AADE-11-NTCE-25

Is It Really Possible to Efficiently Form A Strong Seal inside Subterranean Openings without Knowing Their Shape and Size?

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This paper was prepared for presentation at the 2011 AADE National Technical Conference and Exhibition held at the Hilton Houston North Hotel, Houston, Texas, April 12-14, 2011. This conference was sponsored by the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individual(s) listed as author(s) of this work.

Abstract

We often do not know the shape and size of subterranean openings or mud loss flow paths. With these unknowns, conventional particulate pills tend to fail to match the unknown geometries and dimensions of the flow paths, causing a low success rate.

This paper introduces a new technology that has been successfully applied in the field. It properly integrates highly compressible and permeable foam rubber-like polymer chunks or foam wedges with a high fluid loss particle formula. Because of the unique deformation properties of the foam wedges, this new treatment can form a bridge within a range of small and large openings; it eliminates the absolute need to match the shape and size. Furthermore, the bridge formed by the foam wedges is permeable to the carrying fluid of the fine particle-laden high fluid loss pill. This property enables the fine particles to accumulate across the bridge to form a long and strong plug. Lost circulation can then be cured by enough flow resistance created by the long plug of certain strength.

The placement of the foam wedges into these subterranean openings is achieved by high pump rates. Filter plug formation is controlled by low pump rates. The conventional hesitation squeeze technique can be easily adopted to treat a loss zone with this new technology. It is believed that the technology can be applied to many kinds of mud losses as long as suitable foam wedges are selected; the selection of a suitable foam wedge is a simple process because one size of foam wedges can fit many different sizes and shapes of openings. This can eliminate the need to understand a loss mechanism for selecting sealant materials and for designing specific treating procedures. This versatile and self-diverting technology is also beneficial for curing mud losses when multiple flow paths exist.

Introduction

Lost circulation is a worldwide challenge for the oil industry. In west China, lost circulation is frequently encountered when drilling in one naturally fractured gas reservoir. As much as 5000 cubic meters of expensive heavy mud can be lost while drilling only one of these deep development wells. In a different province, a gas well drilling operation in a mountain area has been losing mud from the top hole to more than 5000 m in depth as a result of natural fractures and vugs.

In the Gulf of Mexico, heavy mud losses are frequently encountered while drilling a formation right below salts because of a rubble zone, a formation layer with large pores, that exists just below the salt. Several thousand barrels of mud losses are common. More important is that these mud losses tend to result in much expensive deepwater rig time.

In Oklahoma, a drilling operation for shale gas development wells has been encountering depleted gas zones and other naturally fractured zones. An operator has experienced mud losses of approximately 30,000 barrels in a well.

In Canada, drilling operations in tar sands frequently encounter wormholes that are created by the production of the heavy oil by thermal recovery.

In the Middle East area, including Saudi Arabia and Oman, a vugular formation exists that has caused heavy mud losses and zonal isolation problems for more than 30 years.

In Kazakhstan, drilling operations frequently encounter vugular formations, and there was no good solution to this long-standing problem.

In Germany, severe lost circulation was encountered in one deep well. More than 20 different types of lost circulation material (LCM) pills were pumped down, with no sign of success. The well was finally abandoned after the local LCM inventory was depleted.

In Mexico along the Gulf of Mexico, there is a naturally fractured carbonate formation with vugs. Mud losses are frequently encountered, and drilling cost over-runs are common.

In Qatar, a reef zone exists in the area where offshore drilling occurs. Large subterranean openings in this area have claimed thousands of barrels of mud.

In California, naturally fractured formations are widespread because of faulting activities. There has not been a satisfactory solution to the heavy mud losses.

In Australia, a geothermal drilling project is planned to drill into fractured granite formations of approximately 300ºC. However, how to cure mud losses when penetrating these large open fractures remains unknown to many.

In Wyoming, a severely depleted fractured gas formation not only caused a great deal of mud losses and non-productive time, but also collapsed casing, resulting in a failure of the entire project. It is common knowledge that depletion of a fractured formation complicates the process of curing mud losses.

There are more of these challenges coming to us because the easy-to-access reservoirs are being depleted, and the oil industry must address a greater challenge to begin drilling these unfriendly formations to meet the ever-growing worldwide energy demand.

These mud loss flow paths, regardless of whether they are fractures, vugs, or large pores, are either open in nature or closed by stress. In other words, the mud losses are basically against the fluid pressure inside these openings or the stress controlling the closure. Stress-related lost circulation can be well addressed by a method known as the Fracture Closure Stress (FCS)[1]. In recent years, field practices[2] and studies[3] have helped to attain great success in the prevention of mud losses in depleted formations. However, lost circulation in those subterranean openings, such as open fractures and vugs, lacked a satisfactory solution.

