

ZoneSeal® Isolation Process and Foam Systems

The ZoneSeal® isolation process helps ensure a stable, foamed slurry. This process includes a fully integrated automated system that adjusts nitrogen content to maintain constant density by accounting for increasing hydrostatic pressure with depth. A constant nitrogen rate would result in variable densities throughout the annulus due to hydrostatic pressure.

Well Depth	Density (lb/gal)	Nitrogen (scf/bbl)
5590	12	11560
7000	12	13534
8000	12	16172
9000	12	20450

There are essentially two states to consider for successfully achieving zonal isolation. The first is the dynamic state when the slurry is being placed in the annulus; the second is the static state, when the cement has set and formed a hydraulic seal between the formation and the casing. Poor performance during either state adds costs to your well. Only an optimized performance during each state is economical when so great an investment is involved.

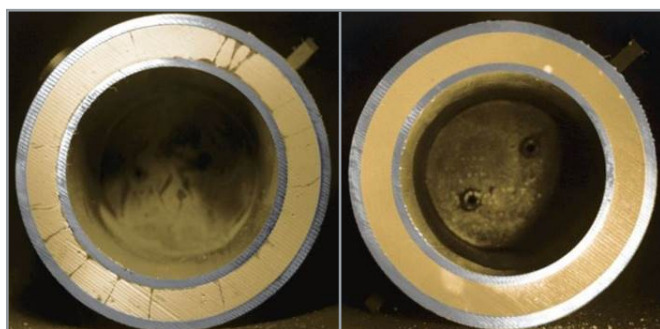


Fig 1: Sectioned samples from laboratory cyclic stress-relaxation tests performed by cementing 5 1/2-in. casing inside of 7 5/8-in. casing. In each test after curing, the internal casing was pressurized simulating actual well conditions. The conventional high-strength neat cement (left) failed when the pressure in the inner pipe reached 4,500 psi. When foam cement (right) was tested in the same way, it showed very slight debonding when cycled to 10,000 psi.

Dynamic State – Pumping Operations

During cementing operations, the slurry provides annular coverage, traveling distances up to tens of thousands of feet and yet remaining pumpable in specific thermal, chemical, frictional and pressure conditions. Additionally, the slurry displaces previous fluids in the fluid train, particularly the drilling fluid, flowing around the casing throughout the annulus to the required top of cement. Foam cement offers significant benefit in regards to mud displacement. Conventional slurries depend primarily on pump pressure to aid with fluid displacement. Foam cement, if infused properly, has an additional driving force: the controlled release of stored energy in the compressed gas bubbles traveling from the high hydrostatic pressure at the bottom of the annulus to lower hydrostatic pressure higher in the annulus.

Static State – Pumping Has Stopped

Gas migration can occur when the slurry is static after pumping stops. Loss of fluid from the slurry to the formation can alter the hydrostatic pressure in the column and provide the opportunity for fluids to migrate into the slurry column. This migration can progress until the cement column achieves a gel strength sufficient to resist the pressure exerted from the formation leaving flow channels through the cement sheath. The bubbles in foam cement actually “plate out” against the formation, helping resist fluid loss to the formation and preventing gas migration or other concerns associated with fluid loss.

Once set, a cement sheath should be designed to maintain integrity for the life of the well, resisting failure. The molecules in the gas bubbles infused throughout a foamed cement sheath can expand and contract with variations in pressure and temperature. As a result, foam cement systems exhibit greater ductility over conventional lightweight cement systems. This ductility allows the cement sheath to withstand higher hoop stresses from casing pressure and temperature cycling because it has an enhanced ability to “give” as casing expands or contracts. (fig 1)

ZoneSeal® Isolation Process – Planning and Operations

Because pressure changes the density of a foamed slurry with a constant nitrogen content, planning a foam job must be rigorous. The job should be engineered to maximize mud displacement, prevent gas or fluids from high-pressure zones from coming in and formations in weak zones from fracturing. Appropriate material testing helps ensure compatibility, foam stability and optimal material selection for individual wells. The slurry should be designed so that the bubbles remain stable as the cement flows into the well and up the annulus. Optimized slurry placement can be achieved with an evaluation of foaming muds, preflushes and spacers ahead of the cement with consideration for fracture gradients, pore pressure and equivalent circulating density.

