

Sealing Fractures: Advances in Lost Circulation Control Treatments

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1. Cook J, Growcock F, Guo Q, Hodder M and van Oort E: "Stabilizing the Wellbore to Prevent Lost Circulation," *Oilfield Review* 23, no. 4 (Winter 2011/2012): 26–35.
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3. Messenger J: "Technique for Controlling Lost Circulation," US Patent No. 3,724,564 (November 12, 1971).
4. Loeppe GE, Glowka DA and Wright EK: "Design and Evaluation of Lost-Circulation Materials for Severe Environments," *Journal of Petroleum Technology* 42, no. 3 (March 1990): 328–337.
5. A pill is any relatively small quantity—generally less than 32 m³ [200 bbl]—of a special blend of drilling fluid designed to accomplish a specific task that the regular drilling fluid is not intended to perform.
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7. For more on wellbore strengthening: Cook et al, reference 1.
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Of the numerous lost circulation treatments available, some are time-consuming and ineffective. Advances in fiber-based technology permit quick and efficient loss mitigation and now include self-degradable fibers. These solutions provide stable plugging and reservoir protection during drilling; the plugs then disperse, enabling production from an undamaged reservoir.

The reduction or loss of fluid returns to the surface can threaten a drilling project. Lost circulation events are not uncommon occurrences and have a range of consequences, from increasing well construction costs to jeopardizing well stability. Loss of circulation occurs mainly as a result of drilling through formations that are fractured, underpressured, cavernous or highly permeable. These thief, or lost circulation, zones can cause drilling crews to lose control of a well because the thief zones take in drilling fluid and prevent its return to the surface.

The economic consequences of lost circulation (LC) may be significant, and operators often add 10% to 20% to their drilling budgets in anticipation of nonproductive time (NPT) attributable to LC. In addition, uncontrolled loss of fluid to the formation may damage the reservoir, altering its characteristics and negatively affecting its production potential.¹

The first recorded use of a fluid other than water for rotary drilling operations was around 1901 at Spindletop in Texas, USA, when drillers pumped mud drawn from earthen reserve pits downhole while drilling the well. No record exists of the properties of this muddy mixture, nor were any discussions or information about it published. The term mud reappeared 13 years later when a *mud-laden fluid*—defined as a

mixture of water and any clayey material suspended in water for a considerable time—was used in a cable tool drilling operation in Oklahoma, USA.²

The history of the first application of lost circulation solutions is as clouded as the history of early drilling fluids. Almost any solid can be used to plug a fractured formation given enough applied pressure and proper particle size or properties. Whether the plug will remain in place when rotation and circulation are resumed, and whether it will withstand vibrations and changes in pressure are different matters. Early lost circulation materials (LCMs) were often chosen because they were readily available near the drilling sites and were inexpensive. They included cottonseed hulls, shredded leather, sawdust, straw and ground walnut shells.³ Frequently, the LCMs were made from leftover materials or waste from manufacturing processes. Today's more complex drilling operations have created the need for specially designed LCMs.⁴

The characteristics of a formation dictate the treatment to control lost circulation. Selection of the correct solution depends on understanding the formation and identifying the type and cause of lost circulation. For example, the actions required to treat fluid losses in naturally fractured rocks differ from those required to treat

10. Cook et al, reference 1.

11. Arshad U, Jain B, Pardawalla H, Gupta N and Meyer A: "Engineered Fiber-Based Loss Circulation Control Pills to Successfully Combat Severe Loss Circulation

Challenges During Drilling and Casing Cementing in Northern Pakistan," paper SPE 169343, presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Maracaibo, Venezuela, May 21–23, 2014.

losses into high-porosity and pressure-depleted formations. Additionally, downhole temperatures and exposure time to them may limit the range of suitable treatments.

Typical lost circulation treatments for fractured reservoirs involve LCM mixed into the drilling fluid, either dispersed throughout the fluid or as a pill.⁵ These treatments are designed to plug fractures. However, even though these materials may provide some level of success, the use of sized materials alone does not ensure loss mitigation, especially in formations with wide fractures. Because the aperture of the fractures is often unknown, the size of the LCM will likely be wrong. If too small, the particles will flow through the fractures; if too large, they will not penetrate the fractures at all. In either case, improperly sized LCM will leave losses uncured.⁵

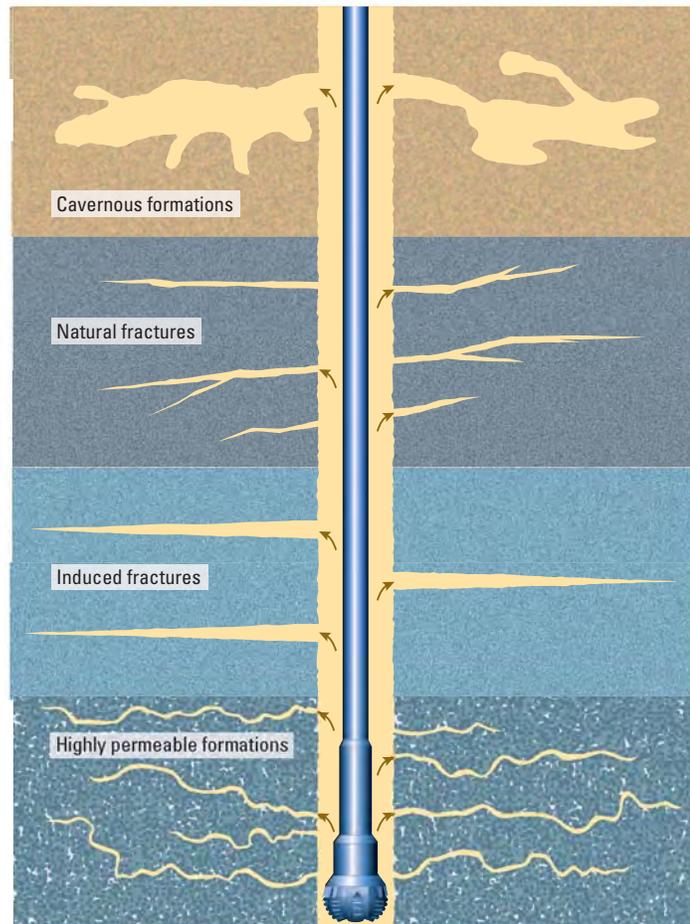
Drilling technology has progressed considerably since the early days at Spindletop; well construction and drilling operations are more cost-effective and can be executed more safely than ever before. As operators target increasingly remote and geologically complex reservoirs, they are pushing the limits of modern drilling fluids and searching for improved technologies to ensure wellbore integrity. To meet these challenges, the industry continues to introduce wellbore strengthening solutions to contain induced fracture growth and prevent uncontrolled LC from the wellbore.⁷

This article presents several remedies to combat drilling fluid losses; case studies illustrate the use of treatments. These treatments are adaptable to a wide range of environments, including naturally fractured formations, depleted reservoirs, carbonate zones and other formations prone to lost circulation problems.