Characteristics of Subterranean Openings

Several characteristics are common of subterranean openings in terms of lost circulation. These characteristics include several unknowns (size, shape, and location), multiple openings, against pressure, and wellbore strength or pressure containment.

Unknown Size

These subterranean openings, including natural fractures, can be of any dimension and range in size from microns to tens of feet. When these openings are not large enough to be detected from the surface, drillers may have no knowledge of their sizes. However, the size may be extremely critical for the selection of a treatment and its correct application. In addition, for very large vugs, such as a cavern, though they are appreciable by bit dropping, there seems to be no good solution available yet.

Figure 1 shows quartz crystals that grew inside natural fractures. These crystals are several millimeters long and were collected at a rigsite in Wyoming along with cuttings from a depth of approximately 17,000 ft. The fractures must be larger than the crystals to enable them to grow inside. Large fractures may even result in bit dropping. **Figure 2** shows a cavern formed by an earthquake in the underground Wonder World Park in San Marcos. It is a good example for unsealed faults.

To complicate the process of sealing these natural openings, it is currently almost impossible to predict the size of these openings before a bit has penetrated through the formation unless their dimensions are in the range of hundreds of feet. Studies now can provide only some statistical information, such as density of various fractures and the probability of the aperture size. What will actually be encountered during drilling, however, remains largely unknown.

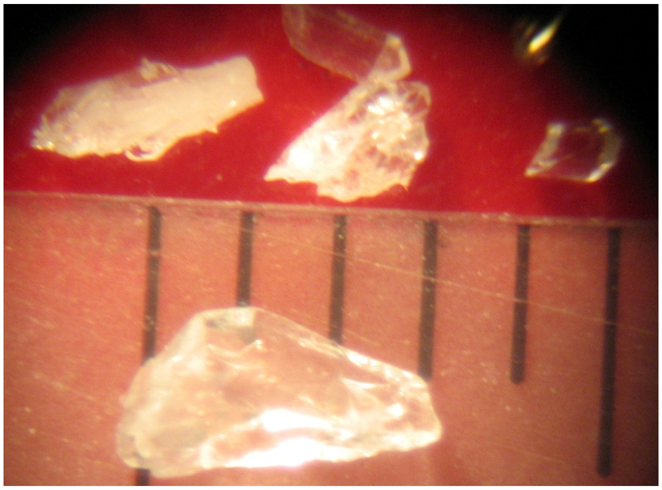

Figure 1. Quartz crystals collected at a rigsite in Wyoming.

Figure 2. A cavern from Wonder World Park in San Marcos, Texas.

Unknown Shape

Although some may assume that fractures generally have similar shapes, their shapes can vary greatly. This variance in shape often requires that a sealant design and its application take the shape into account. In addition, vugs and large pores may also have different shapes. When several of these factors occur in the same interval, it becomes quite challenging to seal these mud loss flow paths when a sealant is designed to work for only one specific shape.

Unknown Location

The location of a natural fracture at the time of a treatment is still often uncertain. At the time that lost returns initially occur, it is very likely the openings are at the bottom of the hole. When there are multiple fractures and a long interval of wellbore has been drilled, it is then complicated to locate all of the openings. Additional complications arise when some fractures open later after downhole conditions change. Furthermore, if some treatments were applied during the drilling of the interval that only temporarily cured some of the losses, it becomes very difficult to determine the location for newly found mud losses.

Multiple Openings

Except for large caverns, it is common for more than one fracture, vug, or large pore to be encountered when these zones are penetrated. For example, multiple fractures are often found in a naturally fractured formation. These fractures were formed under rock deformation over geological time to release stored energy to become more stable. These fractures tend to be generated in brittle formations, such as carbonate formations. Very often, multiple fractures with similar physical properties are generated in a formation.

Figure 3 shows rubble exposed from the retreated glacier in Glacier National Park in Canada. As a result of climate change, the glacier has been retreating over the years, leaving exposed rubble. This rubble can provide a better understanding of the rubble zones that exist below salts and of the difficulty associated with sealing rubble zones during drilling. This is another good example of multiple openings.

Figure 3. Rubble from the Glacier National Park in Canada.

Because of these multiple openings, it is very challenging to cure entire mud losses by applying only one treatment. When multiple openings exist, these openings are often of different sizes and shapes. It is difficult to ensure that a treatment slurry would reach all of the openings with a single treatment if the sealant is not suitable for all the sizes and shapes. Because a slurry tends to flow along the path of least resistance, it is very likely that, without a controlling mechanism, much more of the treatment slurry would go into large openings than small ones. In the end, a wellbore still cannot contain enough pressure because some of the openings remain untreated.