The energy and viscosity of the pumped foam should be maintained to help ensure effective mud displacement.

The design parameters and composition of the slurry should be maintained at all times.

Halliburton's ZoneSeal isolation process uses an Automated Density Control® (ADC®) system to produce a consistent slurry at the desired density as it controls both the injection unit and the nitrogen unit based on the rate of slurry production. The injection unit adds a proprietary Halliburton surfactant blend of foaming agent and stabilizer. The nitrogen unit uses an automated system for precise control and ramping of nitrogen rate to meet job specification, and the foam generator adds mix energy to the slurry to create a stable foam. Data is captured in real time throughout the operation to compare the actual job to the planned job. (fig 2)

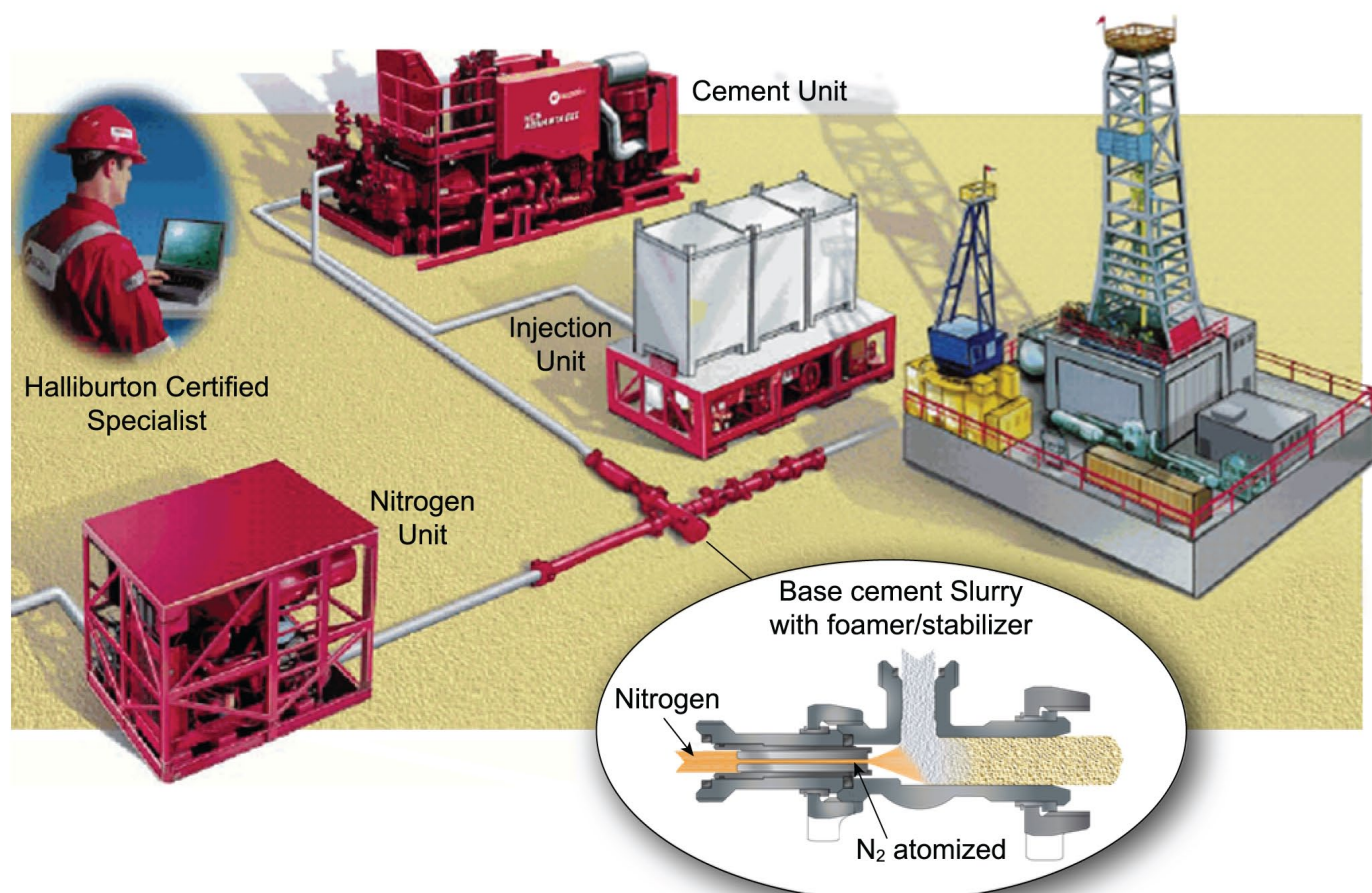
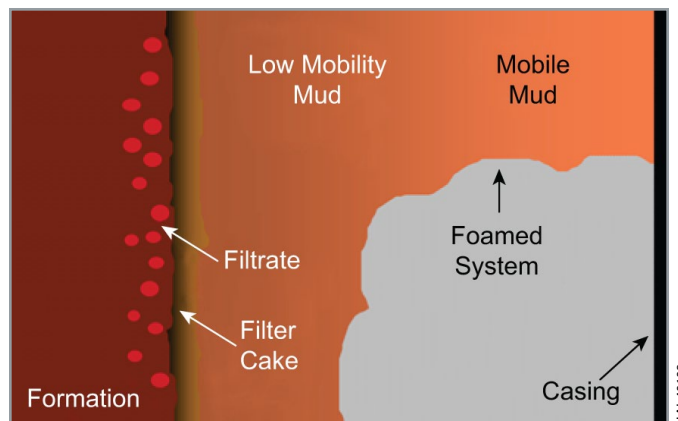