Where Did It Go and What Do We Do Now?

Lost circulation is typically caused by a pressure imbalance and a pathway for fluid to enter the formation. Pressure imbalances occur in certain drilling scenarios. The principal condition for loss of drilling fluid is mud weight that is too high, wherein the mud exerts a hydrostatic pressure that is higher than the formation pressure, which can lead to fracturing of the formation and subsequent fluid loss into the induced fractures.⁸ Pathways for fluid loss include caverns, fractures and unconsolidated formations.

To operate safely in unstable, low-pressure or naturally fractured intervals—risk zones—engineers need to identify them, if possible, prior to drilling. In some types of formations, risk zones are more difficult to map than in



others. For example, the high degree of heterogeneity of carbonate formations makes reservoir characterization problematic. Carbonate formations are highly susceptible to dissolution. This can lead to formation of new pore spaces, and dissolution along fractures and bedding planes can produce large caves.⁹ In considering any formation type, engineers rely on foreknowledge to plan for preventive and remedial actions to counter lost circulation events. The most effective

mitigation is to set protective casing across problematic zones; however, this solution is expensive, limits future drilling options and may compromise logging opportunities.

Lost circulation may be divided into four volumetric loss rate categories: seepage, partial loss, severe loss and total loss (below).¹⁰ As mud loss severity increases, financial losses mount to cover costs for additional drilling fluid, lost circulation treatments, rig time and delays.¹¹

Type of Loss	Severity of Loss
Seepage	Less than 1.6 m ³ /h [10 bbl/h]
Partial	1.6 to 16 m ³ /h [10 to 100 bbl/h]
Severe	More than 16 m ³ /h
Total	No fluid return to the surface

^ Lost circulation classification. Loss is classified based on the rate of fluid volume lost to the formation.

Lost circulation management strategies depend on whether the treatment is applied before or after the loss. Lost circulation can be managed through a four-tiered approach (below). Best drilling practices cover the major types of drilling fluid losses. They include predrill simulations and calculations in which engineers use geomechanical models to determine the risk of lost circulation and wellbore collapse. Best drilling practices to control losses also include approaches such as using expandable casing, managed pressure drilling or casing while drilling. The second tier represents the selection of drilling fluids with rheological properties that reduce the risk of lost circulation. The next tier uses wellbore strengthening materials for loss management. These are mixtures of particulate materials formulated and sized to enter and bridge fractures to isolate them from the wellbore. The top tier includes using LCMs as remedial treatments to correct ongoing lost circulation problems. This tier may include pills to place across lost circulation zones.

When drillers anticipate fluid losses, they pre-treat drilling fluids by adding wellbore strengthening materials such as ground marble and synthetic graphite. Pressure tests conducted

before and after such wellbore strengthening treatments often indicate that these approaches are successful.¹² Adding wellbore strengthening materials is considered a proactive, or preventive, treatment. Lost circulation materials are, on the other hand, considered corrective, or remedial, treatments because these materials are usually added to the drilling fluid after losses occur.

Advances in Lost Circulation Solutions

Lost circulation prevention and remediation are important factors for drilling economically. When drillers cannot prevent lost circulation, they turn to mitigation treatments to regain well control and circulation.

The choice of treatment depends on the targeted geologic formation, the cause of lost circulation and whether a permanent or temporary solution is required. Prevention and mitigation practices are largely dictated by the situation; they take into account parameters such as formation pressure, formation type, drilling fluid properties, local environmental regulations and LCM availability.

Service companies offer a variety of LCMs: They can be flaky, granular, fibrous or acid soluble; they are available in sizes ranging from nano-

meters to millimeters. Mixing different types of LCMs to improve bridging and plugging performance is a common practice. Many service companies offer lost circulation solutions based on natural cellulose fiber, shredded cedar fiber and mineral fiber often combined with solid particles of various sizes. The Halliburton BARO-SEAL lost circulation material, a combination of fibers, granules and flakes sized to plug natural fractures, is one example. The company also offers the BAROFIBRE material, a natural cellulose fiber used to seal and bridge depleted sands and microfractures to reduce seepage loss. The Baker Hughes BAKER SQUEEZ high fluid-loss treatment for partial to severe fluid losses is designed to dewater and leave a solid plug in fractures and vugs.

Engineers at Schlumberger have developed several fiber-based solutions, including the Losseal family of reinforced composite mat pills and CemNET and PressureNET treatments. Although choices are plentiful, and companies offer a wide array of solutions, the preferred solutions will be those that cost effectively solve lost circulation problems quickly, safely and with the least risk.¹³

Filling the Voids

Scientists at Schlumberger took a customized treatment approach featuring engineered fibers and combinations of fibers and solids to obtain lost circulation solutions that perform consistently. These treatments mitigate loss of drilling fluid or cementing fluid in many environments, including formations that have natural fractures, carbonate zones, rubble zones and pressure-depleted zones. All these treatments may be placed at the desired depth without pulling the drillstring out of the hole. This reduces NPT and associated costs.

