Cementing Systems & Products Manual

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Amendments History

Revision :	Date:	Ammendments
0.0	July, 2009	Initial revision
0.1	June, 2010	Addition of C303, C020, C303N sections
0.2	February, 2014	Addition of CemPROTECT systems.
0.3	June, 2016	Addition of CemFLEX section.
1.0	April, 2018	Addition of CemMAX Sytems. Addition of C302k. Revision of C011 section.
2.0	January, 2023	Addition of WellSHIELD and Gunk plugs section. Addition of Gunk plug and extended leak off test procedure. Added lost circulation section.
3.0	March, 2024	Overall revision of all additives and systems. Addition of C051, C052, C104L, C307, C308, C012, WW200 and C524. Revision of exception and job approval procedure. Addition of enhanced balanced plug method section.
3.1	June, 2024	Added C607 to chemicals glossary
3.2	July, 2024	Revised cementing job cycle

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1. Cement Chemistry

1.1.Summary

Faced with the concrete skyline of an urban landscape, few people would guess that cement faces its toughest challenge underground: in oil and gas wells where environmental conditions are far more severe than any encountered on the earth's surface. This section outlines the chemistry of Portland cement, the variety used to cement casings in wells and provide zonal isolation; and explains how additives facilitate cement placement and ensure stability after settling.

1.2.Manufacture of Portland Cement

The raw ingredients of Portland cement are lime, silica, alumina and iron oxide. Lime is obtained from calcareous rock deposits and industrial alkali waste products. Alumina, silica and iron oxide are derived from clays and shales and from blast furnace slag or fly-ash waste from coal-fired power stations. These materials are pulverized into fine powder, combined to obtain a given bulk oxide composition and fed into a rotating kiln. Heated as high as 1500 degC (2730 degF), the raw materials undergo a complex series of chemical reactions to produce the four main compounds that make up cement:

- tricalcium silicate, Ca_3SiO_5 (abbreviated as C3S);
- dicalcium silicate, Ca_2SiO_4 (C2S);
- tricalcium aluminate, $Ca_3Al_2O_6$ (C3A); and
- tetracalcium aluminoferrite, $Ca_3Al_2Fe_2O_{10}$ (C4AF)

These four compounds, as well as minor amounts of free lime and other oxides, leave the kiln as clinker. After the clinker has cooled, a small amount of gypsum ($CaSO_4$, $2H_2O$) is added, and the mixture is pulverized and ground to obtain finished Portland cement.

1.3.Cement Chemical Shorthand

- A = AL_2O_3
- C = CaO
- F = Fe_2O_3
- H = H_2O
- N = Na_2O
- S = SiO_2
- S = SO_3

1.4.Hydration of cement

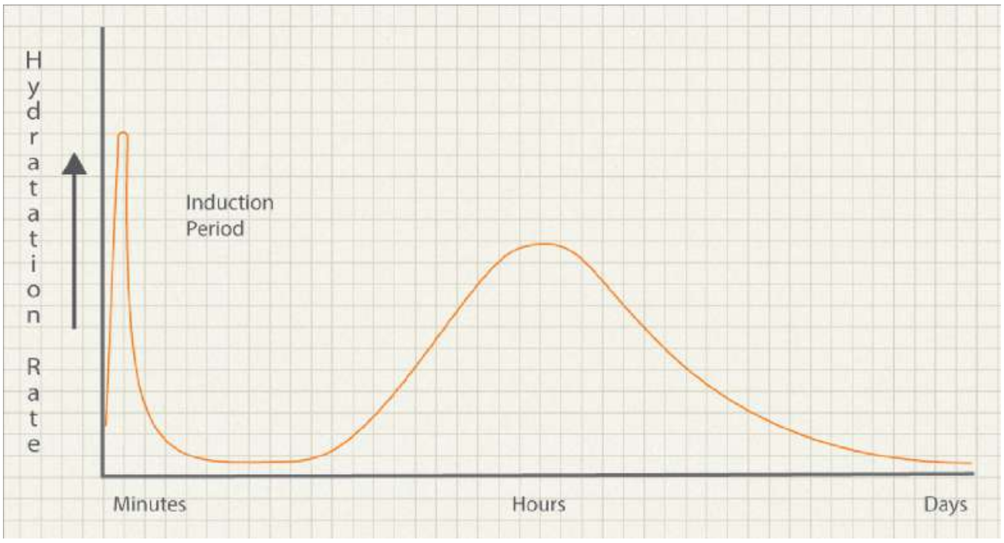
Portland cement is the most common of the ”hydraulic” cements, which set and develop compressive strength through hydration, not by drying out. Hydration involves chemical reactions between water and the cement compounds. It therefore sets and hardens whether left in air or submerged in water. Once set, it has low permeability and resists attack from water. All these attributes make Portland cement ideal for completing wells and maintaining isolation between zones. When mixed with water, silicates C3S and C2S (which constitute up to 80 % of Portland cement) produce similar hydration products:

2C3S + 6H = C3S2H3 + 3CH

2C3S + 4H = C3S2H3 + CH

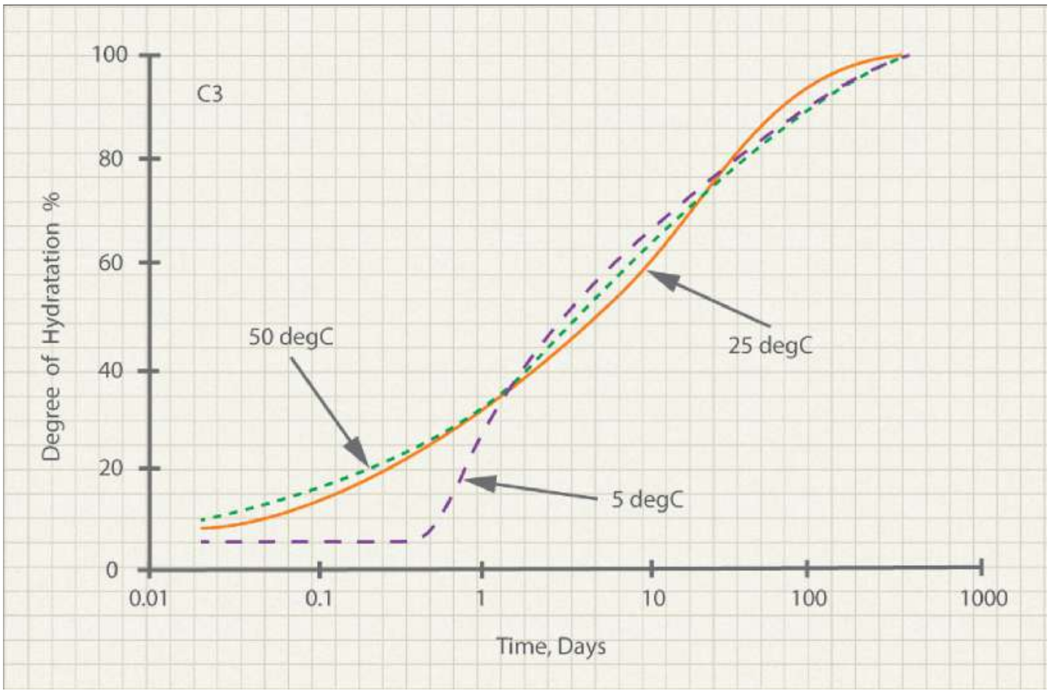
The calcium-silicate-hydrate C3S2H3, also called C-S-H gel, is largely amorphous, comprises roughly 70 % of the set cement and gives cement its strength. Calcium hydroxide Ca(OH)2 [CH], known as portlandite, saturates the cement slurry’s aqueous phase raising its pH to between 12.5 and 13.

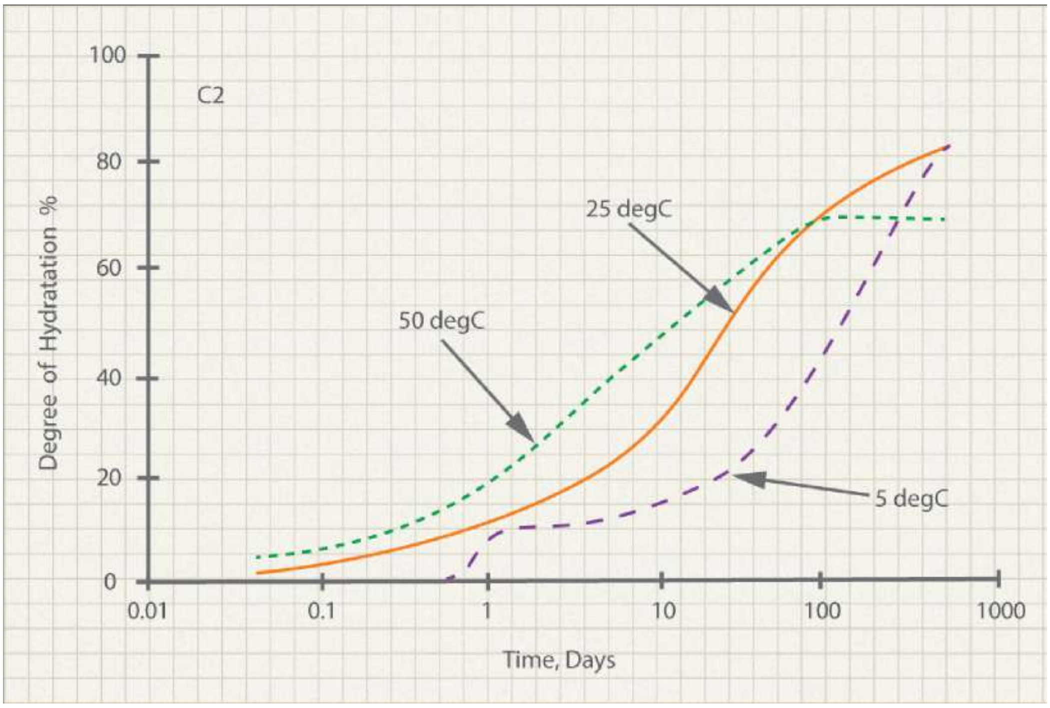
At first, these hydration reactions proceed vigorously and a dense layer of C-S-H gel builds up around each silicate particle. But the gel is relatively impermeable and it soon prevents more water from reaching the surface of anhydrous silicates, hindering further hydration. An interval of low reactivity follows which is called the induction period. Hydration eventually picks up when the permeability of the C-S-H gel layer begins increasing, allowing more water to reach the silicate grain surfaces (see Figure below).



Hydration is at first rapid. It then enters a slow ”induction” period, caused by the hydration product C-S-H gel covering the unhydrated remnants of the silicate grains and preventing water from reaching them. Finally the gel lets water in and hydration picks up.

The onset of setting and early strength development is controlled by C3S because it hydrates more quickly than C2S and because it is more abundant. The C2S component affects the hardened cement’s final strength.





The C3S hydrates more quickly than C2S and dominates early strength development. Hydration rate of both components tends to increase with temperature.

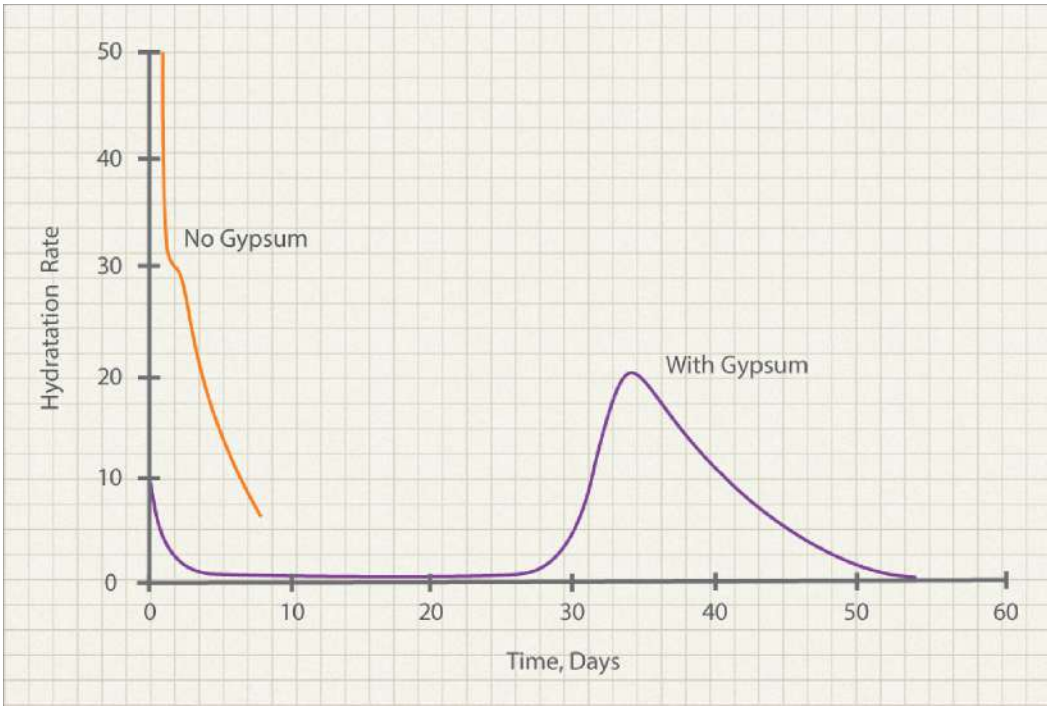
The aluminate components, particularly C3A react most strongly at the beginning of hydration and therefore affect the rheology of the cement slurry and early strength development. Both C3A and C4AF produce the calcium-aluminatehydrate, C3AH6, through intermediate meta stable reactions.

Unlike the C-S-H gel, calcium-aluminate-hydrates are crystalline, not amorphous; and do not form a protective layer around the aluminate grain surfaces.

Consequently, hydration would normally occur rapidly and has to be controlled to prevent premature stiffening of the cement, called ”flash set”. This is where the gypsum added to the clinker to produce Portland cement comes in. Dissolved in water, gypsum releases calcium and sulfate ions. These react with aluminate and hydroxyl ions released by the aluminates forming a trisulfo-aluminate hydrate called ettringite:

[CA . 3CS . 32H]

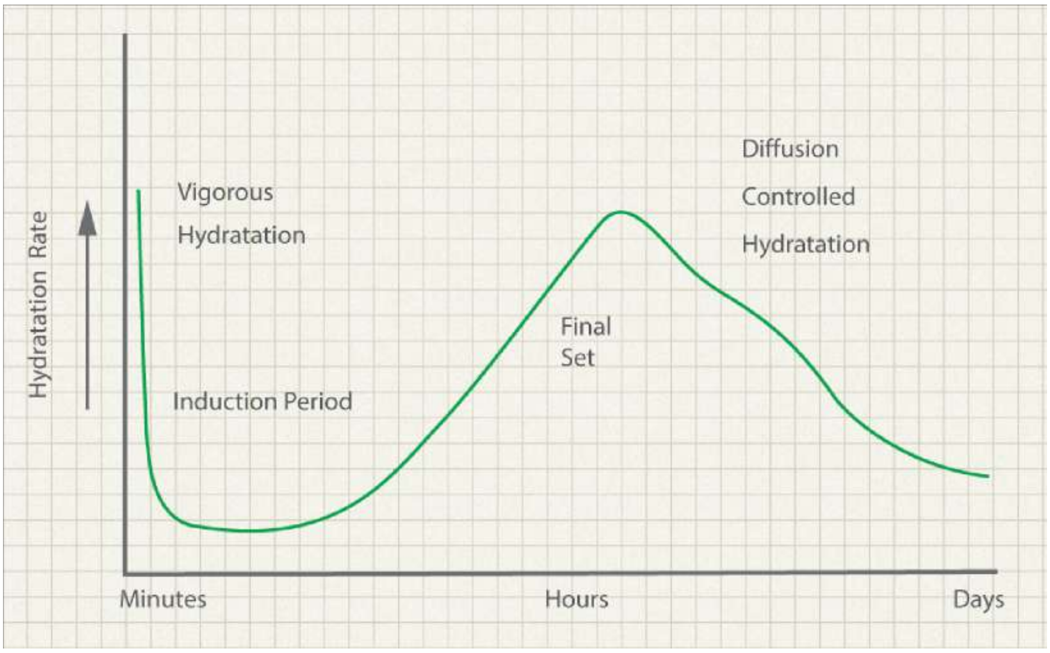
The ettringite precipitates as needle-shaped crystals on the C3A grain surfaces, hindering further hydration and creating an artificial induction period.



The gypsum promotes formation of ettringite around the aluminate grains, which slows hydration and creates an artificial induction period.

As a whole the hydration of Portland cement can be considered a sequence of overlapping reactions leading to a continuous thickening and hardening cement slurry (see Figure below). During initial hydration, when the anhydrous

material is added to water and hydration products begin to form, the cement grains remain independent and the cement slurry can be pumped. This state continues for most of the induction period. But when hydration picks up after the induction period, the cement grains begin to link together and the slurry is not pumpable. Compressive strength develops as the hydration products become intergrown. The reactions speed up as temperature increases.



Final cement strength is provided mainly by the amorphous C-S-H gel created by the cement's hydrating silicate components.

Reaction speed also depends on the relative concentrations of the cement components and their particle size or fineness. For example, the more C3S there is relative to C2S, the quicker a cement sets, because C3S reacts more quickly than C2S. Generally, the finer the cement, the more water is required to prepare a pumpable slurry and the faster compressive strength develops.

Reaction speed is a key factor in designing a cement operation. Another factor is the concentration of C3A.

Portland cements containing low amounts of C3A are less susceptible to sulfate attack-magnesium and sodium sulfates in downhole brines react with the cement's hydration products and cause loss of compressive strength.

Relative concentrations of components and their fineness are criteria by which the API (American Petroleum Institute) classifies oil-field cements. Classes A, B and C (the letters indicate a chronology) were developed in the 1950s and rated for wells less than 1,830 m (6,000 ft) deep. Class B has less C3A and was designed for sulfate resistance. Class C, with more C3S and C3A which is ground much finer, was designed to give high early compressive strength.

Classes D and E, so-called retarded cements, were designed for cementing wells up to 4,250 m (14,000 ft) deep. Their low concentrations of the fast-hydrating C3S and C3A and their coarse grind prolongs hydration and consequently the available pumping time.

In the 1960s, the development of additives extended the depth limitation of all cements. The most recently introduced cements, Classes G and H, have stringent manufacturing specifications and behave more predictably. Class H is normally more coarse than Class G. Classes G and H have a similar composition to Class B. The table below give the percent of different component for each type of cement as well as the particle finesse.

API Class	C_3S %	C_2S %	C_3A %	C_4AF %	Fineness Cm^2/g	Special Application
A	53	24	8	8	1,500 to 1,900	none
B	47	32	5	12	1,500 to 1,900	sulfate resistant

API Class	C_3S %	C_2S %	C_3A %	C_4AF %	Fineness Cm^2/ g	Special Application
C	58	16	8	8	2,000 to 2,800	early setting
D & E	26	54	2	12	1,200 to 1,600	retarded
G & H	50	30	3	12	1,400 to 1,700	more stringent specs

2. Slurry Design

2.1.API Standards

The American Petroleum Institute (API) has designated standards, these standards are accepted as standards for the industry. The specifications for well cements are defined in API Specification 10A, and the specification for materials and testing for well cements are presented in API Specification 10.

2.2.Pumpability & WOC time

Data used to predict the performance of a slurry for field operations are prepared as a cement data sheet. The data sheet is the only accurate source of thickening times, compressive strengths, fluid loss, etc. Data sheets are prepared at the laboratory and represent tests of actual brands of cements and additives which will be used on the job.

The data presented in the manual are known as typical data. They are representative of a typical sample of a specific cement. These data are presented so that a general comparison can be made between various cement systems. They will show whether or not a system is suitable for consideration under a given set of well conditions. Once a general system is selected, laboratory data based on the specific brand of cement and additives should be used for job design.

In many instances, where considerable flexibility exists in pumping time and the development of compressive strength, the typical data are accurate enough to perform a job. But most jobs require more accuracy. For these jobs, cement data sheets are prepared by the laboratory.

Some cement jobs, such as hot deep wells, will require even greater accuracy. For these wells, individual tests are run in laboratory to develop a cement system for that specific job. To make a decision as to the type of data that is needed, a knowledge of the accuracy of performance data is required.

2.3.Accuracy of Performance Data

It must be recognized that the performance of cement slurries will vary, not only due to the difference between brands, but also because of differences between batches of cement bearing the same brand name. This is caused by the fact that cement is primarily manufactured for construction purposes which can tolerate a wide tolerance in specifications. Since the oil industry generally purchases only a small percentage of the cement made, source materials are selected according to their acceptability for use in making construction cement. As a result, the API specifications for the manufacture of oil-well cements must be lenient enough to insure that an adequate supply is always accessible.

The API specifications for Class A, B and C cements closely parallel those for ASTM Type I, II and III construction cements, so that most manufacturers will make their cements according to ASTM specifications, and they are still within API specifications. For this reason, these cements are usually interchangeable.

In addition, the raw materials may change slightly from time to time so that a given class of cement from the same mill will vary from run to run. Yet these runs still meet the manufacturer's specifications.

Presently there are two basic types of cement being manufactured especially for oil-field use. These are API Class G and Class H cements. These cements are manufactured to a much closer tolerance, which has increased their reliability over a much wider temperature range than those of the other API classes of cement. These two classes of cement are similar in chemical composition but differ in grind. Class G has an average Blaine fineness of 3500 and Class H has an average Blaine fineness of 2000.

2.4.Mix Water

In order to have any similarity between the properties of a slurry used in the field and those tested in the laboratory, both must contain the same quantity of each ingredient. If any reliability is to be expected of the thickening times and compressive strengths reported in the laboratory, the field slurry must be mixed with the same quantity of water used in the lab. Unless special tests are conducted for special applications, the standard amount of water designated in Section 5 of API Specification 10 is used in all lab tests performed.

Because of the physical action of slurry mixing in the field, it is possible to add a large quantity of water to cement. However, the proper amount is that quantity which will:

- Provide adequate pumpability,
- Allow complete hydration of all solids present.

The performance properties of a slurry using field-mix water may differ from the same slurry using laboratory-mix water. For a particular well application, cement system design in the laboratory is best achieved by using water samples for the tests that were taken from the rig water source.

2.5.Free Water Content

The API does not define the maximum amount of mix water. Instead, Free Water Content is reported. Free Water is that water which separates from the slurry after 20 minutes mixing in an atmospheric consistometer at 27 degC (80 degF) and standing undisturbed for two hours. The free water is expressed in milliliters (mL) and designated as the Free Water Content.

Any appreciable free-water separation in samples of a field-mixed slurry indicates that either the slurry was not sufficiently agitated to obtain good mixing or that too much water was used. In either case, the cement can be greatly affected.

Provided that the slurry is moved until it begins to reach the end of its pumpability, the excess water will cause a permeable set product to be formed. This set cement will be weak and susceptible to attack by invading fluids.

If the cement is moved only a short time after it is mixed and then allowed to stand dormant, free pockets of water may be formed. In addition to these detrimental effects, there may be places behind the pipe devoid of cement.

2.6.Minimum Water

The API defines minimum mixing water, as that quantity which results in a slurry consistency of 30 Bc after stirring for 20 minutes at 27 degC (80 degF) in an atmospheric consistometer. Slurries with a consistency greater than 30 Bc would be difficult to pump in a reasonable amount of time and would produce excessive pumping pressures.

2.7.Optimum Water (Minimum Water)

The recommended mix water specified for testing procedures (according to Table 5.2 in Section 5 of API Specification 10) is referred to as the optimum water and is the amount used for all API standard tests. The following table provides the API recommended mix water for well cements.

API Cement Class	Percent Mix Water (by weight of cement)	Mix water(gal/sack)
A & B	46	5.19
C	56	6.32
D,E,F & H	38	4.29
G	44	4.97

5.3 % additional mix water is required in all API classes of cement for each 1.0 % (by weight of cement) bentonite.

For laboratory tests and slurry calculations, the standard properties used for water are:

- Density of Water at 27 degC (80 degF) = 8.32 lbm/gal or 62.23 lb/ft3.
- 1.0 ft3 of water = 7.48 gal.
- Hydrostatic gradient of water = 0.432 psi/ft.

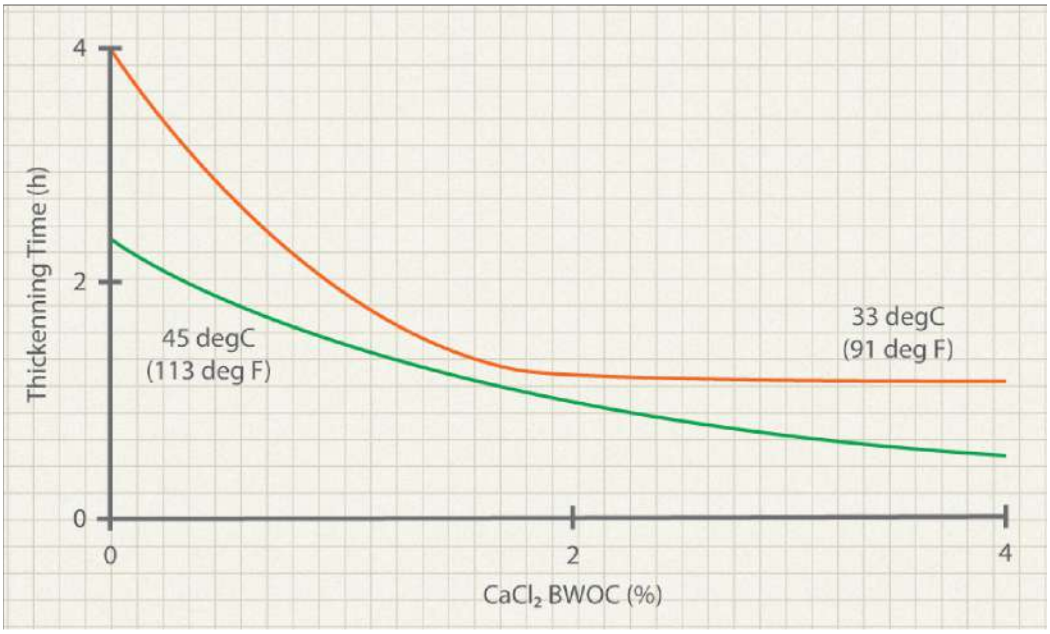
3. Cement Additives

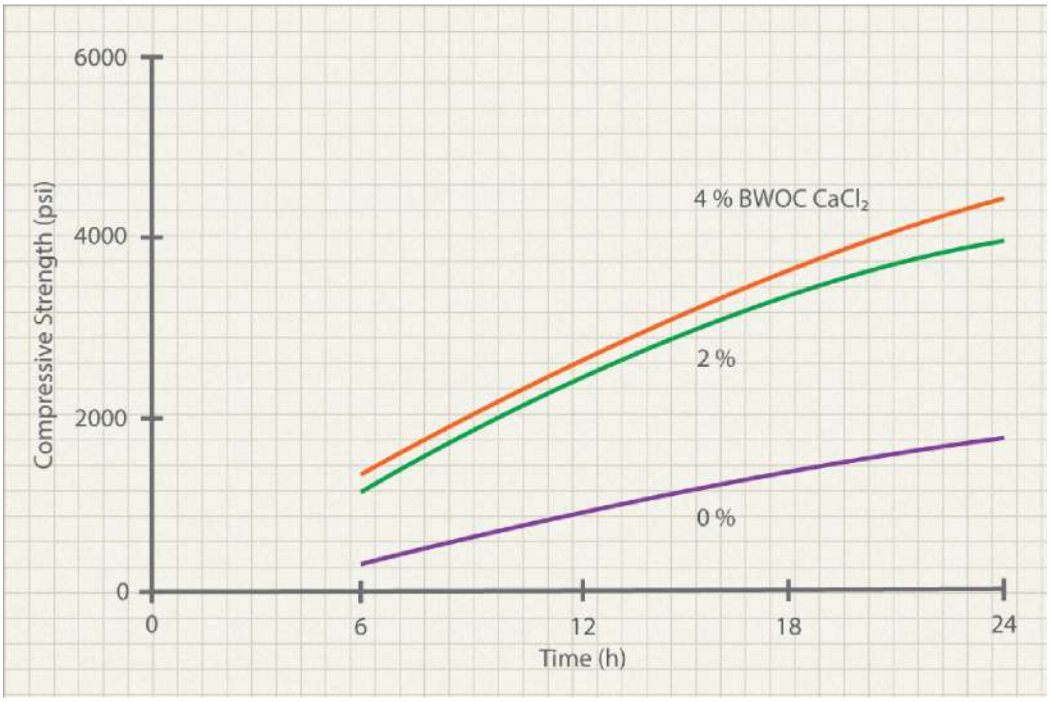
Today's well cements have to withstand an enormous range of well depths and conditions. In permafrost zones, the cement must withstand below-freezing conditions, while in thermal recovery wells or geothermal fields they must endure temperatures above 350 degC (660 degF). They must contend with weak formations, formations that might cause lost circulation, and corrosive and over-pressured formation fluids. How can cement be formulated to accommodate such varied conditions? The answer lies in additives, which come in eight main varieties.

3.1. Accelerators

In shallow, low-temperature wells, accelerators speed up the early stages of hydration and cut the cement's setting time. Accelerators are also used to counteract the setting delay caused by other additives, such as dispersants and fluid-loss agents. The most common accelerator is calcium chloride (CaCl2). Evidence suggests calcium chloride may increase the permeability of the C-S-H gel building around each silicate grain and therefore give water ready access to the grain's anhydrous surface. This would shorten the induction period.

Calcium chloride is normally added at concentrations of 2 % to 4 % by weight of cement (BWOC). Higher concentration decreases thickening time-equivalent to the length of time the slurry is pumpable (see Figure below).



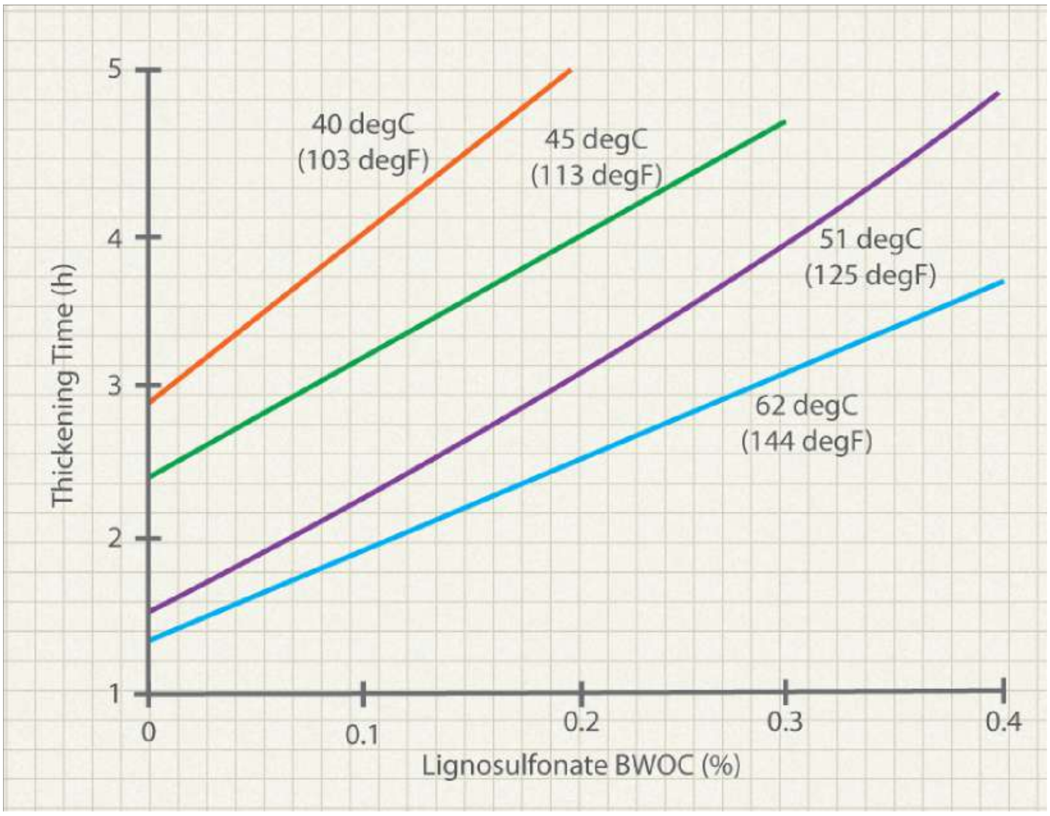


Thickening time, the period during which cement can be pumped, is accelerated by adding calcium chloride [CaCl2] (top). Compressive strength also develops faster with calcium chloride (bottom).

3.2.Retarders

Retarders inhibit hydration and delay setting, allowing sufficient time for slurry placement in deep and hot wells. The technology of retarders is well developed and several types are used. Why they work is something of an enigma, although several theories have been developed. The most common retarders are derived from wood pulp. They are comprised of sodium and calcium salts of lignosulfonic acids and contain some saccharides.

These retarders are thought to adsorb onto the initial layer of C-S-H gel, rendering it hydrophobic and prolonging the induction period. Added in concentrations of 0.1 % to 1.5 % BWOC, they retard hydration at temperatures up to 122 degC (250 degF) (see Figure below). When treated with other chemicals such as borax, lignosulfonates can be used up to 315 degC (600 degF).



Thickening time is prolonged when retarders such as lignosulfonate are added to cement.

Hydroxycarboxylic acids, such as citric acid, tartaric acid, gluconate and glucoheptonate salts, also retard hydration but are not used when the bottom hole temperature is below 93 degC (200 degF). Otherwise, thickening times become excessively long. These compounds attach themselves to calcium ions and as a result are thought to inhibit nucleation and growth of hydration products. The hydroxyl carboxylic acids are well known for their antioxidant and sequestering properties that benefit cement-slurry performance. The antioxidant property improves the temperature stability of soluble compounds such as fluid loss additives.

Cellulose derivatives such as carboxymethyl hydroxyethyl cellulose (CMHEC) have been used for many years as cement retarders. They are generally effective to 120 degC (250 degF). Like the lignosulfonates, they slow hydration by rendering the C-S-H gel hydrophobic. CMHEC imparts some secondary effects such as improved fluid-loss control, which may be desirable, and higher slurry viscosity, which may be undesirable.

