations are governed by the viscosity of the glass bubble-filled fluids and vary only slightly for different bases. As a general rule, the upper limit concentration of Scotchlite glass bubbles is 50% by volume. Above that level, viscosity grows exponentially, although thinning additives and similar products may be used to increase the concentration above 50% by volume.

Performance

The mechanical integrity of Scotchlite glass bubbles is one of the most important factors to consider when thinking about using them to lower fluid density. Because of that, 3M has conducted several experiments to determine their survival rate in a variety of process equipment and
drilling applications. Initial testing at the Drilling Research Center (Houston, Texas) determined the fate of glass bubbles immediately after they exited bit nozzles. These tests showed that glass bubble breakage was minimal, and limited to a very small percentage.

Beyond this experiment, testing of the effect of nozzle impact has been limited, but proper selection of certain parameters will ensure the maximum survivability of the glass bubbles. Nozzle outlet diameter and the standoff are the parameters that can be selected to optimize the integrity of Scotchlite glass bubbles for the most common bit nozzles. In some nozzles, adjusting the angle of the velocity vector around the exit circumference is also effective.

While mechanical integrity is undoubtedly of paramount importance (the bubbles must survive the nozzles to function properly), they must also survive the pressures at depth. For every density of glass bubble, there is a corresponding collapse pressure. Some grades can tolerate very high pressures, in excess of 18,000 psi, making them ideal for use in very deep wells.

Because there is a danger of collapse, the choice of glass bubbles grade should take into account its pressure rating and the largest expected dynamic bottom hole pressure. When sufficiently high pressure ratings are chosen, Scotchlite glass bubbles can work very well. Experiments have shown that the compressibility ratio of glass bubbles/water mixtures is practically identical to the compressibility of pure water—suggesting that Scotchlite glass bubbles are virtually incompressible.

The final test of the mechanical integrity of Scotchlite glass bubbles is likely to be on-site pumps. Drilling fluids incorporating glass bubbles are compatible with centrifugal pumps and with triplex pumps. Tests indicated no change in drilling fluid density, indicating that the glass bubbles were not damaged by either pump.

**Rheology**

The rheology of various systems incorporating Scotchlite glass bubbles is very similar to conventional fluids. Table 1 shows the results for systems using Scotchlite glass bubbles with a true density of 0.38 g/cc in different quantities to achieve high and low density limits. The data were acquired via a standard API test procedure with a Fann 35 viscometer.

<table>
<thead>
<tr>
<th>Fluid Type</th>
<th>Density ppg</th>
<th>Plastic Viscosity, cP</th>
<th>Yield Point lbs/100•ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymeric/Viscoelastic</td>
<td>8.0-6.8</td>
<td>17-42</td>
<td>34-48</td>
</tr>
<tr>
<td>100% Oil</td>
<td>6.8-5.6</td>
<td>19-30</td>
<td>10-18</td>
</tr>
<tr>
<td>60/40 Oil/Water Emulsion</td>
<td>7.2-6.1</td>
<td>27-43</td>
<td>15-24</td>
</tr>
<tr>
<td>Microbubble</td>
<td>7.8-6.2</td>
<td>5.7-15</td>
<td>15-30</td>
</tr>
</tbody>
</table>

**Fluid filtration loss**

The spherical shape and incompressibility of Scotchlite glass bubbles do not make them good fluid loss control or lost circulation agents. By themselves their influence is minimal. In combination with primary agents, however, glass bubbles can play a synergistic role in preventing fluid loss and lost circulation.

That’s because of their large particle size distribution. With a large population of particles in the 10-74 micron range—all at low density—they can act in concert with a primary bridging agent like sized calcium carbonate. Together the two particles form a useful filter cake when the granulometric distribution is chosen according to the permeability and porosity of the reservoir. Recent testing has shown that the addition of calcium carbonate (15 ppb) plus Scotchlite glass bubbles (15 ppb) to an aqueous fluid reduced spurt from 5.8 cc/30 min to 2.2 cc/30 min, and the corresponding total filtrate from 10.4 cc/30 min to 5.8 cc/30 min at a pressure differential of 1500 psi. Scotchlite glass bubbles were also able to compensate for the density increase due to the addition of calcium carbonate, returning it to the level of the original fluid formation.