Against Pressure

Mud is lost against formation fluid pressure inside these openings. In general, the formation pressure is less than that of the fracture closure stress, often defined by the least principal stress. Therefore, the required flow resistance for sealing an opening for the same wellbore strength is greater than sealing an induced fracture.

Wellbore strength

The extent to which a wellbore can contain pressure is defined by two factors: stress and pressure. Although stress exists in a naturally fractured or vugular wellbore, it cannot yet contribute to the pressure containment because of the open channels. In this case, the wellbore strength is defined only by the formation pressure in these open fractures. When the fractures are sealed, the seal creates required flow resistance that satisfies the needed wellbore strength.

Dilemma for Conventional Particulate LCM – A Weak Seal

Particulate pills are the easiest strategy to apply in the field for logistics, mixing, and pumping reasons. Rigid particulates, however, are much more difficult to form an effective seal. These rigid materials must be small enough to enter these openings, and they must be large enough to remain there. Many lab tests on non-tapered slots indicate that particulates smaller than the slot width normally flow through the opening and fail to plug it. Larger particulates always plug the entrance and prevent other smaller particulates from entering. Because the plug formed at the entrance will actually be scraped off by drill bits or stabilizers, only a temporary seal can be formed at best. This temporary effect is sometimes referred to as scabbing. It is therefore required that a fracture be tapered and small. It would be basically impossible for particulates to seal off a much larger hole like a vug. If a solid particulate is elastic or deformable, it surely has a better chance of entering and remaining in the openings to form a seal. A seal means a stop control to a flow. After a seal like this is formed, it tends to remain weak because additional particulates flowing in or packing tight are prevented by the seal that formed initially. Applying squeeze to force additional sealant into the opening for a stronger seal will have to first disrupt this seal; however, a disrupted seal would not stop mud loss flow anymore. We usually do not know the size or shape of these openings before drilling or at the time of lost circulation. This dilemma defines a weak internal seal at best if formed from conventional particulates.

New Plug Forming Assuring Particulate Technology – An Innovative Approach

New Plug Forming Assuring Technology

A Plug Forming Assuring (PFA) wellbore strengthening technology has been proved through field work for open natural fractures. PFA technology has been achieved by using two major components of a particulate pill, although other components are necessary for other functions. The first component consists of many small pieces of specially designed, open cell, foam rubber-like chunks, or foam wedges. **Figure 4** shows some of these foam wedges. The second component consists of many micron-sized particles that can enter very small openings and promote a high fluid loss.

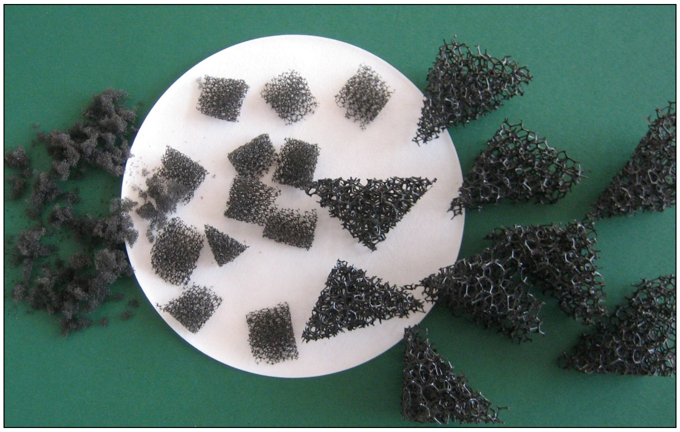

Figure 4. "One Size Fits Many" foam wedges for forming a filtration bridge.

Figure 5. Filter disc with different slots.

Foam Wedges – "One Size Fits Many"

Foam wedges play a critical role in the PFA technology for ensuring the sealing of unknown subterranean openings, such as open natural fractures. These foam wedges are highly compressible and very rubbery or resilient. They can be compressed or deformed to enter an opening that is substantially smaller and different in shape. After they enter an opening, the wedges conform to the shape of the opening and provide a good fit, even though the opening may have a very different shape or size. Because of this "one size fits many" property of the foam wedges, there is no longer any absolute need to know the exact size of the subterranean openings. For example, with only three sizes of foam wedges, such as less than 3 mm, 10 mm, and 25 mm, a large range of fracture openings can be covered. When the opening sizes are within 3 mm, only the foam wedges for less than 3 mm openings are used. When the opening sizes are deemed to be greater than 3 mm but smaller than 10 mm, a mixture of the wedge size for less than 3 mm and 10 mm can be used. If a rough estimate of the fracture size can be provided, then an appropriate foam wedge type or mixture can be easily selected.