Fibrous pill treatment—The Losseal family of reinforced composite mat pills consists of a blend of fibers and solids that bridges and plugs fractured zones during drilling and cementing (next page, top). The Losseal family comprises three solutions optimized for microfractures and fissures, natural fractures and reservoir fractures (next page, bottom). Fracture plugging using Losseal treatments for the first two applications—microfractures and natural fractures—follows a four-step approach: disperse, bridge, plug and sustain; each step is equally important

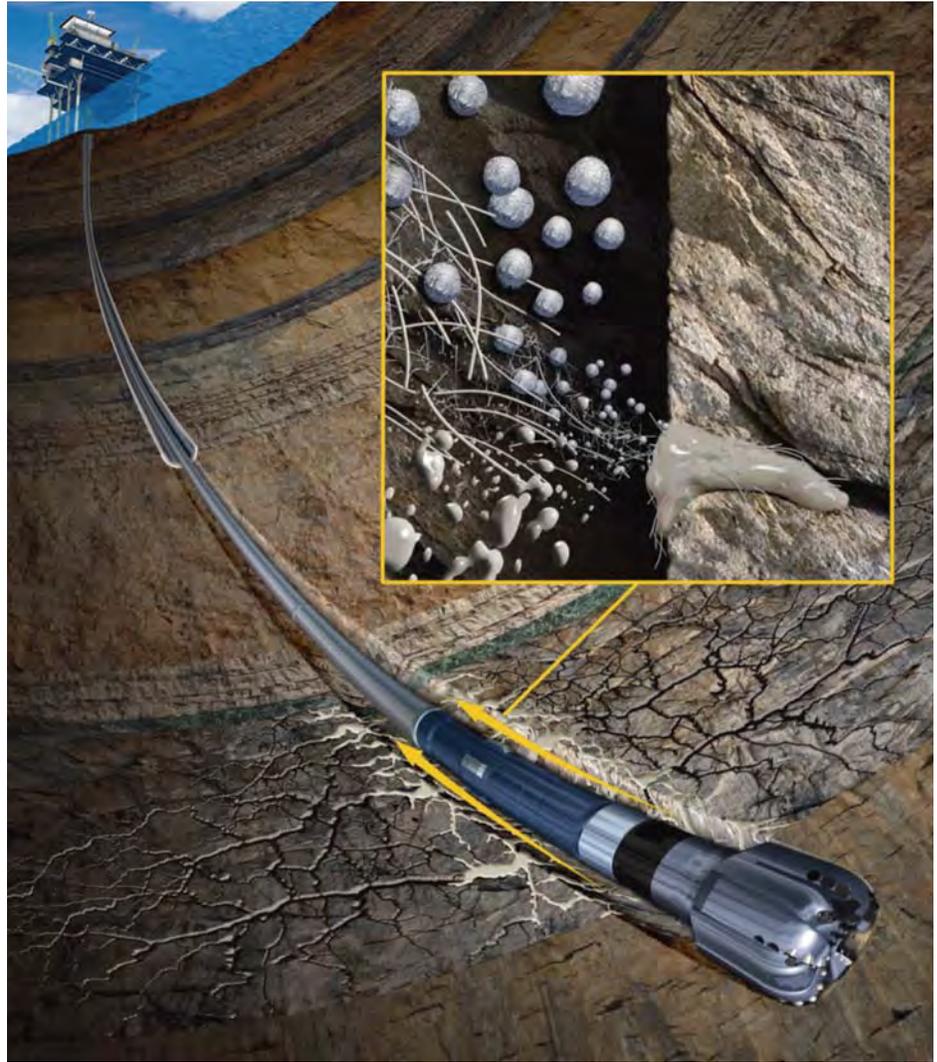


▲ Lost circulation management program. Some experts address lost circulation through a tiered approach. The bottom three tiers focus on lost circulation prevention measures, while the top tier represents remediation measures.

to achieve optimal treatment performance. Depending on the application, one particular step of the four may be the main focus. For example, when a pill is pumped while drilling, it is important to maintain the mechanical properties of the recently formed pill in the fracture while drilling operations continue. The plug must withstand erosional forces (from changes in pump rates and fluid velocities), mechanical forces (from running and rotating pipe) and hydrodynamic forces (from surge and swab). However, in a cementing spacer application, the main focus is to seal off the fractures so that cement is not lost into them. The residual spacer volume is used to displace mud ahead of the cement fluid—the primary purpose of a spacer application.

A Losseal pill creates a strong, impermeable mesh and prevents the flow of drilling and cementing fluids into fracture zones. The pill can seal microfractures and larger natural fractures in both overburden and reservoir drilling. Within limits, the plug can withstand additional pressure from mud density increases as well as future drilling or cementing operations. The Losseal pill is relatively insensitive to fracture width and may be used without detailed knowledge of formation characteristics, whereas the performance of many lost circulation treatments depends on a known fixed fracture width. Losseal pills are typically used for formations that are naturally fractured and in formations with fissures ranging from 1 to 5 mm [0.04 to 0.2 in.] in width. Engineers can perform a plugging efficiency test on site for each first-time use of the Losseal system.¹⁴ Additional tests are not needed as long as loss zone conditions remain the same and the same type of particles is used throughout the operation.

Treating microfractures and fissures— Losseal microfracture lost circulation control treatment is designed to bridge fractures of widths ranging from 1 micrometer to 1 mm. The treatment is compatible with both oil-base and water-base fluids and can be added directly to



▲ Losseal treatment pill. The Losseal pill blends fibers—both stiff and flexible—and solids that are pumped through a BHA to bridge fractures. After only about 60 minutes of soaking time, the resulting pill is able to plug the loss formation. The yellow arrows show the pill flowing up the annulus and into the formation fractures. The solids and fibers (*inset*) in the pill form a mesh, which fills and seals the fractures in the formation.

12. Wang H, Sweatman R, Engelman B, Deeg W, Whitfill D, Soliman M and Towler BF: "Best Practice in Understanding and Managing Lost Circulation Challenges," *SPE Drilling & Completion* 23, no. 2 (June 2008): 168–175.
13. Alsaba M, Nygaard R, Hareland G and Contreras O: "Review of Lost Circulation Materials and Treatments with an Updated Classification," paper AAE-14-FTCE-25, presented at the American Association of Drilling Engineers Fluids Technical Conference and Exhibition, Houston, April 15–16, 2014.
14. In a plugging efficiency test, success is based on the ability of the material to plug a slot similar in width to the anticipated fracture width. The treatment plug also needs to hold a similar pressure to the maximum differential pressure across the thief zone during operations.

Stage	Challenge	Treatment	Fracture Width, mm	Loss Rate, bbl/h
While drilling	Microfractures, fissures	Losseal microfracture lost circulation control, as a pill	Less than 1	Less than 40
	Natural fractures	Losseal natural fracture lost circulation control, as a pill	1 to 5	More than 40
	Reservoir fractures	Losseal reservoir fracture lost circulation control, as a pill	1 to 5	More than 40
While cementing	All	Losseal microfracture lost circulation control, as a spacer	Less than 1	Less than 40
While cementing	All	Losseal natural fracture lost circulation control, as a spacer	1 to 5	More than 40

▲ Losseal solutions and applications. The Losseal family consists of three treatment solutions, some of which may be applied as either a pill or a spacer. The application type dictates which solution should be used.