A relatively new class of retarders, organophosphonates, are effective at bottom hole circulating temperatures as high as 204 degC (400 degF). They tend to tolerate variations in cement composition and can lower the viscosity of high density cement slurries. Little is known about their mode of action.

3.3. Extenders

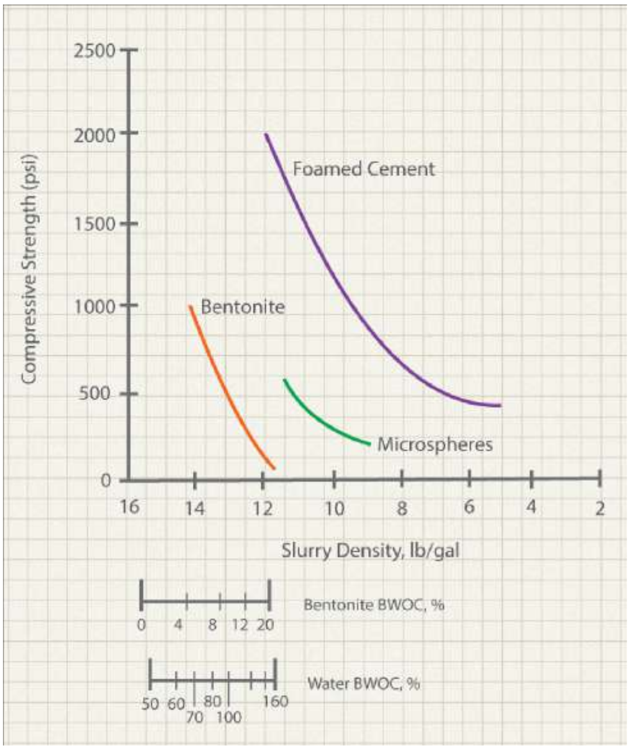
Cement extenders reduce slurry density and lower hydrostatic pressure during cementing operations. This helps prevent the breakdown of weak formations and loss of circulation. They also reduce the amount of cement needed for the cementing operation. Because they are less expensive than cement, they bring considerable savings. Three types of extenders are water extenders, low-density aggregates and gas. Often more than one type is used in the same slurry.

Water extenders allow the addition of water to the slurry while ensuring that solids remain in suspension. The most common is bentonite, a clay mineral that has the unusual property of expanding several times its original volume when placed in water. This increases the slurry's viscosity and its ability to suspend solids. Bentonite is added in concentrations as high as 20 % BWOC. Slurry density quickly decreases with bentonite concentration. However, there is a price to be paid in terms of compressive strength. Another water extender is sodium silicate. This reacts with the calcium hydroxide in the cement slurry to produce a viscous C-S-H gel allowing large volumes of water to be added to the slurry.

Low-density aggregates are materials of density less than that of Portland cement, which is 3.15 g/cm3. The most commonly used are pozzolans, finely-divided siliceous and aluminous materials. They are obtained from volcanic ash, diatomaceous earth and fly ash from coal-burning power stations. Pozzolans not only reduce cement-slurry density, but also increase its compressive strength by reacting with the calcium hydroxide in the slurry.

At present, the most efficient low-density aggregates are microspheres, small gas-filled beads with specific gravities as low as 0.2. Since they are lighter than water, slurry density is substantially reduced without adding large quantities of water. As a result, compressive strength is preserved. The improvement is dramatic when compared with bentonite.

Gases such as nitrogen or sometimes air, are used to prepare foamed cement with exceptionally low density. Similar to microspheres, using air as an extender requires no additional water (see Figure below).



Extenders such as bentonite, foamed cement and microspheres decrease the cement slurry density are used to cut down on cementing costs and protect against the breakdown of weak formations. But they also decrease final compressive strength. The bentonite and foam data were obtained on cement cured at 38 degC (100 degF), and the microsphere data on cement cured at 27 degC (80 degF). Curing time in all cases was 24 h.

3.4. Weighting Agent

In high-pressure gas wells or in physically unstable wellbores, high-density fluids are required to maintain control. In such cases, drilling mud densities often go up to 18 lbm/gal and cement slurries of equal or higher density become necessary.

The most obvious way of increasing cement density is to reduce the amount of water in the slurry. However, this can make the slurry difficult to pump.

Alternatively, materials of high specific gravity can be added. These must have a particle size similar to that of the cement. The most commonly used weighting agents are hematite (Fe_2O_3) and barite ($BaSO_4$) with densities of 41.2 lbm/gal and 36 lbm/ gal respectively.

3.5.Dispersants

Successful cementing relies on good mud removal, which is best achieved by pumping the cement slurry in turbulent flow. Dispersants control slurry rheology and help induce turbulence at low pumping rates. Dispersants also allow the water content of the cement to be lowered without making it difficult to pump.

Basically, dispersants neutralize positive charges on cement particles which would otherwise make them mutually attractive. They effectively break up aggregates into individual particles. At the right concentration, dispersants improve cement homogeneity and lower its permeability. However, an overdose of dispersants can produce a phase separation in the cement slurry that results in cement particles settling out of solution and the development of free water. The most common dispersants are sulfonates containing highly branched polymers. Polynapthalene sulfonate is the most widely used.

3.6.Fluid-Loss Control Agents (FLACs)

When cement is placed across a permeable formation under pressure, a filtration process is created. Water from the slurry escapes into the formation and the cement particles are left behind. If this fluid loss is not controlled, the rheology, thickening time and density of the slurry will change and the cementing job could fail. To prevent water loss and maintain slurry characteristics, FLAC agents are added to the cement slurry. How FLAC agents work is not fully understood.

However, it is known that they reduce the permeability of the cement filter cake that is deposited on the formation surface when fluid loss starts.

Some FLAC agents also increase the viscosity of the aqueous phase of the cement slurry, thus reducing the rate of filtration.

Two types of FLAC agents are used:

- finely-divided materials and
- water-soluble polymers.

Finely-divided materials, such as bentonite, enter the filter cake, lodge between the particles and lower permeability. More commonly used are emulsion polymers made of latex particles that act the same way as bentonite. So-called latex cements have excellent fluid-loss characteristics and can be used to 176 degC (350 degF).

Water-soluble polymers operate by increasing the viscosity of the aqueous phase and/or lowering the filter cake permeability. Water-soluble cellulose derivatives such as hydroxyethyl cellulose (HEC), are also used. However, these can make the slurry more viscous and difficult to mix. Their efficiency also decreases with increasing temperature. Nonionic synthetic polymers, such as polyvinyl alcohol (PVA) are also effective. At high well temperatures, cationic polymers, such as polyethylene imine (PEI), are frequently adopted. These can control fluid loss at temperatures up to 225 degC (437 degF) , but they also encourage slurry sedimentation.

3.7.Lost-Circulation Control Agents

If circulation is lost during a primary cement job, expensive remedial cementing will usually be needed. Circulation loss can occur in fractured, vuggy or cavernous formations. Generally, drilling parameters tell the operator when to expect lost circulation problems.

Circulation losses are normally prevented by adding materials that bridge fractures and block weak zones. Granular materials, such as Gilsonite and granular coal are excellent bridging agents. But ground walnut or pecan shells, coarse bentonite or even ground corn cobs are sometimes used. Cellophane flake is another important bridging agent. The flakes form a mat that seals the face of the fracture and prevents cement from entering the formation. If vugs or caverns in the formation are so large that bridging agents do not work, thixotropic cements can be used. When thixotropic cement enters the formation and slows down, it experiences less shear force and begins to gel, becoming self-supporting and eventually plugging the cavern or vug.

3.8. Special Additives

Additives performing special tasks include antifoaming agents, fibrous additives and agents to prevent gas migration. Antifoaming agents prevent foaming that often arises when additives are mixed into the cement slurry. Excessive foaming can cause a loss in hydraulic pressure possibly wrecking the cementing operation. Polyethylene glycol is the cheapest and most commonly used antifoaming agent. To work properly, it is mixed with the water before slurry preparation. The more expensive silicone emulsions will defeat a foam regardless of when they are added.

Fibrous materials are mixed with cement to increase its resistance to stresses that develop around drill collars or during perforating. Nylon fibers and particulate rubber are the two most popular strengthening agents.

Gas wells present special problems. During drilling and while the cement is being pumped, the hydrostatic pressure of the borehole fluid prevents gas from entering the well-bore. But as soon as the slurry begins setting, it loses its ability to transmit hydrostatic pressure and gas can migrate into the well-bore.

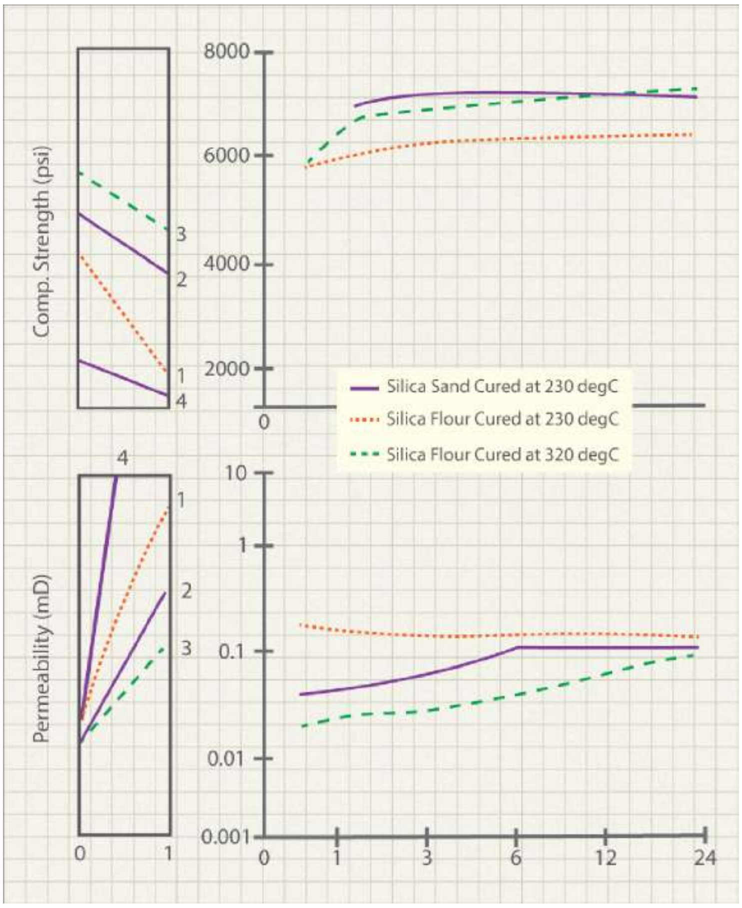
In recent years, additives have been developed to prevent gas migration. Among the most successful are special latices, such as GAS-TIGHT that coagulate at the gas-cement interface forming a membrane impermeable to gas.

3.9. High-temperature wells

High temperatures present the greatest challenge to cementing. High temperatures are encountered in deep oil and gas wells, geothermal wells and thermal recovery wells. Above 110 degC (230 degF), the behavior of Portland cement changes, not only during hydration but also after setting.

High temperature accelerates hydration, so retarders and other additives are used to slow reaction times and allow successful placement. High temperature also affects cement strength after setting. Depending on the temperature and the cement’s C/S ratio, the set cement converts to a variety of calcium silicate phases. Some of these reduce compressive strength and increase permeability.

One such phase is alpha-dicalcium-silicate-hydrate (α-C2SH) that forms from C-S-H gel and calcium hydroxide, which jointly have a C/S ratio of 1.5 to 2.0. Formation of α-C2SH can be prevented by adding about 35% BWOC of silica to the cement, which alters the C/S ratio to about 0.8. The C-S-H gel then produces different calcium silicate phases tobermorite (C5S6H5) and xonotlite (C6S6H) that are stable. Other calcium silicate phases have been extensively studied,and some like truscottite and a sodium substituted calcium silicate, pectolite, have been found stable.



Curing at high temperature. Degradation of cement performance at high curing temperatures (left) and restored performance with added silica (right). Without extra silica, standard classes G and H cements cured at 230 deg C (450 deg F) degrade in compressive strength and permeability. Adding silica sand (grain size 90 to 100 µm) restores performance. At the higher curing temperature of 320 deg C (610 deg F), adding silica in the form of flour (grain size 40 to 50 µm) becomes necessary to restore performance.

Portland cement becomes totally unstable above 400 deg C (750 deg F), which is much lower than the temperature usually found in a fire flood well. For the ultra-high temperatures of thermal recovery, special cements are used that comprise mainly mono calcium aluminate (CA).

4. Sulfate Resistance

Detrimental effects results when sulfate solutions react with cement hydration products. Common oilfield brines contain magnesium and sodium sulfate. When cement cubes are immersed in sulfate water, they gradually weaken and disintegrate. A cement cube will eventually become a pile of solids that are no longer bonded together, if immersed long enough and the sulfate in the water is replenished.

It is not possible to completely eliminate the susceptibility of cement to attack by sulfate-bearing water. However, it can be greatly reduced. Fortunately, this reaction is retarded as the temperature increases. According to the literature, the sulfate attack problem need not to be considered if the downhole temperature is greater than 60 degC (140 degF).

A series of reactions occurs which leads to the ultimate breakdown of the cement. Magnesium or sodium sulfate reacts with lime in the cement to form magnesium or sodium hydroxide and calcium sulfate. The calcium sulfate reacts with the C3A (tricalcium aluminate) to form calcium sulfo-aluminate. This causes expansion and disintegration of the cement because it forms a larger particle than the C3A which it replaces.

Some underground waters contain dissolved sulfates. Where cement is exposed to these waters and there is room for sloughing to occur, it is likely that the cement will be attacked. Expansion, strength loss, sloughing, and cracking will occur. Such an area would be found surrounding a perforation, or in a channel through which the water flows. In such cases, it is possible that large voids could develop behind the pipe leaving the exposed pipe susceptible to corrosion.

When the cement is tightly bonded in all directions behind the pipe and it is exposed to sulfate waters only at the formation face, it is doubtful that any damage will result. It is too difficult for the water to invade the cement.

A certain amount of resistance to sulfates can be imparted to the cement by decreasing the amount of C3A and free lime in the set cement. This is the method used to make sulfate-resistant cements, although it cannot completely eliminate sulfate attack. Sulfate resistance can also be improved by using pozzolanic materials with the cement. These react with the lime to reduce the lime and magnesium sulfate reaction.

Another means of increasing sulfate resistance is to add enough calcium sulfate that the C3A will form calcium sulfoaluminate before the slurry sets. To completely neutralize the C3A, the rule of thumb is to add 1.8 % Calcium Sulfate Hemihydrate CaSO4.1/2H2O (BWOC) per 1.0 % C3A in the cement. This is not detrimental to the set. If either or both of these factors are built in by the manufacturer, sulfate water attack will not be a problem. Sulfate (SO42-) attack should not be confused with the presence of hydrogen sulfide (H2S) in the water. The presence of H2S suggests the presence of SO4, but they are not necessarily found together. H2S will not attack set cement, although it can cause severe pipe corrosion.

5. Field Calculation of Dry (Dehydrated) Cement Density

Portland cement will hydrate or react with about 22 % to 24 % water BWOC, i.e., 20 to 22 lbm of water per sack of cement. Excess water remains free in the pores of the set cement. If the cement is subjected to dehydrating (drying) conditions, for example high borehole temperatures at low pressure and moisture, par t or all of the excess water can eventually evaporate from the cement. This will result in decreased cement ”density”.

The ultimate dry density of a dehydrated cement may be found from the following formula:

$$\text{dry density (specific gravity)} = \frac{A + 22 - W}{A} \times \frac{\text{slurry weight (lbm/ft}^3\text{)}}{62.23}$$

where:

A	total pounds of slurry produced from one sack (94 lb) of Portland cement which equals slurry weight (lb/ft^3) times slurry yield (ft^3/sk)
W	pounds of water used in slurry which equals gallons of water per sack multiplied by 8.32
62.23	weight of water (lbm/ft^3)
22	pounds of water that will react (hydrate) with one sack (94 lbm) of Portland cement.

6. Cement Gelation

Gelation can be defined as a premature viscosification or a gel-strength build-up of the cement slurry. Gelation is an important and difficult problem to deal with. Gelation can be the cause of job failure also, a gelling system has some unpredictable characteristics (i.e., rheological behavior, thickening time and pumping time). Gelation can be due to one or several of the following items:

- Cement itself.
- Quality of the water used.
- Additives used (mainly the type of retarders), and
- Temperature at which the slurry is tested.

In this section, several types of gelation will be defined and some ways to overcome this problem will be suggested. However, since the exact chemical basis for each type of gel is not fully understood and since gelation is a complex problem involving numerous parameters and solutions, the information given below should be considered primarily as a guideline.

6.1.What is a Gel and How is it Detected ?

Under dynamic conditions (i.e., the slurry is stirred in a viscometer, an atmospheric or pressurized consistometer), a gel can be described as a premature viscosification or a consistency increase, which is detected by abnormally high rheological parameters or by an early increase in Bearden consistency on the thickening time curve. Because of the different scale of magnitude of the two measurements, a gel detected when measuring rheological parameters may not be detectable on a thickening-time curve. At present, four classifications for gelation can be distinguished.

Note: Under static conditions, a gel is described as a gel-strength build-up, which can be detected from the 10-min gel-strength measurement during a rheological test. Consequently, the three factors (rheological parameters, 10-min gel strength and thickening time curve) are necessary to ascertain gelation. Tertiary and quaternary gels are likely to become unpumpable before the end of slurry placement, or may cause high displacement pressures.

6.1.1.Primary Gel

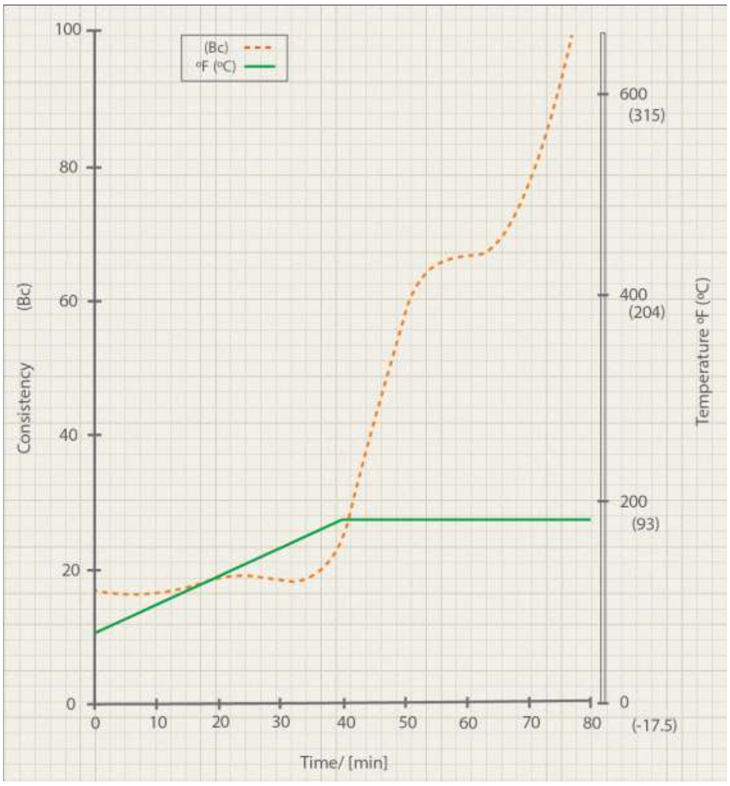
Occurring at the mixing stage, this gel is formed when the slurry is left in a static state immediately after mixing. Primary gelation can lead to an unpumpable slurry after a short period of time. The primary gel is easily detectable in the laboratory by looking at the rheological behavior of the slurry at room temperature: If the mixing rheology of such a slurry is measured, the slurry may appear quite fluid for readings at 300, 200, 100, 6 and 3 rpm. But after leaving the slurry static for 10 min, the 3-r pm peak reading will show a drastic increase of the shear stress. The latter may decrease slightly, but will never reach a low level. The slurry shows an irreversible gel-strength build-up.

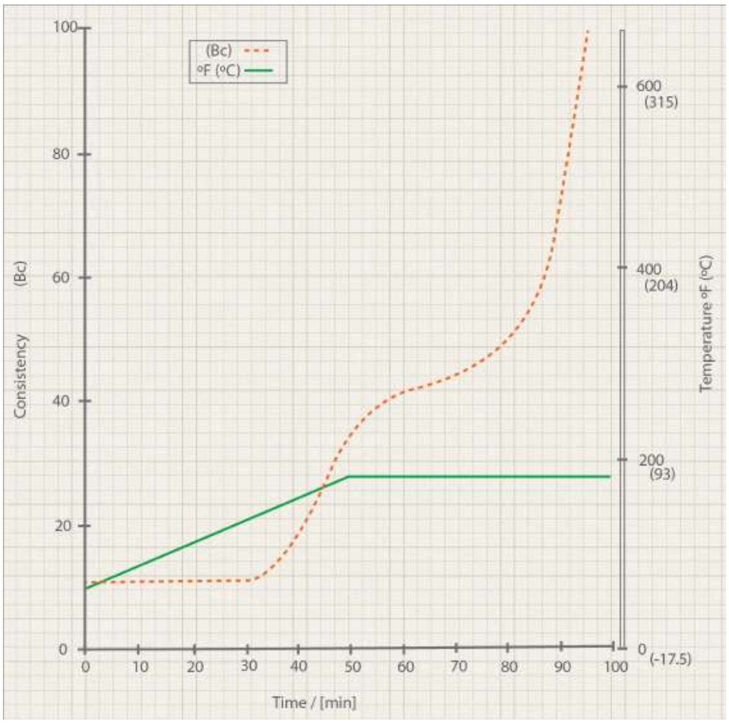
6.1.2.Secondary Gel

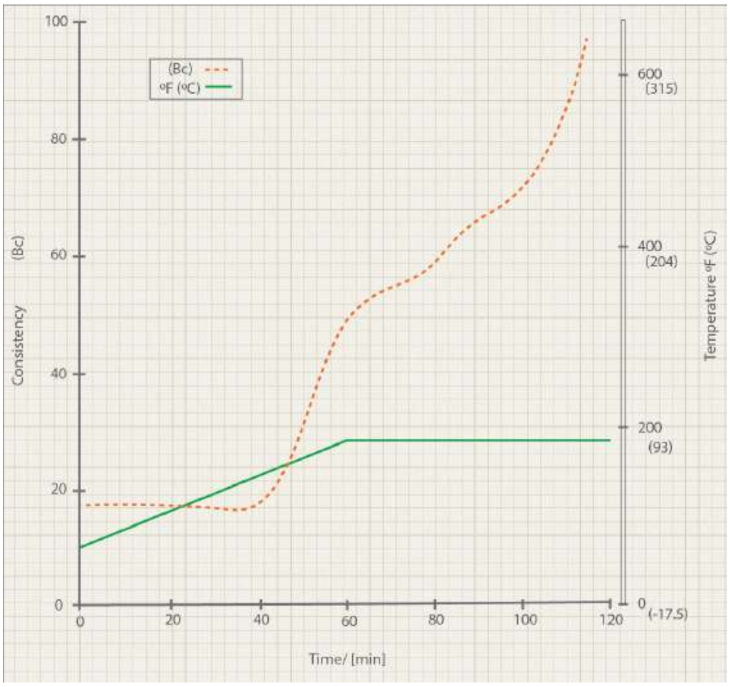
This gel can be detected from abnormally high dynamic rheological parameters, or from static 10-min gel strength run at BHCT (bottom-hole circulating temperature). Normally, no gelation tendency is observable during the thickening time test. This type of gel can have serious consequences for field operations, since any prolonged shutdown period could cause difficulties when restarting. The secondary gel is detectable in a laboratory using the same method as with the primary gel but at circulating temperature: i.e., all of the rheological tests must be performed at BHCT.

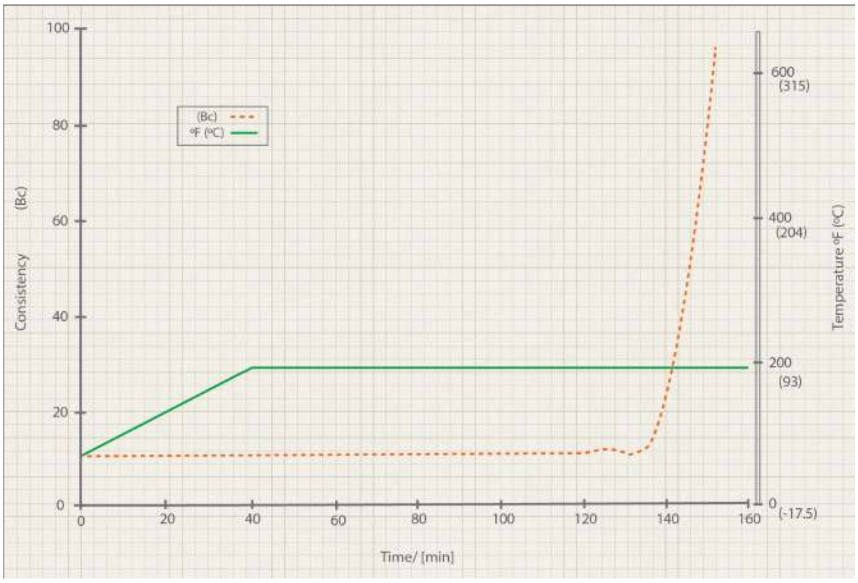
6.1.3.Tertiary Gel

This gel is easily noticed from the thickening time curve, as shown earlier, It consists of a consistency increase at some stage during the thickening-time test. The consistency increases to a high level at this time (normally between 20 and 70 Bearden units), and stays at this level until the final set of the slurry (the gel stage is a plateau).





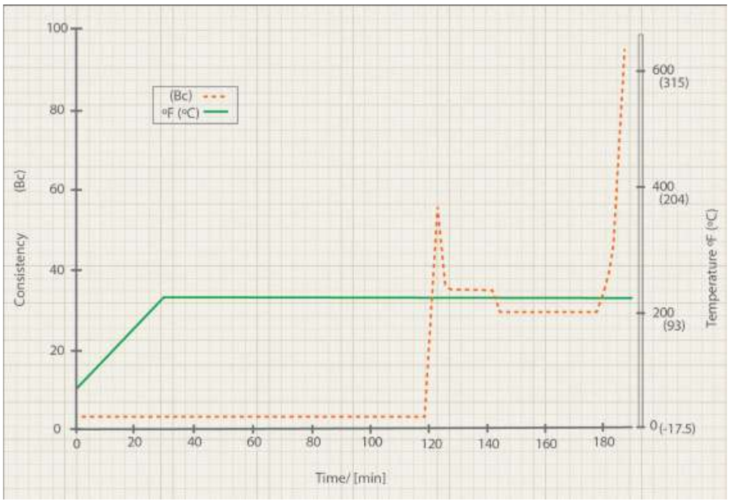




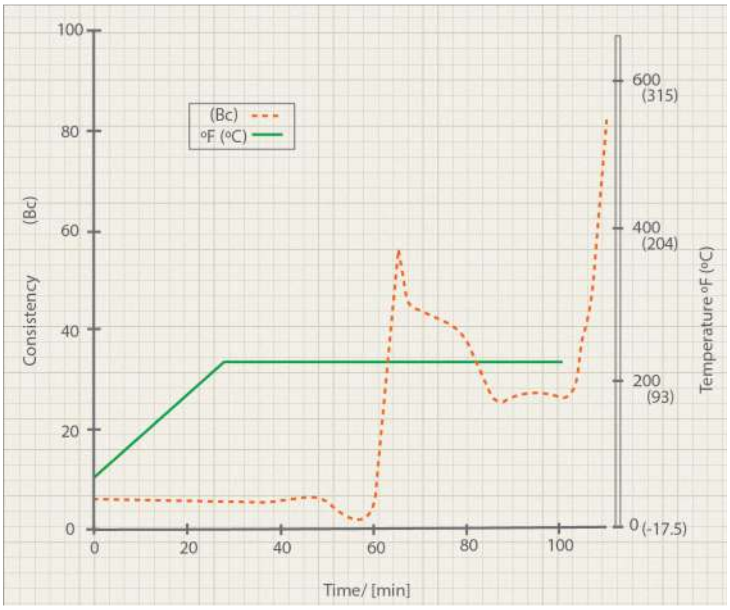
6.1.4.Quaternary Gel

This gel is similar to the tertiary gel, but the consistency of the slurry decreases after reaching a high level (20 to 70 Bc) and stays at a reasonable or a lower level until the set of the slurry (the gel stage is a peak). This is shown in figures below:

(Bc)
ºF (ºC)
Consistency (Bc)
Temperature ºF (ºC)
Time/ [min]
600 (315)
400 (204)
200 (93)
0 (-17.5)



(Bc)
ºF (ºC)
Consistency (Bc)
Temperature ºF (ºC)
Time/ [min]
600 (315)
400 (204)
200 (93)
0 (-17.5)



(Bc)
ºF (ºC)
Consistency (Bc)
Temperature ºF (ºC)
Time/ [min]
600 (315)
400 (204)
200 (93)
0 (-17.5)

6.2.Why Does Gelation Occur and How to Solve it

6.2.1.Primary Gel

Cements which are poor in free sulfates are usually subject to this type of gelation. The main effect is that insufficient sulfates are available to form ettringite. As discussed earlier , Cement chemistry and additives, the formation of ettringite is an important factor in the control of the hydration of the very reactive aluminate phase. To overcome this problem, the addition of C606 anhydrous sodium sulfate is often effective. C606 works by increasing the sulfate content and allowing the formation of ettringite, which regulates the hydration of aluminates. The necessary concentration of C606 in such slurries is largely dependent on the cement, but a typical range would be between 0.5 % and 1.0 % BWOC. C606 can impart good rheological properties and can overcome the problem of false setting with sulfate deficient cements while not impairing the other characteristics of the slurry (i.e., fluid loss, compressive strength). If no improvement in the gelation problem is observed at 1.0 % BWOC, then the gelation problem is NOT due to a lack of sulfates. Increasing the C606 concentration above 1.0 % may allow the precipitation of secondary gypsum and compound the gelation problems. There is also the likelihood of uncontrolled expansion due to internal sulfate attack.

6.2.2.Secondary Gel

The reactions involved in the formation of a secondary gel are not well understood at this time. It is likely that a number of factors are involved. The quality of the mix water, the cement itself, the additives used and the circulating temperature can all contribute to this type of behavior. It has been shown that the distribution of the aluminate phase at the surface of cement grains can predispose the cement to the occurrence of a secondary gel. In other words, cement for which the surface of the grains is highly covered by aluminates will react quickly and intensively with water when subjected to heat and agitation, yielding abnormally high gel strengths and often high rheological parameters. There are no universal solutions, but a number of empirical field solutions have been found to work. Some of these potential solutions include the following:

- Increase the dispersant concentration.
- Use the correct retarder for the temperature range at which the slurry is designed; i.e., C102/C103 instead of C100 at temperatures above 71 degC [160 degF] .
- Reduce the density when possible.

Note: The problem of salt-rich slurries will be treated in a special paragraph, but gelation occurring in such cases is generally of the secondary type.

6.2.3.Tertiary Gel

Several reasons can account for the occurrence of such a gel. Possible causes can be a strong reactivity of the aluminate phase and/or instability of the ettringite at elevated temperature. In addition, the presence of some types of organic contaminants, even at very low levels, can dramatically affect the performance of a cement, particularly with regard to tertiary gelation. This is one of the reasons why the use of grinding aids (which are normally organic materials) is prohibited in the manufacture of API Class G and H cements. However, it is possible that such cements can be contaminated in the grinding mill when it also has been used for processing construction cements (OPC). This explanation should be considered in cases where gelation cannot be explained by any other means.

For overcoming this type of gelation, the addition of C400 at a level of 0.1 gal/sk or 1 % BWOC has been shown to be effective. Adding silicates will lead to a thinner slurry at BHCT. However, it should be noted that the fluid-loss control may be impaired by these additions so a small amount of retarder should be added to balance the accelerating effect.

6.2.4.Quaternary Gel

This type of gel is very similar to the tertiary type, but the chemistry may be totally different. Several answers can be proposed to explain the cause of such a gel:

- Quality of mix water: a salty water may be the cause of such gels.
- Certain retarders which can greatly affect the characteristics of the slurry.

Obviously in a case of bad-quality mix water, changing the water will solve the problem. When that is not possible, increasing the dispersant concentration may solve the problem. Also, some retarder aids may help to avoid gelling tendencies. In some cases C508 (Sodium Tetraborate Decahydrate), at a level of 0.2 % to 1.5 % BWOC, has shown good characteristics to solve the gelation without impairing the other characteristics of the slurry. Nevertheless when using C508, special care should be taken to minimize its concentration, as it may be detrimental to fluid-loss control.

6.3.Special Systems

6.3.1.Salt-Rich Slurries

With certain cements (mainly DTD type cements), salt-rich systems have shown a tendency to gel. This gel is a secondary type, i.e., it is seen mainly from the 10-min gel during the rheological test at BHCT.

A salt-rich slurry containing 18 % to 30 % BWOW C505 can be designed by adding sufficient quantities of dispersant C507. This type of slurry is surprisingly very thin, but with certain cements (DTD), some difficulties can arise with this type of design; i.e., gelation at BHCT. One main solution can be investigated: add far more dispersant to exceed a critical point where the dispersant has a contrary effect (some cements may require as much as 0.7 gal/sk of C507 for good rheologies in a salt-saturated system).

6.3.2.GasTIGHT C303 Slurries

Depending on the cement and especially on the temperature, some cases of gelation of C303 slurries have been reported. This may occur when C303 is used near its upper temperature limit or with some very reactive Class A cements. In such cases, it is probably preferable to use the high-temperature Latex stabilizer additive C020. This has been found, in many cases, to extend the practical temperature range for C303 systems.

7. Accelerators

In shallow, low-temperature wells, accelerators speed up the early stages of hydration and cut the cement's setting time. Accelerators are also used to counteract the setting delay caused by other additives, such as dispersants and fluid-loss agents. The most common accelerator is calcium chloride ($CaCl_2$).

