Mud Removal—Clearing the Way for Effective Cementing

Drilling mud removal is a key step for attaining successful cementing operations. Although mud removal technology has featured the use of spacers for many years, spacer design and composition have not kept up with the increasing complexity of drilling fluid chemistry. Recent industry efforts are now providing enhanced and optimized spacer solutions that clean the wellbore more efficiently, helping ensure zonal isolation and well integrity from cementing operations.

Primary cementing is a critically important facet of well construction. To qualify as properly cemented, a well must have a continuous and impermeable hydraulic seal within the annulus that isolates each zone along the wellbore. To obtain this seal, cementing operations must prevent the cement from bypassing, mixing with or being contaminated by fluids in the annulus during cement placement.

Zonal isolation relies on effective mud removal: the displacement of drilling fluids and accompanying deposits from the casing–borehole wall annulus. To achieve optimal mud removal, the displacement operation must ensure...
that the drilling fluid is thinned and dispersed and that debris such as pipe dope and scale is lifted out of the well. In addition, drilling fluid must be effectively displaced, mudcake thinned and weakened and uncontaminated cement allowed to reach a predetermined height in the annulus.

During cementing operations, a cement slurry is pumped into a well in which the annulus is filled with drilling fluid. Typically, the drilling fluid and cement slurry are incompatible and may form a highly viscous and unpumpable mixture. To prevent mixing of the two fluids, a fluid compatible with both the cement slurry and the drilling fluid—a spacer—is pumped between the two. The spacer also clears drilling fluid from the casing and formation walls.

**Displacement**

Today, operators pump a spacer that has specific fluid properties behind the drilling fluid and ahead of the cement slurry. To improve cleaning and displacement efficiency, operators often add surfactant and solvent combinations to the spacer fluid to lower surface tension and to dissolve and disperse sludge and pipe dope.

Typically about 5% to 10% of the spacer fluid volume contaminates a portion of the cement slurry. Because spacer chemistries may affect cement properties, this contamination may alter cement thickening, setting time, rheology, compressive strength and compromise zonal isolation.

Ensuring the proper rheological and chemical properties of displacement and drilling fluids is essential to fluid design. The cement slurry, spacer and drilling fluid need to have proper rheological properties, or rheological hierarchy, such that each fluid pumped is more viscous than the fluid pumped before it. For wells drilled with oil-base drilling fluid, the operator is often concerned about leaving the casing and formation in an oil-wet condition, which weakens cement bonding. To address this problem, cementers add surfactants to the spacer to change the wettability of the casing and the formation near the wellbore from oil-wet to water-wet.

The flow regime of the fluids is also important (Figure 1). In laminar flow, viscous friction forces dominate; the maximum velocity is at the center of the borehole, and the velocity reduces gradually to zero at the wellbore wall. In turbulent flow, the energy of fluid motion dominates; the particles move in an erratic circular motion, and the velocity of the fluids along the walls is nearly the same as that at the center of the borehole. Cementers usually prefer turbulent flow for drilling fluid removal. However, in narrow hole sizes, laminar flow may be preferred.

![Figure 1. Mud removal flow dynamics. In laminar flow (left), flow lines are parallel, and individual particles move in parallel paths. Mud particles tend to accumulate in static mud layers near the borehole wall, making complete mud removal difficult. In turbulent flow (right), the energetic, swirling eddies entrain more mud particles than do laminar flow paths before becoming saturated. The turbulent eddies also move surfactants or dispersants in the spacer fluid throughout the borehole to deform and remove the static mud layer at the borehole wall.](image-url)
because turbulent flow may increase flow rates and friction pressures, which can induce fluid losses into the formation and well instability; maintaining flow against high friction forces may require high surface pump pressures, which could result in downhole pressures that exceed formation fracture pressure.

By using a displacement fluid that is of higher density than that of the drilling fluid, engineers are able to ensure a flat and stable interface between the two fluids and to avoid fingering—a condition whereby the interface of two fluids bypasses sections of the reservoir as it moves along, creating an uneven, or fingered, profile. Because improper friction pressure may also cause fingering, operators typically ensure that friction forces created by displacing fluids are higher than those created by the displaced fluids, which also helps keep a flat and stable interface between the fluids.

Mud traces or residues in the annular space may cause improper cement setting and the formation of mud channels, leaving conductive paths in the cement sheath. These can become fluid migration pathways between zones and cause hydrocarbons to flow to a low-pressure zone via the annulus. Fluid migration may also cause an excessive pressure difference across the annulus, which can lead to casing deformation and ultimately to a loss of well integrity.

 Fluid migration pathways can be created when the casing is off-center in the borehole (Figure 2). To avoid this type of mud channeling, centralizers are used to keep the casing centralized in the wellbore, which enables even distribution of cement in the annular space (Figure 3).