^ Losseal microfracture material. The Losseal microfracture solution is an engineered fiber treatment, combining specific fibers (light gray) with solid bridging materials (dark gray).

the drilling fluid in a spacer or as a stand-alone pill. The Losseal microfracture solution comes as a single-bag add-on for easy design and preparation (above). In some cases, the Losseal microfracture solution has been added to cementing fluids, bringing the top of cement to the required level.

Pill for natural fractures—The Losseal natural fracture lost circulation control pill is designed to bridge and plug large fractures of widths ranging from 1 to 5 mm. The system takes advantage of a dual fiber combination with a solids package that can be optimized for efficiency. The system can also be fully tailored to match the unique needs of the loss zone and required placement, making the performance fit for purpose. The pill can be pumped through open-ended drillpipe for efficient plugging of zones. To avoid premature screenout or plugging, it can be pumped through the bit nozzles, which may require changes to the pill formulation such as reducing total solids, using smaller sized solids and reducing the amount of fiber. The plugging performance can be demonstrated via a modified fluid loss cell, in which the flow performance through restrictions such as bit nozzles can also be simulated.

The Schlumberger fibers for lost circulation control disperse easily in fluids and work by combining an interlocking network of fibers with sealing material of various sizes. Fiber dispersion is important to avoid premature bridging and

plugging of surface and downhole equipment, and good dispersion also enhances bridging in the fractures. The bridge of fibers is still permeable, and the solids fit in the fiber matrix, filling the pores to create a sealing plug that can withstand differential pressures. The resulting compact, impermeable seal plugs pores and fractures, mitigating lost circulation risk during drilling, casing and cementing operations. The Losseal blend can be added to spacers between cement application stages, spotted ahead of the cement or added directly into the cement during pumping operations.¹⁵ Use of the material helps operators prevent lost circulation, reestablish circulation and run casing with limited losses, and then pump cement to achieve the desired top of cement level. This solution allows operators to place treatments precisely in a target zone and reduce pretreatment loss rate by more than 90%.

The Losseal natural fracture treatment was applied successfully in the Costero field near Villahermosa, Mexico, where lost circulation is a primary cause of NPT. A Schlumberger Integrated Project Management (IPM) team, operating on behalf of a client, experienced oil-base mud (OBM) losses of 2,000 bbl [320 m³] in a 5%-in. hole in a carbonate formation. The casing was set at 19,173 ft [5,844 m], and the losses occurred between 18,963 [5,780 m] and 19,173 ft. The IPM team responded by reducing the relative

density of the mud from 1.12 to 1.01 [from 9.35 to 8.43 lbm/galUS or from 1,120 to 1,010 kg/m³], resulting in a kick.¹⁶ The well stabilized with mud at a relative density of 0.97 [8.1 lbm/galUS or 970 kg/m³], but this mud density would not allow further drilling into the deeper formations.

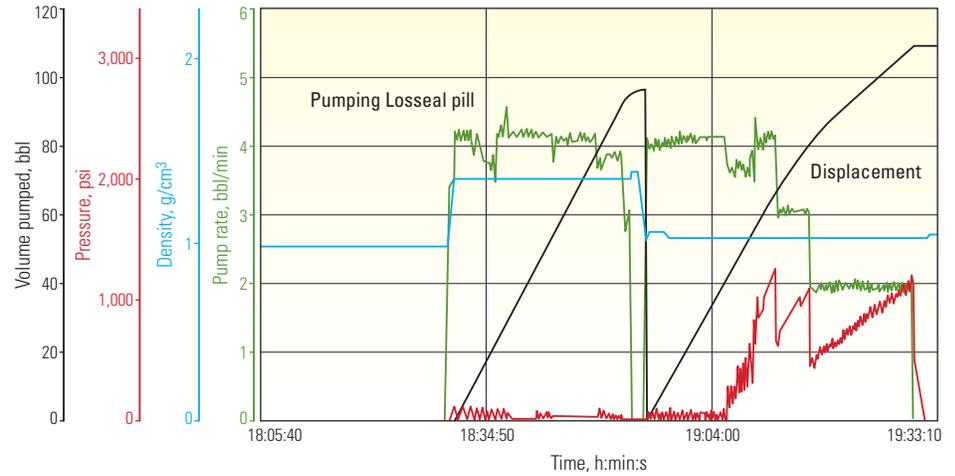
The IPM team chose to pump a Losseal pill because OBM is expensive and limited data were available on fracture width, fracture density and downhole temperature after the losses. Based on fluid loss rate and formation temperature, engineers selected the appropriate particle size for the Costero well—a 90-bbl [14.3-m³] pill, including 2.9 lbm/bbl [8.3 kg/m³] of fibers and a 217-lbm/bbl [620-kg/m³] blend of coarse, medium and fine solids. The pill was then placed as a balanced plug before a squeeze pressure of 200 psi [1.4 MPa] was applied.¹⁷ Because the system worked immediately upon pill placement and stopped static and dynamic losses in a single one-hour treatment, no trip was required (next page, top). The drilling crew increased the mud density to 1.15 relative density [9.6 lbm/galUS or 1,150 kg/m³] without encountering any losses and drilled successfully to TD. The team also completed the cementing operation that followed the Losseal pill without significant losses.

Schlumberger engineers also utilized the Losseal natural fracture lost circulation solution for an operator in south Texas. The operator planned to cement the intermediate section of a well in a single stage at a depth of 10,000 ft [3,050 m]. After drilling through the Austin Chalk and the naturally fractured Buda Limestone formation below it, the driller encountered severe mud losses and was unable to regain full circulation. The drilling crew attempted to control the losses by reducing drilling fluid density and by adding several LCM products, but these efforts were unsuccessful. Schlumberger engineers then provided the Losseal natural fracture solution, enabling the driller to regain full circulation prior to cementing and to maintain full circulation throughout the subsequent cementing treatment.

Because the operator had reduced the mud density, the oil-base drilling fluid could not reliably suspend all fibers during the treatment. The solution was a high-density fluid that had high solids content (more than 30%) and exhibited no dynamic settling of the solids. Plugging efficiency tests performed to optimize Losseal fiber concentration showed that a 2.0- to 3.0-lbm/bbl [5.7- to 8.6-kg/m³] concentration could plug slots up to 0.2 in. [5 mm] across with a differential pressure of 1,000 psi [6.9 MPa].