7.1.C013 Calcium Chloride

7.1.1.Summary

Calcium Chloride is the most effective and economic accelerator for Portland cement. The Sprint code for calcium chloride flakes is C013. Calcium chloride acts as an accelerator at all concentrations. It serves as a total accelerator in that it reduces the thickening time and also increases early strength development.

Care is required in measuring the amount of C013 used since the addition of 5 % or more may cause the slurry to flash set.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C013	2.2	0.0546	High	White powder

7.1.2.Slurry Design

The addition of calcium chloride to water increases the temperature of the water. This must be taken into consideration when mixing a slurry because this can effect its thickening time. One pound of C013 can be expected to increase the temperature of a barrel (bbl) of slurry by about 1 degF.

C013 effectiveness is reduced as the mix-water ratio of the slurry is increased. Additives such as extenders, which require additional mix water, dilute the calcium chloride and make it less effective. However, some acceleration will always be realized. Concentration

Calcium chloride is used for early strength development at a concentration of from 1 % to 4 % by weight of dry cement. Additional accelerator will not increase the compressive strength of the set slurry.

A C013 concentration of 2 % BWOC is considered to be optimum. The general rule is 2 % C013 will reduce the thickening time by half and will increase the early strength by 50 % to 75 %.

7.1.3.Compatibility

C013 is compatible with almost all additives. C013 may have an adverse affect on other additives such as fluid-loss additives and viscosifiers.

7.1.4.Field Mixing Procedure

Flake calcium chloride (C013) is often added to the mix water in advance of the cement job. However, simulated cement-mixing tests and returns from shallow jobs indicate when dry-blended with the cement, flake calcium chloride will have time to go into solution.

Any C013 caking that occurs in storage must be pulverized before the dry-blending operation. Large lumps will not dissolve fast enough to be effective and also can also cause plugging of equipment. The screen in the blend hopper must be used to catch the lumps of calcium chloride.

7.1.5.Job Design Data

The following data are intended as a guideline only. There will be variation from one brand of cement to another.

% C013	33 degC (91 degF)	39 degC (103 degF)	45 degC (113 degF)
0	4:45	3:35	2:42
2	2:04	1:43	1:30
4	1:20	-	-

Table : C013 and API Class G Cement (Thickening Time (h:min))

%C13	16 degC (60 degF)			27 degC (80 degF)			38 degC (100 degF)		
	6 hr	12 hrs	24 hrs	6 hr	12 hrs	24 hrs	6 hr	12 hrs	24 hrs
0	not set	60	415	45	370	1260	370	840	1780
2	125	480	1510	410	1020	2510	1110	2370	3950
4	125	650	1570	545	1245	2890	1320	2560	4450

Table : Compressive Strength for class A Cement

% C013	33 degC (91 degF)	39 degC (103 degF)	45 degC (113 degF)
0	4:45	3:35	2:42
2	2:04	1:43	1:30
4	1:20	-	-

Table : C013 and API Class G Cement (Thickening Time (h:min))

%C13	16 degC (60 degF)			27 degC (80 degF)			38 degC (100 degF)		
	6 hr	12 hrs	24 hrs	6 hr	12 hrs	24 hrs	6 hr	12 hrs	24 hrs
0	not set	60	375	35	370	1000	170	1000	2000
2	80	370	900	300	1000	1700	550	1500	2150
4	220	525	1100	400	1100	2000	750	1650	2250

Table : Compressive Strength for class G Cement

7.2.C013L Calcium Chloride Liquid

7.2.1.Summary

C013L is a liquid form of calcium chloride which is widely used as an accelerator for cement slurries wherever a liquid additive is advantageous.

C013L may be used in both fresh water and seawater ; but the concentration should be limited to 0.2 gal/sk when mixing with seawater.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C013L	1.38	0.0869	38%	6	Transparent liquid

7.2.2.Slurry Design

C013L has the same effect on slurry-thickening time as solid CaCl2 dry blended with the cement - provided the amount of water used is adjusted to provide an equivalent amounts of CaCl2.

C013L ranges from 32 % to 38 % calcium chloride. One gallon of C013L is equivalent to 3.5 lbm to 4.5 lbm of C013 (77 % CaCl2).

Thickening time data for C013L is generally run at 0.2 and 0.4 gal of C013 per sack. This is roughly equivalent to 1 % and 2 % calcium chloride by weight of cement.

Where thickening time is critical, laboratory tests should be run using the actual volumes of C013L rather than interpreting from a table for C013.

7.2.3.Effect on Sea Water

C013L is widely used offshore where seawater is used to prepare the slurry. Because seawater contains salts including CaCl2, these slurries are more accelerated than fresh water slurries.

No more than 0.2 gal C013L per sack is normally recommended with seawater.

Additional accelerator will seldom improve compressive strength.

Thickening time and compressive strength data should be developed in the laboratory using the actual brand of cement as well as the seawater to be used on the job.

7.2.4.Field Mixing Procedure

The preferred method of mixing is to blend C013L into the mix water. The mix water must be agitated to thoroughly blend the accelerator throughout the mix water.

The volume of C013L must be included as part of the mix water.

7.2.5.Job Design Data

Some idea as to the range of thickening times and compressive strengths that can be expected may be obtained from the table below. These data are intended as a guideline only. There will be variations from one brand of cement to another.

C013L gal/sk	33 degC (91 degF)	39 degC (103 degF)	45 degC (113 degF)
0	4:05	3:35	2:35
0.2	2:40	1:45	1:30
0.4	1:45	1:25	1:00

Table : C013L and API Class G Cement (Thickening Time (h:min))

C013L gal/sk	16 degC (60 degF)		27 degC (80 degF)		38 degC (100 degF)	
	8 hr	24 hr	8 hr	24 hr	8 hr	24 hr
0	not set	375	195	1000	625	2000
0.2	200	900	650	1700	1000	2150
0.4	350	1100	755	2000	1210	2250

Table : Compressive Strength for class G Cement

8. Retarders

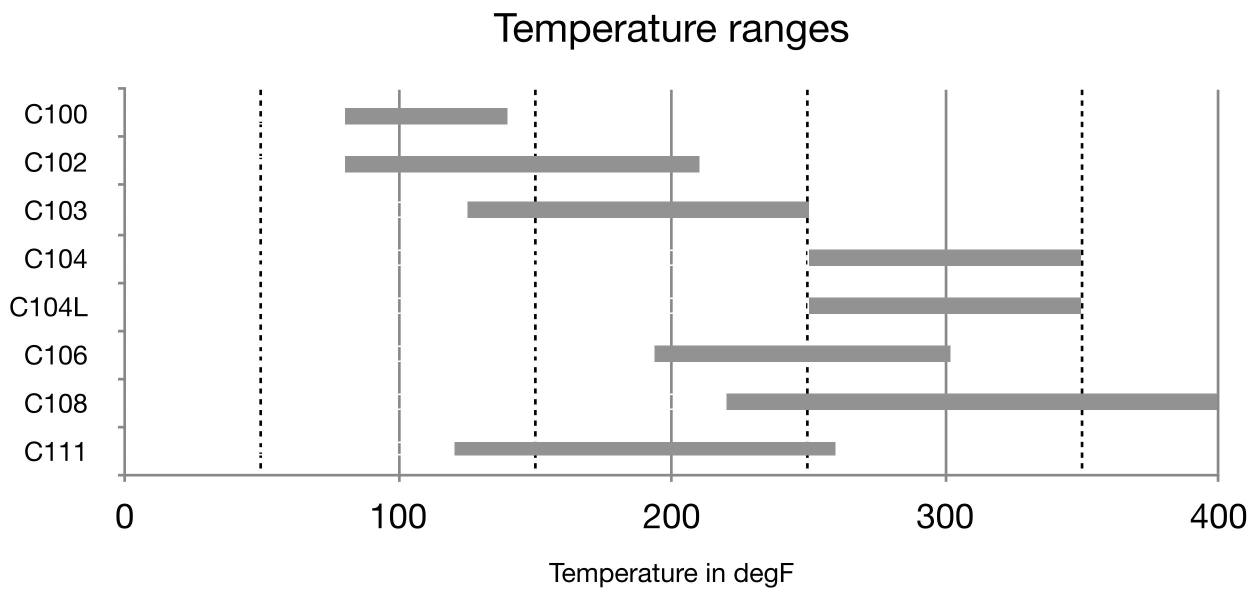
The selection of a retarder additive for a particular application is based not only on the expected bottom-hole circulating temperature but also on:

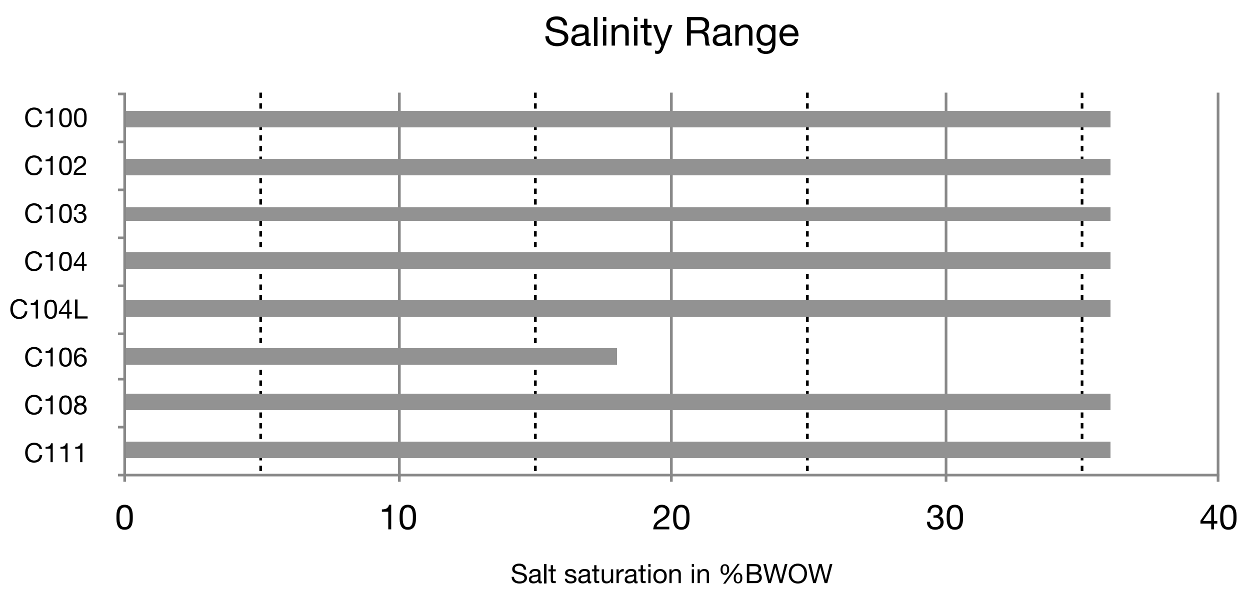
- The effects the retarder additive will have on the other cement properties (fluid loss, free fluid, early compressive strength etc.).
- The compatibility of the retarder additive with other additives selected (latex, salt, mix water, etc.)
- In some cases, the retarder additives which are physically available.

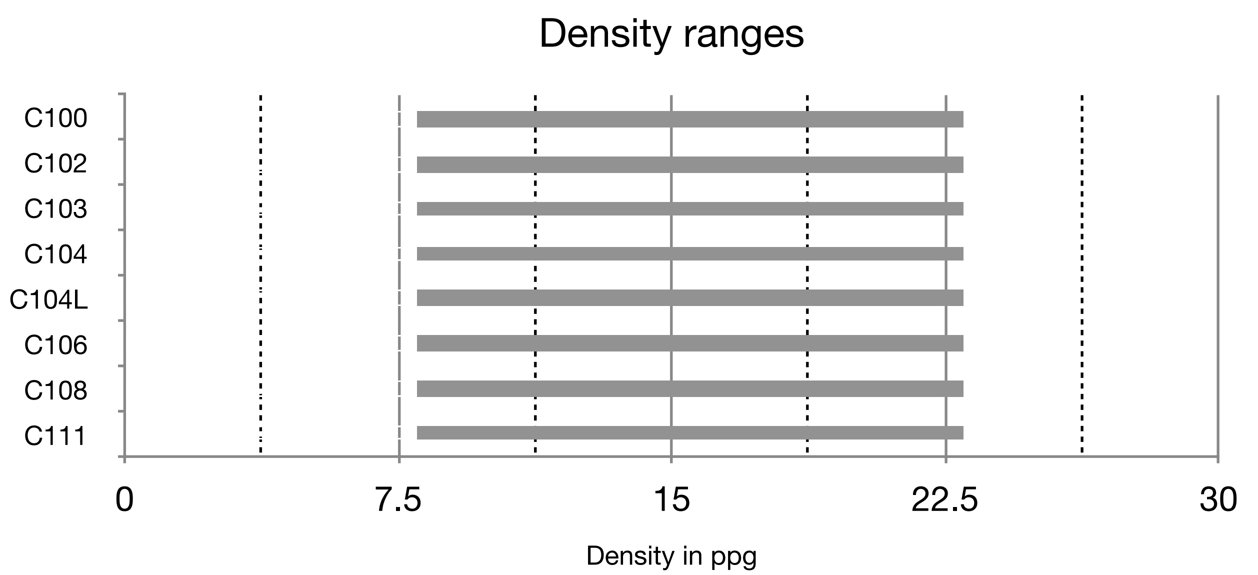
Therefore, only general guidelines for retarder selection are presented in this manual section. For temperature-range applications, a preferred range is presented in the table. This range reflects the temperatures, for typical slurry designs, at which the retarder works best, but by no means should be taken as granted. The other additives present in the cement slurry system, the type of cement, the brands of cement, the mix water quality, etc. play also a very important role in the retarder efficiency. Lab testing of the final slurry with the selected retarder is absolutely mandatory not only to verify the thickening time but also the other properties.

Retarders Summary

Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
C100	Low Temp Powder Retarder	Fresh and sea water slurries. Preferred retarder for bentonite slurries. Cost effective low temp Retarder.	Sensitive to cement variation and dispersing side effect	80 - 140 (Up to 185 with dispersant)	1.42
C102	Low to Mid Temp Powder Retarder	Fresh and sea water slurries. Less sensitive to cement variation. Cost effective low to mid temp Retarder.	Dispersing side effect	80 - 210 (up to 310 with C508)	1.32
C103	Mid Temp Liquid Retarder	Fresh and sea water slurries.	Dispersing side effect	125 - 250 (up to 310 with C508)	1.27
C104	High Temp Powder Retarder	Fresh and sea water slurries. Early compressive strength development.	Slight dispersing side effects. Sensitive to concentration errors.	250 - 350	1.79
C104L	High Temp Liquid Retarder	Fresh and sea water slurries. Early compressive strength development.	Slight dispersing side effects	250 - 350	1.25
C106	Mid to High Temp Liquid Retarder	Fresh water and up to 18% BWOW salt water.	Sensitive below 240 deg F.	194 - 302	1.30
C108	High Temp Liquid Retarder	Fresh and salt water slurries. Provides consistent and predictable thickening times. Suitable for long cement columns.	Sensitive below 220 deg F. Slight dispersing side effects.	220 - 400	1.08
C111	Mid to High Temp Powder Retarder	Fresh and salt water slurries. Provides consistent and predictable thickening times.	Requires additional dispersant. Slight gelation have been observed in lab tests.	140 - 260	2.3


Temperature ranges
C100
C102
C103
C104
C104L
C106
C108
C111
0
100
200
300
400
Temperature in degF


Salinity Range
C100
C102
C103
C104
C104L
C106
C108
C111
0
10
20
30
40
Salt saturation in %BWOW


Density ranges
C100
C102
C103
C104
C104L
C106
C108
C111
0
7.5
15
22.5
30
Density in ppg

8.1.C100 Retarder

8.1.1.Summary

Retarder C100 can be used to provide most cement systems with optimum thickening times up to 60 deg C (140 deg F) BHCT. This BHCT limit can be extended to 85 deg C (185 deg F) when a dispersant or a retarder aid C508 is also incorporated in the cement system.

C100 reduces the cement slurry viscosity and aids some cement slurries in obtaining moderate fluid-loss control.

C100 can be used in cement slurries prepared with fresh water or sea water. It is compatible with all API classes of cement and with most cement additives.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C100	1.42	0.0845	High	Brown Powder

8.1.2.Slurry Design

Retarder C100 is a calcium/sodium lignosulfonate blend similar to some materials marketed as mud-thinning agents. Because it is a good dispersant, C100 reduces the viscosity of cement slurries, especially in slurries containing bentonite. For cement slurries containing 12% or more bentonite, C100 aids in obtaining moderate fluid-loss control. For these reasons, C100 is the preferred retarder for bentonite slurries.

C100 functions as a retarder by absorbing on to cement-particle surfaces slowing the hydration rate. C200 has a synergistic effect on the retardation properties of C100. The thickening times run longer than normally would be expected.

For example, a Class G cement slurry containing 0.5% C100 was found to have a thickening time over three hours at 140 deg F. The addition of 0.4% C200 dispersant increased the thickening time to above seven hours. Because of its compatibility, effectiveness over a wide temperature, and dispersant properties, Retarder C100 is the most commonly used Sprint retarder at low temperatures.

It has been observed with some cements that at low end of the temperature range (Below 100 degF), C100 tends to accelerate the cement slurry when used at low concentrations (below 0.3% - 0.4% BWOC). In such cases, the cement at the top of the cement column can set earlier than the bottom cement. The reason for this behavior is still not fully understood.

8.1.3.Compatibility

C100 can be very sensitive to variations in cement quality. With some cements, severe gelation difficulties have might be encountered when using C100. In such cases, the use of C102 is recommended instead.

8.1.4.Job Design Data

Typical thickening time and compressive strength data are presented to illustrate the performance of C100, and are intended to be used as a guideline only. Data for API Classes A and G a cements are presented hereafter. Because of the variation in different cement brands, pre-job laboratory testing is essential.

% C100	Curing Temperature 38 degC (100 degF)		Curing Temperature 60 degC (140 degF)		Curing Temperature 82 degC (180 degF)	
	12 h	24 h	12 h	24 h	12 h	24 h
0.0	1,600	3,200	3,000	4,450	4,500	5,650
0.2	1,050	3,150	1,800	4,400	3,150	5,500
0.3	800	3,000	1,500	4,200	2,600	5,200
0.4	600	2,750	1,250	3,800	2,000	4,700
0.5	75	1,500	250	2,950	900	4,050

Table API Compressive Strength Cured Under API Recommended Pressure for Class A Cement Slurry of 15.8 ppg

% C100	100 degF	125 degF	133 degF
0.1	03:35	2:03	-
0.3	03:57	2:14	-
0.35	-	2:39	2:44
0.4	4:45	-	-
0.5	5:36	-	3:25

Table: API Thickening Time (h:min) Simulated Well Depth/API Casing Schedules for Class G Cement Slurry of 15.8 ppg

%	Curing Temperature 38 degC (100 degF)			Curing Temperature 60 degC (140 degF)			Curing Temperature 82 degC (180 degF)		
C100	8 h	16 h	24 h	8 h	16 h	24 h	8 h	16 h	24 h
0.0	1,200	2,300	3,100	1,900	2,750	3,400	2,750	3,100	3,650
0.1	900	2,150	3,000	1,700	2,600	3,350	2,700	2,950	3,650
0.2	650	1,800	2,750	1,300	2,300	3,150	2,150	2,750	3,650

Table: API Compressive Strength (psi) Cured Under API Recommended Pressure for class G Cement Slurry of 15.8 ppg

8.2.C102 Retarder

8.2.1.Summary

Retarder C102 is a modified grade lignosulfonate. It can be used to provide cement systems with optimum thickening times up to 98 deg C (210 deg F) BHCT. This BHCT limit can be extended to 154 deg C (310 deg F) when used in conjunction with a "retarder aid" such as C508 or XS5118.

C102 effectively retards most API cements and is compatible with all cement additives. It reduces the cement slurry viscosity and does not impair the fluid-loss control properties of fluid-loss additives. Unlike retarder C100, gelation is seldom encountered in slurries containing C102. C102 is less sensitive to variations in temperature, concentration and cement quality.

C102 can be used in cement slurries prepared with fresh water or salt water. Saltwater concentrations may range from 3 % (seawater) to 37 % (salt-saturated water).

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C102	1.32	0.0909	High	Yellow or Brown Powder

8.2.2.Slurry Design

The retarder response is consistent up to 98 deg C (210 deg F). When used in conjunction with C508, the temperature range is extended to 154 deg C (310 deg F) but with reduced C102 efficiency.

Like most other lignosulfonate retarders, C102 is an effective dispersant. In most cases, it is a stronger dispersant than C100, and as such, slurries mixed with C102 will require less additional dispersant to permit proper mixing and/or turbulent-flow placement.

In all cases, C102 response is less dependent of cement brand, whereas C100 response is subject to wide variation depending on cement brand.

Similarly to C100, It has been observed with some cements that at low end of the temperature range (Below 100 degF), C102 tends to accelerate the cement slurry when used a low concentrations (below 0.3% - 0.4% BWOC). In such cases, the cement at the top of the cement column can set earlier than the bottom cement. The reason for this behavior is still not fully understood.

Note: C102 is effective to 98 deg C (*210 degF) without retarder aids and gelation may occur above 104 degC (220 degF) with some cements.*

8.2.3.Concentration

The typical concentration (BWOC) of C102 required to give four-hour thickening time ranges from 0.4 % to 1.0 % depending on the temperature and cement. In addition, the use of dispersants in conjunction with C102 increases the retarder efficiency and reduces the amount needed to achieve a similar thickening time. At 85 degC (185 degF) BHCT, a four-hour thickening time is readily achieved in most cements using 0.4 % C102 (BWOC) for a freshwater slurry and 0.6 % C102 (BWOC) for a seawater slurry. Because C102 is temperature-stable, it can be used at high temperatures; but above 85 degC (185 degF) the retarder concentration must be increased from 0.4 % to 1.0 % as the BHCT approaches 98 deg C (210 degF).

Between 52 degC and 85 degC (125 degF and 185 degF), only small changes in concentration are required to obtain the desired thickening time; whereas above 85 degC (185 degF), a relatively large change in retarder concentration is required to obtain the desired thickening time as BHCT temperature increases.

8.2.4.C102 Extended Temperature Range

The C102 temperature range can be extended to 154 degC (310 degF) using C508 as a retarder aid. Adequate thickening times are easily obtained at this temperature using approximately 1 % C102 in conjunction with 2 % to 4 % C508.

8.2.5.Compatibility

In general, seawater and salt-saturated slurries require a higher C102 concentration than those mixed with fresh water. Therefore, it is necessary to run compressive strength tests to determine if the slurry will set at the cement top.

C102 is incompatible with C509 Expandable Cement Agent as C102 reduces the thixotropic properties of the cement slurry.

8.2.6.Job Design Data

The thickening-time and compressive-strength data in this document are intended to be used as guideline only. Pretesting under specific conditions with the cement designated for the job is required to predict the properties of the cement slurry.

C102(%)	52 degC (125 degF)	62 degC (144 degF)	85 degC (185 degF)	102 degC (215 degF)
0.2	2:26	2:07	1:45	-
0.3	5:33	4:56	3:10	1:50
0.4	-	6:53	5:03	1:40
0.5	-	-	-	2:46
0.8	-	-	-	3:00
1.0	-	-	-	4:17

Table : Typical thickening Times (h:mn) of class G Cement Slurries. 15.8 lbm/gal Slurry DensityFresh-MixWater

C102 (%)	C030 (%)	Curing Temperature (degC (degF))	Compressive Strength (psi)
0.3	0.0	93 (200)	5,000
0.6	0.0	93 (200)	6,900
0.4	0.0	110 (230)	5,000
0.8	0.0	110 (230)	7,800
0.4	0.0	127 (260)	6,700
0.8	35.0	127 (260)	4,300
0.4	0.0	143 (290)	6,100

Table: 24-h Compressive Strength of Class G Cement Slurries

8.3.C103 Liquid Retarder

8.3.1.Summary

Liquid Retarder C103 is a liquid modified lignosulfonate retarder. It can be used to provide cement systems with optimum thickening times from 52 degC to 121 degC (125 degF to 250 degF) BHCT. This BHCT limit can be extended to 154 degC (310 degF) when used in conjunction with a ”retarder aid”.

C103 effectively retards most API cements, and is compatible with all cement additives. It reduces the cement slurry viscosity and does not impair the fluid-loss control properties of fluid-loss additives. Unlike Retarder C101, gelation is seldom encountered in slurries containing C103; and C103 is less sensitive to variations in temperature, concentration and cement quality.

C103 can be used in cement slurries prepared with fresh water or salt water. Saltwater concentrations may range from 3 % (seawater) to 37 % (salt-saturated water).

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C103	1.27	0.0944	40% - 70%	6.06	Dark Brown Liquid

8.3.2.Slurry Design

It is easily dispersible in the mix water to provide uniform distribution throughout the cement slurry.

The optimum BHCT range for C103 is between 52 degC and 121 degC (125 degF and 250 degF). Retarder response is consistent over this temperature range and is almost independent of variations in cement quality. When used in conjunction with retarder aid C508, the temperature range is extended to 154 degC (310 degF) but with reduced C103 efficiency.

Like most other lignosulfonate retarders, C103 is an effective dispersant and as such, slurries mixed with C103 will require less additional dispersant to permit proper mixing and/or turbulent-flow placement. Unlike other liquid lignosulfonate retarders, C103 remains very fluid and exhibits no deposits or crystallization at temperatures as low as 0 degC (32 degF).

Note: Although C103 is effective to 121 degC (250 degF) without retarder aids, gelation may occur above 104 degC (220 degF) with some cements. Also, because C103 is a powerful retarder at lower temperatures, compressive strength testing is required to verify that the cement will set at the cement column top.

8.3.3.Concentration

The recommended concentration for C103 is between 0.05 to 0.25 gal/sk of cement. Figure below shows the relationship between concentration and temperature for a four-hour thickening time, using both fresh and salt saturated water.

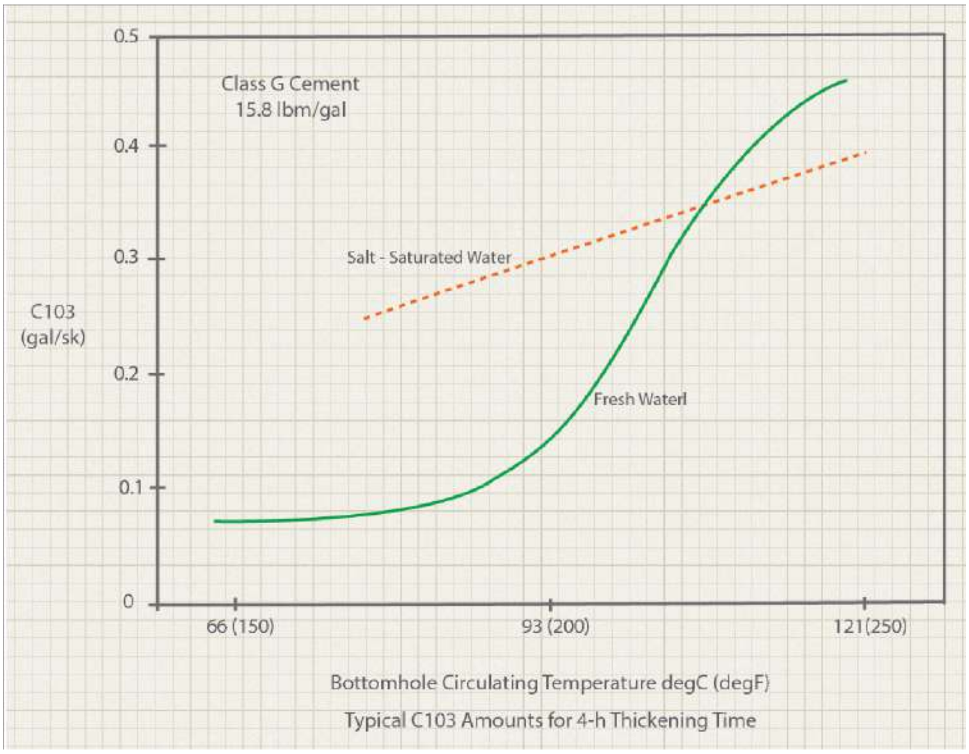


Fig. Typical C103 Amounts for 4-h Thickening Time

8.3.4.C103 Extended Temperature Range

The C103 temperature range can be extended to 154 degC (310 degF) using C508 as a retarder aid. Retarder aid C508 has to be dry blended or added to the mix water before the C103 because of their limited solubility in C103.

8.3.5.Compatibility

C103 is compatible with most API cements and Sprint cement additives. It is compatible with fresh, sea or salt-saturated mix water. The use of salt-saturated water increases the efficiency of C103 above 102 degC (215 degF), but decreases it at lower temperatures.

C103 is incompatible with C509 Expandable Cement Agent as C103 reduces the thixotropic properties of the cement slurry.

8.3.6.Field Mixing Procedure

In some operations, it may be desirable to blend C103 with other liquid additives so that they can be metered with one pump. When mixed with C103, some liquid additives form very thick mixes. In these cases, the additives should be diluted by mixing into water. A summary of dilutions is shown in Table below.

Additive	Relative Combined Viscosity	Dilution Required
C400 Extender	Very Thick	30 %
C201 Dispersant	Slightly Thick	None

Table 8.6 Dilution required for easy handling-based on the combined volume of liquid agents

8.3.7.Job Design Data

The data presented here on thickening times and compressive strengths are intended to be used as guideline only. Pretesting under specific conditions with the cement designated for the field application is required to determine the properties of the cement slurry.

C103 gal/ sk	C030%	Water %	Type of Water	API Sch.7 85 degC (185 degF)	API Sch. 8 102 degC (215 degF)	API Sch. 9 118 degC (245 degF)
0.10		44	F.W.	4:10		
0.20		44	F.W.	8:15		
0.30		44	F.W.	-	3:40	
0.40		44	F.W.	-	6:00+	
0.40	35	56	F.W.	-	-	2:20
C103 gal/ sk	C030%	Water %	Type of Water	API Sch.7 85 degC (185 degF)	API Sch. 8 102 degC (215 degF)	API Sch. 9 118 degC (245 degF)
0.50	35	56	F.W.	-	-	6:30
0.12	-	69	S.S.W.	1:54		
0.20	-	-	S.S.W.	2:35	2:18	
0.25	-	-	S.S.W.	3:27		
0.30	-	-	S.S.W.	-	3:34	
0.35	-	-	S.S.W.	-	5:09	
0.40	-	-	S.S.W.	-		4:20
0.40	35	84	S.S.W.	-	-	3:34
F.W: Fresh Water S.S.W.: Salt Sarurated Water						

Table: Typical Thickening Times (h:min) of Class G Cement Slurries. 1896 kg/m (15.8 cubic lbm/gal) Slurry Density

C103 (gal/sk)	C030 (%)	Water (%)	Curing Temperature degC (degF)	Compressive Strength (psi)
0.2		44.0	93 (220)	5,060
0.4		44.0		not set (1)
0.3	35	56.0	110 (230)	4,440
0.4	35	56.0		4,270
C103 (gal/sk)	C030 (%)	Water (%)	Curing Temperature degC (degF)	Compressive Strength (psi)
0.4	35	56.0	127 (260)	2,900
0.5	35	56.0		Not Set (1)
1. Not Set or lower strength under API test conditions; i.e at 3,000 psi curing pressure, but thickening-time tests under simulated bottomhole pressure tests show that the cement slurry will gain strength rapidly after the elapsed thickening time.				

Table: 24-h Compressive Strength of Class G Cement Slurries. 1896 kg/m (15.8 lbm/gal) SlurryDensity,FreshMixWater

8.4.C104 HT Retarder

8.4.1.Summary

C104 is a hydroxycarboxylic acid salt based retarder used in cementing high temperature wells where the bottom hole circulating temperature is in excess of 250 deg F., C104 provides effective retardation of the cement slurry in casing, liner, squeeze and abandonment applications.

C104 has a dispersing property and therefore might require the use of anti-settling agents in conjunction to avoid free water problems.

Where fluid loss control is required, C104 may be used in conjunction with fluid loss additives.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C104	1.79	0.0669	High	White crystal or powder

8.4.2. Compatibility

C104 is compatible with:

- freshwater slurries up to 177 degC (350 degF),
- seawater slurries up to at least 177 degC (350 degF),
- with most FLAC, dispersants, silica flour, antifoamers/defoamers and weighing additives.
- C104 is compatible with C303 under conditions that primarily depend on the cement brand and the choice of dispersant. When slurries are properly dispersed, good fluid-loss control can be achieved at temperatures up to 177 degC (350 degF).

C104 is compatible with most typical SPRINT additives however caution should be exercised when working on a new slurry design.

8.4.3.Slurry Design

C104 provides slurries with long and predictable thickening times at temperatures ranging from 121 degC to 177 degC (250 degF to 350 degF). Typical C104 concentrations are between 0.2% and 1.5% BWOC. The necessary concentration at a particular temperature may be dependent on the additives used.

C104 is a very active retarder and can be sensitive to mixing errors and temperature variations. It is not recommended for dry blending due to the small concentrations and dry blending inconsistencies. To reduce mixing errors on field, it is highly recommended to use C104L instead.

It is important to run a compressive strength test at the TOC conditions to ensure that the appropriate WOC time is taken especially in long columns.

In most cases, slurries can be retarded to 7 h to 9 h, yielding an increased safety margin in terms of the pumping time without impairing the WOC time.

Slurry density does not limit the use of C104.

8.5.C104L HT Liquid Retarder

8.5.1.Summary

C104L is a chemical derivative liquid version of C104 with an active component of 52%. It provides optimum thickening times for a temperature range between 121 deg C and 177 deg C (250 deg F and 350 deg F). Due to its dilution level, it is less sensitive to concentration changes or mixing errors compared to the powder version and, provides better test repeatability.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C104L	1.25	0.0959	52%	1.33	Amber Liquid

C104L has a dispersing property and therefore might require the use of anti-settling agents in conjunction to avoid free water problems.

Where fluid loss control is required, C104L may be used in conjunction with fluid loss additives.