Foam Wedges – Form an Internal Filtration Bridge

Because of the uniquely high compressibility of the foam wedges, they can easily be placed inside a smaller opening. Lab tests were performed on slurry with the foam wedges for sealing up to 3 mm against a disc with slots of 1 mm, 2 mm, and 3 mm in width (**Figure 5**). The results indicate that at a high flow rate, the foam wedges can easily pass through. At a low rate, however, they can block all slots and enable a filter plug to form on the foam wedges.

In rigsite applications, a high pump rate can be used to drive them into smaller subterranean openings, overcoming the resistance or dragging force from the wall. At a lower rate, such as when the pump is shut in or the pump rate is reduced to a certain level, the high permeability of the foam wedges enables the majority of the carrying fluid to flow through the foam wedges. Consequently, the lower rate will not apply enough force to push the foam wedges further into the openings; the wedges stop moving forward and begin to accumulate to form a filtration bridge. In cases such as a rubble zone, injected slurry flows away from a wellbore in a radial flow pattern. In these cases, the linear flow speed naturally decreases away from the wellbore, even with a constant pump rate. This means that the foam wedges larger than the pore sizes should stop moving forward at a certain point and begin to accumulate, regardless of how large the pump rate is.

Furthermore, these "one size fits many" foam wedges do not form a seal directly. Instead, they only form a filtration bridge due to their high permeability. These foam wedges can have permeability values that well exceed 10 darcies. The filtration bridge provides a plug forming assurance for the second component of the technology: fine particles in a carrier fluid that promotes high fluid loss when squeeze pressure is applied.

High Fluid Loss Slurry – Plug Forming Inside Openings

The second component, high fluid loss fine particles, can be mixed with water or base oil. It is designed to have an enormously high fluid loss. For example, forming a plug such as those shown in **Figure 6** with an API fluid loss cell at a 100 psi pressure differential requires approximately 30 seconds. To ensure a filter plug forming with the method, it is so designed that the majority of the particles will not pass through the pores of the foam wedges.

Figure 6. High quality plugs formed by filtration.

After being pumped into the openings treated with foam wedges, the particle slurry then will rapidly begin to create a filter plug on the foam wedge filtration bridges, even under a small pressure differential.

These particles can be so fine that they can enter large or small openings rather than block the entrance. **Figure 7** shows results from a lab test; a varied size of a gap was formed by a tube inside a fluid loss cell (left), and the gap is uniformly sealed by a filter plug by the fine particles regardless of the width of the gap (right).

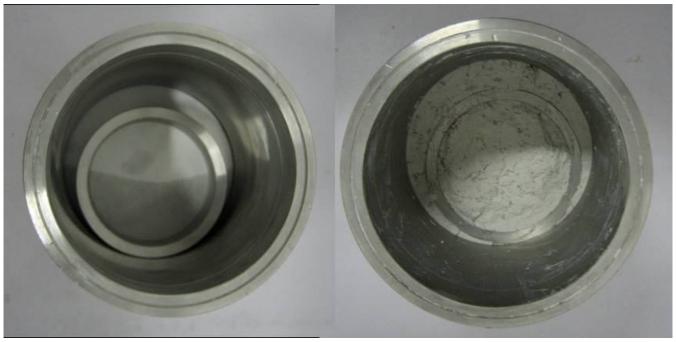

Figure 7. Lab apparatus showing a particulate plug seal forming in a gap that has a varied size.

Squeeze to Gain Enough Strength

With plugs such as these inside the subterranean openings, the wellbore strength gained is primarily determined by two factors: plug shear strength and plug length. Plugs failed in shearing mode when they were extruded by applied pressure differentials. **Figure 8** shows lab results on shear strengths of plugs formed with two different pressure differentials. High fluid loss squeeze pills differ from cement slurry. Cement slurry can gain strength with time. However, a high fluid loss squeeze pill normally can only achieve strength after forming a plug by squeeze. When no plug is formed, there will be no strength. Therefore, assuring the plug formation is critical for this type of technology to effect. Figure 8 indicates that the plug is stronger when additional squeeze pressure is applied to pack the filter plug tighter. At a packing pressure of 50 psi, the plug immediately formed has shear strength of 20 psi. However, when the packing pressure differential is increased to 100 psi, the plug shear strength is 58+ psi; this means that a plug of only 3.5 in. long is sufficient to create 400 psi extrusion resistance or additional wellbore strength. If the fracture to be sealed is 100 ft tall along a wellbore and 0.5 inch wide, the total sealant or plug volume is only approximately 2.4 ft^3. To form this plug volume, approximately two barrels of slurry is needed to be squeezed away. If the plug is squeezed for a higher strength, this volume can be even less. One can tell that this is a trivial volume in comparison with a regular squeeze job requiring approximately 80 bbl as the total slurry volume. The majority of the slurry is only used to fill up the wellbore interval to cover all potentially weak zones.