The Losseal pill was prepared on location and spotted across the entire suspected thief zone, from 6,800 to 9,800 ft [2,100 to 3,000 m]. To avoid possible contamination and destabilization of the pill, which could happen should it come in contact with the drilling fluid, a weighted spacer was pumped both ahead of and behind the pill. A soft squeeze, with a low applied pressure, was then performed to help initiate the bridging and plugging mechanism of the LCM particles. A total squeeze pressure of 250 psi [1.7 MPa] was applied and no pressure reduction was observed, indicating that the Losseal natural fracture pill had sealed off the loss zone. The reestablishment of full circulation immediately following the treatment was another proof of success. Drillers were also able to maintain full circulation throughout the cementing treatment by adding this LCM fiber to all fluids, the weighted spacer and the cement for the rest of the job. Pressure tests verified that the measured pressures matched the design pressures, indicating that the treatment had worked as expected (below right).

Treatment for reservoir drilling—When lost circulation occurs while drilling through a reservoir section, operators must stem fluid loss or risk damaging the zone’s producibility. Schlumberger engineers have developed a family of reinforced composite mat pills made of a blend of dissolvable fibers to provide lost circulation mitigation in naturally fractured reservoirs, carbonate formations and depleted reservoirs; the pills are designed to plug fractures that have widths from 1 to 5 mm. The pills have three components: viscosifiers, fibers and solids. The combination remains stable long enough over a broad range of bottomhole temperatures to allow well completions but then degrades with time, leaving the formation undamaged. The Losseal reservoir lost circulation treatment, which can pass through drillbit nozzles as small as 6.35 mm [0.250 in.] and through downhole logging equipment, elimi-

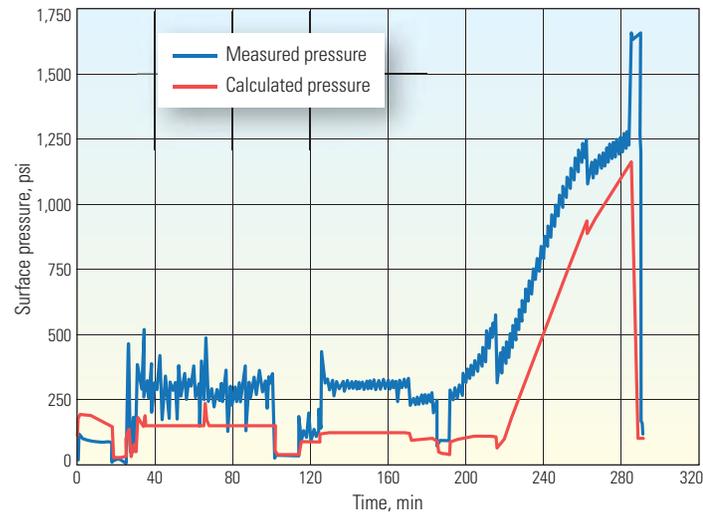


▲ Losseal pill placement. As pumping of the treatment is initiated, density increases (light blue). The pressure (red) increases on displacement when Losseal fibers are pushed into the formation and start to bridge and plug the fractures. The pressure drops as the pump rate (green) is reduced and increases again at constant pump rate, demonstrating the continued bridging and sealing effect of the Losseal treatment. The black line represents volume pumped.

nates the need to pull out of the hole to accommodate pumping of the pill.

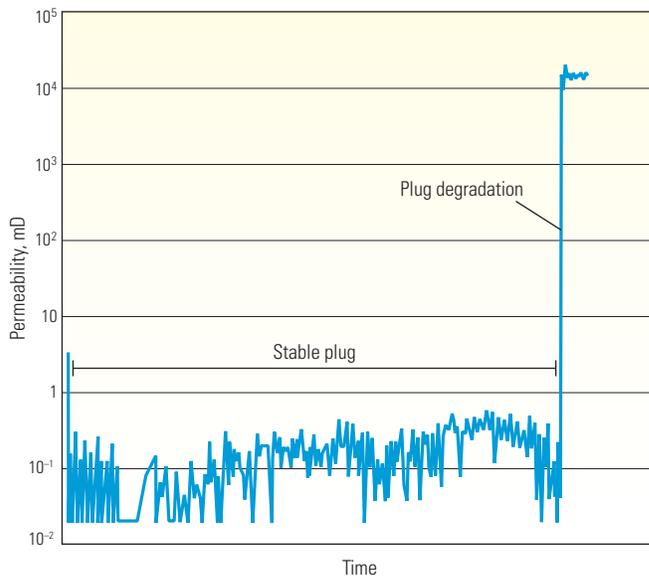
The relationship between fiber degradation and plug stability has been established through laboratory experiments. In these experiments,

developers create a plug inside a metal tube connected to a pump. The tube is then placed in an oven, and a continuous flow of a fluid analogous to the drilling fluid is applied at high pressure. The resulting pressure response is monitored



▲ Pressure test. The postjob evaluation compares calculated with actual recorded pressure during a Losseal application in a well in south Texas. A hydraulic simulation model uses well geometry data, such as hole size and deviation and casing or drillpipe sizes, taking into account fluid density and fluid viscosity, to calculate the estimated pressures during pumping. The model does not simulate possible losses; hence, any trend deviations between measured and calculated pressure could indicate a lost circulation event. The curve of the actual measured pressure (blue) follows the same trend as the curve of the calculated pressure (red), indicating that no fluid is lost to the formation and that what is pumped in is being circulated. Friction pressures and annular restrictions cause the offset between calculated and measured pressures. The pressure buildup after about 200 min indicates the rising of the denser fluid—the cement—into the annulus.

15. A spacer is viscous fluid used to aid removal of drilling fluids before a primary cementing operation. The spacer is prepared with specific fluid characteristics, such as viscosity and density, and engineered to displace the drilling fluid while enabling placement of a complete cement sheath.
16. A kick occurs when the pressure in the wellbore is less than that of the formation pore pressure. When the mud weight is too low and the hydrostatic pressure exerted on the formation by the fluid column is less than the pore pressure, formation fluid can flow into the wellbore.
17. A balanced plug is a plug of cement or similar material placed as a slurry in a specific location within the wellbore to provide a means of pressure isolation.