8.5.2.Compatibility

C104L is compatible with:

- freshwater slurries up to 177 degC (350 degF),
- seawater and salt slurries up to at least 177 degC (350 degF),
- with most FLAC, dispersants, silica flour, antifoamers/defoamers and weighing additives.
- C104L is compatible with C303 under conditions that primarily depend on the cement brand and the choice of dispersant. When slurries are properly dispersed, good fluid-loss control can be achieved at temperatures up to 177 degC (350 degF).

C104L is compatible with most typical SPRINT additives however caution should be exercised when working on a new slurry design.

8.5.3.Slurry Design

C104L provides slurries with long and predictable thickening times at temperatures ranging from 121 deg C to 177 deg C (250 deg F and 350 deg F). Typical C104 concentrations are 0.1 gps to 0.3 gps. The necessary concentration at a particular temperature may be dependent on the additives used.

The thickening time is relatively less sensitive to the C104L concentration when compared to C104 i.e. Small concentration errors do not dramatically affect the thickening time due to its dilution level, contrary to C104.

In most cases, slurries can be retarded to 7 h to 9 h, yielding an increased safety margin in terms of the pumping time without impairing the WOC time.

Slurry density does not limit the use of C104L.

8.6.C106 MT-HT Liquid Retarder

8.6.1.Summary

SPRINT C106 retarder is used in mid to high temperature cement systems, and at BHCT temperatures between 90 and 150°C（194-302F). The C106 is used in freshwater or saline water systems and is salt-tolerant up to half-saturation. The product is mixed with water, and is compatible with all types of brackish water.

C106 is a blend of synthetic organophosphonate and hydroxycarboxylic salt giving it high efficiency performance at high end temperatures.

In low temperature environments, the final compressive strength of set cement may be influenced and reduced. Also, in cases of long liners where temperature at the liner top is considerably lower than the BHCT used to design the cement slurry, the setting of the cement at the top of liner might be excessively delayed as well as the compressive strength build up.

The C106 has a certain dispersion effect. In the cement slurry system containing C106, suspension agent should be added to decrease the free fluid if necessary.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C106	1.30	0.0922	50%	6.44	Brownish black liquid

8.6.2.Compatibility

C106 is compatible with:

- freshwater slurries up to 302 degF,
- Up to 18% BWOW salt slurries up to 302 degF,
- with most FLAC, dispersants, silica flour, antifoamers/defoamers and weighing additives.

C106 has been used successfully with C303 GAS-TIGHT systems up to 271 deg F BHCT. The compatibility at higher temperatures have not been tested at the time of this revision and therefore caution should be taken in such scenarios.

8.6.3.Slurry Design

A C106 typical concentration is between 0.025 gps and 0.15 gps however concentration as high as 0.38 gps have been used successfully.

Due to the C106 dispersion effect, anti-settling agents such as C524 can be used in conjunction to eliminate free water problems.

C106 performance has been found to be sensitive at temperatures below 240 deg F. It is recommended in such cases to use C108 retarder instead to reduce thickening time sensitivity due to variations in mixing concentrations or inaccuracy of BHCT estimation.

Below are typical designs with C106 retarders.

Slurry 1, 15.8 ppg at 271 deg F BHCT

Density (ppg)	15.80	Yield cu, ft/sk	1.551
Mix Water (g/sk)	4.749	Mix Fluid (g/sk)	6.59
Porosity	56%	Batch Mix Time	30 mins

Code/Type	Description	Unit	Conc.	Lab conc.	Conc. for 1 bbl
C517	Cement Class G	sx	100	582.51 gm	3.619 sx
C030	Silica Flour	%bwoc	35.0 %	203.88 gm	119.094 lbs
C011	Defoamer	gps	0.02	1.03ml	0.072 gal
C302k	Flac	%bwoc	0.35	2.04 gm	1.191 lbs
C524	Anti-Settling Agent	%bwoc	0.25	1.46 gm	0.851 lbs
C303	Gastight Latex	gps	1.20	62.05 ml	4.344 gal
C020	Latex Stabilizer	gps	0.20	10.34 ml	0.724 gal
C106	HT Retarder	gps	0.38	19.65 ml	1.376 gal
H2O	Water			245.59ml	0.410 bbl

Thickening Time:	
30 Bc	7:49
70 Bc	7:51

Compressive Strength:	
Time (hr: min)	Strength (psi)
12:00	1344
24:00	2284

Slurry 2, 15.5 ppg at 218 deg F BHCT

Density (ppg)	15.50	Yield cu, ft/sk	1.602
Mix Water (g/sk)	6.761	Mix Fluid (g/sk)	6.97
Porosity	58%	Batch Mix Time	30 min

Code/Type	Description	Batch #	Unit	Conc.	Lab conc.	For 1 bbl
C517	Cement Class G	06-2023-01	sx	1.00	564.11 gm	3.506 lbs
C030	Silica Flour	2023-06-01	%Bwoc	35.00	197.44 gm	115.331 lbs
C011	Defoamer	2261075306	gps	0.02	1.00 ml	0.070 gal
C302	HT FLAC	20230130	%Bwoc	0.63	3.55 gm	2.076 lbs
C524	Anti-Settling	8R254954A0	%Bwoc	0.50	2.82 gm	1.648 lbs
C106	HT Retarder	HTR20170222	gps	0.10	5.01 ml	0.351 gal
H2O	Water	Field sample			339.58 ml	0.566 bbl

Thickening Time:	
30 Bc	06:39
70 Bc	06:56

Compressive Strength:	
Time (hr: min)	**Strength (psi)**
12:00	1825
24:00	1972

8.7.C108 HT Liquid Retarder

8.7.1.Summary

Liquid Retarder C108 is a synthetic retarder that can be used to provide cement systems with optimum thickening times from 104 to 204 deg C (220 to 400 deg F) BHCT.

C108 effectively retards all API cements and is compatible with all cement additives. It has a slight dispersing action with most cements which results in some thinning of the cement slurry. C108 can be used in slurries prepared with either fresh water or seawater.

C108 is a synthetic retarder that provides consistent and predictable retardation in cement slurry with almost constant retarder response from 220°F to 400°F. C108 can be easily dispersed in cement slurry mix water and helps early compressive strength development at top of liner temperatures.

Code	SG	Absolute Volume (gal/lbm)	pH	Appearance
C108	1.08 - 1.12	0.110	6.0 - 9.0	Clear light yellow

8.7.2.Compatibility

C108 is compatible with:

- freshwater slurries.
- seawater and salt slurries.
- with most FLAC, dispersants, silica flour, antifoamers/defoamers and weighing additives.
- GasTIGHT systems

8.7.3.Concentration

The normal concentration range of C108 is from 0.05 gal/sk to 1.5 gal/sk of cement.

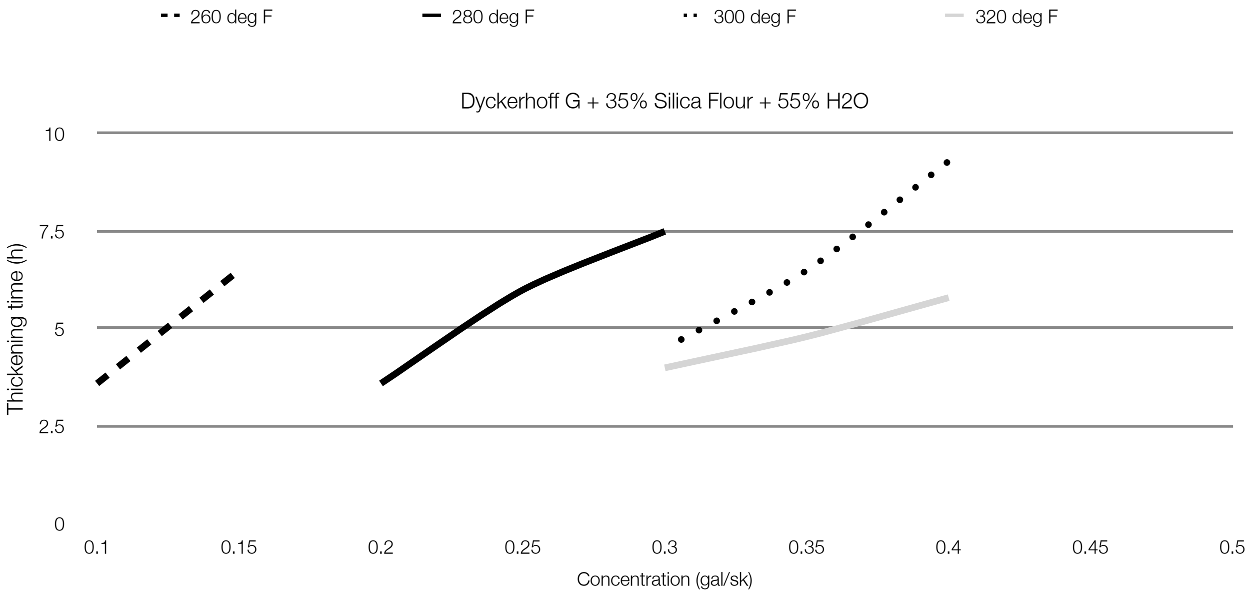
Specific thickening time for slurry design must be determined in the laboratory. The specific brand of cement along with the additives to be used on the job must be made available for these tests. If free fluid or sedimentation is encountered during laboratory testing, Anti-settling Agent C154 can be used to cure the problem.

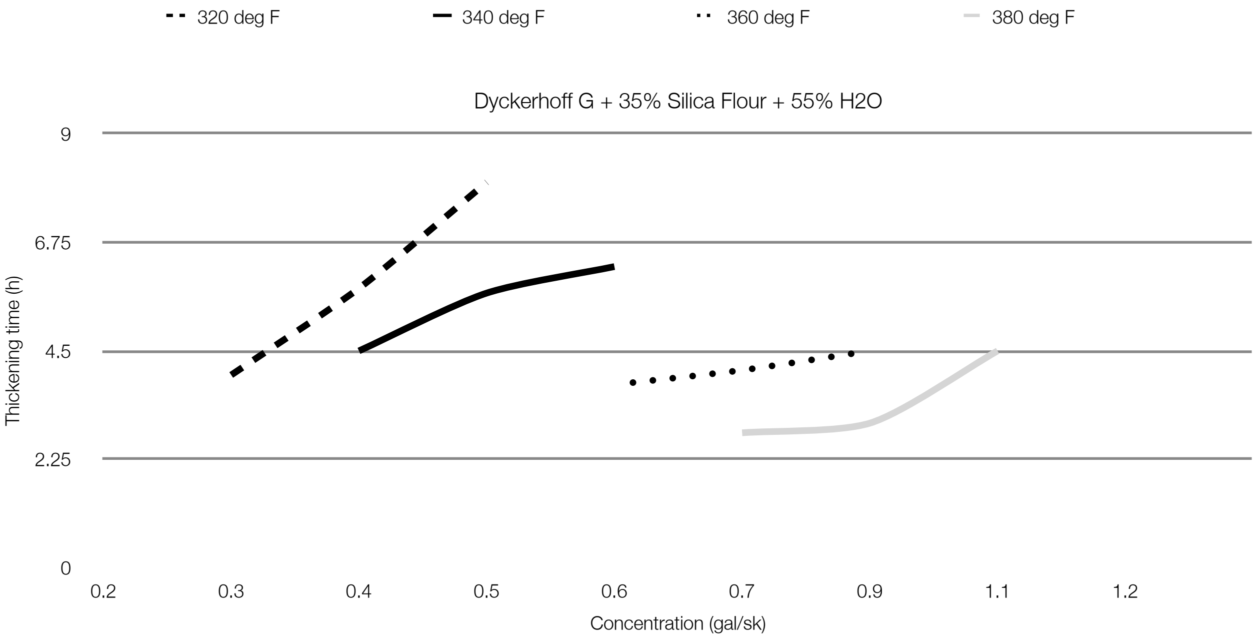
8.7.4.Field Mixing Procedures

In some operations, it may be desirable to blend two liquid additives so they can be metered with one pump. In such case the blend must replicated in the lab to ensure that the chemicals are compatible (No gel nor precipitation).

8.7.5.Slurry Design

Slurry Design with 15.8 ppg class G cement





8.8.C111 MID-HT Temperature Retarder

8.8.1.Summary

C111 is a dry synthetic retarder that provides consistent and predictable retardation in cement slurry with almost constant retarder response from 120°F to 260°F. C111 is particularly suitable for mid to high offshore applications.

C111 effectively retards all API cements and is compatible with all cement additives. C111 can be used in slurries prepared with either fresh water or sea water.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C111	2.3	0.0521	High	Off white powder

8.8.2.Compatibility

C111 is compatible with:

- freshwater slurries.
- seawater and salt slurries.
- with most FLAC, dispersants, silica flour, antifoamers/defoamers and weighing additives.
- GasTIGHT systems

8.8.3.Concentration

The normal concentration range of C111 is from 0.1 to 1.0 % BWOC.

Specific thickening time for slurry design must be determined in the laboratory. The specific brand of cement along with the additives to be used on the job must be made available for these tests.

8.8.4.Field Mixing Procedures

C111 disperses readily in water with moderate agitation.

8.8.5.Slurry Design

C111 is a not non dispersing retarder and will require additional dispersant relative to other retarders. It suitable for slurries exhibiting stability issues.

Thickening time for 15.8 ppg UCN Class G Slurry

C111 %BWOC	150 deg F	175 deg F	200 deg F
0.2	3:10	3:00	2:59
0.25	4:25	3:52	3:32
0.35	7:00	6:30	5:20

Thickening time for 15.8 ppg UCN Class G Slurry + 35% Silica Flour

C111 %BWOC	225 deg F	250 deg F
0.4	2:57	-
0.5	4:36	-
0.6	6:48	2:36
0.7	-	3:13
0.8	-	4:18

Thickening time for 15.8 ppg Saudi Class G Slurry

C111 %BWOC	150 deg F	175 deg F	200 deg F
0.25	2:50	2:21	2:18
0.3	3:48	3:15	3:12
0.4	6:27	5:55	5:10

Thickening time for 15.8 ppg Saudi Class G Slurry + 35% Silica Flour

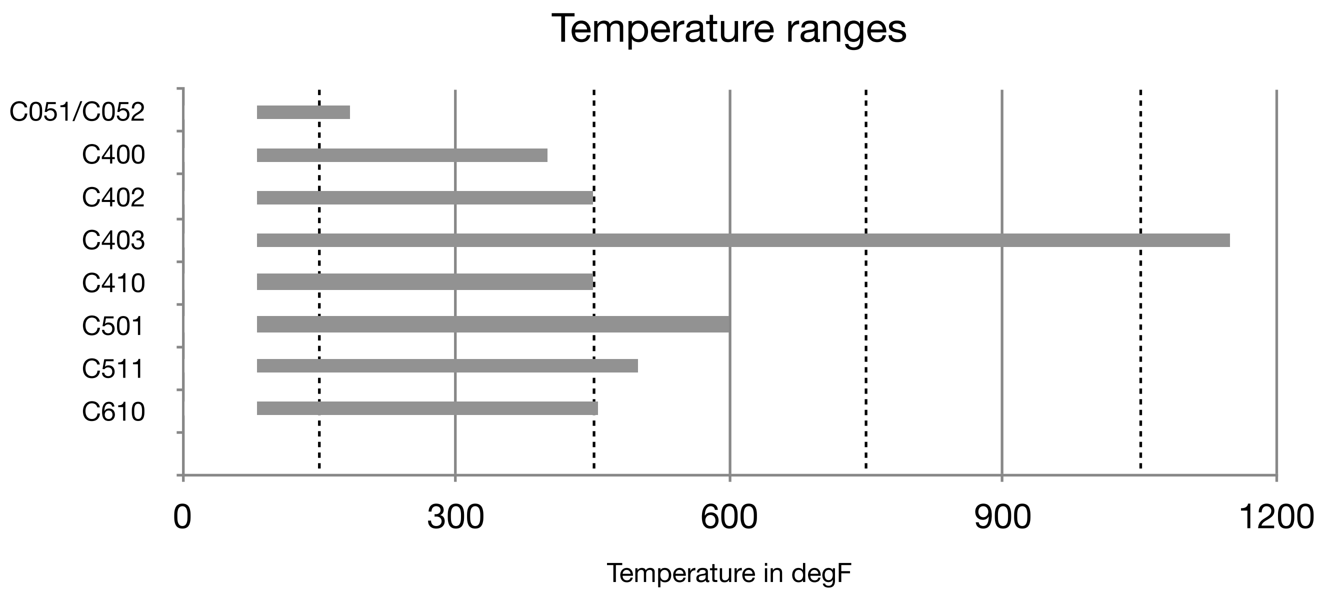
C111 %BWOC	225 deg F	250 deg F
0.5	1:35	-
0.6	3:03	-
0.7	6:34	1:20
0.9	-	3:36
1.0	-	5:59

9. Extenders & Lightweight Additives

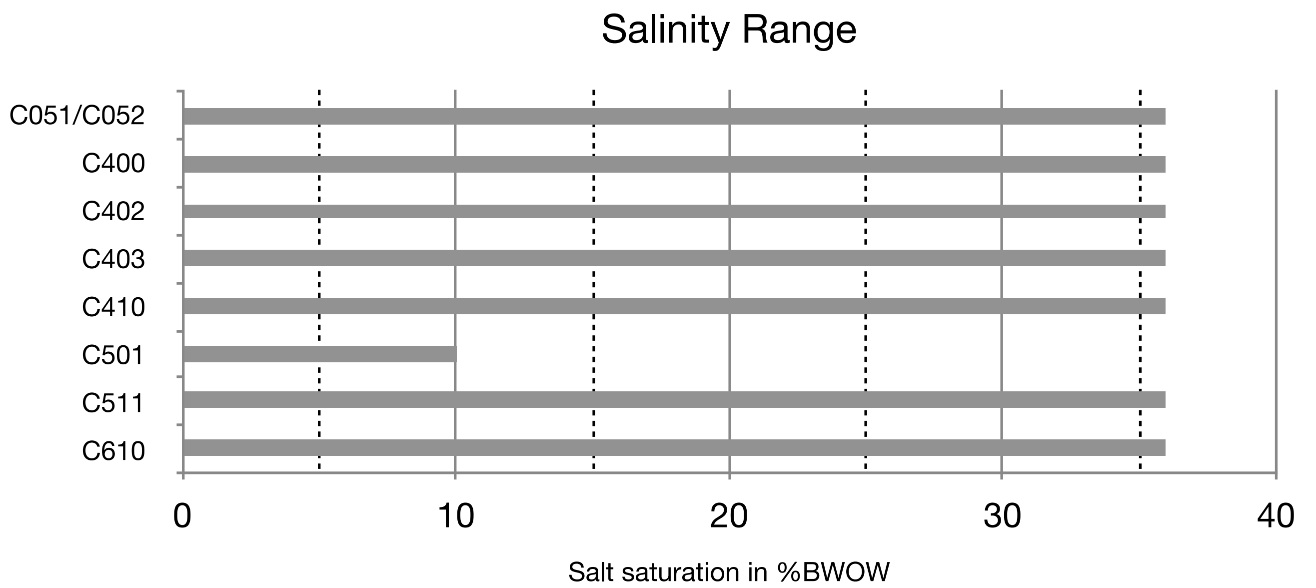
Cement extenders reduce slurry density and lower hydrostatic pressure during cementing operations. This helps prevent the breakdown of weak formations and loss of circulation. They also reduce the amount of cement needed for the cementing operation. Because they are less expensive than cement, they bring considerable savings. Three types of extenders are water extenders, low-density aggregates and gas. Often more than one type is used in the same slurry.

Extenders and Lightweight Additives Summary

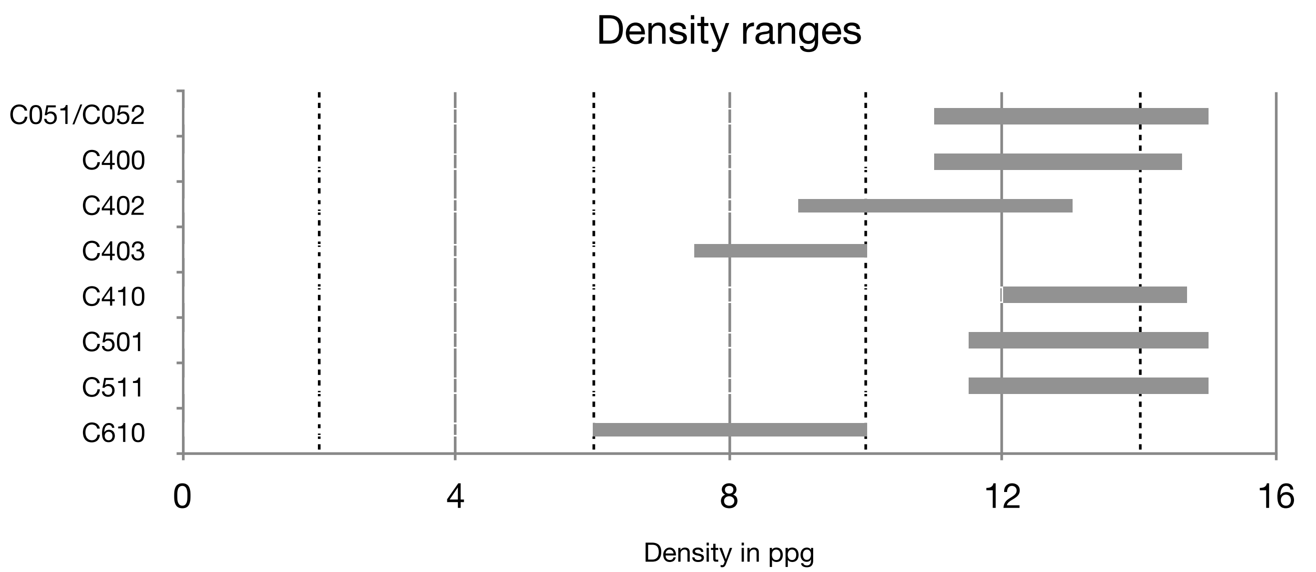
Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
C051	Extender	Fresh and salt slurries. Reduces slurry density down to 11.0 ppg.	• Difficult to retard over 185 deg F • Time consuming blending operations with powder version	80 - 185	2.35
C052	Liquid Extender	Fresh and salt slurries. Reduces slurry density down to 11.0 ppg.	• Difficult to retard over 185 deg F	80 - 185	1.4
C402	Ceramic Micro-spheres	Fresh and salt slurries. High compressive strength and low porosity applications. Reduces slurry density down to 9 ppg.	• Crushing effect. • Rated up to 5000 psi BHP. • High rheology. • Can exhibit sedimentation if not carefully designed.	80 - 450	0.7 - 0.9
C403	Hollow Glass Microspheres	Fresh and salt slurries. High compressive strength and low porosity applications. Reduces slurry density down to 7.5 ppg.	• Crushing effect. • Rated up to 6000 psi BHP. • High rheology. • Can exhibit sedimentation if not carefully designed.	80 - 1149	0.4 - 0.5
C410	Pozzolan Fly Ash	Fresh and sea water slurries. Improved sulfate resistance. Reduces slurry density down to 11.9 ppg.		80 - 752	2.2-2.6
C501	Bentonite Extender	Fresh and sea water slurries. Cost effective extender.	• Low compressive strength and high porosity. • Decreased efficiency with higher salt concentrations.	80 - 600	2.65
C511	Attapulgite Extender	Improved hydration efficiency in salt water systems.	Low compressive strength and high porosity.	80 - 500	2.65
C601	Cement Foaming Agent	For foam cement applications. Can produce stable foam in slurries as low as 6 ppg in HPHT conditions.		80 - 450	1.05



Temperature ranges
C051/C052
C400
C402
C403
C410
C501
C511
C610
0
300
600
900
1200
Temperature in degF



Salinity Range
C051/C052
C400
C402
C403
C410
C501
C511
C610
0
10
20
30
40
Salt saturation in %BWOW



Density ranges
C051/C052
C400
C402
C403
C410
C501
C511
C610
0
4
8
12
16
Density in ppg

9.1.C051/ C052 Extenders

9.1.1.Principal Use

C051 is formed during the production of ferrosilicon or silicon metal. C051 consists of microsilica – an extremely fine, amorphous type of silicon dioxide. The large surface area of C051 particles increases the water demand in preparing a pumpable slurry. Slurries with densities as low as 11 ppg (1,32 SG) can consequently be prepared with little or no free water.

Code	SG	Absolute Volume (gal/lbm)	Solubility		Appearance
C051	2.35	0.0511	Non Soluble		Gray Powder
Code	**SG**	**Absolute Volume (gal/lbm)**	**pH**	**% Activity**	**Appearance**
C052	1.4	0.0856	5.0	52	Gray Liquid

Non-homogeneous cement columns are not acceptable as they jeopardize mechanical strength of set cement and proper zonal isolation. Therefore stable cement slurry is crucial. The interstitial surface tension created by C051 prevents other solids, including cement particles, from settling. Even when used with other extenders, C051 will help to create high quality, homogeneous cement slurry. The C052 liquid version of C051 is ideal where environmental concerns prevent the usage of dry blended additives.

9.1.2.Concentration

The normal concentration of this material is about 8 to 15% BWOC; however, up to 28% BWOC is possible.

9.1.3.Slurry Design

Summary

Condensed silica fume is highly reactive and, because of its fineness and purity, is a very effective pozzolanic material.The fineness of condensed silica fume also promotes improved fluid-loss control, perhaps by reducing the permeability of the initial cement filtercake). For this reason, it is also used for the prevention of annular fluid migration. In addition, it is used as a source of silica in thermal cement systems. High retarder concentrations are often required owing to the high specific surface area of silica fume.

C051 can be used up as an extender up to 185 deg F only, as it becomes difficult to retard and encounters gelation issues at higher temperatures.

C051 Behaviour

- It acts as an additional cementitious material, reacting with calcium ions in solution in the cement slurry to form calcium silicate hydrate (C-S-H) gel. It is this gel which allows the use of large quantities of mix water without excessive free-water separation. This formation of C-S-H gel also accelerates the reaction of tricalcium silicate with the mix water by lowering the concentration of divalent calcium in solution, thus reducing the thickening time and improving early compressive strength development. For reference, a 12.5 ppg slurry with C051 alone can provide a compressive strength above 1000 psi within 12 hours.

- Since it is composed of small particles, it acts as an excellent plugging agent, decreasing the permeability by filling the void space around the cement particles which are normally up to fifty times larger than C051.

Slurry density

C051 can be used independently to reduce the slurry density to 11.0 ppg. It can be also used in conjunction with C402 and other lightweight materials to design slurries down to 10.0 ppg.

9.1.4.Compatibility

- Due to the high surface area of C051, some mixing difficulties may be encountered even at densities not ordinarily associated with high viscosity. Addition of C200/ C201/ C204 dispersants to the mix water will improve the mixability of the slurry and, in normal concentrations, should not cause free-water problems.
- Can be used with any retarder up to 185 deg F. Retardation becomes difficult above the specified temperature due to the reactivity of the material. In case of usage above 185 deg F, the slurry has to be approved by the regional technical engineer/ manager. Mix fluid aging sensitivity tests need to be performed before commencing the operation.
- Foaming problems might be expected. C010 and C012 can be added to the mix water to avoid foam entrapment.
- C051 can be used in conjunction with C410 to produce LW slurries down to 10.5 ppg and with C402 down to 10.0 ppg to produce cost efficient lightweight slurries.

9.1.5.Field Mixing

C051 poses some problems for both bulk handling and field mixing because of its extremely small particle size. In both cases, the best success is first to blend the C051 with some other bulk additive, and always maintain C051 concentrations of less than 20 % BWOC in any blend. At these concentrations and with good bulk handling techniques, C051 should move pneumatically and slurry mixing will be possible with conventional mixing equipment. However, mix rates will be limited to four barrels per minute, and higher than normal dust hazards can be expected. Erratic bulk delivery can be expected.

C051 can be added to the mix fluid however good and constant shearing and agitation is required to properly disperse the particles.

9.1.6.C052 Liquid Extender

C052 liquid form can be used as an alternative to avoid the bulk mixing and supply difficulties encountered with the powder version. Caution must be exercised as C052 tends to settle in the drums when left static for long periods and therefore agitation is required before field usage.

9.1.7.Physical Description

- Suspension of micro-silica in water.
- 92-94% amorphous silica.
- Particle size 0.17 microns.

9.2.C400 Sodium Silicate

9.2.1.Principal Use

C400 is silicate based liquid extender used to reduce slurry density and increase yield. C400 is used to produce an economical low density slurry while, improves their compressive strength. C400 is typically used in designing light weight slurries in surface and intermediate casings where a long column of light weight cement is required to be placed against low frac gradient formation.

C400 provides slurry with a controlled shorter thickening time and better compressive strength compared to C501 Bentonite. Which improves casing bond and set cement properties.

C400 can be used to prepare light weight slurries using both fresh and sea water at densities as low as 11.5 ppg without exhibiting excessive gelation.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C400	1.33	0.0901	30% - 40%	11.58	colorless to hazy thick liquid

Component	% by wt
Na2O	11.5
SiO2	31.0

9.2.2.Concentration

Typical concentration used from 0.2 to 1.3 gps.

9.2.3.Slurry Design

C400 is a silicate solution which forms a silicate gel when added to seawater or water containing calcium chloride. It is this gel structure which allows the use of large quantities of mix water without excessive free-water separation. This is a totally different mechanism than employed by other extenders, such as bentonite, which literally absorb the excess water.

9.2.4.Testing Guidelines

API schedules must not be considered when performing a thickening time test on slurries containing C400 as an extender. CemPRO+ must used to determine the appropriate ramp time and BHCT temperature.

A mix fluid aging test must be performed as follows:

- Mix fluid aging time starts at the moment C400 is added to the mix fluid.
- In case of batch mixing: 30 min mix fluid aging period before addition of the cement and running subsequent tests.
- In case of fly mixing: One test with 30 min aging and one with 120 min minimum mix fluid aging period or time until last barrel is mixed with cement before addition of the cement and running subsequent tests.
- If more delays are expected with aged mix fluid then additional tests must be run to consider the delay.

C400 has an accelerating effect at low temperatures and therefore special attention is required during thickening time design. The final time must be considered to the point of the departure and not the time for 70 BC.

9.2.5.Compatibility

- Calcium chloride C013 does not accelerate strength development in C400 slurries, and may actually increase the thickening time at low concentrations (<1.5% BWOC). It may also induce free fluid when used in excessive amounts.
- Latex additives MUST NOT be used in C400 slurries.
- Although compatible with other additives when diluted in the mix water, C400 is strongly incompatible with most additives in concentrated form.

9.2.6.Field Mixing

- If prepared with C013 Calcium chloride. C013 must be added in the mix water prior to adding the C400.
- C400 can cause precipitation with some mainly used chemicals. This is not detrimental to the slurries properties however it is crucial to keep constant agitation/ circulation to keep the mix fluid homogenous.

9.2.7.Packaging

C400 is supplied in 55 gal drums.

9.3.C402 Cenospheres

C402 is composed of hollow microspheres of aluminosilicate, whose specific gravity is lower than water. The particle size, similar to silica flour enables the blending of the material with cement to form a slurry with densities as low as 9.0 ppg.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C402	0.7-0.9	0.1715-0.1334	Non Soluble	Tan to Gray Powder

Since the material is hollow, increased pressure and excessive shear increase the amount of the broken spheres, resulting in higher slurry density after placement. Additionally, because the material is lighter than water, special attention must be given to slurry density segregation.

C402 can be mixed with C051 or C060 Micro-Silica and cement to create a blend with the following advantages:

- Reduced C402 requirements
- Improved slurry stability
- Easier handling and mixing of the finished product than either of the two materials separately.

9.3.1.Application Ranges for C402:

- Temperature: from 40 to 450°F (4 to 232°C)
- Salinity: from fresh water to 37% C505 (BWOW)
- Density range: from 9.0 to around 12.5 ppg (not cost effective above this density)
- Maximum pressure: 5000 psi BHP. For high pressure applications C404 must be used as a coarse light weight material.

9.3.2.Slurry Design

C402 is composed of microspheres of aluminosilicate with a narrow particle size range around 120 micron, and a specific gravity around 0.75 kg/L. The microspheres are derived from fly ashes, and contain N_2 and CO_2 gas. This low specific gravity allows the addition of solid materials while reducing the density of the resulting slurry. For properly designed slurries, the resulting set cement will have higher compressive strengths and lower permeabilities than is achievable with chemical extenders, even down to densities of 9 lbm/gal (1.08 S.G.). Applications of C402 include the following:

- Cementing surface and conductor pipes through unconsolidated formations and low fracture pressures.
- Eliminating the requirement for multistage cementing
- Grouting
- Plugs in severe lost-circulation conditions
- Insulative cements
- Thixotropic Cement with low density without sacrificing the thixotropic properties of the slurry.

C402 is also the preferred method for extending GasTIGHT, since it allows low density without increasing slurry porosity.

Refer to section LW and ULW Systems sections for slurry designs and more details.

9.3.3.Retarders

C402 is similar in chemical nature to a fly ash, and is compatible with all Sprint retarders. As most retarders are also dispersants (secondary effect), care should be taken to avoid over dispersion, since C402 separation can occur.

9.3.4.Accelerators

As with retarders, C402 is compatible with all accelerators. Because accelerators can also disperse a cement system leading to C402 separation, the slurry stability must be checked.

9.3.5.Rheology Ranges

C402 requires a minimum yield value (5 to 10 lbm/100 ft2) to maintain slurry stability. Instability with C402 can exist in these two instances:

- There is the potential for sedimentation of the cement if the slurry is over dispersed.
- Since the spheres are lighter than water, they can float to the top of the slurry if the yield value is insufficient.

Under normal design considerations, C402 slurries should not require dispersants. In fact, maintaining sufficient viscosity is more frequently the problem. Details on slurry separation are discussed under the density section.

9.3.6.Salt Ranges

Ceramic Micro-Spheres slurries can be blended with salt concentrations up to 37% C505 (BWOW). However, since salt reduces the effect of many polymer viscosifiers (as well as inhibits the hydration of clays), it is used to give the slurry good stability.

C402 slurries can be mixed with fresh water or seawater, as long as minimum viscosity values are maintained, and attention is given to compatibility with other additives in the slurry.