In addition, maximum pressure that can be held by a plug is also proportional to its length. For example, a plug that is 3.5 in. long can hold 400 psi; a plug that is 7 in. long can hold 800 psi. Higher extrusion resistance can be achieved by either packing the plug tighter, extending the plug, or both.

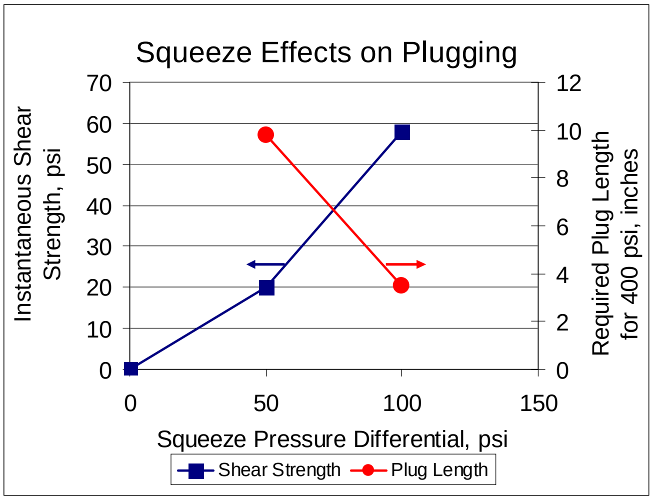

Figure 8. Lab test results for plug strengths under various pressure differentials and related plug lengths for 400 psi parallel fracture extrusion resistance.

The shear strength shown in Figure 8 is a physical strength. It is created by the inter-particle friction, which is sensitive to the loading force acting between particles and to particle packing. With a hesitation squeeze, enough physical strength can be immediately achieved through applied squeeze pressure. In addition to this physical strength, chemical strength or bonding of the particles with favorable chemical reactions can also help to create a high extrusion resistance.

Squeeze to Monitor Progress and Customize the Plug for the Required Wellbore Strength

Because of the plug forming assurance from the foam wedges, squeeze techniques can be applied. A typical squeeze method is the so-called hesitation squeeze technique. This technique not only provides a good control to form the plug, but also offers a means to monitor the squeeze progress.

With cycles of pump-on and pump-off, the foam wedges can be placed inside smaller openings, forming an infiltration bed. With the cycles, fine particles can be deposited on the bed to form a filter plug. When filter plugs begin to form, the flow resistance through these subterranean openings can be substantially increased, and the responded pump pressure during subsequent pumping should begin to increase accordingly. This will provide a clear indication of the onset of the filter plug formation. With this being achieved, an additional increase in pump pressure can push the plug slightly forward to provide more room to increase the plug length. The increasing squeeze pressure can also pack the plug tighter to increase the strength of the plug. The squeeze pressure would indicate the progress of a treatment. The pump rate and squeeze time can be adjusted based on the pressure changes. When the pressure finally reaches the designed squeeze pressure, the treatment can be stopped immediately and pump pressure bled off to enter the clean-out phase. Hesitation squeeze technique provides a means to customize the plug length and strength to the need for a specific wellbore strength. Therefore, no waiting time is necessary after the hesitation squeeze.

It is also important to gradually squeeze to reach the required wellbore strength plus a safety factor of approximately 50 to 100 psi. With this safety factor, a more reliable wellbore strengthening effect can be achieved.

Although the plug can be of super high permeability to its carrying fluid, such as water or oil, for the filter plug to form, grow, and strengthen, it is designed to be impermeable to a regular whole mud. A regular mud can easily deposit a thin mud cake on the plug, preventing further mud flow through the plug.

The function of the foam wedges is to provide a means for the particles to accumulate to form a plug. After a plug begins to form, additional particles can accumulate behind it without disrupting it because of its high fluid loss property or high permeability. Foam wedges are not necessary for retaining the strength of the plug.