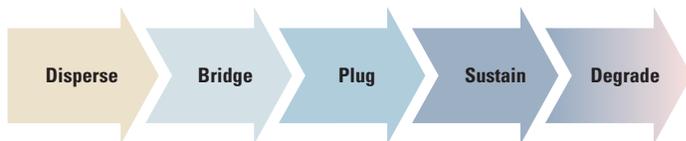


^ Losseal treatment for reservoir drilling. Losseal fibers degrade with time (*top*, time increasing to the right). Technicians regulate pill pH levels to control degradation time and to achieve a wide range of fiber stability durations, from one day to eight weeks. Here, an accelerant has been added that causes all fibers to dissolve within a desired time frame. A plot of system stability (*bottom*) shows permeability as a function of time. Permeability through the plug is low, as designed, until the plug disintegrates.

versus time. A sudden pressure drop indicates that the plug material is starting to degrade and be cleaned away and that permeability is being restored (*above*). Engineers used the results from these experiments to establish pill formulation guidelines. Factors that affect the performance of this fibrous pill solution include fluid viscosity, fiber concentration, fiber geometry, flow rate and fracture width. Engineers are currently working to extend the temperature stabil-

ity of the Losseal fibers beyond their rating of 85°C [185°F], and mid- and high-temperature fibers are being tested in the field to confirm both plugging performance and temperature stability performance up to 150°C [300°F].

Unlike other Losseal products, the Losseal pill for reservoir drilling is designed to degrade over time (*below*). The pill disperses into the carrier fluid, leaves the mud to bridge fractures and plug vugs, is sustained throughout drilling opera-



^ Losseal solution for reservoir drilling. The Losseal reservoir drilling treatment is a five-step solution. This treatment disperses in the chosen fluid; it then bridges and plugs the targeted fractures, remains stable throughout the operation and finally degrades.

tions and then dissolves with time, leaving the formation undamaged. Plug degradation is catalyzed by downhole temperature and pressure conditions and can be engineered to match drilling and completion schedules. The pill requires less than one hour to mix and can be deployed at temperatures between 40°C and 150°C [100°F and 300°F] and at mud densities from 1,030 to 1,440 kg/m³ [8.6 to 12 lbm/galUS]. After the pill is placed, a soaking time of around 60 min allows the system to flow into the fractures; pill performance is enhanced by the application of pressure to help the treatment enter, bridge and plug the fractures. The pill degradation time is adjustable, ranging from one day to eight weeks.¹⁸

The Losseal treatment for reservoir drilling was introduced in 2014 and was recently utilized by an operator in the Middle East to reduce mud and cement losses during the drilling phase while avoiding damage to the reservoir. The operator was drilling two wells as part of a cyclic steam injection project and experienced total losses at 341 m [1,120 ft] while drilling the 8½-in. section. The drilling crew continued drilling to the target depth of 472 m [1,550 ft]; loss rates reached 32 m³/h [200 bbl/h]. Because this was the intended production and injection zone, ensuring that any lost circulation treatments would neither inhibit future production nor damage the formation was crucial.

The operator needed to mitigate losses before running and cementing the 7-in. casing; the objectives were to avoid the loss of cementing fluids to the reservoir and to bring cement to the surface. The operator selected the Losseal treatment for reservoir drilling. The fibers and solids were mixed on site within an hour and the treatment material was successfully pumped. When the pill entered the loss zone, a slight rise in pump pressure indicated that fluids were rising into the annulus; returns to the surface were reestablished. After the drillstring was pulled out of the hole to 61 m [200 ft] above the top of the pill, the hole was circulated with water, and returns to the surface were observed again. The drilling crew then ran the drillpipe into the hole to the top of the loss zone, and circulation was reestablished followed by fluid returns to the surface. This treatment was successfully executed for two wells in this area.

After several months, both wells began production from the treated reservoir zones; no remedial treatment was necessary. Well testing confirmed that in both treated wells, the initial production rates, or productivity indexes, were higher than their predicted rates. These results indicated that the treatment had dis-

solved as designed, leaving the producing reservoir undamaged.

Fiber network—Deploying CemNET fibers—engineered for use in cementing fluids—is another method to seal fluid loss zones. The fibers are inert and entangle to form a resilient fiber network across a thief zone, allowing the driller to regain and maintain circulation. CemNET advanced fiber technology, which can be deployed in cement slurries across zones with expected losses, tolerates temperatures up to 232°C [450°F]. The CemNET fibers do not alter the cement slurry viscosity, thickening time, tensile strength, shear strength, compressive strength or fluid loss (right). The CemNET fibers disperse and mix readily in the slurry or fluid. Application of the CemNET treatment facilitates cement placement, eliminates excess cement costs and minimizes remedial cementing operations to repair low cement tops.¹⁹

The CemNET treatment was successfully employed in an operation in the North Sea, where an operator was experiencing severe losses while drilling out from the primary cement job in a well in the Haltenbanken area offshore Kristiansund, Norway. The cement job was executed according to plan, and the shoe was pressure tested. The shoe track, plugs, float and cement were then drilled out. However, after the rathole was cleaned out and the driller pulled the BHA out above the 7-in. liner shoe to circulate, severe losses occurred. Several LCM pills were pumped, but losses soon recurred.

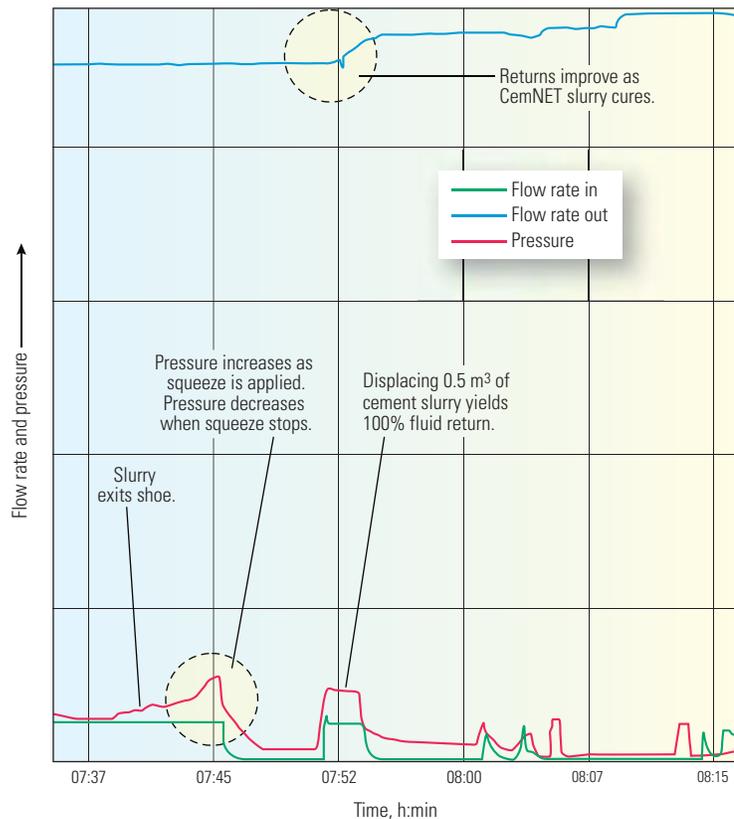
After spending 87 hours attempting to control the losses, the operator decided to try fiber-based treatments. The driller pulled the BHA out of the hole and then used the squeeze method to place a cement slurry containing CemNET LCM fibers. The cement stinger was placed, and the cement line was pressure tested successfully.²⁰ Engineers determined the final injection rate and pressure