9.3.7.Slurry Density Ranges

As stated earlier in this section, the normal application density of C402 is from 9.0 to 12.5 ppg (1.08 to 1.44 S.G.). The upper limit is a cost consideration. At densities above 12.5 ppg (1.44 S.G.), alternative extenders give competitive performance characteristics, since they do not exhibit pressure limitations.

The following table provides data on density at surface and density at pressure for slurries containing only C402.

Test Pressure psi	Design Density lbm/gal (S.G)	Measured Density lbm/gal (S.G)	Water Content gal/sk	C402 Content % BWOC
0	9.0 (1.08)	9.0 (1.08)	19.3	100
1500		9.1 (1.09)		
3000		9.6 (1.15)		
5000		9.9 (1.19)		

0	9.4 (1.13)	9.4 (1.13)	12.6	85
1500		9.55 (1.15)		
3000		10.2 (1.22)		
5000		10.5 (1.26)		
0	10.0 (1.20)	10.0 (1.20)	10.3	63
1500		10.1 (1.21)		
3000		10.6 (1.27)		
Test Pressure psi	Design Density lbm/gal (S.G)	Measured Density lbm/gal (S.G)	Water Content gal/sk	C402 Content % BWOC
5000		10.9 (1.31)		
0	10.6 (1.27)	10.6 (1.27)	9.4	47
1500		10.7 (1.29)		
3000		11.2 (1.35)		
5000		11.5 (1.38)		
0	11.0 (1.32)	10.9 (1.31)	9.6	36
1500		11.0 (1.32)		
3000		11.4 (1.37)		
5000		11.6 (1.39)		
0	11.5 (1.38)	11.5 (1.38)	8.3	30
1500		11.6 (1.39)		
3000		12.0 (1.44)		
5000		12.2 (1.47)		
0	12.0 (1.44)	12.0 (1.44)	7.9	23
1500		12.1 (1.45)		
3000		12.4 (1.49)		
5000		12.6 (1.51)		
0	13.0 (1.56)	13.0 (1.56)	6.8	14
1500		13.0 (1.56)		
3000		13.2 (1.59)		
5000		13.4 (1.61)		

9.4.C403 Hollow Glass Microsphere

9.4.1.Summary

C403 is a hollow glass microsphere used to reduce slurry densities below 10.5 ppg while achieving high compressive strength. C403 allows the design of cement slurries with density below that of water. C403 can be used at a maximum BHP of 6000 psi (pressure above which 20% of the bubbles will be collapse). C403 is thermally stable up to 1149 degF.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C403	0.4-0.5	0.2997-0.2398	Non Soluble	White Powder

Since the material is hollow, increased pressure and excessive shear increase the amount of the broken spheres, resulting in higher slurry density after placement. Additionally, because the material is lighter than water, special attention must be given to slurry density segregation.

9.4.2.Application Ranges for C403:

- Temperature: from 40 to 450°F and above (4 to 232°C)
- Salinity: from fresh water to 37% C505 (BWOW)
- Density range: from 10.5 to around 7.5 ppg (not cost effective above this density)
- Maximum pressure: 6000 psi BHP.

9.4.3.Slurry Design

Hollow Glass Microspheres (also known as Glass Bubbles) are hollow glass spheres made of chemically stable Soda-lime-borosilicate glass with thin walls (wall thickness 1~3.5μm). As the design slurry density reduces below 9.0 ppg, adequate slurry properties are no longer achievable using C402 alone and there C403 must be used. Applications of C403 include the following:

- Better density reduction capacity
- Lowest effective density at any pressure
- Help prevent problems associated with lost circulation, including reduced top-of-cement (TOC) and formation damage/reduced well productivity
- Help achieve highest strength-to-weight cement designs
- Increased yield per sack of cement

Refer to section LW and ULW Systems sections for slurry designs and more details.

9.5.C410 Pozzolan Fly Ash

9.5.1.Principal Use

C410 Extender is an artificial pozzolan material which is derived from burning coal at power-plants. The material is known as fly ash. It is used to reduce the cost of the cement slurry by increasing the yield obtained from a sack of cement. The extender, being a pozzolan material, reacts with the free lime liberated by the hydration of Portland cement. This reaction product forms a cementitious material which is very durable. The set cement system develops more strength, and is more resistant to sulfate water attack and strength retrogression than a system prepared from a non-pozzolan extender such as bentonite.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C410	2.2-2.6	0.055-0.046	Non Soluble	Tan to Gray Powder

When one sack of cement hydrates, about 20 to 23 lb of free lime [Ca(OH)2] is liberated. This compound contributes nothing to the strength of the set cement and is fairly soluble, so that it can be dissolved and removed by water contacting the cement. This contributes, in part, to a weakening of the cement. The silica from the pozzolan combines with the lime to form a stable, cementitious compound (calcium silicate hydrate) which is very durable and resist expansion.

The densities and absolute volumes of fly ash from different sources may be different.

A sack of Portland cement has an absolute volume of 0.038 gal/lb or 3.59 gal/sk. In other words, 94 lb of cement (one sack) when mixed with water will increase the volume of the resulting slurry by 3.59 gal. An equivalent sack is defined as the weight of any cementitious material which has an absolute volume of 3.59 gal.

The term 50:50 indicates 1/2 sk of pozzolan and 1/2 sk of cement. This ratio would therefore require 37 lb C410 extender and 47 lb of cement. Thus, 84 lb of this blend will displace 3.59 gal of water and is equivalent to 94 lb of Portland cement.

The weights of other additives, except salt, are calculated as a percent of the 84-lb equivalent sack of 50:50 C410 extender cement blend. The term "sack" is still retained as a conventional unit for mixing slurries even though the cementing materials are handled in bulk volumes.

2% bentonite (C501) is added to the system to improve the slurry properties. In a 50:50 blend, the weight of bentonite is based on the equivalent sack weight of 84 lb. Bentonite provides an increased yield making a more economical slurry; improves fluid-loss control and reduces free water. The slurry is mixed with 44% water.

The maximum water requirement is the amount of water that will provide a slurry that will not exceed an API Free Water Content of 10 mL (4 %).

Data on the commonly used 50:50 C410 extender to cement ratio are presented for Class G. These data are intended to serve as a general guide to slurry design.

9.5.2.Concentration

Table: C410 Fly Ash and Minimum Water Requirement for Non Extended Slurry

C410 ratio	Class G ratio	C410 lb	Class G lb	Mix water gps	Slurry Density ppg	Slurry Yield cuft/sk
25	75	18.5	70.5	5.24	15.1	1.19
35	65	25.9	61.5	5.17	15.0	1.18
50	50	37	47	5.00	14.7	1.16
65	35	48.1	32.9	4.85	14.5	1.14
75	25	55.5	23.5	4.75	14.3	1.12

Table: C410 Fly Ash Extended Slurry Design and Water Requirement

	Minimum Water Requirement				Maximum Water Requirement			
C501	Percent Water	Mix Water gps	Slurry Density ppg	Slurry Yield cuft/sk	Percent Water	Mix Water gps	Slurry Density ppg	Slurry Yield cuft/sk
0	38.9	3.93	15.5	1.01	46.8	4.73	14.8	1.11
2	49.5	5	14.7	1.16	57.4	5.8	14.2	1.27
4	60.1	6.07	14	1.31	68	6.87	13.6	1.42
6	70.7	7.14	13.6	1.47	78.6	7.94	13.2	1.57
8	81.3	8.21	13.1	1.61	89.2	9.01	12.8	1.73
10	91.9	9.28	12.8	1.77	99.8	10.0	12.5	1.88

9.6.C501 Bentonite Extender (Dry Blended)

Bentonite is a fine clay powder used as an extender cement slurries. In cementing, bentonite allows the use of additional amounts of mix water without water separation. This increased water content results in a lower density slurry and a greater yield. Bentonite also reduces the fluid loss of cement slurries.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C501	2.35	0.0511	Non Soluble	Light Brown

The "peptized bentonite" as used in drilling muds should not be used with cement. These low-grade calcium bentonites which are chemically treated to increase the yield of the mud can affect the thickening time of the cement slurry.

Bentonite is used in concentrations up to 25% BWOC. The slurry viscosity will generally increase as the concentration of bentonite increases; therefore, it is necessary to add a dispersant when using more than 6% bentonite. C200 dispersant, C100/ C102 Retarder will greatly improve the mixing of a bentonite slurry. Bentonite is generally used in a cement slurry for the following reasons:

- Light Weight Slurries: the bentonite absorbs about 5.3% water for each 1% bentonite. It makes a very light cement slurry without water separation. These lightweight slurries are of particular importance when cementing zones where loss of circulation is a problem.
- Increased Yield: The added water that reduces the density also increases the volume of slurry or the yield obtained from a sack of cement. Where compressive strength is not important, increasing the slurry yield provides a more economical cement system.
- Improved Fluid Loss Control: Bentonite was the first additive used to lower the fluid loss from cement slurries. Although not as effective as the fluid loss control additives, bentonite decreases the damage to formations resulting from the loss of cement filtrate. Also, increased fill-up can result from the controlled fluid loss and reduced slurry density. The combination of properties resulting from the addition of bentonite can sometimes eliminate multiple-stage completions. Complete wetting must occur before the bentonite becomes effective in reducing water loss. Dispersants usually aid in obtaining lower water loss because they increase the rate of wettability. The addition of 8 % to 12 % gel will reduce the water loss to about half that of the neat slurry. An organic dispersant should be used with bentonite concentrations exceeding 6 %. When fluid-loss control is of primary concern, other more efficient fluid loss control additives for cement should be used.
- Prolonged Suspension of Solids: The increased slurry viscosity resulting from the addition of bentonite helps to prevent segregation of solids.
- Physical Properties of Bentonite Cement Slurries: The table below illustrates the physical properties of bentonite cement slurries for Class A, G and H cements. The addition of bentonite to a cement slurry requires additional mix water. A rule of thumb is 5.3 % additional water for each 1 % bentonite. For example, a Class A cement slurry having a normal water-cement ratio of 0.46, to which is added 3 % bentonite, will require an increase in water-cement ratio to 0.619 (61.9 % water).

Table: Physical properties of bentonite cement slurries

% C501	Class H - 42 % Water			Class G - 44 % Water			Class A or H - 46 % Water		
	Water L/t (gal/sk)	Slurry density kg/L (lbm/gal)	Yield ft 3 / sk	Water L/t (gal/sk)	Slurry density kg/L (lbm/gal)	Yield ft 3 / sk	Water L/t (gal/sk)	Slurry density lbm/gal	Yield ft 3 / sk
0	421.7 (4.75)	1.92 (16.0)	1.11	441.2 (4.97)	1.89 (15.8)	1.14	461.7 (5.20)	1.87 (15.6)	1.18
2	529.1 (5.96)	1.81 (15.1)	1.28	547.8 (6.17)	1.80 (15.0)	1.31	567.3 (6.39)	1.77 (14.8)	1.34
4	634.8 (7.15)	1.74 (14.5)	1.45	653.4 (7.36)	1.73 (14.4)	1.48	673.0 (7.58)	1.70 (14.2)	1.52
6	741.3 (8.35)	1.68 (14.0)	1.62	760.0 (8.56)	1.67 (13.9)	1.65	780.4 (8.79)	1.64 (13.7)	1.52
% C501	Class H - 42 % Water			Class G - 44 % Water			Class A or H - 46 % Water		
	Water L/t (gal/sk)	Slurry density kg/L (lbm/gal)	Yield ft 3 / sk	Water L/t (gal/sk)	Slurry density kg/L (lbm/gal)	Yield ft 3 / sk	Water L/t (gal/sk)	Slurry density lbm/gal	Yield ft 3 / sk
8	847.9 (9.55)	1.61 (13.4)	1.79	866.5 (9.76)	1.62 (13.5)	1.82	887.8 (10.00)	1.59 (13.3)	1.86
10	953.5 (10.74)	1.58 (13.2)	1.96	972.2 (10.95)	1.57 (13.1)	1.99	994.3 (11.20)	1.55 (12.9)	2.03
12	1,060.9 (11.95)	1.53 (12.8)	2.13	1,078.7 (12.15)	1.52 (12.7)	2.16	1,099.1 (12.38)	1.51 (12.6)	2.20
16	1,176.3 (13.25)	1.49 (12.4)	2.48	1,291.8 (14.55)	1.47 (12.3)	2.51	1,311.3 (14.77)	1.46 (12.2)	2.55
20	1,486.2 (16.74)	1.44 (12.0)	2.82	1,504.0 (16.94	1.43 (11.9)	2.85	1,522.6 (17.15)	1.41 (11.8)	2.89

9.6.1. Thickening Time

The effect of bentonite on thickening time varies with the temperature and concentration. The thickening time is generally reduced by the addition of bentonite. In the intermediate temperature range, the addition of 1 % to 6 % bentonite can lengthen the thickening time slightly, while increasingly higher concentrations will gradually reduce the time to less than that of neat cement. With Class A or C cements, at temperatures below 32 degC (90 degF), the addition of bentonite tends to increase thickening times.

The effect of bentonite on thickening time is such that a definite trend cannot be established. It is imperative that test data be obtained from the Laboratory on any bentonite slurry if thickening time or compressive strength is critical.

9.6.2.Compressive Strength

As shown in Table 9.7, compressive strength is reduced as the concentration of bentonite increases. This results from the dilution of the slurry caused by the large amount of water required. As with neat cement, strength increases with temperature and time. High concentrations of bentonite should not be used in cements at temperatures over 105 degC (220 degF) without special consideration to prevent strength retrogression.

Table: Effect of C501 on compressive strength

% C501	Compressive Strength, psi				
	38 degC (100 degF)		93 degC (200 degF)		Permeability
	1 Day	7 Days	1 Day	7 Days	7 Days
4	1,000	3,000	2,400	3,200	0.001
8	600	2,200	2,000	2,500	0.003
12	300	1,600	1,000	1,800	0.008
16	200	1,200	800	1,500	0.014
20	100	1,000	500	1,200	0.022

9.6.3.Permeability

The permeability of set bentonite cement is greater than that of neat cement. Increased permeability can be detrimental since it may promote susceptibility to attack by sulfate waters and corrosive fluids.

9.6.4.Field Mixing Procedures

As long as the bentonite can be permanently suspended in the cement slurry, it is not essential that the bentonite be completely wetted during the mixing operation. This allows the pumping of a less viscous slurry. Hydration of the gel will continue to completion as long as water is available. The slurry will continue to thicken as it is being placed in the well. Elevated downhole temperatures will also contribute to the hydration of the slurry.

9.7.C501 Bentonite Extender & C511 Attapulgite (Pre-Hydrated)

9.7.1.C501 Bentonite

The expansion properties of bentonite are greatly enhanced when it is blended with the mix water and allowed to completely hydrate prior to starting the job. The process takes about 30 minutes with fresh water. Although additional time up to 2 hrs on location is required, the efficiency of bentonite as an extender can be increased by as much as 400 %.

Good circulation (as well as agitation) is required in the mixing tank used to mix the mix fluid. A sample of the mix fluid should be taken from the top most part of the mixing tank and the bottom to ensure the mix fluid is consistent.

Special precautions must be taken to ensure the final cement system to be pumped has the required thickening time, as defined by the POD (Point-Of-Departure) and not by the 100-Bc time. C501 slurries tend to develop high gel strength, especially at low temperatures. This can occur either in graduated intervals as gel structures are formed after mixing or as a rapid steady increase to a consistency plateau that may exceed 30 Bc. Any stop during mixing, or displacement of a C501 slurry should be minimized, as gelation may prevent any further movement of the slurry. On the other hand, once this gelling sequence begins or the consistency plateau is reached, the slurry is actually in the setting process. Any shearing of the slurry beyond this point, referred to as point of departure (POD), is extremely detrimental to the slurry behavior and compressive strength development since gel structures deteriorate with continuous shear.

When bentonite is dry-blended with cement and added to water, it never completely hydrates. This is due to the effect of water soluble materials in the cement such as calcium oxide. When bentonite is pre-hydrated with fresh water before adding cement, it absorbs a much larger volume of water.

A slurry containing 2 % bentonite BWOC pre-hydrated with fresh water will absorb as much water as a slurry prepared with 8 % bentonite dry-blended in the cement. By pre-hydrating the bentonite, much more water can be used in the slurry without water separation.

The mixing of cements containing high percentages of dry blended bentonite is difficult. Pre-hydrating the bentonite provides a means of preparing large volumes of low-density bentonite cements.

Table 9.8 Comparison of pre-hydrated and dry-blended bentonite slurry properties

Percent Prehydrated Bentonite	Percent Dry-Blended Bentonite	Fresh Water L/t (gal/sk)	Slurry density kg/L (lbm/gal)		Slurry Yield ft 3 / sk	
			Prehydrated	Dry-Blended	Prehydrated	Dry-Blended
0	0	461.7 (5.2)	-	1.87 (15.6)	-	1.18
0.5	2	568.2 (6.4)	1.77 (14.8)	1.77 (14.8)	1.34	1.35
1.0	4	674.7 (7.6)	1.69 (14.1)	1.70 (14.2)	1.50	1.52
1.5	6	781.3 (8.8)	1.62 (13.5)	1.64 (13.7)	1.66	1.69
2.0	8	887.8 (10)	1.57 (13.1)	1.59 (13.3)	1.83	1.86
2.5	10	994.3 (11.2)	1.52 (12.7)	1.55 (12.9)	1.99	2.03
3.0	12	1,100.9 (12.4)	1.49 (12.4)	1.51 (12.6)	2.16	2.20
4.0	16	1,314.0 (14.8)	1.43 (11.9)	1.46 (12.2)	2.48	2.55
5.0	20	1,527.0 (17.2)	1.38 (11.5)	1.41 (11.8)	2.81	2.89

Bentonite can be pre-hydrated in sea water or light brine; but the salt inhibits the hydration of the gel, and reduces the yield of the slurry. 2 % pre-hydrated gel slurry is equivalent to 4 % dry-blended gel.

9.7.2.C511 Attapulgite (Salt-Water Gel)

Attapulgite is a special clay used to prepare a salt-water mud and as a gelling agent in salt-cement slurries. Attapulgite is commonly called salt-water gel. By pre-hydrating attapulgite clay with sea water, the efficiency of the gel can be increased by as much as 500 % over a dry-blended, cement-gel mixture.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C511	2.35	0.0511	Non Soluble	Light beige

Thickening time

Thickening times are dependent on the amount of water in the slurry. The thickening time of a pre-hydrated bentonite slurry, for practical purposes, is the same as the thickening time of a dry-blended system having the same amount of mix water per sack. Compressive strength

Pre-hydrating the bentonite does not appreciably change the compressive strength as long as the amount of mix water remains constant.

Viscosity

The initial viscosity of a pre-hydrated bentonite slurry is about the same as that for a dry-blended system of the same density.

Types of gel

There are many forms of bentonite sold for use in drilling fluids. Some of these, especially the ”peptized” bentonites, adversely affect the thickening time of a cement slurry. Only laboratory-approved gels should be used.

Field mixing procedures

The procedure for pre-hydrating Bentonite C501/ Attapulgite C511 is as follows:

1. Select a clean mixing tank with the capacity to hold and ability to gauge the required mix water volume. Capabilities for bentonite addition and proper tank circulation must be available, such as with a mud hopper or cement mixer. This must be considered during pre-job planning.
2. Fill the mixing tank with the required amount of mix water plus the non-pumpable dead water volume for the tank.
3. Add the Antifoam Agent to the water (if required for any additives in the cement system).
4. Add the non-peptized bentonite to the water while circulating. The amount of bentonite added equals the bentonite required for the desired concentration based on the total water volume.
5. Continue to circulate until complete hydration of the bentonite and gelation of the mix water occurs. This should take approximately 30 min.
6. Maintain tank circulation until ready to start the job.

9.8.C601 Cement Foaming Agent

9.8.1.Principal Use

When cementing weak formations that are fractured and highly permeable, the formation can only support fluids with very low density, sometimes less than that of water. C601 provides a very stable foam in various cement slurry systems even at densities as low as 6 lb/gal.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C601	1.05	0.0844	100%	4-7	Light Amber Liquid

Also, is noted that for a given foam density, the size of the bubbles and the pore-size distribution (PSD) is strongly affected by the pressure and the amount of shear with which the foam is mixed. A high pressure and a high shear field will create a foam with small bubbles and a narrow pore-size distribution. A low pressure and a low shear field will create a foam with large bubbles and a broad pore-size distribution.

Foams are usually characterized by their quality (FQ) which is the ratio of gas volume to the total-system volume expressed in percent. Foam quality is easily derived from the base-slurry density D_{BS} and foamed cement density D_{fc}.

$FQ = D_{BS} - D_{FC} \;/\; D_{BS}$

To calculate the foamed cement density D_{FC} at a given depth, the following values must be known:

- the pressure and temperature at this depth to calculate the nitrogen volume factor BN_2
- the nitrogen ratio R
- the base slurry density D_{BS}.

The foamed cement density can then be calculated from the equation

$D_{FC} = (0.00172*R+D_{BS}) / (R/BN_2 + 1)$

D_{FC} and D_{BS} are expressed in lbm/gal, SAL in scf of nitrogen per bbl of nitrogen and R in scf of nitrogen per bbl of base slurry.

Foamed cement slurry can be generated, circulated, compressed and extended without affecting its stability as long as the foam quality does not exceed 80%. Also, Set foamed cement presents good cohesion when the quality remains below 70%.

A compressive strength of 500 psi can be reached at foam qualities lower than 50%. Meanwhile, above 35% quality, the permeability of foamed cement increases dramatically due to interconnection between bubbles.

Also, foamed cement exhibit good fluid-loss properties and good durability under high-temperature and high pressure conditions.

For neat cement foamed at various qualities, fluid loss decreases as foam quality increases.

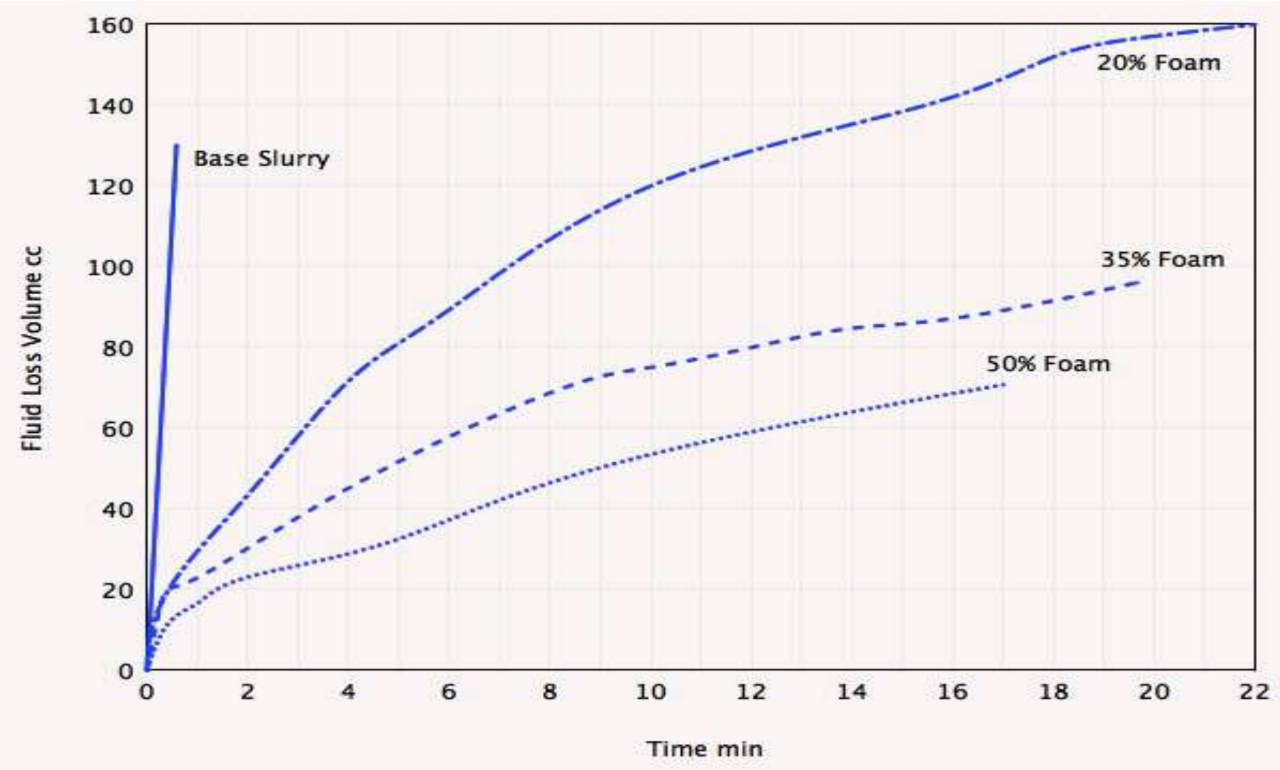


Fig. Influence of Foam Cement Quality on Fluid Loss

9.8.2. Stability and Compatibility

Stability and compatibility tests should always be performed prior to any foamed cement job.

The compatibility of a surfactant with cement additives is to proceed as follows:

- Pour 1 cm of surfactant in 100 cm^3 of the water which will be used for the base slurry.
- This water should also contain all the soluble additives that will be used in the cement.
- Foam the mixture one minute in a closed Waring blender at 12,000 RPM.
- Pour the foam in a graduated cylinder. The foam should occupy at least 600 cm3
- The half-life of the foam the should be longer than six minutes (half-life of the foam is defined as the time required to get 50 cm^3 of liquid at the bottom of the foam column).

When this test is performed in the presence of salt, it becomes evident that salt reduces slightly the stability of aqueous foams generated with C601.

Tests should also be performed with the base slurry. A minimum 70% foam quality should be obtained. To perform this test:

- Prepare the base slurry following the API procedure.
- Add the surfactant and mix gently one minute in the Waring blender at a very low speed (900RPM).
- Keep a slurry volume in the blender which corresponds to 30% of the blender volume.
- Close the blender and mix for one minute at 12,000 RPM.
- Foam should occupy the entire volume of the blender.

- This foam should remain stable until the cement sets, i.e ., no bubble should be seen bursting at the surface and no difference in density should be observed from the top to the bottom of the set foam.

These tests require a minimum of equipment and must be performed prior to any foamed cement job. This procedure of testing foam generation and stability in a Waring blender at atmospheric pressure is quite dramatic. A foam which is stable under these conditions will be even more stable in the high-pressure and high-shear environment encountered in the field.

Tests were performed to evaluate the compatibility of C601 surfactants with C011 and C010 antifoam agents which were added to the mix water of the base slurry while the foaming agent was added to the slurry.

The antifoam agents are detrimental to the stability of foamed cement. However, if excessive foaming is encountered in the tank during a job where the cement is batch mixed, it is better to add some antifoam agent and solve this problem than to have to stop the job.

9.8.3.Concentration

C601 dosage rates vary from 0.5% to 1.5% of liquid fraction in the slurry. In order to achieve optimum foaming, each slurry should be tested to determine the proper dosage. C601 should be mixed with the water prior to the addition of solid components.

9.8.4.Job Design

Two goals should be achieved by the job design:

- Maintain the hydrostatic profile of the column between the pore and fracture pressures during the entire circulation.
- Obtain a density profile at the end of the job such that the cement offers enough compressive strength to support the casing and provides zonal isolation.

Three main ideas should be kept in mind when designing the treatment:

- Make the operation as easy as possible.
- Put as much cement as possible into the well i.e., use as little nitrogen as possible.
- Four critical parameters which can be adjusted are
- number of stages: The choice of the number of stages should be made according to the following considerations:
- Adjusting the pump rate of a nitrogen unit does not present any major difficulty. It also requires close coordination between people to ensure that the slurry, surfactant and nitrogen rates are correct.
- A multiple-stage treatment risks the breakdown of the formation as the first stages (with the lowest nitrogen ratio) are circulated past the zone with the critical fracture gradient.
- The placement of several stages is very sensitive to hole geometry. If a good caliper is not available, then the precise placement of the different stages is not possible. If an accurate hole volume cannot be obtained and a job is designed by simply calculating an excess volume, then it is quite possible for the first few stages to be circulated to the pit. If this happens, then the compressive strength of the entire column suffers due to incorrect nitrogen ratios placed in the annulus. The same difficulty will be encountered if washouts are expected or if lost circulation zones are encountered and the fluids then end up too low in the annulus.

- For these reasons, a one-stage design (constant nitrogen ratio) should be attempted first. If some requirements cannot be met, only then should multiple stages be considered.

- Nitrogen ratio for each stage: At this step of the design, the main idea is to minimize the amount of to nitrogen while maintaining an acceptable hydrostatic-pressure profile during the entire circulation. If the hydrostatic pressure is measured at a given depth, this pressure should remain constant as long as there is mud above that point. When the foam passes that depth, the hydrostatic pressure will decrease if the foam density is less than the mud density. If the foam density is higher, the hydrostatic pressure will increase, reach maximum and then decrease due to gas expansion as the foamed slurry approaches the surface. This maximum hydrostatic pressure occurs when the foam density equals the mud density at the mud/foam interface. To determine the nitrogen ratio, the most critical zone and the maximum allowable hydrostatic pressure it can withstand must first be identified. The optimum nitrogen ratio is then the value for which the pressure across this zone is equal to the maximum acceptable hydrostatic pressure when the density at the top of the foam column equals the mud density.

- Back-pressure to apply on the annulus: When the foam approaches the surface, the return rate suddenly increases, and the column expands and becomes extremely light. To avoid this effect, a back-pressure is applied on the return line. Its value is critical because it directly affects the amount of base fluid in the well. The choice of the optimum back-pressure depends on the desired density profile for the foam column after the job is completed. If more cap slurry is pumped after the back-pressure has reached atmospheric pressure, then the cap slurry becomes too heavy and will fall in the annulus, compressing the foam further. The amount of cap slurry pumped can be designed to provide hydrostatic pressure equal to the back-pressure, reducing the chance that it may be necessary to perform a remedial top-up job later to raise the cement top.

- Length of the cap slurry and the method of placement.

- For the cap slurry, two possibilities exist

- Circulate it in front of the foam: This method is easier to perform because the base slurry used for the foam can be the same slurry for the cap. In this case, a certain amount of unfoamed slurry is injected before the nitrogen pumping commences. However, this solution presents some technical drawbacks where, the high-density slurry cap would fall down the casing (due to the low density of mud) and the foam which is pumped right after the cap slurry is in "vacuum" due to this U-tube effect and can be destabilized. Another drawback of the cap ahead of the foamed cement is that it is hard to know exactly where the cap will end up at the end of the job. It is better to take foam returns and then bullhead the cap slurry.

- or first circulate the foam to the surface and then inject the cap slurry down the annulus on top of the foam. This last operation is often referred to as “bull-heading" the cap slurry. This method is used in cases where the mud density is low which usually implies that a high-density slurry cap would fall down the casing.

9.8.5.Job Execution Considerations

Proper mixing of foamed cement requires the following three separate operations to be correctly executed at the same time.

a. The base cement slurry is mixed at the design density and pumped at the design rate(s).

b. The foamer/stabilizer solution is added to the cement slurry at the design rate(s) or concentration.

c. The nitrogen is pumped at the design rate(s).

A recommended typical job procedure is listed below:

- Before pumping the job, the proper wellhead equipment must be in place. A positive annular seal at surface is necessary so that all returns can be controlled through the kill line.
- Without a positive seal, the risk of a foamed cement blowout exists. The preferred configuration would be a BOP stack with casing rams and and a Hydril.
- An-other good technique is to set the casing in the wellhead slips and flange it up. A pressure gauge between the BOP and the kill-line manifold will aid in monitoring the annulus back-pressure.
- A check valve is required between the cementing unit and the foam generator (the nitrogen unit has a check valve permanently mounted on its discharge).
- The cementing head and landing joint must be in excellent condition. All connections must be tight and have an airtight seal to prevent nitrogen leak-age. Their threads must not be damaged.
- The cementing-head manifold must be integral.
- The foam generator is used to create a stable foam.
- A 90-durometer urethane cementing plug is recommended because softer plugs sometimes leave a cement sheath inside the casing.
- Mud conditioning is important to prevent foam channeling past the mud.
- Radio headsets are necessary for good communication.
- The base slurry density must be consistent to generate a predictable foamed cement density.
- Use a batch mixer whenever practical; if not available, use a large-capacity recirculating mixer.
- Attempt to keep the base slurry rate as constant as possible; this makes it easier to maintain the proper foamer rate and gas ratio.
- The use of two cement pumpers, one for mixing and the other for pumping, in conjunction with a batch mixer or recirculating mixer will achieve this constant slurry rate.
- The foam-generator cross is positioned in the treating line as shown in Fig. 9.2. When laying the nitrogen line, be sure it is clean and take extreme care not to get mud or dirt into it.
- Debris could easily lodge in the small holes of the disperser causing excessive pressures or complete nitrogen-flow blockage.
- Pump nitrogen through the disperser prior to the job to ensure the disperser holes are clear. A 500- to 1000-psi differential pressure across the disperser is desirable for optimum foam generation. Therefore, the disperser is sized to the anticipated maximum and minimum nitrogen rates using the values found in the graph Fig. 9.3.
- Foamer/stabilizer addition is critical for the foam generation and foamed cement stability. Without it, the slurry is merely nitrified, not foamed. The nitrogen quickly breaks out of the slurry, causing extensive voids and potential job failure. Because the foamer/stabilizer is so important, every precaution should be taken to ensure the performance of the additive system. When a small amount of foam is required, it is possible to batch mix the base slurry prior to the job. In that case, it is easier to add the surfactant to the batch-mixed slurry. The only precaution is to mix it very gently with the paddles to avoid possible foaming in the tank. When large foam amounts are required, the foamer/stabilizer mixture is injected into the slurry up-stream of the foam generator, allowing it to be adequately mixed into the slurry. A

recommended practice is to include foamer/stabilizer, at the recommended concentrations for the foamed slurry, in the fluid or slurry preceding the foam. Two methods are commonly used:

- high-pressure injection into the main treating line
- injection into the suction manifold of the downhole pump on the cementing unit.