**Reducing formation damage**

The tight filter cake formed by calcium carbonate and Scotchlite glass bubbles also helps to reduce formation damage and restore the formation’s original permeability. When a control fluid is used—devoid of glass bubbles or calcium carbonate—permeability returns of only 60% were obtained. In contrast, when the tight filter cakes were removed with low-pressure backflooding (< 10 psi), the formation exhibited a nearly 100% return to the previous permeability level.

**Lubricity and casing wear**

Solid plastic spheres are often used to reduce friction in highly-deviated wells. Scotchlite glass bubbles, because they are nearly perfect spheres, have been shown to help reduce casing wear and increase lubricity without the addition of solid spheres. Drilstring friction is reduced regardless of the base. When using a polymer mud base, the addition of 35% by volume of Scotchlite glass bubbles reduces the friction coefficient from 0.25 to 0.18. A casing wear study, with a water-based mud, showed a reduction in wear by 68% when glass bubbles were added.

**Reuse and recovery**

Not only are expensive compressors unnecessary when using Scotchlite glass bubbles as a density reducing agent, the glass bubbles themselves are reusable, greatly reducing potential costs.

The small particle size of Scotchlite glass bubbles allows their use in surface cleaning equipment. Shale shakers and hydrocyclones have been successfully used with no ill
effect to the glass bubbles. A mesh count larger than 100 but smaller than 200 should theoretically allow all the Scotchlite glass bubbles safely through the screen while trapping the cuttings. When a hydrocyclone is employed, the tendency is for the glass bubbles to remain in the fluid and travel on to the overflow discharge. Because of the low density of the glass bubbles, the inlet pressure needs to be monitored closely so that the separation is optimal. If the correct procedures are followed, however, the bubbles are once again ready to head into the borehole.

Recovery is slightly more complicated, but not overly so. Experience has shown that reclamation with conventional shale shakers or hydrocyclones are not efficient methods. Recovery is best accomplished by making use of the product’s low density.

Less dense than water, all Scotchlite glass bubbles can be expected to float, especially if the rheological properties of the fluid are destroyed by the addition of additional water. Experiments have shown that the separation of Scotchlite glass bubbles from a water-based fluid by means of dilution is possible. The test sample, a water-based fluid containing 10 ppb bentonite, 35% by volume glass bubbles, and 2% sand, reached a separation plateau of 84% after 30 minutes and 88% after 24 hours. Other samples were recoverable up to 95% with different dilution rates. More experiments and field trials need to be done, but it is clear that floatation is a potentially viable and economical method of reuse.

Conclusion

3M™ Scotchlite™ Glass Bubbles are an ideal alternative to aeration in creating low density drilling fluids. Using glass bubbles provides an incompressible, single-phase fluid—one with simple, predictable hydraulics, able to survive pressures higher than 18,000 psi. Drilling fluids made with glass bubbles are so predictable, in fact, that at balance or near balanced drilling can be used in even sensitive strata without significant danger to the formation.

Glass bubbles are compatible with conventional solids control equipment and pumps. They require no compressors and are readily field mixed. Explosion potential is reduced when using drilling fluids made with Scotchlite glass bubbles because air is never in contact with any petroleum or natural gas products. For the same reason, drillstring corrosion is greatly reduced.

Field trials have been conducted in re-entry and inclined wells in many areas of the world, including depleted reservoirs and geologically-fractured formations. Scotchlite glass bubbles have performed well, successfully meeting the challenge.

For more information on Scotchlite glass bubbles for low density drilling fluids, please contact Frank Williamson at 281-412-4704, or visit us at www.3m.com/oilandgas on the internet.