^ CemNET engineered fiber technology. Dry CemNET fibers (left) form a sheet-like network when mixed with water (right), enabling the network to seal lost circulation zones. CemNET fibers are dispersible in any cement system and can be added and mixed quickly in a mixing tank.

and then pumped base oil and a spacer followed by the fiber-laden cement slurry. The base oil and part of the spacer were displaced without any returns, indicating continued losses. The drilling crew started injection at 200 L/min [1.26 bbl/min] into the loss zone below the liner shoe. The

CemNET slurry immediately plugged the loss zone upon arrival downhole (below). When the CemNET slurry reached the open hole, the pressure increased from 0.1 MPa to 1.4 MPa [14.5 to 203 psi]. Injection was stopped; the driller bled off pressure through the choke and opened the pipe rams. The



^ CemNET slurry squeeze offshore Norway. The surface mud log recorded pump-in (green) and flow out (blue) processes. As the CemNET slurry squeeze exited the shoe and entered the loss zone, pressure (red) built up, and circulation was reestablished.

18. Soaking time is the time it takes after placing the Losseal pill at the desired location to achieve the desired mesh, or grid, that produces the optimal bridging and plugging effect.
19. A low cement top is produced when the cement slurry fails to fill the annulus up to the intended level. This condition can be caused by loss of cement to the formation. For more on combating lost circulation while cementing: Daccord G, Craster B, Ladva H, Jones TGJ and Manescu G: "Cement-Formation Interactions," in Nelson EB and Guillot D (eds): *Well Cementing* 2nd ed. Houston: Schlumberger (2006): 202–219.
20. A cement line pressure test is conducted by applying pressure from the cement unit to the cement head or master valve connected to the well to check for leaks or any damage in the line. Common practice is to test lines up to 6.9 MPa [1,000 psi] above the maximum allowed treating pressure or to the working pressure of the treating iron system, whichever is lower.



▲ PressureNET treatment. PressureNET technology combines the strength and light weight of a lost circulation material such as vitrified shale particles (*left*) with the strength of CemNET fibers (*right*).

cement slurry remaining in the stinger was displaced out of the hole by the pump and pull method.²¹ Downhole losses were controlled, and full circulation was reestablished following the CemNET squeeze. The operator has experienced similar positive results with the CemNET fiber for loss control, and this approach has become part of the operator's contingency package.

A combination of the CemNET and Losseal treatments was used in Argentina in 2013. The drilling crew experienced partial losses when placing slurry during a cementing operation. The top of cement (TOC) was 1,100 m [3,600 ft] below the expected level, and the postjob report showed a difference between the actual and simulated pressures, indicating that fluid had been lost to the formation, which explained the TOC depth difference.

Engineers designed the cement operation for the next well based on lessons learned from the first well. Schlumberger engineers used CemNET additive in part of the slurry and Losseal microfracture treatment as the spacer. No losses were experienced while the cement slurry was placed, and data showed good agreement between calculated and actual pressure curves. The final TOC was 100 m [300 ft] above the calculated level, and cement evaluation logs showed a good cement bond. CemNET and Losseal treatments prevented losses while increasing the equivalent circulating density (ECD) when the slurry was being placed.²² When losses occurred, the treatments mitigated them through effective bridging and plugging mechanisms. As a result, the operator developed a contingency plan using the combination of CemNET fibers and Losseal material for the remaining wells in the area.

Combination lost circulation solution—The PressureNET fiber- and solids-based lost circulation solution combines dispersible CemNET fibers

with vitrified shale particles to stop lost circulation in shale, dolomite and limestone formations (*above*). The combination is capable of bridging openings up to 3 mm [0.1 in.] in width at pressures up to 5.5 MPa [800 psi]. The particles are chemically inert in most fluids. The variable-sized shale particles build up throughout the CemNET fiber network, creating a base for cement slurry solids to pack off and plug the lost circulation zone. The strength of the PressureNET shale particles helps this LCM withstand high differential pressures across fractures, thereby reducing the volume of lost drilling fluid and cement. The treatment can be added to cement slurries, spacers and drilling fluids in batch mixers or mud pits. The impermeable network created by this treatment can support the hydrostatic pressure of a cement slurry column and withstand additional pressure resulting from subsequent primary or remedial cementing operations.

In early 2013, Apache Corporation suffered severe losses while cementing production strings in wells in the Canyon Granite Wash in Oldham County, Texas. The operator used foamed cement, but the cement could not be pumped to the desired height in the annulus in two-thirds of the wells.²³ As a result, Apache was forced to perform costly and time-consuming squeeze pressure treatments before the wells could be put on production.