Fig 2: A typical location layout for the ZoneSeal® isolation process looks similar to this. Halliburton's Automated Density Control system helps ensure that the job proceeds according to specification and real-time data capture helps monitor the job throughout and enable more informed post-job evaluation.

ZoneSeal® Isolation Process – Wellbore Preparation

Common causes for a loss of zonal isolation from the cement sheath are due to:

- Poor primary cementing practices:
 - Thick mud filter-cake lining the hole and preventing good formation bonding. Proper displacement techniques are recommended.
 - Gas/fluid invading the cement while it sets. During gelling and prior to complete hydration, conventional cement can lose the ability to transmit hydrostatic pressure to the formation. When this occurs, fluids from the formation can percolate into the cement where it can form channels that can become future flow paths for formation fluids/gases.
- Cement failure after setting:
 - Mechanical shock from pipe tripping and drilling.
 - Expansion of the casing and compression of the cement during pressure testing and completions.
 - Expansion and contraction of the pipe due to cycles in production pressure and temperature.



As mud sits in the hole during the time it takes to run casing, filtrate can be lost to the permeable formation. The partially dehydrated (gelled) mud adheres to the wall of the formation. This is called filter cake, which is more viscous than the mud next to the casing, that remains mobile. Between the two is low-mobility mud, which requires pressure forces to induce mobility. Mobility is required for displacement. Properly foamed cement provides additional driving force for displacement due to the controlled release of energy from the compressed gas bubbles as the slurry travels up the annulus. (fig 3)