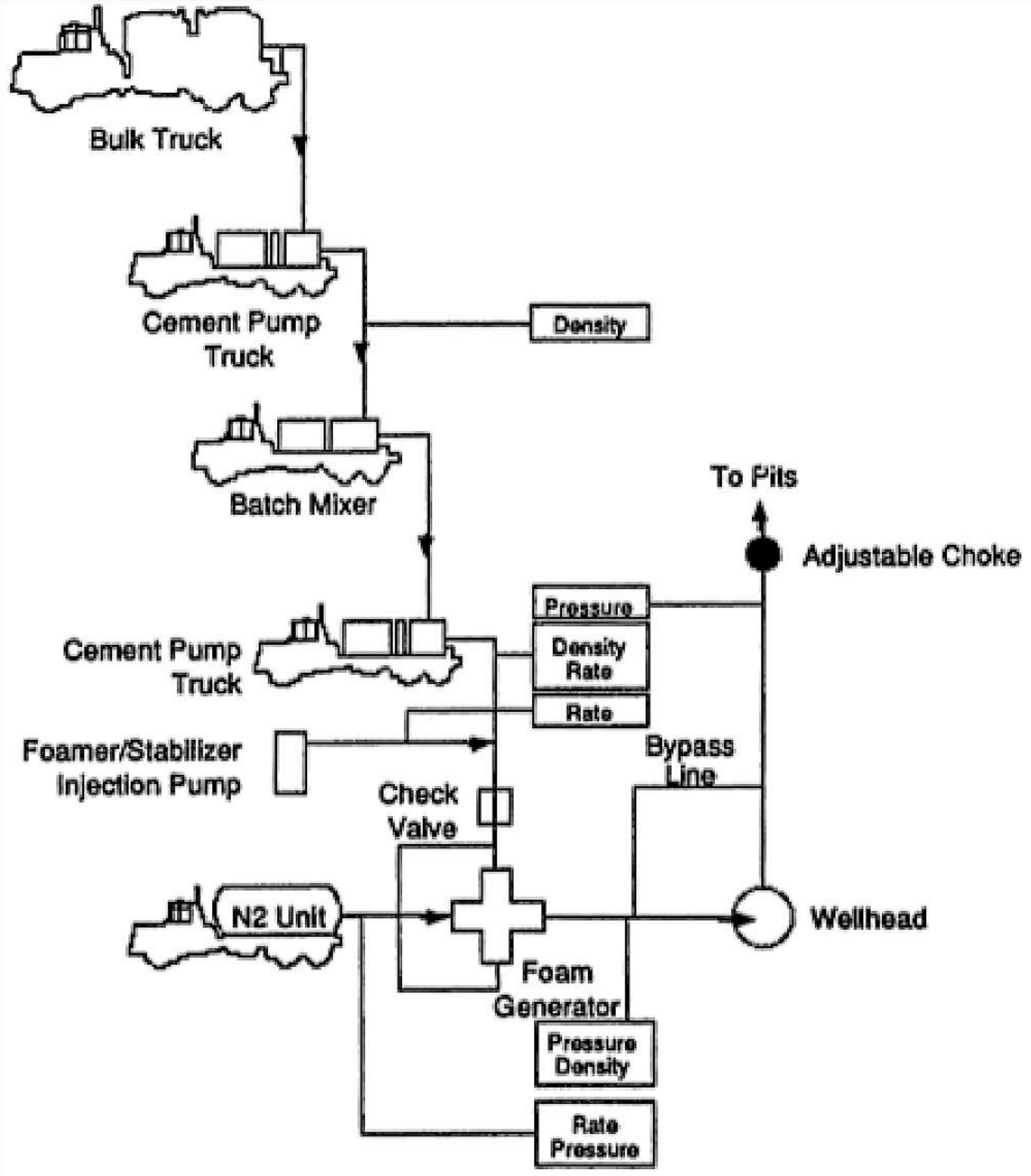
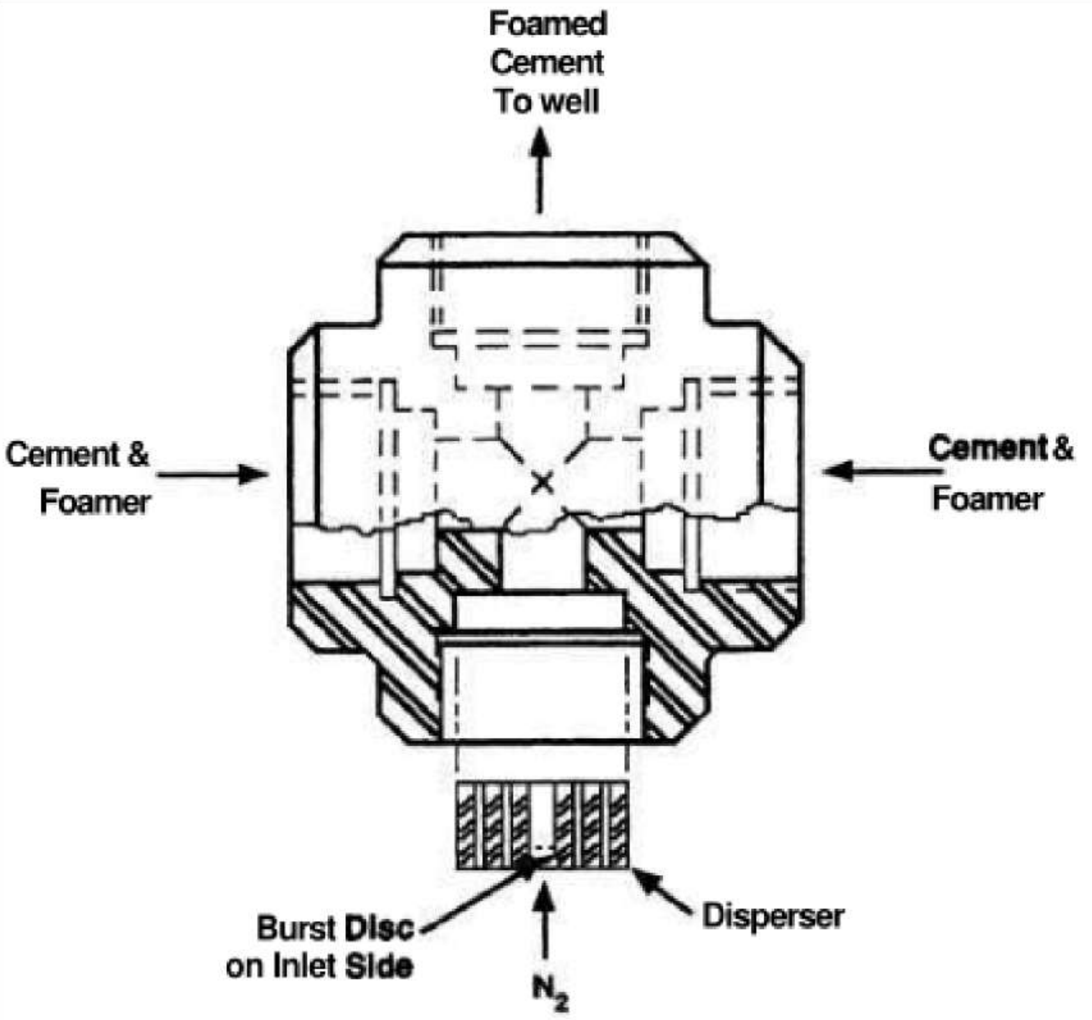


Fig. Foam Cementing Rig Up



Cross **41620-2 1/2-in.** Bore

Bushing

519131	**16-3/64-Holes**	**10,000-psi** Disc	**8,000-psi** WP
519132	**16-3/64-Holes**	**15,000-psi** Disc	**12,000-psi WP**

Cross 49498 **2-7/8-in.** Bore

Bushing

519133	**16-3/32-Holes**	**10,000-psi** Disc	**8,000-psi** WP
519134	16-3/32-Holes	15,000-psi Disc	**12,000-psi WP**

Fig. Above figure Foam Generator Adjustment Treatment Procedure

Foam Cementing Typical Job Procedure:

1. Rig up to the cementing head and annulus.
2. Close the casing rams and Hydrill open the kill line to the pit.

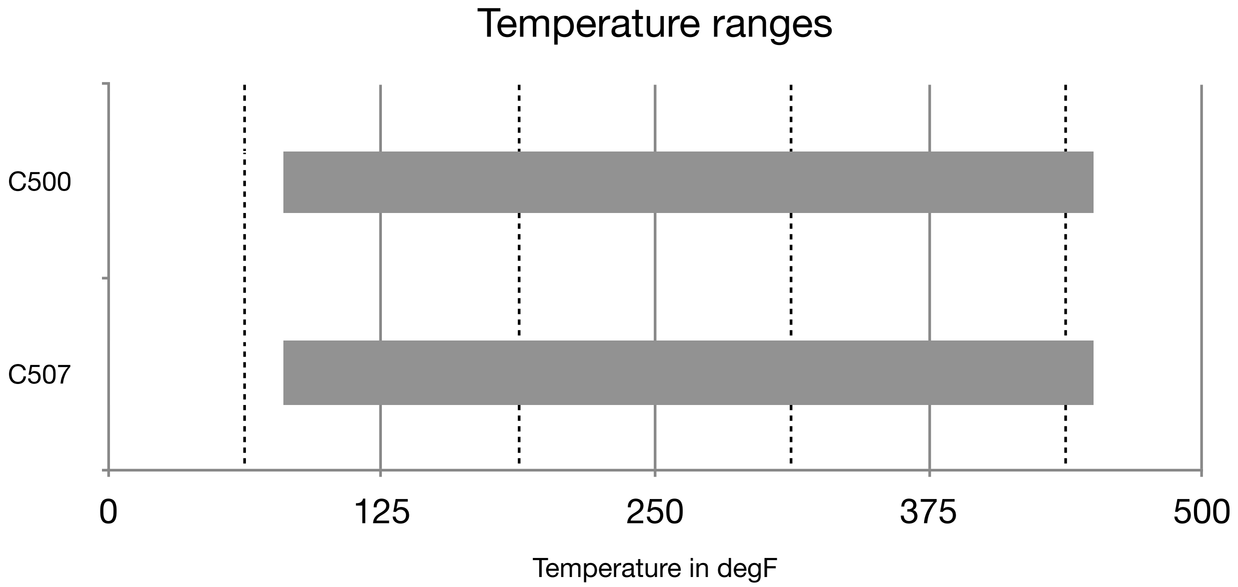
3. Start pumping to condition the mud and circulate the hole.
4. Pump the chemical wash and spacer.
5. Drop the bottom rubber plug.
6. Pump the cap slurry (if applicable).
7. Start pumping the base slurry and foamer/stabilizer.
8. Start pumping the nitrogen - adjust the nitrogen and foamer/stabilizer rate to achieve the design ratio.
9. Stop pumping nitrogen.
10. Stop pumping the foamer/stabilizer.
11. Pump the tail slurry (if applicable).
12. Flush out the treating lines.
13. Drop the top plug, start pumping the displacement volume and monitor the annular returns. (Some treatments require back pressure on the annulus during the displacement. If so, when foam returns begin at surface, adjust the choke on the flow line to maintain the desired back pressure. Continue monitoring the returns and back pressure until the top plug is bumped.)
14. Shut in the annulus.
15. Pump the cap slurry down the annulus (if applicable).
16. Pump water behind the cap slurry. Over displace by at least one barrel to prevent cement contamination at the BOP stack.

10. Weighting Agents

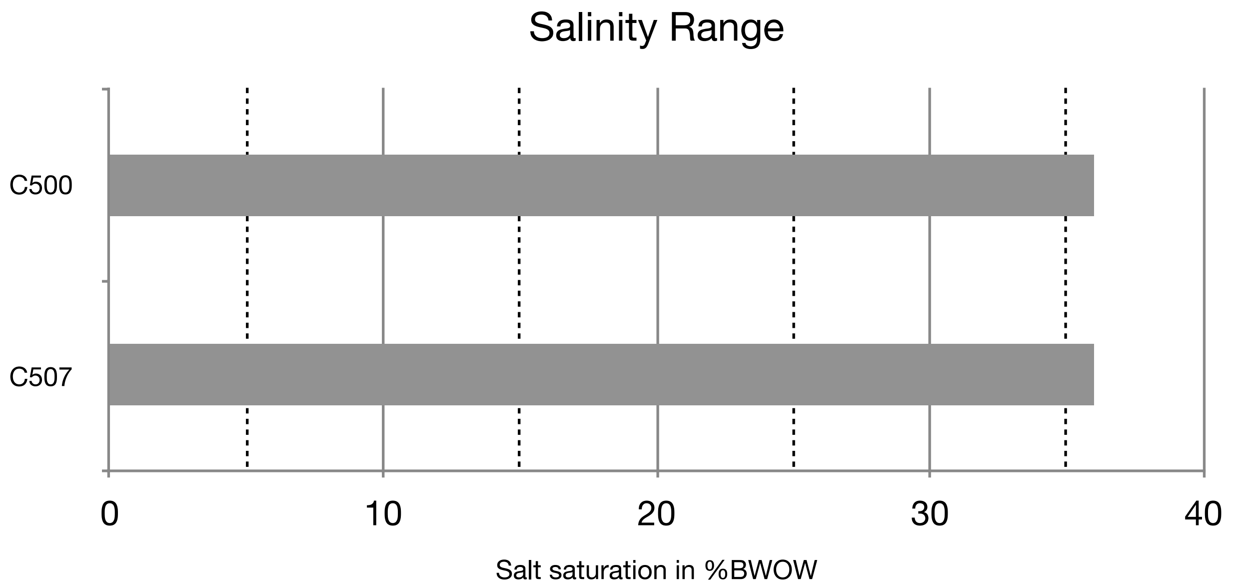
In high-pressure gas wells or in physically unstable wellbores, high-density fluids are required to maintain control. In such cases, drilling mud densities often go up to 18 lbm/gal and cement slurries of equal or higher density become necessary.

Weighting Agents Summary

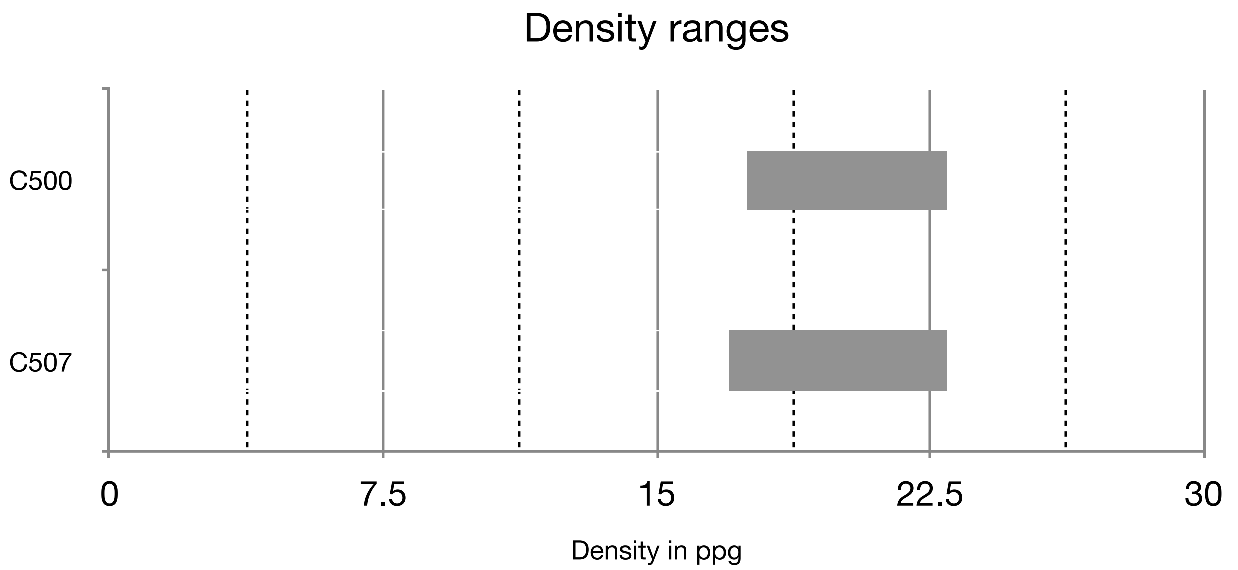
Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
C500	Hematite	For slurries 17.5 ppg and above.	Could exhibit settling if the slurry does not build enough carrying viscosity.	80 - 450	5.1
C507	Non-Magnetic Weighting Agent	Up to 23 ppg slurries. Can be wet blended.		80 - 450	4.9



Temperature ranges
C500
C507
0
125
250
375
500
Temperature in degF



Salinity Range
C500
C507
0
10
20
30
40
Salt saturation in %BWOW



Density ranges
C500
C507
0
7.5
15
22.5
30
Density in ppg

10.1.C500 Hematite

Hematite C500 is an inert iron oxide mineral with a high specific gravity. As a weighting material, it is highly efficient because it may greatly increase slurry densities without adversely affecting the cementitious properties of the cement system.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C500	5.0 to 5.1	0.0235	Non Soluble	Dark red to brown

The use of dispersant is recommended only when it is desirable to reduce the water content. In this case, it should be used sparingly since the thinning action on the slurry may permit separation of the heavier C500.

Slurries weighing more than 19 lb/gal can be prepared; however, the Regional Laboratory should be consulted for the proper slurry design. Additives, such as retarders, can critically affect the viscosity of these dense slurries resulting in either C500 settling or mixing difficulties.

The C500 can only be dry-blended with cement. Since it is not chemically reactive, C500 can be used with most other cementing additives. However, adequate precautions should be taken to ensure that slurry viscosity is sufficient to prevent the C500 from settling out.

Beyond slurry density of 19 ppg, where, hematite slurries will exhibit excessive viscosity due to the reduced water content, it is recommended to use only SPRINT UHWC Ultra Heavy-Weight cement blend as a weighting agent.

10.2.C507 Non-Magnetic Weighting Agent

As a heavyweight additive with a high specific gravity and superior flow properties, C507 out-performs all comparable additives.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C507	4.9	0.0243	Non Soluble	Dark red

C507 is a self-stabilizing densifier mainly composed of manganese oxide (>90% Mn_3O_4). C507 is produced during the manufacture of ferromanganese (FeMn), following reaction at temperatures of 1000-1750 °C.

C507 consists only of divalent and trivalent manganese (Mn[II] and Mn[III]) with no harmful Tetravalent manganese (Mn[IV]).

Pumpable slurries, up to a density of 22 ppg (2.64 SG) can easily be achieved using C507. The designed slurries will exhibit low rheologies and no settling.

C507 is environmentally safe and classified on PLONOR list. Apart from being a weighting agent, C507 also, provides a number of additional benefits:

- Improved slurry stability.
- Can be pre-mixing with water.
- Low rheology slurries.
- Non abrasive additive.
- Effective tracer material.
- Non-magnetic densifier.

C507 has, in addition to its physical characteristics, a very strong red-brown color. This feature imparts the additional benefit of using C507 as a colored tracer, ideal for kick-off plugs.

11. Dispersants

11.1.Introduction

Well cement slurries are highly concentrated suspensions of solid particles in water. Their rheological properties are related to those of the supporting liquid rheology, the solid volume fraction (volume of particles/volume of slurry) and inter-particle interactions. The aqueous phase of a cement slurry contains ionic species and organic additives. Therefore, the rheological properties of the aqueous phase can differ greatly from those of water, notably when high-molecular weight water-soluble polymers (e.g., fluid-loss control agents) are added. The viscosity of the interstitial fluid can also vary significantly with temperature.

The solid volume fraction (SVF) can vary from about 0.2 for extended slurries to about 0.6 for reduced-water slurries. High SVF values generally result in high slurry viscosities. Particle interactions depend primarily on the surface-charge distribution effects due to organic molecules adsorbed at the solid-particle surfaces. Without modification, most cement slurries would not have the correct rheological properties for proper placement in long, narrow annuli.

Dispersants provide cement slurries with lower rheologies and improved mix-ability. This means lower friction pressures and lower critical rates for turbulence. Dispersants achieve this by separating the cement particles and suspending them uniformly in the mix water. A secondary benefit of dispersants is that they usually enhance fluid-loss control.

The dispersant choice in slurry design may or may not be critical depending on the application. In some applications, selection of the wrong dispersant may result in undesirable slurry properties such as excessive free fluid and/or sedimentation. Generally these applications are used when the slurry must be designed to achieve a low critical turbulent flow rate and/or to exhibit a low dynamic pressure during placement.

11.1.1.Slurry Design

For primary-cement jobs, effective slurry placement in turbulent flow and/or at acceptable dynamic pressures requires the proper selection of a dispersant. The dispersant choice is dependent upon:

- Dispersibility behavior of the cement.
- Bottom-hole circulating temperature.
- slurry properties.

11.1.2.Cement Dispersibility

The main criteria for dispersant selection is the dispersibility behavior of the cement. This behavior is specific to each cement brand and must be determined for proper dispersant selection.

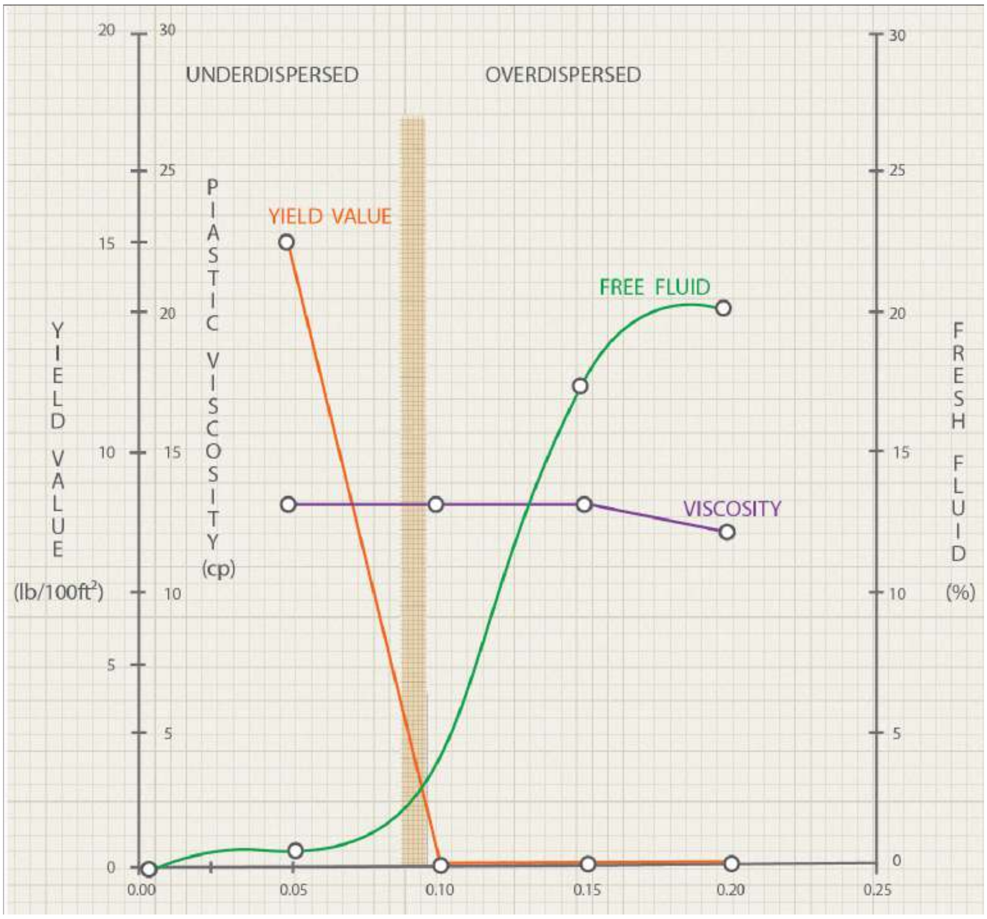
For freshwater slurries, cement is classified as ETD (Easy-To-Disperse) or DTD (Difficult-To-Disperse). For saltwater slurries, cement is classified as ETDS (Easy-To-Disperse in Salt) or DTDS (Difficult-To-Disperse In Salt). For these classifications only, freshwater slurries are defined as any slurry containing less than 5 % BWOW salt and saltwater slurries are defined as any slurry containing more then 5 % BWOW salt.

There is no relationship between ETD and ETDS or DTD and DTDS classification for a specific cement brand. For example, a certain cement brand classified as ETD is not necessarily an ETDS cement but may be classified as DTDS. Therefore, the dispersibility behavior of a cement brand must be determined individually for freshwater and saltwater slurries. There are two laboratory procedures for distinguishing the dispersibility behavior of particular cement - one for freshwater systems and the other for saltwater systems.

11.1.3.Dispersibility Testing for Freshwater Systems

Laboratory testing is performed with the cement, tap or de-ionized water, and increasing amounts of C201 (0 gal/sk, 0.05 gal/ sk, 0.10 gal/sk, 0.15 gal/sk and 0.20 gal/sk for instance). The following steps are followed for each C201 concentration:

- Prepare the cement slurry using the API-recommended water requirement.
- Measure the rheology and free fluid at 85 degC (185 degF) according to API Specification 10.
- Determine the yield value (Ty).
- Plot the free fluid and yield value vs the C201 concentration as shown in Figure below.
- Testing is continued with increasing amounts of C201 until the yield value is repeatedly low for three to four consecutive tests.
- If the resulting graph is similar to that of the Figure, the brand of cement is classified as the EDT type. On the other hand, if the free fluid is zero or small over a range of C201 concentrations at low yield values, then the cement is a DTD type.



11.1.4.Dispersibility Testing for Saltwater Systems

Laboratory testing is performed with the cement, tap or de-ionized water at a fixed salinity (30 % BWOW preferred), and with D201 concentrations ranging from 0.2 gal/sk to 0.5 gal/sk in 0.05 gal/sk increments. The following steps are followed for each C201 concentration:

- Prepare the cement slurry at a density between 16.2 ppg and 16.6 ppg (Use the same density for all tests.).
- Measure the rheology at room temperature.
- Determine the yield value (Ty).
- Plot the yield value vs the C201 concentration.

ETDS cements should show low yield values (less than 10 lbf/100 ft2) across the entire C201 range, while DTDS cements typically will show a sharp decrease in the yield value with increasing C201 concentration. Furthermore, at the upper end of the concentration range, DTDS cements still will exhibit an irreducible yield value to around 5 to 10 lbf/100 ft2; while ETDS cements should show a yield value close to zero.

11.1.5.Dispersant Selection

The dispersant selection is primarily influenced by the dispersibility behavior of the cement brand. However, the BHCT application and the slurry property requirements can affect the final choice. The dispersants currently available are C200, C201 (the liquid version of C200) and C204.

The salt system dispersants additives used are C200, C201. C204 can be used in fresh water as in salt solutions.

To ensure favorable rheological properties of a cement slurry, dispersants such as solid C200 or Liquid C201 or C204 must often be added to the mix water. The molecules of these dispersants carry several negative charges, and can adsorb onto positively charged areas of cement particles. As a result, the electrostatic attraction between particles, which was responsible for the high yield value and viscosity, is lost. The slurry is then dispersed and flows easily.

The adsorption of this kind of dispersant can create interfacial barriers between the cement surfaces and water, which reduces the cement hydration rate. At low temperature, this retarding effect can significantly extend the thickening time and the development of the compressive strength.

When dispersion is achieved through an electrostatic mechanism, it is strongly affected by the presence of salt, and particularly when C013 calcium chloride is added to accelerate cement hydration. In this case, more dispersant is needed and the viscosity tends to increase.

The dispersant C204 allows the cement dispersion which is not achieved through an electrostatic mechanism, but through a steric effect. As a result, the addition of salt (C013 or C505) does not affect rheology. Good rheological properties are achieved with a minimum amount of dispersant compared to C201. The retarding effect of C204 is negligible.

C204 is a non-retarding powder dispersant for use in cement slurries with or without salt or containing latex for anti gas migration purposes. It also enhances fluid loss control with most conventional fluid loss additives, and on its own C204 enhances rheological properties thus improving flow characteristics. C204 can be utilized up to temperatures as high as 450°F BHCT.

11.1.6.Temperature Selection Criteria

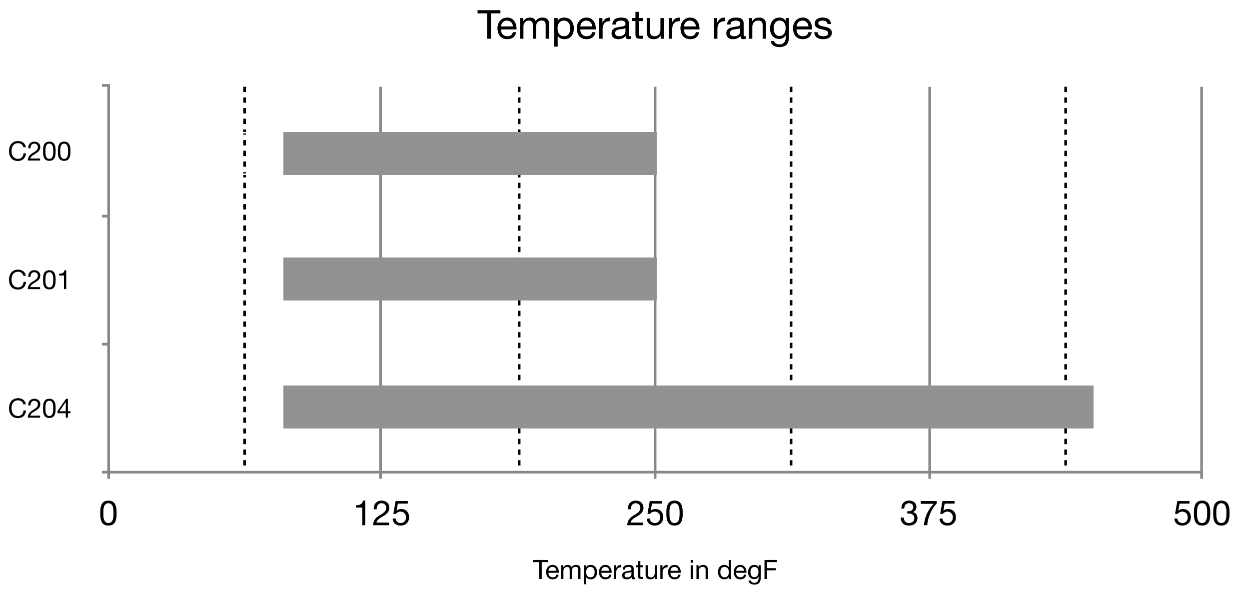
C200/C201 will extend appreciably the thickening time of a cement slurry. For applications with the BHCT less than 66 degC (150 degF), the extended thickening time may be unacceptable. C204 has a minimal-retarding effect on cement slurries and may be considered as a better alternative for this situation.

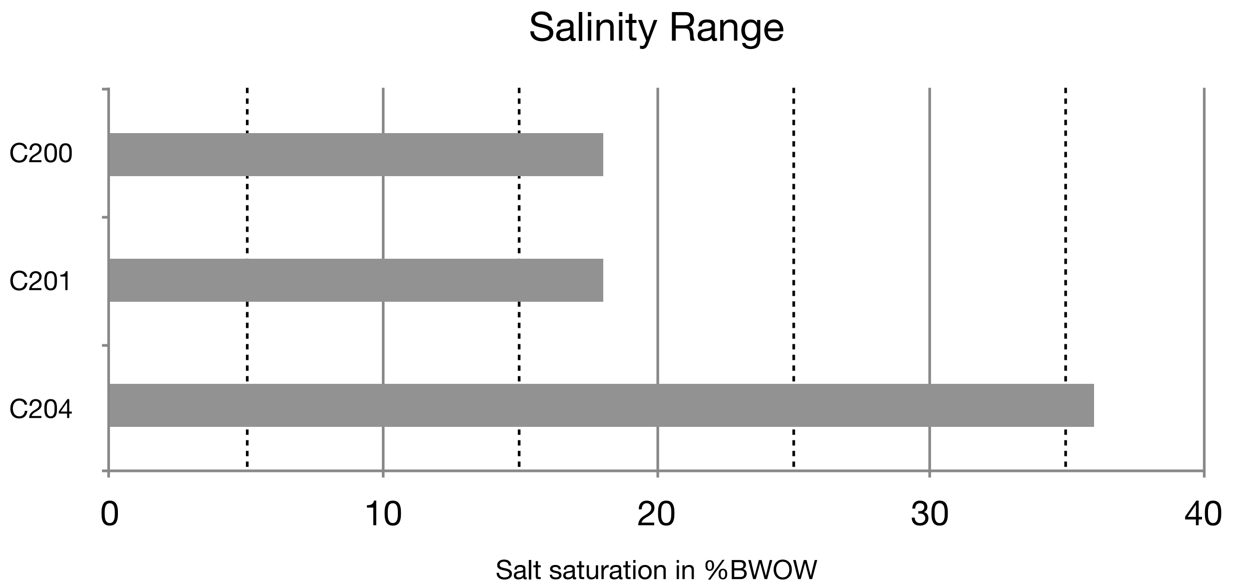
For applications with the BHCT between 66 degC and 85 degC (149 degF and 185 degF), all dispersants discussed may be used. The choice is dependent on the dispersant performance for the particular application.