Figure 9 summarizes the designed working mechanism of the PFA technology. Foam wedges are pumped into the openings to form a filtration bridge on which the high fluid loss slurry will deposit its fine particles to form a filter plug that is impermeable to mud. An additional increase in squeeze pressure will either move the plug a little further for growing it longer or pack the plug tighter.

Foam Wedges – Self-Diverting

When pumping a fluid into multiple subterranean openings, the majority of the fluid will follow the opening with the least resistance. Without control, one treatment may not be able to treat all of the loss channels and result in failure of the treatment. When foam wedges are pumped down, majority of them will also initially go to the least resistant path. When additional foam wedges are pumped into this least resistance flow path, the flow resistance will gradually increase. During this process, when the resistance is sufficiently large, additional fluid can then be diverted to other less resistant flow paths. The foam wedge slurry has a self-diverting property, which is so critical for treating multiple openings. The hesitation squeeze technique can be used to promote this self-diverting property by intentionally accumulating the foam wedges with pump-on and pump-off cycles. With this self-diverting property, there is no absolute need to know the exact locations of the openings, which enhances the probability for success.

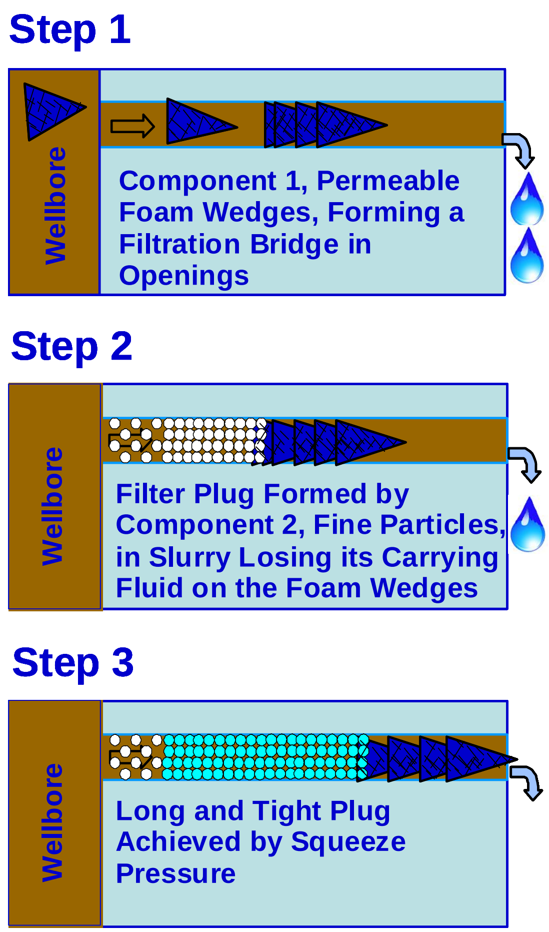

Figure 9. Designed working mechanism for the PFA technology.

Versatile PFA Technology

Unlike other conventional technologies, the uniquely high compressibility and permeability of the foam wedges enable the PFA technology to seal the following flow paths:

1. Natural fractures
2. Highly permeable zones
3. Rubble zones
4. Vugular zones
5. Open faults
6. Reef zones
7. Cement channels (shoe squeezes)
8. Large perforations
9. Induced fractures
10. Breathing fractures
11. Multiple loss zones and multiple loss types
12. Cross-flows

Sealing Unknown Openings – Small and Large

The first eight types listed are basically open channels to be sealed off. They can all be plugged as long as the foam wedges are within a range that can form a filtration bridge to enable the formation of a sufficiently long filter plug.

However, when there are some openings much larger than the foam wedges, bit dropping may be detected at the surface during drilling. In such a case, the foam wedges can be directly mixed with cement slurry to be pumped to plug the openings. Other than the filtration bridge function for forming a cement filter plug in the smaller openings, in those larger openings, the foam wedges can prevent cement slurry from flowing away before cement sets up. Lab tests indicate that, when added enough, the foam wedges can make the cement slurry behave much more viscous. Furthermore, the micro-pores in the foam wedges can trap the cement slurry and at least slow down the cement slurry from draining out. Without such control, because of density differential, the cement slurry tends to be displaced away by such as surrounded lighter mud.

When all the openings are not very large, such as those pores formed by large sand grains or gravel-like materials, although it may be less challenging than for rubble zones, the foam wedges may still be needed as a screen inside these large pores to enable the fine particles to form a sealing plug. When the pores are not large enough for foam wedges to enter, the fine particles, when designed correctly, can be just large enough to form a barrier that a whole mud cannot pass through.