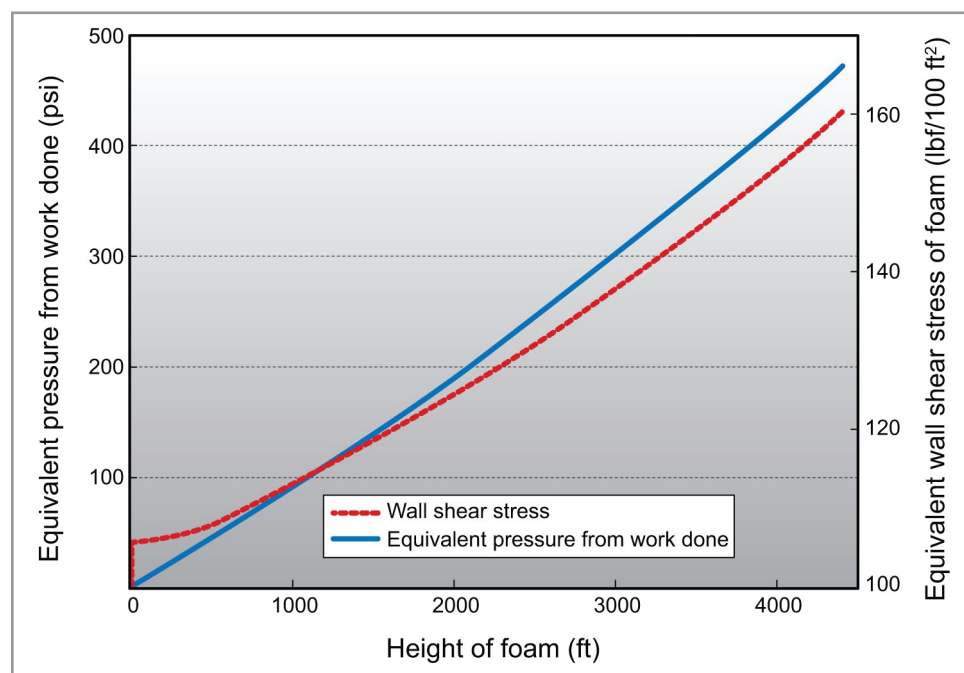


Fig 3: Graphed from laboratory test results, the blue line indicates the work done from expansion of the foam bubbles traveling from the shoe to shallower vertical depths. With released pressure comes released energy. Work done at the end of placement with this test was approaching 10^5 Joule, a pressure force aiding in the displacement of the fluid above. The red dotted line shows the wall shear stress, which keeps increasing as foam flows up the annulus. This contributes to erodability of filter cake resulting in displacement efficiency.

ZoneSeal® Isolation Process – Results Derived from Properties

Benefits of Foam Cement	
Property	Result
During pumping operations and when under pressure in the confines of the annular space, foam cement slurries are high-energy, high-viscosity systems that are more efficient at displacing mud than conventional slurry systems. Preflushes and spacers can also be foamed to make them more efficient.	Complete mud removal prepares the wellbore to receive cement by allowing direct contact with the slurry and the outer casing wall and formation to help facilitate shear-bond values for zonal-isolation integrity.
The compressed gas bubbles in foam cement shrink or expand, but they do not move around, remaining discrete instead.	Virtually no gas migration into the cement, neither during placement operations nor while setting, helping to maintain pressure as the cement hydrates.
The bubbles actually “plate out” against the formation and form a barrier.	Lower water loss to the formation, helps prevent gas migration, formation swelling, washouts, other damage.
The density of foam cement can be varied as needed using the same base slurry, even within the same job.	Hydrostatic pressure can be tailored to help protect weak formations and control high-pressure zones.
Foam cement can be mixed at very light weights, even as low as 4 lb/gal.	Helps secure lost-circulation zones.
Foam cement does not require excess water to achieve low densities.	Higher compressive strength than water-extended slurries of equivalent density making foam cement ideal for placing across zones targeted for perforating / fracturing.
Stable bubbles encased throughout the sheath make foam cement compressible, allowing the sheath matrix to flex, resisting stress cracking, and helping the bond remain intact as the casing expands and contracts.	Helps maintain wellbore integrity by resisting failures that could result in issues that may require remediation or shut in such as sustained casing pressure or unwanted produced water requiring treatment and disposal. Production can be maintained and remediation or treatment costs eliminated.
The tensile strength and mechanical properties of foam cement make it ideal for use across the production zone.	Helps overcome the risk of fracture initiation and propagation during hydraulic fracturing treatments to maintain isolated stages for an optimized stimulation treatment that delivers planned production volumes.
Foam cement can have lower thermal conductivity.	Retention of heat as fluid is injected into the well leads to fewer problems with paraffin, asphaltine and gas hydrate precipitation during hydrocarbon production.