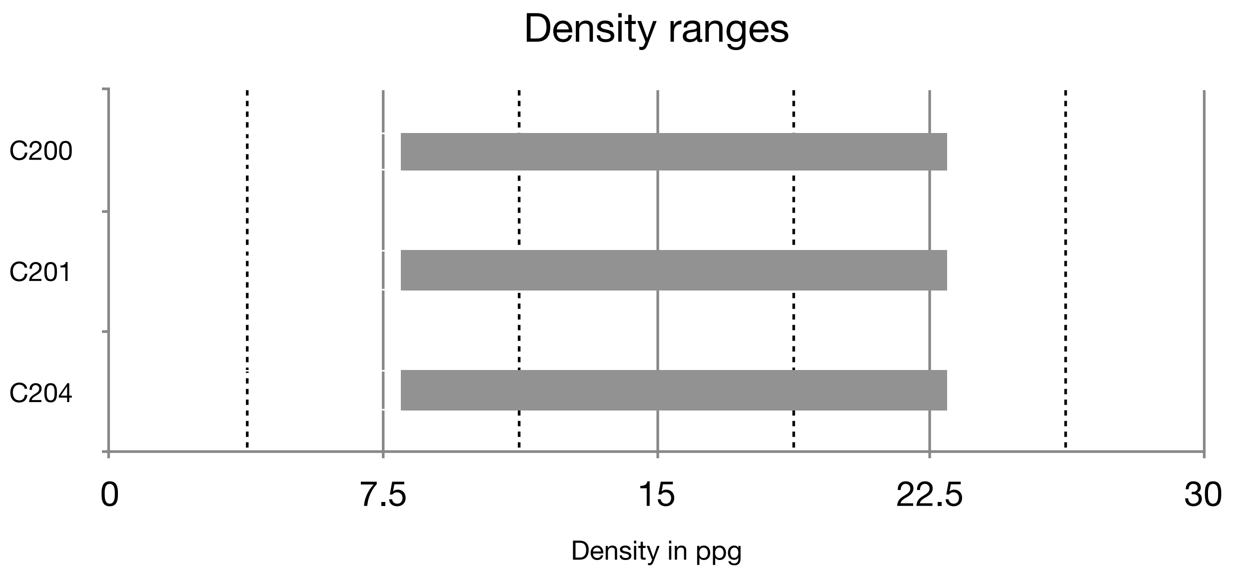
For applications with the BHCT above 85 degC (185 degF), laboratory verification of dispersant effectiveness cannot physically be determined at this time. However, field case studies indicate slurries with C200 and C201 exhibit reduced friction pressures during placement in wells with a BHCT up to 150 degC (300 degF) - characteristic of dispersed systems. Other studies with C204 is effective in providing slurry dispersibility above 85 degC (185 deg F) and up to 450 deg F.

Dispersants summary

Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
C200	Dispersant	Fresh water and salt slurries up to 18% BWOC.	• Can lead to slurry viscosification if concentration is low. • Reduced efficiency with higher salt concentration.	80 - 250	1.43
C201	Liquid Dispersant	Fresh water and salt slurries up to 18% BWOC.	• Can lead to slurry viscosification if concentration is low. • Reduced efficiency with higher salt concentration.	80 - 250	1.24
C204	High Temperature Dispersant	Fresh water and salt slurries. Non-retarding dispersant.	• Powerful dispersant at low temperatures which can cause settling if not designed carefully.	80 - 450	1.23


Temperature ranges
C200
C201
C204
0
125
250
375
500
Temperature in degF


Salinity Range
C200
C201
C204
0
10
20
30
40
Salt saturation in %BWOW


Density ranges
C200
C201
C204
0
7.5
15
22.5
30
Density in ppg

11.2.C200 Dispersant

11.2.1.Principal Use

C200 dispersant provides cement slurries with lower rheologies and improved mixability. This means lower induced ECD and critical rates for turbulence. C200 applications for assisting in proper cement slurry design include:

- primary cement slurry placement in turbulent flow.
- primary cement slurry placement at minimal dynamic pressures (in the presence of a potential lost circulation zone).
- cementing operations involving small diameter tubulars.
- slurry viscosity reduction to improve pumpability, and mixability.
- reduced slurry porosity.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C200	1.43	0.0838	High	Yellow or brown powder

C200 is compatible with most cementing additives. It can be used in salt solutions up to salt saturation but requires higher concentrations than needed in fresh water. C200 is normally dry blended with the cement, but can be added directly to the mix water if required.

C200 has a retarding effect on cement slurries and may cause settling of cement particles when used at high concentrations.

C200 can be used with up to approximately 18 % BWOW salt solutions. C200 also, provides excellent fluid loss control in addition to being an efficient dispersant.

C200 is effective and can be used at temperature up to 250 deg F.

11.2.2.Concentration

C200 functions as a dispersant or thinner in the cement slurry by separating the cement particles and suspending them uniformly in the mix water. The separation of the cement particles by the dispersant results in minimum resistance to movement and greater mobility of the particles.

In terms of slurry design, C200 use assists turbulent flow design, lowers friction pressure, lowers viscosity and enables reduced water slurries to be used.

C200 is used in concentrations ranging from 0.1 % to 1.5 % BWOC. The C200 concentration required will vary with its application and cement brand used. C200 is effective and can be used at temperature up to 347 deg F.

For whipstock plugs, typical C200 concentrations range from 1.0 % to 1.5 % while for slurry viscosity reduction, concentrations as low as 0.1 % may only be needed. Some cements are easy to disperse and need little C200, while others are difficult to disperse and require more C200.

The concentration of C200 has to be carefully designed since too much C200 will lead to ”over-dispersion”. The cement particles will settle and excessive free-water development may occur. In cases where over-dispersion is a problem, C204 should be used instead of C200. Also, the use of Anti-settling Agent C514 is a potential solution. C200 has a beneficial effect on fluid-loss control. It should be used in slurries containing FLAC cement additives whenever possible.

Note: Since C200 drastically reduces the cement-slurry viscosity, it is absolutely necessary to control the slurry density using densitometer and pressurized mud-balance method readings only. DO NOT ATTEMPT TO ADJUST THE DENSITY BY THE APPEARANCE OF THE SLURRY!

The required concentration of C200 to achieve a yield value less than 10 lbf/100 ft2 is dependent on the cement brand. For Easy-To-Disperse cement, 0.3 % C200 is usually needed; while for Difficult-To-Disperse cement, 0.6 % C200 might be required.

If concentrations are too low, C200 effects are not pronounced and can sometimes lead to slurry viscosification depending on the cement and temperature.

This table presents typical data only. It is not intended to be used for job design. For flow calculations, data must be developed using the actual materials for the job.

C200 Concentration (%)	Test Temperature 84 degF with 15.8 ppg Class G		Test Temperature 238 degF with 14.0 ppg Class G	
	Ty (lbf/100 ft^2)	Pv (cP)	Ty (lbf/100 ft^2)	Pv (cP)
0.0	22.91	54.96	15.3	40.12
0.3	22.63	42.98	15.19	35.76
0.4	6.49	31.0	-	-
0.5	-	-	5.20	11.25
0.8	-	-	3.96	7.39

11.3.C201 Liquid Dispersant

11.3.1.Summary

Liquid C201 is a water solution of C200. As with C200, it provides cement slurries with lower rheologies and improved mix-ability. This means lower friction pressures and lower critical rates for turbulence. C201 applications for assisting in proper cement slurry design include:

- primary cement slurry placement in turbulent flow.
- primary cement slurry placement at minimal dynamic pressures (in the presence of a potential lost-circulation zone).
- cementing operations involving small-diameter tubulars.
- slurry viscosity reduction to improve pumpability, and
- reduced-water slurries.

C201 was developed to provide greater flexibility in areas where dry-blending facilities are not available.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C201	1.24	0.0966	40%	8.25	Brown liquid

Liquid C201 is compatible with most cementing additives. It can be used in salt solutions up to salt saturation but requires higher concentrations than needed in fresh water. C201 has a retarding effect on cement slurries and may cause settling of cement particles when used at high concentrations.

C201 can be used with salt saturated systems up to approximately 18 % BWOW salt solutions. In slurries containing 18 % BWOW salt or greater, C201 provides excellent fluid-loss control in addition to being an efficient dispersant.

C201 is effective and can be used at temperature up to 250 deg F.

11.3.2.Slurry Design

Liquid C201 is a water solution of C200. With only minor agitation, it is readily dispersible in the mix water to provide uniform distribution throughout the cement system. At 0.025 gal/sk, C201 will provide approximately the same activity as 0.1 % C200 dry blended. For slurry calculations, the mix water should be reduced by the volume of C201 to maintain the same slurry density and yield.

Liquid C201 functions as a dispersant or thinner in the cement slurry by separating the cement particles and suspending them uniformly in the mix water. The cement particle separation by the dispersant results in minimum resistance to movement and greater particle mobility. In terms of slurry design, C201 use assists turbulent flow design, lowers friction pressure, lowers viscosity and enables reduced-water slurries to be used.

C201 is used in concentrations ranging from 0.02 gal/sk to 0.4 gal/sk. The concentration required will vary depending on the application and cement brand used. For whipstock plugs, typical C201 concentrations range from 0.25 gal/sk to 0.4 gal/sk; while for slurry-viscosity reduction, concentrations as low as 0.02 gal/sk only may be needed. Some cements are easy to disperse and need little C201, while others are difficult to disperse and require more.

The concentration of C201 has to be carefully designed since too much C201 will lead to ”over-dispersion”. The cement particles will settle and excessive free-water development may occur. In cases where over-dispersion is a problem, C204 should be used instead. Also, the use of Anti-settling Agent C505 is a potential solution.

Liquid C201 has a beneficial effect on fluid-loss control. It should be used in slurries containing FLAC cement additives whenever possible.

11.3.3.Field Mixing Procedures

Note: Since C201 drastically reduces the cement-slurry viscosity, it is absolutely necessary to control the slurry density using densitometer and pressurized mud-balance method readings only. DO NOT ATTEMPT TO ADJUST THE DENSITY BY THE APPEARANCE OF THE SLURRY!

11.3.4.Job Design Data

The tables below shows the influence of C201 on slurry rheology and thickening time.

This table presents typical data only. It is not intended to be used for job design. For flow calculations, data must be developed using the actual materials for the job.

Table 11.1 Typical Rheological Properties of C201 Cement Slurries. Cement mixed at 15.8 lbm/gal Slurry Density, Test

C201 Concentration (gal/sk)	Ty (lbf/100 ft^2)	Pv (cP)
Dyckerhoff G		
0.00	28	32
0.01	31	30
0.04	18	29
0.06	2	28

Table : Typical Thickening Times of C201 Slurries

BHCT degC [degF]	C201 Concentration (gal/sk)	C103 Retarder Concentration (gal/sk)	Thickening Time (h:min)
54 [129]	0.07	0.00	3:15
85 [185]	0.10	0.00	1:09
	0.15	0.00	2:32
	0.20	0.00	2:47
102 [215]	0.10	0.10	3:44

11.4.C204 HT Dispersant

11.4.1.Summary

C204 is a non-retarding powder dispersant for use in fresh and salt water cement slurries. It also enhances fluid loss control with most conventional fluid loss additives, and on its own C204 enhances rheological properties thus improving flow characteristics. C204 can be utilized up to temperatures as high as 450°F BHCT.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C204	1.23	0.0974	High	Tan powder

C200/C201 will extend appreciably the thickening time of a cement slurry. For applications with the BHCT less than 66 degC (150 degF), the extended thickening time may be unacceptable. C204 has a minimal-retarding effect on cement slurries and may be considered as a better alternative for this situation. C204 is effective in providing slurry dispersibility above 85 degC (185 deg F) and up to 450 deg F.

11.4.2.Slurry Design

Depending on the slurry properties required and other factors, C204 can be effective at concentrations as low as 0.1% BWOC. Generally 0.2 to 0.3% is required in most slurries containing fluid loss additives.

C204 can be a powerful retarder and dispersant at low temperatures (below 140 degF), which can cause settling or long WOC at TOC conditions. In such cases, C200/ C201 are the preferable choices of dispersant.

11.4.3.Field Mixing Procedures

Note: Since C204 drastically reduces the cement-slurry viscosity, it is absolutely necessary to control the slurry density using densitometer and pressurized mud-balance method readings only. DO NOT ATTEMPT TO ADJUST THE DENSITY BY THE APPEARANCE OF THE SLURRY!

11.4.4.Job Design Data

At the time of this revision, C204 has not been used in field applications. Below are lab reference values of C204 with class G cement only.

Class G Cement, C204 Rheology

Slurry Density (ppg)	BHCT (degF)	C204 %BWOC	Pv (cp)	Yp (lbf/100ft2)
15.8	80	0.0	54.96	22.9
15.8	80	0.1	27.8	6.71
13.0	380	0.5	36.0*	4.54*
* Cement slurry gels up without the use of C204				

12. Fluid Loss Additives

12.1.Introduction

The selection of a fluid-loss additive for a particular application is based not only on the desired fluid-loss control but also on

- the effects the fluid-loss additive will have on the other cement properties
- the compatibility of the fluid-loss additive with other additives selected
- the performance efficiency (cost effectiveness) of the fluid-loss additive
- in some cases, the fluid-loss additives which are physically available.

Therefore, only general guidelines for FLAC· selection are presented in this section.

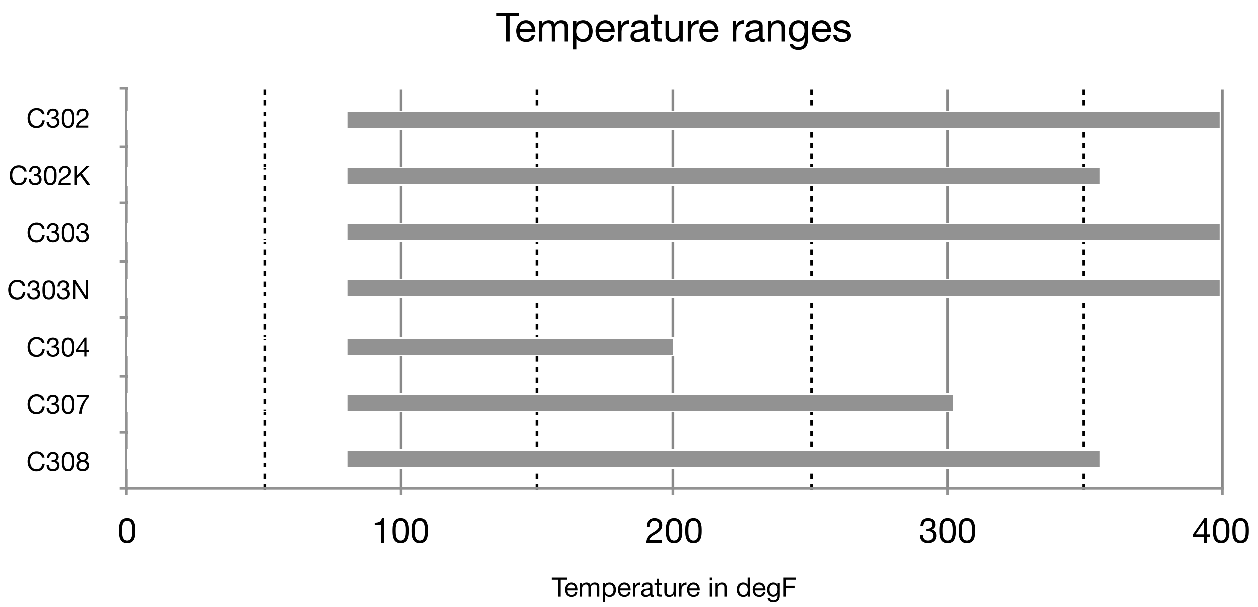
For temperature-range applications, a preferred and maximum range is presented in the tables below. This range reflects the temperatures, for typical slurry designs, at which the desired fluid-loss control can be achieved while the other slurry properties normally remain acceptable.

Fluid-loss additive selection outside of the preferred temperature range may result in, for example, very long thickening times at the low end of the temperature range, or unacceptable fluid-loss control and/or excessive concentrations at the high end of the temperature range.

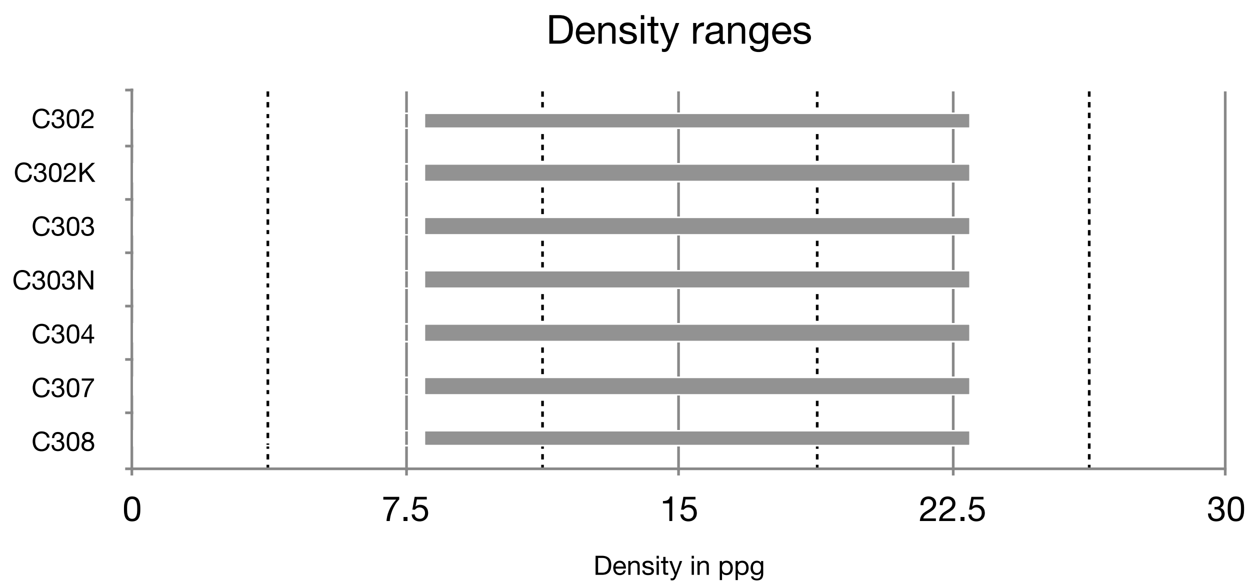
As with all proprietary products and services, care should be taken to avoid loss of samples.

FLAC Summary

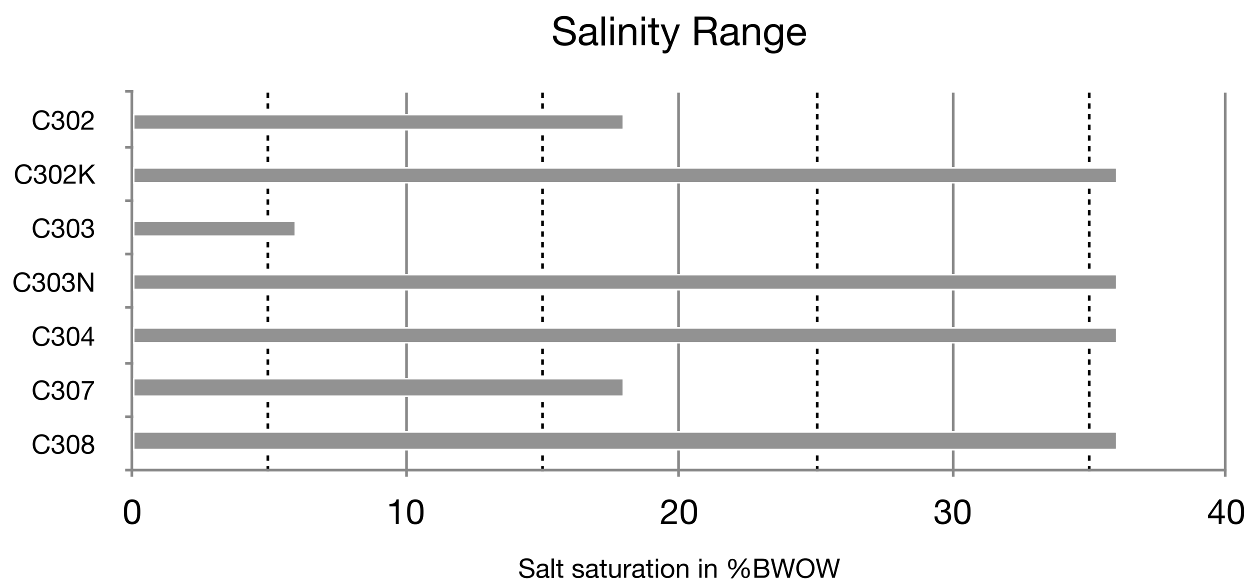
Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
C302	WR FLAC	Fresh and up to 18% salt saturated slurries. Preferred FLAC for HW and UHW systems	Dispersing side effects. Can cause settling with LW systems.	80 - 400	1.5
C302K	WR FLAC	Fresh and up to 36% salt saturated slurries. Preferred FLAC for LW and ULW systems	Can cause gelation issues with some HW systems	80 - 356	1.59
C303	GasTIGHT FLAC	Fresh and up to 6% salt saturation. Used as an anti-migration additive, flexibility agent and bonding agent.	Delayed compressive strength development. Increased rheology. Mild retardation below 125 degF.	80 - 250 (up to 400 degF with C020)	1.02
C303N	WR Liquid FLAC	Fresh and up to 36% salt saturated slurries. Effective with all densities,	Dispersing side effects.	80 - 400	1.13
C304	LT-MT FLAC	Fresh and up to 36% salt saturated slurries.	Reduced efficiency with high water content slurries.	80 - 200	1.39
C307	WR FLAC	Fresh water and up to 18% BWOW salt water.	Unknown as of this revision	80 - 302	1.59
C308	WR FLAC	Fresh and up to 36% salt saturated slurries.	Unknown as of this revision	80 - 356	1.59



Temperature ranges
C302
C302K
C303
C303N
C304
C307
C308
0
100
200
300
400
Temperature in degF



Density ranges
C302
C302K
C303
C303N
C304
C307
C308
0
7.5
15
22.5
30
Density in ppg



Salinity Range
C302
C302K
C303
C303N
C304
C307
C308
0
10
20
30
40
Salt saturation in %BWOW

12.2.C302 Wide Temperature Range FLAC

12.2.1.Summary

SPRINT C302 is a water-soluble AMPS based polymeric fluid loss additive with dispersive properties (Especially at low temperatures) in powder form, which can control fluid loss through adsorption and aggregation reducing pore size and enhancing viscosity of water phase.

It can be used with seawater, and high concentrations of salt. Good salt tolerance makes it effective for a variety of cement compositions, including those with salt concentrations of up to 18%. This additive helps control fluid loss at temperatures up to 400 degF, and it can be used in normal and heavyweight cement slurries.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C302	1.5	0.0799	High	White powder

12.2.2.Slurry Design

C302 is an effective fluid loss additive with high purity and low dosage. The C302 temperature range is 80 degF to 400 degF and it is typically used at a dosage of 0.2%-2.0%(BWOC) and It provides fluid loss control in low, normal or high density cement slurries.

Note: C302 has been observed to cause settling with some lightweight systems. In that case, C302K is the preferable choice of FLAC.

The below results provides its performance at three different temperatures with three highly used retarders of SPRINT (lignosulfonates, gluconates, and organophosphates). The fluid loss value in all tests was less than 50 cc/30min. The below fluid designs are for 15.80 ppg conventional slurry and 20.0 ppg HW slurry are given below. The test are conducted at 180 Deg F, 220 Deg F, and 250 Deg F for 15.8 ppg and at 135 Deg F at 20 ppg.

Slurry 1, 15.8 ppg recipe for 180 deg F

Code	Description	Batch	Conc.	Unit	Lab conc. /600 ml
C517	Cement (Class G)	UCN-10/2020/4	100	1 sk.	776.67 gm
H2O	Water	Tap water	0.583	bbl/bbl	349.62 ml
C011	Defoamer	DF16792131218	0.02	gps	1.38 ml
C302	FLAC	12/20/001	0.7	%BWOC	5.44 gm
C200	Dispersant	CD16725BO1018	0.3	%BWOC	2.33 gm
C102	Retarder	6160927	0.15	%BWOC	1.17 gm

Slurry 1, Rheology

Description	Unit	At 80 Deg F	At 180 Deg F
Plastic viscosity	cP	83.06	125.25
Yield Point	lbf/100 ft^2	6.02	11.53
10 sec gel	lbf/100 ft^2	5	6
10 min gel	lbf/100 ft^2	17	14

Slurry 1, Fluid Loss

Description	Unit	At 180 Deg F
Pressure	Psi	1000
Filtrate	ml	18
Time	min	30
API fluid loss	ml/30 min API	36

Slurry 1, Thickening Time

Consistency	Time
30 BC	08:06 (hh:mm)
70 BC	08:19 (hh:mm)
Transition time (30 BC -70 BC)	13 minutes

Slurry 2, 15.8 ppg recipe for 220 deg F

Code	Description	Batch	Conc.	Unit	Lab conc. /600 ml
C517	Cement (Class G)	UCN-10/2020/4	100	1 sk.	588.82 gm
C030	Silica Flour	SF18064AW0621	35	%BWOC	206.09 gm
H2O	Water	Tap water	0.551	bbl/bbl	330.90 ml
C011	Defoamer	DF16792131218	0.02	gps	1.05 ml
C302	FLAC	12/20/001	1.0	%BWOC	5.89 gm
C514	Anti-Settling Agent	SPR-1	0.30	%BWOC	1.77 gm
C200	Dispersant	CD16725BO1018	0.15	%BWOC	0.88 gm
C104	WR Retarder	2019-0510	0.20	%BWOC	1.18 gm

Slurry 2, Rheology

Description	Unit	At 80 Deg F	At 190 Deg F
Plastic viscosity	cP	193.28	177.93
Yield Point	lbf/100 ft^2	7.56	10.20
10 sec gel	lbf/100 ft^2	6	7
10 min gel	lbf/100 ft^2	12	15

Slurry 2 , Fluid Loss

Description	Unit	At 220 Deg F
Pressure	Psi	1000
Filtrate	ml	21
Time	min	30
API fluid loss	ml/30 min API	42

Slurry 2, thickening time

Consistency	Time
30 BC	03:46 (hh:mm)
70 BC	03:50 (hh:mm)
Transition time (30 BC -70 BC)	4 minutes

Slurry 3, 15.8 ppg recipe for 250 deg F test

Code	Description	Batch	Conc.	Unit	Lab conc. /600 ml
C517	Cement (Class G)	UCN-10/2020/4	100	1 sk.	588.90 gm
C030	Silica Flour	SF18064AW0621	35	%BWOC	206.11 gm
H2O	Water	Tap water	0.541	bbl/bbl	324.67 ml
C011	Defoamer	DF16792131218	0.02	gps	1.05 ml
C302	FLAC	12/20/001	1.0	%BWOC	5.89 gm
C514	Anti-Settling Agent	SPR-1	0.25	%BWOC	1.47 gm
C108	HT Retarder	KK7C0191AO	0.15	gps	7.84 ml

Slurry 3, Rheology

Description	Unit	At 80 Deg F	At 190 Deg F
Plastic viscosity	cP	179.06	159.20
Yield Point	lbf/100 ft^2	6.47	7.85
10 sec gel	lbf/100 ft^2	5	6
10 min gel	lbf/100 ft^2	22	9

Slurry 3, Fluid Loss

Description	Unit	At 250 Deg F
Pressure	Psi	1000
Filtrate	ml	22
Time	min	30
API fluid loss	ml/30 min API	44

Slurry 3, Thickening Time

Consistency	Time
30 BC	07:14 (hh:mm)
70 BC	07:23 (hh:mm)
Transition time (30 BC -70 BC)	9 minutes

Slurry 4, 20.0 ppg recipe for 135 deg F

Code	Description	Batch	Conc.	Unit	Lab conc. /600 ml
C517	Cement (Class G)	UCN-10/2020/4	100	1 sk.	633.86 gm
C500	Hematite	FE-CR-36/19	40	%BWOC	253.54
C507	Micromax	MPP790	40	%BWOC	253.54
H2O	Water	Tap water	0.484	bbl/bbl	291.95 ml
C011	Defoamer	DF16792131218	0.02	gps	1.13 ml
C302	FLAC	12/20/001	0.5	%BWOC	3.17 gm
C200	Dispersant	CD16725BO1018	0.15	%BWOC	0.95 gm
C102	Retarder	6160927	0.05	%BWOC	0.32 gm

Sluury 4, Rheology

Description	Unit	At 80 Deg F	At 135 Deg F
Plastic viscosity	cP	83.06	125.25
Yield Point	$lbf/100\ ft^2$	6.02	11.53
10 sec gel	$lbf/100\ ft^2$	5	6
10 min gel	$lbf/100\ ft^2$	17	14

Slurry 4, Fluid Loss

Description	Unit	At 135 Deg F
Pressure	Psi	1000
Filtrate	ml	18
Time	min	30
API fluid loss	ml/30 min API	36

Slurry 4, Thickening Time

Consistency	Time
30 BC	03:19 (hh:mm)
70 BC	03:28 (hh:mm)
Transition time (30 BC -70 BC)	9 minutes

12.3.C302K Wide Range FLAC

12.3.1.Summary

Sprint C302K is a high purity AMPS based fluid loss additive. The C302K Provides Fluid loss control in low, normal and high density cement slurries, and is typically used below the temperature of 356°F, BHCT. The C302K has no effect of retardation on the cement slurry and ensures fast development of compressive strength of the set cement. The C302K can be used in cementing moderate pressures gas zones provided a right angle set property of the slurry is achieved along with selected dispersant and retarder additive.

The C302K features excellent salt tolerance up to salt-saturation of 35%, and is suitable for both fresh and salt water system.

When slurry is mixed using C302K, the cement slurry demonstrates good pumpability, average rheology and the system becomes stable with little to no free water. The C302K does not lead to over-dispersion nor does it over extend the thickening time.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C302K	1.59	0.0754	High	White powder

12.3.2.Slurry Design

The C302K is soluble in cold water. It can be both dry or water mixed and shall effectively control fluid loss for temperatures up to 356°F, BHCT.

The usual concentrations are 0.2% to 2.5% in the temperature range of 80 degF to 356 degF. A higher concentration of C302K can be required at higher temperatures or with salt saturated slurries. In those conditions, a fluid loss test will determine the dosage.It must be noted that the use of dispersant greatly improves the efficiency of C302K and therefore lower concentrations can be used.

The C302K is typically added to the mix fluid however the following variance of the product can be also available as needed.

C302K has no known limitations besides those that are set by the slurry design requirement. It has been observed to cause gelation issues with some heavyweight systems in which case the use of C302 is preferable due to its dispersing nature.

12.3.3.Compatibility

The C302K is well compatible with other additives and is suitable for all API classes of cement.

12.4.C303 GasTIGHT FLAC

12.4.1.Summary

C303 additive is an aqueous dispersion of solid polymer particles. The dispersed polymer particles block pore spaces between cement grains reducing permeability and restricting movement of gas through the matrix. When the latex beads contact an exposed gas-liquid interface they coalesce and form a coherent, low permeability plastic film. This acts to block migration of gas and fluids into the cement. For this mechanism to occur, gas must enter the latex-based slurry. In addition, potential migration is reduced due to the improved bonding to casing and formation interfaces and excellent fluid-loss control.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C303	1.02	0.1162	58%	7.02	Milky white liquid

C303 is a liquid additive for cement slurries and is designed to give low fluid loss characteristics and to help prevent gas migration into and up to the annulus. The active component is a synthetic latex which is compatible with most other additives.

C303 is an aqueous based Latex polymer that is blended into the mix water prior to preparation of the cement slurry. C303 has a mild-retarding effect when used alone below BHCT < 125°F. Depending on the cement type and the thickening time desired.

C303 may require the use of an accelerator at low temperatures or at low densities when mixed with fresh water. The recommended accelerator is sodium silicate C400. The fluid loss control performance of C303 is improved when used in conjunction with dispersants and most retarders. The use of dispersant alone is sufficient to provide retardation up to about 150°F BHCT. Typically, the addition of a retarder is required above 150°F.

Adding latex to Portland cement considerably increases the tensile and flexural strengths. This is due to improvement in the cement hydrate-aggregate and to the high tensile strength of latex film. Various factors, such as the type and quantity of latex, cement, aggregates, and the water/cement ratio, curing method, and testing procedures affect the measured flexural and tensile strengths. The density of the latex-modified cement depends on latex/cement ratio and the amount of air-entrainment in the mortar. An increase in latex/cement ratio increases the flexural strength. This can be a very beneficial improvement when cement have to resist dynamic and impact loads. The modulus of elasticity in tension decreases as the latex/cement ratio increases. The modulus of elasticity in compression and the Poisson's ratio of latex-modified cement are given in Table below.

An increase in the polymer/cement ratio generally reduces the modulus of elasticity.

Table: C303 Effect on Poisson's Ratio and Elasticity

C303 % of slurry	Modulus of Elasticity in Compression x 10^5 kg/cm^2	Poisson's Ratio
5	2.28 (32.4 psi)	0.16
10	2.43 (34.5 psi)	0.18
15	2.42 (34.4 psi)	0.18
20	2.02 (28.7 psi)	0.18

Adding latex in sufficient quantities will increase the ultimate strain capacity, ductility, and toughness of Portland cement. However, there can be a significant, often undesirable, change in modulus of elasticity in compression.

12.4.2.Slurry Design

C303 is used to control fluid loss in fresh water and sea water slurries.

C303 can be used with different cement classes A, C, G & H from 70 deg F and up to a temperature of 250 deg F (122 deg C).

C303 can be used in a wide range of slurry densities starting from 8 ppg and up to 20 ppg. The concentration required will vary depending on the application and cement brand used.

A typical concentration will vary from 0.5 up to 3.5 gps is used to control fluid loss down to very low values. It is also noted that the use of dispersants and retarders along with C303 will improve its fluid loss control efficiency.

C303 does not affect thickening times significantly and most types of retarders are compatible. A dispersant is necessary with C303 to achieve good fluid loss control.

C303 may require the use of an accelerator at low temperatures or at low densities when mixed with fresh water. The recommended accelerator is sodium silicate C400 also Calcium Chloride C013 can be used as an accelerator at low temperatures.

The fluid loss control performance of C303 is improved when used in conjunction with dispersants and most retarders. The use of dispersant alone is sufficient to provide retardation up to about 150°F BHCT. Typically, the addition of a retarder is required above 150°F.

Stabilizer C020 is used to extend the useable temperature range of C303 to 400F. It is used roughly at 4% of the C303 loading, depending on temperature. Lab testing is required to obtain the optimum ration.

12.4.3.Compatibility With Additives

C303 can be used with most cement additives including all retarders and accelerators. If required, it may be possible to design C303 cement systems for use with fresh or seawater as the mix water. However, FLAC C302/C302K are better alternatives for salt systems. When used with a salt system, it is highly recommended to perform a latex stability test with the salt mix water to ensure no lumps or precipitation are formed at downhole conditions.