Final choice of spacer type designs and solutions for oil-base and water-base drilling fluid applications vary widely and are subject to operator preference and service company recommendations. Although operators may have unique preferences, most spacer options are specific to an operational area and considered standard. To ensure successful mud removal, the spacer must be optimized for the specific well conditions and drilling fluid.

By changing spacer composition, viscosity and density, or by adding various surfactants and solvents to the spacers, cementers can significantly improve mud removal.

Cleaning the Way

Over the past few years, to meet the needs of increasingly complex wells and to ensure long-term well integrity, researchers have made considerable improvements in drilling fluid chemistries. Although these fluids can boost drilling performance, because of their increased complexity, they may be more difficult to remove from the well prior to cementing. Developments in spacer technology have not kept up with those of oil-base drilling fluids; the industry is still using generic surfactants and solvents in viscosified spacer fluids.
Spacer design, selection and testing are performed on a case-by-case basis because oil-base drilling fluid composition and downhole conditions vary significantly. Although standard API test regimes and other recommended practices are available for spacer evaluation and testing, some exhibit low repeatability and others apply only to fluids at temperatures below 88°C [190°F].

To enhance reliability and repeatability of the engineered spacer evaluation, Schlumberger researchers used improved laboratory procedures and equipment (Figure 4). For example, cleaning tests can now be performed under pressurized conditions and at temperatures exceeding 88°C. In addition, engineers select optimal spacer chemistry as a function of the base oil, salinity and temperature conditions in each well by applying response surface methodology (Figure 5).

A mature development field in Asia, operated by Mubadala Petroleum, comprises six platforms and a floating production, storage and offloading vessel. The field is located in the Gulf of Thailand and produces oil from layered sandstone reservoirs in which bottomhole temperatures can reach 105°C [221°F]. The producing section is drilled using an 80/20 oil/water ratio low-toxicity oil-base drilling fluid and cemented with extended Class G cement.

The operator has drilled more than 100 wells in this field using a conventionally weighted spacer that has additional surfactant for mud removal. Recent quality assessments of primary


5. Response surface methodology is a statistical experimental design process. This methodology explores relationships between several explanatory variables and one or more response variables, and its main purpose is to use a sequence of designed experiments to obtain an optimal response. Response surface methodology is often used to refine models after important factors have been determined using factorial designs.

6. Neat cement slurries are prepared from API Class A, C, G or H cements and typically have densities in excess of 1800 kg/m³ [15 lbm/galUS]. Any material that has a density lower than cement can be used as an extender and act to reduce cement slurry density.

Figure 3. Welded bowspring centralizer. A centralizer (left) is made up of a hinged collar and bowsprings. The bowsprings press against the wellbore wall (right) to keep the casing positioned toward the center of the wellbore, and the hinged collars secure the centralizer on the casing or liner. Centralizers are placed on the casing to keep the casing positioned in the center of the wellbore. When cement is pumped after the spacer, the centralized casing will ensure that the cement will be evenly distributed in the annulus to yield a perfect seal.

Figure 5. Engineered spacer design. Based on tests leading to the development of the CemPRIME spacer technology, engineers created a surfactant selection diagram. The diagram gives a recommendation on the surfactant blend based on spacer salinity, bottomhole temperature and a nonaqueous drilling fluid (NAF) base oil type. Two surfactants and three solvents make up the five formulas that are efficient in the majority of cases.
cement jobs in production sections have indicated the operator has achieved suboptimal zonal isolation. Engineers suspect that residues from oil-base drilling fluids have hindered proper spacer placement and adversely affected the set properties of the cement.

Even though it had not experienced problems with nonproductive time or service quality issues, because zonal isolation is a critical factor for success in the planned wells of a nearby field, the operator sought to assess and improve spacer performance. Engineers sent samples of the oil-base drilling fluid to a regional laboratory to compare the efficiency of the CemPRIME engineered chemistry, which was recently developed by engineers at Schlumberger, with that of the conventional spacer that the operator had used. Laboratory tests indicated that the performance of the engineered spacer, when compared with that of the conventional spacer, provided a two-fold increase in cleaning efficiency.

During tests, the cement was contaminated with 10% spacer. Although contamination from the previously used formulation modified the cement’s compressive strength by 40% over a 24-hour period, contamination by the engineered spacer had essentially no effect on compressive strength.

On the basis of these test results and other laboratory tests and evaluations, the operator opted to test the engineered spacer while cementing a production zone. Upon completion of primary cementing, engineers confirmed zonal isolation through cement bond logs and ultrasonic imaging. They also determined that the top of cement was on target and that implementing the engineered spacer did not affect job execution. Following this success, the operator is implementing the engineered spacer for planned wells in the same field.