Sealing Induced Fractures

Induced fractures and breathing fractures are actually less challenging to address with this new PFA technology. These stress-related fractures are closed when the fracture pressure is less than the closure stress. Because of the dragging effect of these foam wedges and the high fluid loss property of the slurry, a "fracture screen-out" effect inside the fracture can soon occur and form an immobile mass; this results in a sealed facture that has a short and fat shape. This is the most desired result for the FCS treatments, according to Dupriest[1].

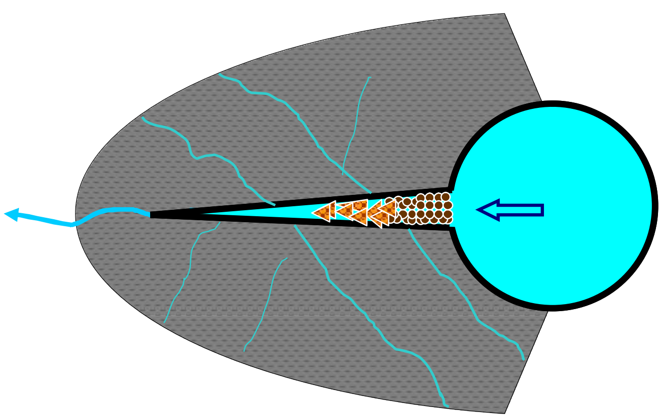

Figure 10. Treating an induced fracture in a shale formation with a natural fracture system.

When treating an induced fracture in a shale formation, the fracture screen-out effect from foam wedges can promote a lower fracture tip pressure by forming a seal earlier and nearer to the wellbore. When other natural fractures exist (**Figure 10**) or when the shale is bounded with sandstone formations (**Figure 11**), the foam wedges can provide extra fluid leaking-off to maintain a low pressure on the fracture tip side and therefore can help to stabilize the fracture longer.

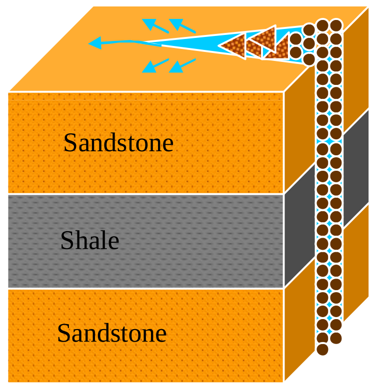

Figure 11. A weak shale formation bounded with two sandstone formations.

Sealing Dynamic Losses

A cross-flow is a situation in which a high pressure influx from the zone flows through an existing wellbore into a low stress or pressure exit zone without control. For a cross-flow, it is very difficult to seal the influx zone to stop the flow. It is much less challenging when a treatment is focusing on creating a barrier at the exit zone. With a cross-flow, when the flow rate is high, the treating slurry placed at the exit zone tends to be diluted rapidly and is rendered functionless. However, these foam wedges may help a great deal.

To control an on-going back-flow from drill pipe, a TIW valve can be mounted onto drill pipe. However, the TIW valve must be mounted when it is in the open position. After the TIW is mounted on the drill pipe, the back-flow is then controlled by closing the valve. The back-flow makes it impossible to mount a closed TIW valve in a flowing situation. This is also true for curing a cross-flow. The highly permeable foam wedges, just like an open TIW valve, create only small restrictions to the flow inside the openings in the exit zone to enable them to accumulate and form the needed filtration bridge. Then the high fluid loss slurry pumped into the openings can form a filter plug to seal them off. If the exit zone is a permeable fracture, this formulation can achieve a seal even more quickly because an immobile mass can form faster.

Loss Type Differentiation

For conventional lost circulation materials, selecting the right material for the right mud loss type is critical to its success. However, because of the lack of sufficient information at the rig site, it is very difficult to understand a loss type within a short time.

However, when a treatment is so versatile, differentiating the loss type is no longer particularly important. The priority then becomes a much less challenging estimate for selecting the size of the foam wedges. Because the foam wedges are highly deformable, an accurate estimate is not necessary. Other than a vugular zone, the subterranean openings are not likely to be very large. In most cases, only small foam wedges are needed. When a large opening is encountered, appreciable bit bouncing or bit dropping can help to determine the size of foam wedges to be used and whether cement slurry treated with foam wedges should be applied.

Field Application

General Pumping Procedure

The foam wedges and the high fluid loss particle slurry can be applied separately, but for simplicity in operation, the preferred application is to mix the foam wedges with the high fluid loss particles. A typical field application procedure consists of the following:

1. Mix foam wedges and the high fluid loss particles together with water or base oil.
2. Pump the pill downhole to cover the entire loss zone or above the zone.
3. Apply the hesitation squeeze technique to form a filtration bridge and filter plug.
4. Squeeze to the desired wellbore strength plus a safety factor of approximately 50 to100 psi.
5. Wash through and clean out possible leftovers inside the wellbore.
6. Perform a pressure test to verify the wellbore strength, if needed.