Foam Quality (volume percentage of nitrogen)	Class G cement – Thermal Conductivity (W/m-k)	Class H cement - Thermal Conductivity (W/m-k)
0	0.86	0.81
20	0.70	0.66
40	0.51	0.54
This data is the average of results for samples tested in the temperature range from 104°F to 180°F (40°F to 82°C)		

Foam cement heading downward inside pipe

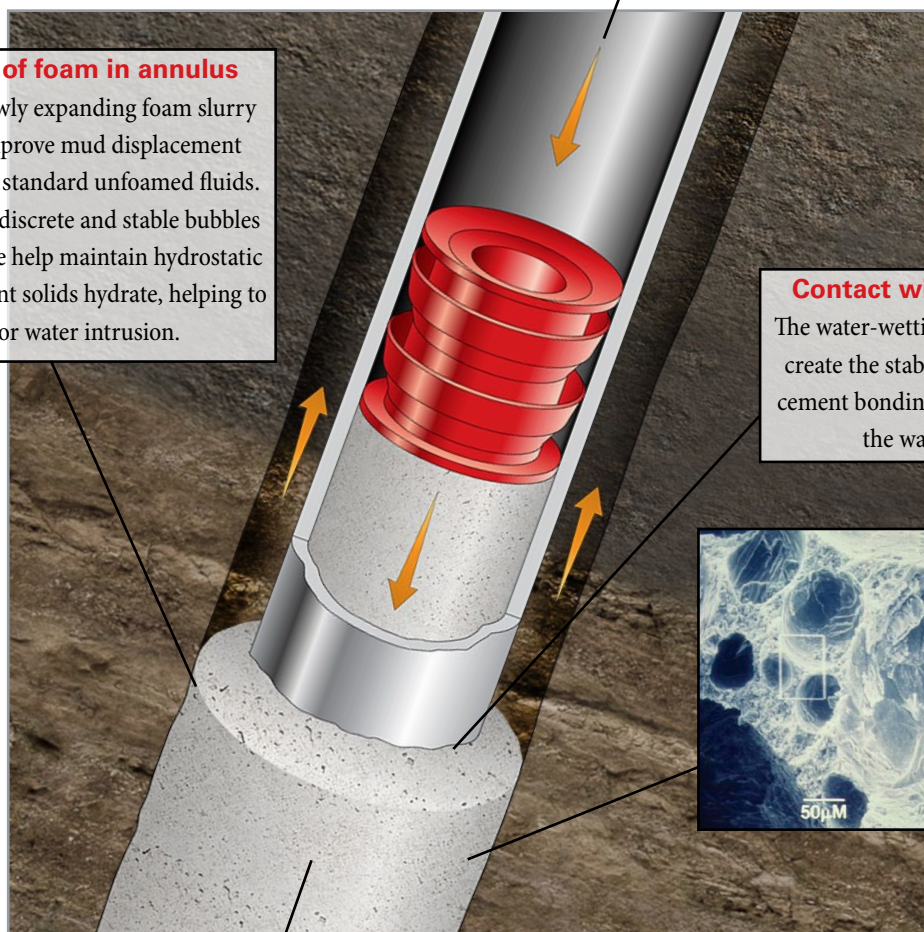
Stable and properly foamed preflush, spacer, or cement slurry is pumped down the pipe from the surface. Overall foam density increases as the hydrostatic pressure increases and the nitrogen bubbles decrease in size, making it imperative to adjust the amount of nitrogen to impart the necessary density as the gas compresses and density increases.

Leading Edge of foam in annulus

The viscous and slowly expanding foam slurry helps to greatly improve mud displacement efficiency over most standard unfoamed fluids. Once static, the still discrete and stable bubbles in the foam structure help maintain hydrostatic pressure as the cement solids hydrate, helping to prevent gas or water intrusion.

Contact with pipe exterior

The water-wetting surfactants used to create the stable foam help improve cement bonding to both the pipe and the wall of the hole.

**Foam cement heading upward outside pipe**

Once the foamed slurry is pumped out the bottom of the pipe, the energized fluid begins to expand as the foam rises in the annulus and hydrostatic pressure decreases. The expanding bubbles of a stable foam remain discrete and can cause the overall foam matrix to expand and fill the hole, even where washouts have occurred. The bubbles also act as a micro-bridging agent. By plating out on the hole wall, they help reduce both whole fluid and filtrate loss to the formation.

Gas Bubbles

Electron-microscopic images of foamed cement show stable discrete bubbles that have minimal permeability. These bubbles expand or contract in response to temperature and pressure changes.

**For more information on ZoneSeal® isolation process,
please call your local Halliburton representative or email us at cementing@halliburton.com.**

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