In some wells that have technically demanding objectives, conventional spacer solutions may not be the best choice despite the appeal of lower cost. In 2014, Schlumberger scientists rolled out a new process for designing and executing the spacer MUDPUSH Express for cementing. While its predecessor, MUDPUSH II for cementing, is a standard industry batch-mixed spacer, this new spacer features on-the-fly mixing—an automatic volumetric mixing system. The spacer can be mixed using traditional dry blend additive, and the new solution allows continuous mixing of the mud removal system using a standard cementing unit equipped with a circulating mixer and an averaging tub. This process provides efficiency gains during the mud removal process by simplifying mixing and eliminating the need for additional resources.

A rapid-hydrating polymer that provides required spacer viscosity facilitates immediate mixing; the system starts out as a laboratory-confirmed dry blend containing barite, a rapid-hydrating polymer and an antifoaming agent. When combined with water in the recirculating mixer, the polymer is hydrated and ready for pumping within one minute. Cement engineers confirm spacer quality at the wellsite using a funnel viscometer and pressurized mud balance. If changes in well conditions occur before the spacer is pumped, the spacer blend can be modified prior to mixing.

A 3D Point of View

Many operators choose mud displacement solutions based on prior experience or accepted practices rather than an approach in which the choice is part of an integrated, engineered operation. As a consequence, displacements have been compromised when the various parties focus exclusively on their respective segments during the planning phase.

This lack of integration can cause engineering teams to neglect critical transition elements, leaving the well poorly prepared for completion or production operations. Improper wellbore preparation is a major cause of reservoir damage and restricted production. Failure to adequately design and execute drilling fluid displacement operations may also require additional rig time to repair damage and recover production. Operators estimate that 30% of failed completion operations are caused by inadequate removal of debris or mud or a combination of these.

A properly designed spacer will facilitate effective displacement of the drilling fluid, controlled fluid losses and thinning and weakening of the mudcake and will leave the casing and the formation near-wellbore water-wet for better mudcake dispersion and easier lift-off during production. If a spacer fails to meet any of these objectives, a well may experience a cementing failure.

In extreme cases, the selection and use of a poor spacer solution can have catastrophic consequences. Spacer selection was a component of the report on the April 2010 Macondo well blowout. The final incident report states that the Macondo blowout was a result of a series of risk-increasing decisions and actions that failed to mitigate those risks. The report also referenced the choice of lost circulation material as a spacer and the possible introduction of risk through clogging of lines that are used for certain well integrity tests. Clogged lines can limit the rig crew’s ability to conduct an accurate negative pressure test of the production casing cement job.

Integrated Solutions

After analyzing more than 40 well operations and combining findings with the latest generation chemical, mechanical and hydraulic technologies, specialists from M-I SWACO have developed the SMART 3D displacement strategy. This is a customized engineered displacement solution; the main focus of this strategy is to mitigate risk and operational problems that result from debris and incompatible drilling or completion fluids remaining in the wellbore (Figure 6).

In 2014, an operator from Romania applied this SMART 3D strategy for a land well to increase cleaning efficiency and reduce rig time related to mud removal. The casing cleanup and displacement bottomhole assembly (BHA) were modeled using specialized software and included casing cleaning tools. Various laboratory tests, performed in Romania using mud samples from the field, were conducted to assess cleaning efficiency, and the results helped engineers select and design suitable chemical displacement pills.

Hydraulics parameters were identified using a hydraulics software program that provides estimated pressures and equivalent circulating densities (ECDs) for each stage of the completion operation. In addition, software simulations showed engineers the flow regimes for each fluid, considering flow rates, rheological properties and hole size. The ability to identify individual flow regimes is important because each pill has unique physical characteristics, and although some pills need to be in laminar flow, others need to be in turbulent flow to maximize cleaning performance.


After evaluating results, the Romanian operator recognized the benefits of such an approach and chose to apply the integrated SMART 3D strategy to future displacements in land operations. Operators in the Gulf of Mexico, Angola, Central West Africa, continental Europe and in California, USA, have experienced similar success with the strategy, achieving enhanced and quicker displacements as well as increased production compared with results in operations in which traditional spacer solutions have been used.

Planning Ahead
Advances in drilling fluids and cementing technologies have been driven in large part by increasingly complex wells and operations and must be paced by advances in mud removal. The industry is investing resources to meet those challenges by developing new solutions that take an integrated approach to the entire wellbore, formation, drilling fluid, cement and hardware systems to ensure that each stage is optimally engineered and planned. Similarly, operators and service companies are pursuing greater integration in engineering and planning to enable proficient, quality operations. The goal is to achieve an efficient displacement operation that provides long-term well integrity enabled by a clean wellbore. —IMF

Figure 6. Integrated displacement technology. The SMART 3D technology features new-generation tools, chemicals and hydraulic simulations to efficiently prepare a well for completions or production. Mechanical tools, such as scrapers (left), brushes (center) and magnets (right), help ensure a properly engineered mechanical cleanup and represent one of the three interdependent components of the SMART 3D strategy. The tool setup, spacer design and hydraulic system can be tailored for each particular well.