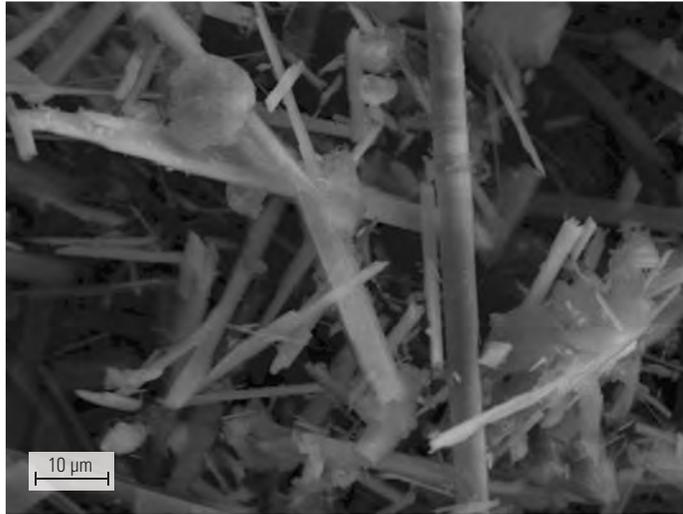
The Canyon Granite Wash is composed of arkosic clastic and carbonate sediments that were eroded from the Amarillo Uplift during the middle to late Pennsylvanian age. The formation has been producing since the late 1950s, although recent activity after a long hiatus introduced fracture stimulation and acidizing, which have produced excellent results. However, depleted zones are encountered when drilling, which

makes the formation prone to breakdown and more difficult to drill and complete. After the well experienced lost circulation and cementing problems, Apache approved the PressureNET solution for cementing the production casing in the Bivins Lit well. Following a successful job, as indicated by an observed pressure increase, per design, a cement bond log evaluation indicated that the top of cement met and even exceeded the required height by several hundred feet. Based on experience from the Bivins Lit well, Apache has chosen the PressureNET solution for several more cement jobs.

Defluidizing lost circulation solution—In situations of partial or severe losses, the FORM-A-BLOK high-performance, high-strength pill may be an option. The pill combines an inert blend of mineral, synthetic and cellulosic fibers that are coated to allow the fibers to mix in freshwater, brine or nonaqueous fluids.²⁴ FORM-A-BLOK pills can treat fluid losses in fractures, caverns or vugs and work in temperatures up to 177°C [350°F]. Standard rig equipment can be used to mix the pill. The pill does not require an activator or retarder and does not depend on temperature to form a plug. The recommended concentration of FORM-A-BLOK additive is 114 kg/m³ [40 lbm/bbl] for all freshwater, seawater and oil-base or synthetic systems except for nonaqueous slurries with densities at or above 1,790 kg/m³ [14.9 lbm/galUS], which require a concentration of 57 kg/m³ [20 lbm/bbl].

In loss situations, this treatment is applied as a squeeze pill to cure losses rapidly. The driller pumps the pill into the annulus; the volume pumped is at least 150% of that of the loss zone. Squeeze pressure causes the treatment pill to rapidly lose its carrier fluid to the formation (*next page*). The solids left behind pack into voids and fractures to form a high-strength plug that seals the loss zone. In addition to handling partial and severe loss situations, the FORM-A-BLOK pill can be applied as a quick-acting plug for wellbore strengthening operations, as an openhole remedial or preventive lost circulation squeeze, as an aid to improve casing shoe integrity and as a cased hole squeeze to seal perforations and casing leaks.

After experiencing total lost returns during a formation integrity test, an operator offshore Indonesia chose the FORM-A-BLOK pill as the solution. The integrity test was performed after drilling out the cement and 20 ft [6 m] of new formation. The objective was to achieve a 14.0-lbm/galUS [1,680-kg/m³] ECD without fracturing the formation. The operator isolated the



▲ FORM-A-BLOK high-strength additive. This scanning electron microscope image (*top*) shows the fibrous lattice form of a FORM-A-BLOK pill. After the placement of the pill, pressure is applied, which results in a defluidized fibrous lattice (*bottom*).

well with the upper pipe rams and started increasing the wellbore pressure. A pressure of 4.6 MPa [670 psi] was held for five minutes, after which the operator attempted to increase the pressure to 6.9 MPa [1,000 psi]. The formation broke down at 6.4 MPa [930 psi], and all returns were lost. Before the pressure test, the operator had perforated and squeezed a calcium carbon-

ate pill to contain losses in a thief zone. The engineers estimated that the thief zone was located directly above the casing shoe.

A fluids engineering team from M-I SWACO, a Schlumberger company, suggested the use of the FORM-A-BLOK pill to isolate the perforations and avoid recurring losses of the water-base drilling fluid. The operator immediately dis-

placed the well with seawater and pulled the BHA up to 20 ft above the top of the perforations, while the rig crew mixed a 40-bbl [6.4-m³] FORM-A-BLOK pill. A total of 37 bbl [5.9 m³] of the pill was pumped through the bit at a rate of 3 bbl/min [0.5 m³/min] with no observed pressure on the standpipe, which meant that losses were not yet controlled. The pill was followed by 58 bbl [9.2 m³] of mud. Afterward, the drilling crew observed displacement returns, and the pressure increased to 0.8 MPa [116 psi], indicating that the pill had begun sealing off the perforations. Immediately after spotting the pill, the crew applied a squeeze pressure, forcing the pill to release its fluids and leave a malleable, solid plug in place. The squeeze pressure was repeated, leaving a total of 15.8 bbl [2.5 m³] of FORM-A-BLOK material squeezed into the formation. Full circulation was restored, water-base mud was reestablished as the displacing fluid without incident, and drilling operations recommenced without further losses.

Flexible Future in Fiber

These lost circulation treatments have been used in hundreds of jobs around the world. Important benefits of these solutions include their ease of use, the time they save by not having to pull out of the hole and the limited time needed for treatments to have the desired effect.

Because of the diversity in lost circulation treatments and the variety of loss situations, drilling experts must work on a case-by-case basis to match the proper treatment to a specific loss situation. These treatments have proved to efficiently mitigate losses in fractured formations. Developments in lost circulation solutions, such as fiber technology, provide efficient and resilient treatments while saving rig time. The hunt for improved, more reliable treatment solutions is not over, and the future of fiber technology promises further advances. —IMF

21. In the pump and pull method, the cement slurry is pumped through a drillstring equipped with a tailpipe. During the placement of cement in the borehole, cement inside the tailpipe is pumped out while the tailpipe is pulled through the zone. This avoids the risks of cementing the pipe in place or leaving cement in the tailpipe after the operation is completed.

22. Equivalent circulating density (ECD) is the effective density exerted by a circulating fluid against the formation that takes into account the pressure drop in the annulus above the point being considered.

23. Foamed cement is a homogeneous, ultralightweight cement system consisting of base cement slurry, gas and surfactants. Foamed cements are commonly used to cement wells that penetrate weak rocks or formations with low formation fracture gradients.

24. Sanders MW, Scorsone JT and Friedheim JE: "High-Fluid-Loss, High-Strength Lost Circulation Treatments," paper SPE 135472, presented at the SPE Deepwater Drilling and Completions Conference, Galveston, Texas, USA, October 5–6, 2010.