Field Cases

This technology has been successfully used in China for curing mud losses in highly fractured formations. Successful applications include those deep and high pressure gas wells in northwest China.

These gas wells have a highly fractured zone at approximately 5000 m defining a very narrow mud weight window, and the required mud weight is usually approximately 2.3 to 2.4 sg. It is critical to cure the mud losses for drilling. The wellbore must also be strengthened to ensure cementing quality for later gas production. Resistivity image logs from the wells in this area have shown many natural fractures penetrating the wellbore. **Figure 12** shows a section of the logs. Foam wedges and particles are generally mixed together in saturated salt water and weighted to 2.3 to 2.4 sg to be placed in the zone, followed by a hesitation squeeze.

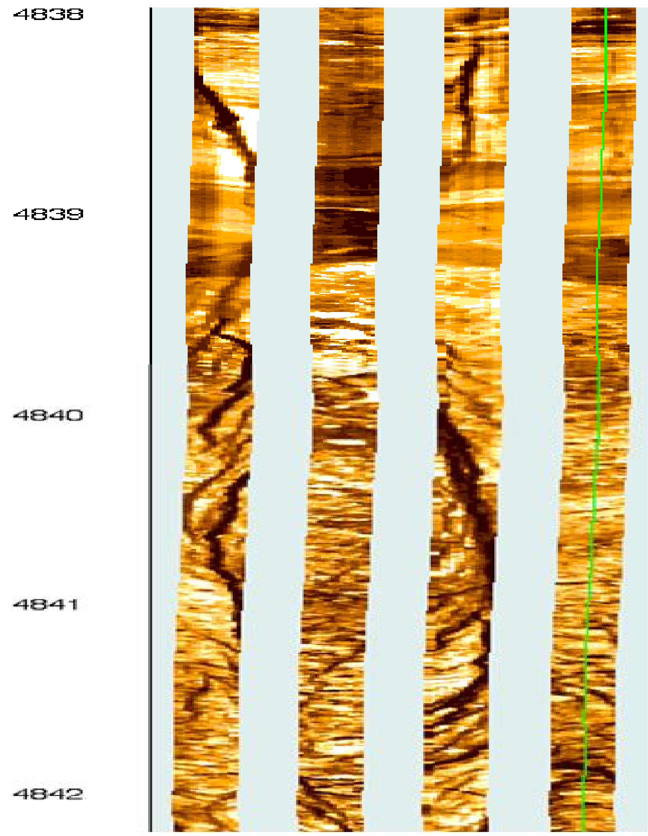

Figure 12. Resistivity image log shows natural fractures penetrated by a wellbore.

Conclusions

1. Lost circulation is a worldwide challenge for drilling. Better solutions are needed for lost circulation in subterranean openings, such as large pores, open fractures, and vugs.
2. Unknown critical factors, such as size, shape, and location of multiple openings have been technical barriers for conventional particulate technologies.
3. The two major-component plug forming assuring technology, in concept, uses highly compressible and permeable sized foam wedges and high fluid loss particle slurry. It promotes the formation of filtration bridges inside those openings, then deposits long and tight filter plugs on the bridges to seal off the openings.
4. Because of their high compressibility, foam wedges can be “one size fits many.”
5. Because of their high permeability, formed filtration bridges can ensure long filter plugs formed by the high fluid loss fine particulate slurry.
6. Hesitation squeeze can be used to apply this technology. High pump rates are used to place foam wedges into smaller openings. Low pump rates are used to ensure that the foam wedges engage the wall to form filtration bridges and to deposit filter plugs.

7. The PFA technology can be effective on many types of mud losses as long as the foam wedges and related other components are properly sized for the openings. Because of its versatility, it may eliminate the burden of understanding a loss mechanism for selecting a specific product, favoring quicker decision making and less inventory.
8. When much larger subterranean openings are encountered, the PFA technology can be applied by mixing foam wedges directly with cement to be pumped into the openings for assuring a cement plug forming.
9. The PFA technology has been successfully applied in the field for curing mud losses in naturally fractured formations.

Nomenclature

API	*American Petroleum Institute*
bbl	*Barrel*
ft	*Feet*
LCM	*Lost circulation material*
PFA	*Plug Forming Assuring*
psi	*Pound per square inch*
sg	*Specific gravity*
TIW	*Texas Iron Works*

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