12.4.4.Dispersants

Dispersants such as C200 and C204 should be used to optimize for different well conditions, cement batches, and other additives, to obtain a suitable yield value (Ty) at BHCT. The yield value, calculated from measurements obtained with a Fann 35 rotational viscometer, should be designed for optimum mud-removal techniques and to avoid gel development in the slurry before hydration begins. The optimum yield values for C303 GAS-TIGHT slurries are between:

- 0.5 lbm/100 ft2 and 5.0 lbm/100 ft2 for Class G slurries mixed with fresh water; and
- from 0.5 lbm/100 ft2 to 10.0 lbm/100 ft2 for similar Class H slurries.

Due to the coarser particle size distribution of Class H cements, yield values below 5.0 lbm/100 ft2 may be difficult to obtain without excessive free fluid. For slurries mixed with sea or salt waters, the maximum recommended yield value is 10.0 lbm/100 ft2. For slurry densities above 18.0 lbm/gal, yield values up to 30.0 lbm/100 ft2 are acceptable provided the 10-min gel strength is within 10 % of the calculated yield value. C200/C201 is the preferred dispersant for C303 slurries.

12.4.1.Retarders

To optimize gas migration prevention, the length of the thickening time (TT) should be designed according job time times 1.5 or job time plus two hours whichever is longer. C303 slurries should be preferentially retarded with C102 or C103 when the BHCT is below 110 degC (230 degF).

Laboratory testing is absolutely necessary to ensure that no incompatibility problem (e.g., gelation) is experienced with the retarder. C108 is not recommended since it may impart some gelation to latex slurries. It should be kept in mind that gelation problems may also depend on the cement used.

The thickening time profile of the slurry must not indicate any gelation or abnormal thickening.

12.4.2.Mix Water

C303 GAS-TIGHT slurries can be prepared with either fresh water or seawater. However, fresh water should preferentially be used when available on offshore rigs.

12.4.3.Compatibility With Other Additives

C303 can be used within slurries at any density range, unless the SVF is below 37 %. C303 is NOT compatible with conventional extender like bentonite C501, C051/ C052 or sodium silicate C400. C303 can be used in combination with the following additives:

- C010 as antifoam agents.

Note Either antifoam agent should be added to the mix water before adding any other additive as Latex slurries show a high tendency to generate large quantities of foam.

- The recommended anti-settling agent is C514 and C524. It can be used when excessive free-water development and/ or cement/ solid particles sedimentation is observed. The concentration of this additive must be as low as possible since it may impair fluid loss control and may impart gelation. A typical concentration of C514 is 0.1 % to 0.2 % BWOC. C514 should be preferentially pre-hydrated in mix water.
- C303 is compatible with all the conventional solid additives such as C500, C507, C504, C030 and C031.
- Compatibility problems have been reported with expanding agents.

12.4.4.Field Mixing Procedures

C303 should be added and blended to the mix water prior to preparation of cement slurry.

Good circulation (as well as agitation) is required in the mixing tank used to mix the mix fluid. A sample of the mix fluid should be taken from the top most part of the mixing tank and the bottom to ensure the mix fluid is consistent.

12.4.5.Job Design

Typical data showing the effect of C303 on fluid loss and thickening time is presented in Table below. Laboratory should be consulted for help in designing the slurry. The following is a rough guide based on BHCT:

- 30C-----------0.5-1.0 gps
- 50C-----------1.0-1.5 gps
- 85C-----------1.5-2.5 gps
- 100C----------2.5-3.0 gps
- >100C--------3.0-3.5 gps

CemDESIGN should be used to calculate the minimum required concentration of C303 to provide anti-migration properties. Lower than the calculated concentrations will only provide bonding improvements.

Stabilizer C020 is used to extend the useable temperature range of C303 to 400F. It is used roughly at 4% of the C303 loading, depending on temperature. Lab testing is required to obtain the optimum ration.

EFFECTS OF C303 ON FLUID LOSS AND THICKENING TIME for API Class H + Fresh Water @ 16.4 lbs / gallon							
C303 gps	C200 % BWOC	NaSiO2 % BWOC	Temp Deg F	Pv cP	Yp lb/100ft2	Fluid Loss cc/ 30min	T.T. HH:MM
1.5	0	0	80	105	20	95	6:15
1.5	0	0.2	80	105	35	100	4:45
1.5	0	0.4	80	66	46	100	2:45
1.5	0.15	0	80	46.5	3.5	55	10:25
1.5	0.3	0	80	37.5	0.5	40	20:45
1.5	0.5	0	80	39	1	40	23:00
1.5	0.5	0.4	80	57	5	50	5:45
1.5	0	0	150	156	94	170	1:30
1.5	0.15	0	150	36	0	50	2:10
1.5	0.25	0	150	91	3.5	35	6:00
1.5	0.5	0	150	28	1.5	40	9:00
1.5	0.5	0.15	150	33	1	50	4:55
1.5	0.5	0.15	200	21	0	60	4:15
1.5	0.5	0.2	200	22	0	55	6:25
1.5	0	0.35	200	48	0	76	6:31

12.5.C020 HT Latex Stabilizer

12.5.1.Summary

C020 is a stabilizer for use with C303. C020 increases the thickening time of C303 slurries.

By increasing the stability of C303 latex at high temperature, C020 largely diminishes the risks of premature gelation for any latex-cement slurry. Moreover, C020 has no specific effect on the thickening time, prevents ”false setting” due to gelation, provides a ”right-angle set” and improves the cement setting hardness.

Since C020 does not harm any cement properties, overdosing the C020 concentration cannot lead to a job failure, while under dosing could lead to drastic problems during the pumping operation. C020 is optimized in the laboratory through thickening time testing, so that the cement slurry does not gel up at 100 Bc but sets and hardens in a minimum period of time.

The minimum recommended concentration of C020 is 4 % by volume of C303 used.

12.5.2.C020 As A Dispersant

C020 tends to slightly disperse the cement slurry in fresh water. This is particularly true when C200/C201 and/or latex C303 is present in the slurry. The concentration of additives must then be optimized to prevent over dispersion.

12.5.3.C020 as a Latex Stabilizer To Salt

C303 has proved to be more efficient for gas-migration prevention at low temperatures (below 121 degC [250 degF] BHCT), which is frequently the application range of saltwater-base slurries. Moreover, a C303 slurry is already stable by itself up to 8 % BWOW C505. For these reasons, C303 is expected to be the best candidate in a salt system, the following conclusions can be drawn:

- C303 slurry not stabilized with C020 is stable up to 8 % BWOW C505
- C303 stabilized with C020 is stable up to 18 % BWOW C505

C020 acts as a very good dispersant and a strong stabilizer in latex salt slurries, and overdosing C020 with regard to C303 does not cause drastic problems with respect to the rheology.

12.5.4.Slurry Design

The concentration requirement is dependent upon the cement type, BHCT, slurry density, C303 concentration, and the thickening time desired. Laboratory data presented are only intended as guidelines. Prior to the job, any slurry design for actual job application should be thoroughly tested in the laboratory with samples of cement, water and additives coming from the location.

C020 can be used with different cement classes A, C, G & H from 70 deg F and up to a temperature of 320 deg F. C020 can be used in a wide range of slurry densities starting from 8.0 ppg and up to 23 ppg.

The typical concentration of C020 will range from 0.4 to 1% bwoc. C020 stabilized slurries may require the use of an accelerator at low temperatures or at low densities when mixed with fresh water. The recommended accelerator is sodium silicate. The fluid loss control performance of C303 slurries is improved by the addition of C020. The addition of C020 will require an increase in the C011 antifoam concentration.

EFFECTS OF C020 ON THICKENING TIME for Class G + 35% Silica Flour + 2.5 gps C303 + 0.5% bwoc C200 + Fresh Water @ 15.8 lbs / gallon						
Density ppg	C020 % BWOC	C103 % BWOC	BHCT Deg F	HH:MM to 30 Bc	HH:MM to 100 Bc	Transition Time HH:MM
16.4		0.15		4:29	5:19	0:50
16.4	0.1	0.15		5:56	6:04	0:08
		0.15		0:52	0:55	0:03
	0.1	0.15		5:36	5:49	0:13
16.4		0.2		2:25	3:46	1:21
16.4	0.1	0.2		3:51	4:13	0:22
	0.1	0.2		2:23	3:32	1:09
	0.15	0.2		2:08	4:45	2:37
	0.2	0.2		4:44	4:55	0:11
	0.25	0.2		4:45	5:08	0:23

12.6.C303N GasTIGHT FLAC

12.6.1.Summary

C303N is a liquid, anionic, grafted-polymer solution. It is a cement fluid loss additive which provides highly effective fluid loss control, particularly at temperatures above 200°F (90°C). C303N may be used in a variety of cement slurry systems due to its dispersible characteristic that imparts a very low rheology. In addition, C303N may be used as a gas migration control additive due to its excellent fluid loss control.

Code	SG	Absolute Volume (gal/lbm)	pH	Appearance
C303N	1.13	0.1061	5.01	Opaque amber liquid

C303N is a fluid-loss control agent designed for use in cement slurries prepared with fresh water, salt water and sea water. C303N systems can be designed to control the rate of water loss from cement systems used in both primary and squeeze cementing operations.

C303N can be used with any brand of cement. It can be used in the temperature range up to 400°F.

C303N has various benefits such as:

- Excellent fluid loss control
- Passes North Sea Environmental requirements being nontoxic, non-bioaccumulating as well as biodegradable above 20% by OECD 306
- No adverse effect on cement thickening time or compressive strength development
- Applicable at temperatures up to 400°F (204°C)
- Applicable in a wide variety of systems, including freshwater and seawater slurries, and saturated salts systems

12.6.2.Concentration

C303N dosage rates vary from 0.2 to 1.0 gallon per sack of cement. In order to achieve optimum fluid loss control, each slurry should be tested to determine the proper dosage. C303N should be batch mixed with cement mixing water in order to achieve optimum fluid loss control.

12.6.3.Slurry Design

C303N provides cement slurries with a right angle set behavior that helps minimizing gas migration through the annulus and while cement is setting.

C200 dispersant can be used together with C303N to optimize fluid-loss control however, special attention to settling should be checked.

In case of settling, C514 anti-settling agent should be added to the slurry composition and rheology to be checked for surface as well as downhole temperatures.

Also, 10 minutes and higher static gel strength should be checked in case C514 is added to the slurry design.

Below is a typical design for GasTIGHT slurry using C303N

Table: C303N Slurry Design

	15.8 ppg at 180 deg F BHCT	15.8 ppg at 230 deg F BHCT
Density	15.8	15.8
Yield	1.165	1.534
Cement	4.8 Sx	3.7 Sx
C030 Silica Flour	-	35% bwoc
C011 Defoamer	0.02 gps	0.02 gps
C200 Dispersant	0.7% bwoc	-
C303N GASTIGHT	0.3 gps	0.35 gps
C305 FLAC	0.2% bwoc	-
C102 Retarder LT	0.17% bwoc	-
C104 Retarder MT-HT	-	0.23% bwoc
C402 Cenosphere	-	-
C514 Antisettling Agent	-	0.5% bwoc
PV	59	89
Ty	9	10
TT	4:50	4:50
24 hrs CS	4500 psi	3850 psi
FL	55	57

12.6.4.Compatibility With Additives

C303N can be used with most cement additives including all retarders and accelerators. If required, it may be possible to design C303N cement systems for use with seawater as well as for salt saturated systems.

C303N has no adverse effect on cement thickening time or compressive strength development.

12.6.5.Field Mixing Procedures

C303N should be added in the mix fluid and thoroughly circulated immediately prior to cement job.

12.7.C304 LT FLAC

12.7.1.Summary

C304 is a low temperature range polymer that is dry blended with the cement powder or mixed in the mix fluid prior to preparation of the cement slurry. C304 is a mild-retarding fluid loss agent for BHCT < 200°F. Depending on the cement type and the thickening time desired, C304 may require the use of an accelerator at low temperatures or at low densities when mixed with fresh water. The fluid loss control performance of C304 is improved when used in conjunction with dispersants and most retarders.

C304 is a fluid-loss control agent designed for use in cement slurries prepared with fresh water, salt water and sea water. C304 is designed to control the rate of water loss from cement systems used in both primary and squeeze cementing operations.

C304 can be used with any brand of cement. It can be used in the temperature range of 80 to 200°F.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C304	1.39	0.0862	Low	White to Yellowish Powder

12.7.2.Slurry Design

The typical concentration range for C304 is 0.1% to 3.0% BWOC depending on the slurry type and the required fluid loss value. When the cementing temperature is 140°F or less, high C304 concentrations exhibit a retarding effect on Portland cements. The thickening time can be reduced by incorporating an accelerator. Calcium Chloride C013 can be used to accelerate C304 cement systems, but this will somewhat affect fluid-loss control. Laboratory thickening time tests should be run on the blend before the job. Alternatively, C304 can be used if short thickening times are required.

Where 4 to 6 hr working time is desired, such as in the hesitation squeeze technique, no retarder is normally needed to depths of 6000 ft. If high early strengths are desired at temperatures above 100°F, 1% of C013 cement accelerator can be added but caution from early setting must be exercised.

C200 dispersant can be used together with C304 to optimize fluid-loss control. Lightweight, high-water-content slurries will require more C304 than neat-cement slurries for comparable fluid-loss control. It is very difficult and expensive to control fluid loss in cements containing pozzolan extenders, diatomaceous earth or perlite because of the dilution effect of the excess water.

For this reason, C302K has been developed especially for use in high-water content slurries.

12.7.3.Compatibility

C304 can be used with most cement additives including all retarders and accelerators. If required, it may be possible to design C304 cement systems for use with seawater as the mix water. However, FLAC C305, C302, C302K and C303N are better alternatives for salt systems.

12.7.4.Field Mixing Procedures

C304 can be either dry blended in the cement or pre-hydrated in the mix water.

12.7.5.Slurry Design

Typical data showing the effect of C304 on fluid loss and thickening time is presented in Table below. Laboratory should be consulted for help in designing the slurry.

EFFECTS OF C304 ON FLUID LOSS for API Class H + Fresh Water @ 16.0 lbs / gallon						
C304 % BWOC	**API Fluid Loss in cm^3 per 30 minute's**					
	80°F	**100°F**	**125°F**	**150°F**	**175°F**	**200°F**
0.5	70	80	135	205	285	435
0.75	40	42	52	87	145	240
1	20	21	24	45	68	148

EFFECTS OF C304 ON THICKENING TIME for API Class H + Fresh Water @ 16.0 lbs / gallon					
C304 % BWOC	**API Thickening Time HH:MM**				
	100°F	**125°F**	**150°F**	**175°F**	**200°F**
0.5	5:59	3:45	2:18	1:25	1:05
0.75	+6:00	4:41	3:15	2:15	1:07
1	+6:00	5:08	3:31	2:31	1:16

12.8.C307 Fluid Loss Control Additive

12.8.1.Summary:

C307 is a synthetic polymer-based fluid loss for cement. It is a high purity low dosage FLAC which is effective for low, normal, and high-density cement slurries.

C307 is typically used below the temperature of 150°C (302°F BHCT). The C307 is a non-retarding fluid loss and helps in fast compressive strength development of the set cement.

C307 features good salt tolerance which is up to a salt-saturation of 18%. Hence it is recommended for both fresh and salt-water systems. The slurries prepared with C307 do not lead to over-dispersion or thickening and do not require additional dispersant.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C307	1.59	0.0754	High	White powder

12.8.2.Slurry Design:

The recommended dosage range of C307 is 0.6% BWOC to 4.5% BWOC. For reference, 0.6% BWOC of C307 will control a 15.0 ppg neat class G cement slurry below 100 ml/30 min API at surface condition. 4.5% BWOC C307 can control a 13.0 ppg neat class G cement slurry below 200 ml/30 min API at 302 degF.

12.8.3.Compatibility With Other Additives:

C307 can be used with all API classes of cement and most cement additives including all retarders and accelerators. The C307 should be stored in ventilated, cool, and dry area, and exposure to sun and rain should be avoided.

12.9.C308 Fluid Loss Control Additive

12.9.1.Summary:

C308 is a synthetic polymer-based fluid loss for cement nearly similar in composition to C308. It is a high purity low dosage FLAC which is effective for low, normal, and high-density cement slurries.

C308 is typically used below the temperature of 180°C (356°F BHCT). The C308 is a non-retarding fluid loss and helps in fast compressive strength development of the set cement.

C308 features good salt tolerance which is up to a full salt-saturation of 36%. Hence it is recommended for both fresh and salt-water systems. The slurries prepared with C308 do not lead to over-dispersion or thickening and do not require additional dispersant.

C308 offers a more efficient performance at higher temperatures compared to C307.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C308	1.6	0.0749	High	White powder

12.9.2.Slurry Design:

The recommended dosage range of C308 is 0.6% BWOC to 4.0% BWOC. For reference, 0.6% BWOC of C3078 will control a 15.0 ppg neat class G cement slurry below 100 ml/30 min API at surface condition. 4.0% BWOC C308 can control a 13.0 ppg neat class G cement slurry below 50 ml/30 min API at 356 degF.

12.9.3.Compatibility With Other Additives:

C308 can be used with all API classes of cement and most cement additives including all retarders and accelerators. The C308 should be stored in ventilated, cool, and dry area, and exposure to sun and rain should be avoided.

13. Antifoamers & Defoamers

13.1.C010 Antifoamer/ Defoamer

13.1.1.Summary

C010 is a polyalcohol-based liquid anti-foaming agent for cement slurries. C010 is compatible with all commonly used cement additives. C010 can be added to all cement slurries for the prevention of air entrapment in the slurry during mixing. It can be used both as a defoamer or antifoam.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C010	0.84	0.1427	30% - 40%	4.8	Clear, pale yellow to amber liquid

Certain materials used to modify the properties of cement slurries are known to cause foaming or air entrainment. This air entrapment can result in several mixing problems. In extreme cases of air entrapment transfer pump cavitation may occur.

The most common problem is the slurry density will appear to be less than desired as determined by common density measuring devices. This leads to the operator reducing the water content in order to raise the surface density to the specified value and to the problem of increasing the actual slurry density to account for the apparent error in slurry density.

The increase in the actual slurry density will have the negative effect of increasing the slurry viscosity, reducing the slurry volume, and reducing the thickening time.

Also, a severely reduced pumping time may be the end result, especially if retarders and other additives are premixed in the water.

C010 is used to help prevent foaming and air entrainment caused by additives such as retarders, fluid loss agents, and salt.

No effect on cement properties has been found with C010, and it is compatible with all API classes of cement and all additives.

13.1.2.Concentration

A typical concentration of:

- 0.25 to 0.5 gal per 10 bbls of mix water is used for different fluids, gels and CemBOND spacers.
- For cement slurries a concentration of 0.01 to 0.05 gal/sk of cement can be used.
- C010 can be used up to a temperature limit of 450 deg F and for all slurry densities. C010 is the usual antifoam for use in chemical washes.

For C303 and salt based slurries it is recommended to use C010 de-foamer/ Antifoam.

13.2.C011 Defoamer

13.2.1.Summary

C011 is a silicone-based liquid de-foamer for cement slurries with 30% active component. C011 is compatible with all commonly used cement additives.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C011	1.0	0.1199	30%	7.25	Milky White

C011 is used as a foam breaker, so it is preferably added after or during slurry mixing. C011 has been found to be ineffective when used as an Antifoam. Sometimes, C011 has been observed to increase foaming when added before slurry mixing.

It should be noted that in cold water, high mixing energy is required for C011 adequate dispersion.

Air entrapment can result in several mixing problems. In extreme cases of air entrapment transfer pump cavitation may occur. The most common problem is the slurry density will appear to be less than desired as determined by common density measuring devices. This leads to the operator reducing the water content in order to raise the surface density to the specified value and to the problem of increasing the actual slurry density to account for the apparent error in slurry density.

The increase in the actual slurry density will have the negative effect of increasing the slurry viscosity, reducing the slurry volume, and reducing the thickening time.

Also, a severely reduced pumping time may be the end result, especially if retarders and other additives are premixed in the water.

C011 has been observed to be inefficient with Latex and salt based slurries. In such case, C010 and C012 are the preferable choices.

No effect on cement properties has been found with C011, and it is compatible with all API classes of cement and all additives.

13.2.2.Concentration

A typical concentration of:

- 0.01 gal/sk to 0.05 gal/sk in all applications is advised for foam breaking.
- And a concentration of 0.1 gal/bbl in typically used for CemBOND spacers.
- C011 should not be stored or exposed to a temperature of 0 deg C or below as product will solidify and shall not be active even if later de-solidified.
- A winterized version of the C011 needs to be ordered if expected to be exposed to low temperatures.

13.3.C012 Antifoamer/ Defoamer

13.3.1.Summary

C012 is a tributyl phosphate based liquid anti-foaming agent for cement slurries. C012 is compatible with all commonly used cement additives. C012 can be added to all cement slurries for the prevention of air entrapment in the slurry during mixing. C012 can be used up to a temperature limit of 350 deg F and for all slurry densities. It can be used both as a defoamer or antifoam i.e. can be added before or after slurry mixing.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C012	0.93	0.1289	70%	4.56	Colorless Liquid

Certain materials used to modify the properties of cement slurries are known to cause foaming or air entrainment. This air entrapment can result in several mixing problems. In extreme cases of air entrapment transfer pump cavitation may occur.

The most common problem is the slurry density will appear to be less than desired as determined by common density measuring devices. This leads to the operator reducing the water content in order to raise the surface density to the specified value and to the problem of increasing the actual slurry density to account for the apparent error in slurry density.

The increase in the actual slurry density will have the negative effect of increasing the slurry viscosity, reducing the slurry volume, and reducing the thickening time.

Also, a severely reduced pumping time may be the end result, especially if retarders and other additives are premixed in the water.

No effect on cement properties has been found with C012, and it is compatible with all API classes of cement and all additives.

13.3.2.Concentration

A typical concentration of:

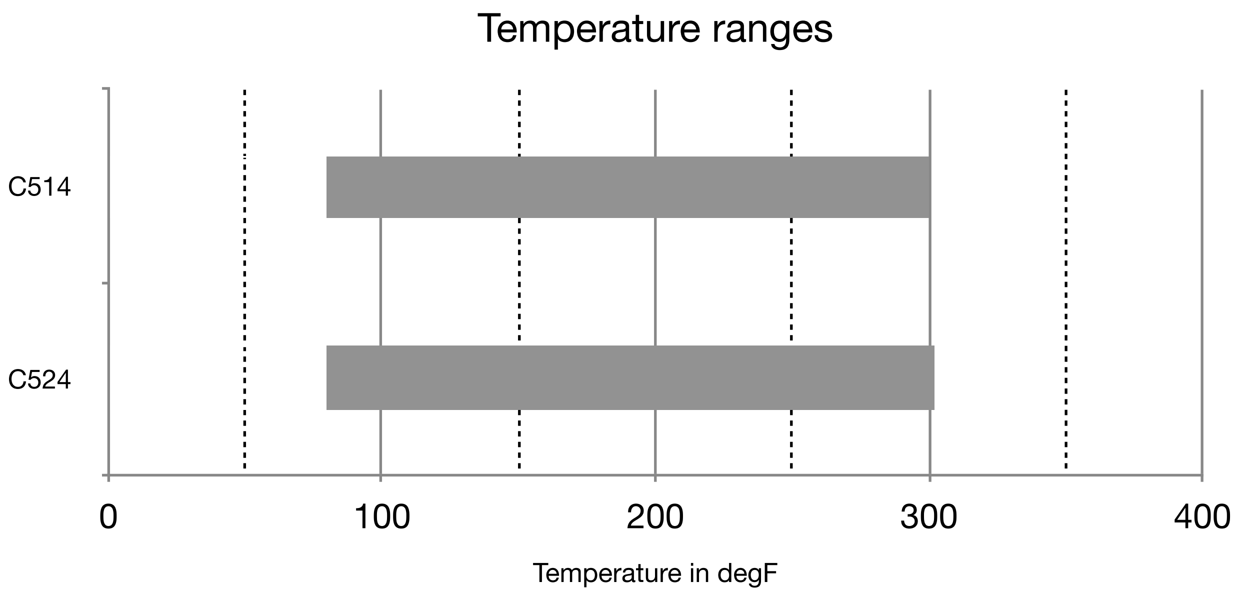
- 0.25 to 0.5 gal per 10 bbls of mix water is used for different fluids, gels and CemBOND spacers.
- For cement slurries a concentration of 0.01 to 0.05 gal/sk of cement can be used.

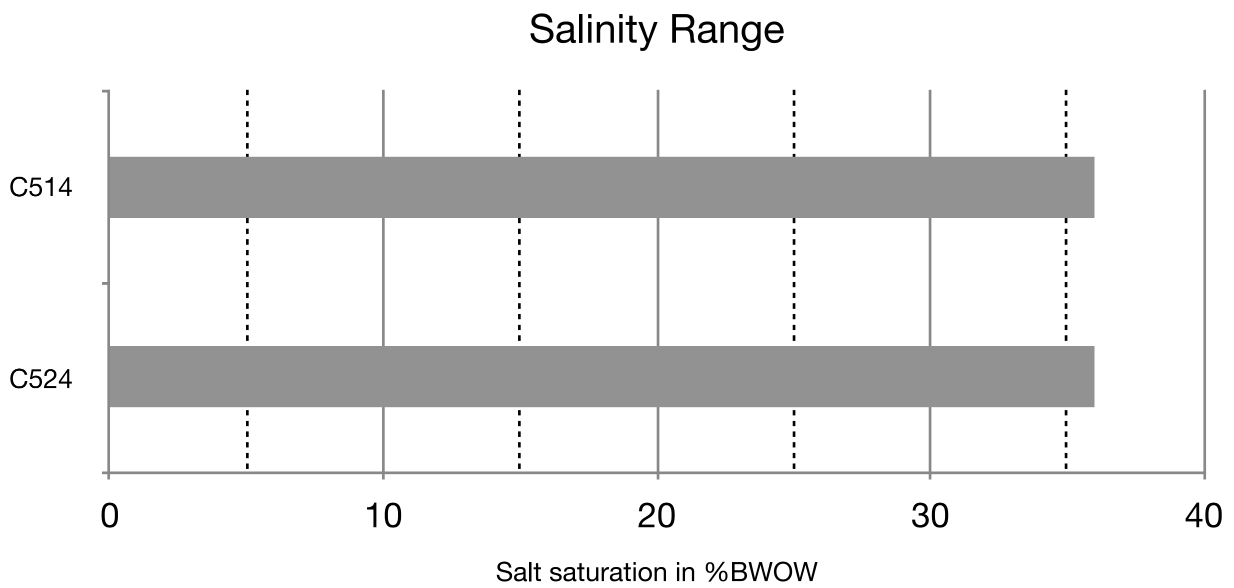
14. Special Additives: Anti-Settling Agents

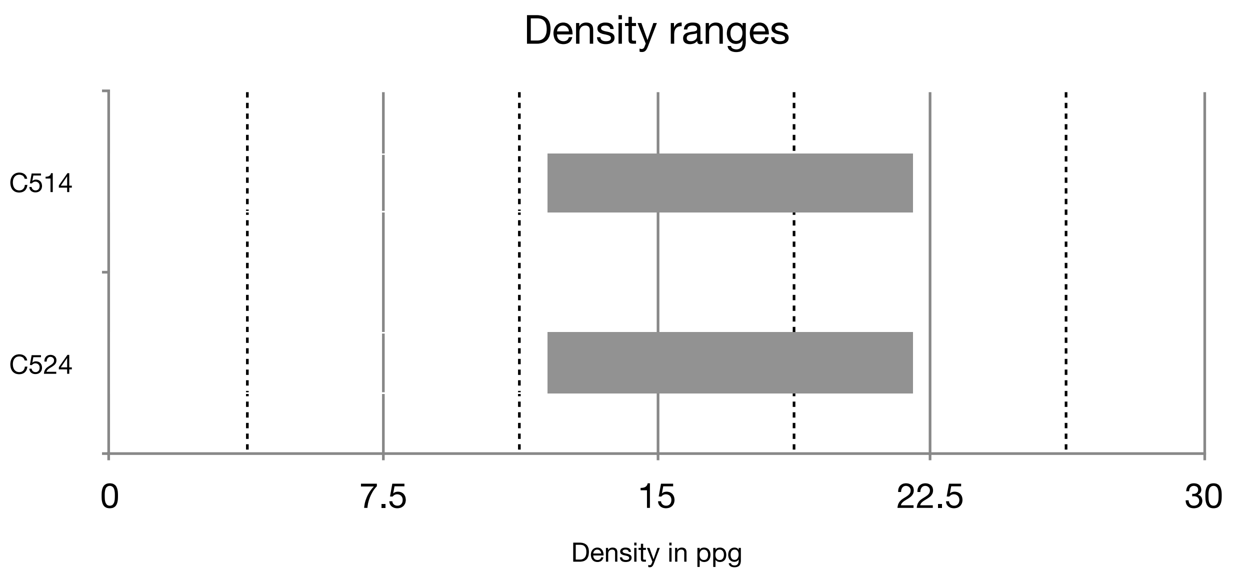
Non-homogeneous cement columns are not acceptable, particularly when the wellbore is highly deviated or horizontal. Sufficient set-cement strength and zonal isolation are jeopardized under such circumstances. A plot of free water and yield value versus PNS dispersant concentration, reveals a narrow range within which the slurry is sufficiently fluid and yet stable. In a field environment, it is difficult to control additive concentrations within such a narrow range. Therefore, anti-settling agents are often added to broaden the concentration range within which low yield values and low free water can be obtained). Anti-settling agents are materials that restore some of the yield value but at a level compatible with the pumping conditions and friction pressure the exposed formation can bear.

Anti-settling Agents Summary

Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
C514	Anti-Settling Agent	Fresh water and up to salt saturation slurries	Impaired efficiency with salt concentrations above 5% BWOW although it is more resistant to salt than C524	80 - 300	2.37
C524	Anti-Settling Agent	Fresh water and sea water slurries	Impaired efficiency with salt concentrations above 5% BWOW	80 - 302	2.48


Temperature ranges
C514
C524
0
100
200
300
400
Temperature in degF


Salinity Range
C514
C524
0
10
20
30
40
Salt saturation in %BWOW


Density ranges
C514
C524
0
7.5
15
22.5
30
Density in ppg

14.1.C514 Anti-Settling Agent

C514 prevents solids settling in cement slurries that are over-dispersed or in high-density slurries where weighting agents such as hematite are used. It can also be used to eliminate free water in highly extended slurries. C514 is functional up to 300 deg F BHCT.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C514	2.37	0.0505	Non Soluble	Off White

Slurry densities ranging from 12 lbm/gal to 22 lbm/gal have been successfully stabilized using C514. Normal concentrations range from 0.2 % to 0.6 % C514 by weight of cement although concentrations up to 1.5% BWOC can be used, depending on the type of application, the slurry density and the severity of the problem.

C514 can be used in fresh water or seawater slurries. C514 provides a better salt tolerance then C524 however the effectiveness will still deteriorate with increasing salt concentration.

C514 is compatible with all Sprint additives and Portland cements. It may be dry blended with the cement, or pre-hydrated in the mix water.

14.1.1.Typical Slurry Applications

C514 prevents free-water development and settling in potentially unstable cement slurries, such as:

- Low-rheology slurries where typical yield points are less than 5 lbf/100 ft2. It should be noted that when C514 is used, the rheology of the stabilized slurry will increase and the critical pump rates for turbulent flow will be higher. In such cases, a compromise between rheology and stability is required.
- Over-dispersed systems where C200/C201 dispersants must be used with ETD cements. A combination of C514 and C200 or C201 will prevent free fluid and settling. This situation may arise if cement brands or batches are changed.
- C514 may be used to prevent sedimentation in heavyweight cement slurries containing weighting agents such as C500 Hematite. Concentrations of 0.1 % to 0.3 % C514 have been used in slurries mixed up to 22 lbm/gal.
- C514 helps stabilize low-density cement slurries used alone with concentrations as high as 1.5 % BWOC; or in combination with C400 or C501 extenders. In the latter case, lower than normal slurry densities can be achieved since it is possible to increase the water content without the development of free fluid.
- In some cases, certain cement systems may prove difficult to mix at their API mix water-to-cement ratio (i.e., density). The application of small concentrations of C514 will allow the slurry density to be reduced by the addition of extra mix water, thus improving mixability while preserving slurry stability.
- The efficiency of the C514 may be improved by the addition of a dispersant (C200, C201) to such systems.
- C514 may be suitable for other applications but careful testing in the laboratory must be performed using materials which are to be used for the particular job.

14.1.2.Particular Points To Check

- Foaming: Some foaming may appear during C514 pre-hydration in the mix water. The use of C011 instead of C010 is recommended in this case.

- Salt Slurries: It is possible to use C524 to reduce free fluid development in salt slurries, but very often zero-free fluid will be impossible to obtain: 1 % to 2 % remaining free fluid will normally be observed. In the case where C524 is pre-hydrated, salt must be added after the complete hydration of C524.
- Addition of Dispersants: When no dispersant is included in the slurry design, it may be difficult or impossible to solve free-water problems using C514. In such cases, the addition of some dispersant (for instance 0.2 % C200 BWOC) allows C514 to recover its efficiency.
- Mixing Energy: Several studies have shown that the rheology of a slurry, as well as other properties (e.g., fluid loss), depend on the mixing energy applied. Mixing according to API Specification 10 provides fairly high energy (5.9 kJ/kg) compared to the mixing energy applied using, for instance, the conventional jet mixer (1-2 kJ/kg). Due to incomplete deflocculation of the cement during mixing, higher rheologies and higher API fluid-loss values are often obtained during field mixing when the mixing energy is low. This effect may cause problems when mixing high-density (>15.8 lbm/gal), high-plastic-viscosity (>150 cP) cement slurries where C514 is pre-hydrated in the mix water. The increase in rheology as a result of low field-mixing energy may cause slurry mixability problems.

An indication that such a problem may exist can be found using the ”low mixing-energy rheology” test. The test simply consists of the viscosity measurement of a slurry mixed in the laboratory at lower energy than recommended by API.

The mixing energy used in this test is very close to the energy provided by conventional jet mixers. The rheology values obtained will be very similar to those experienced during slurry mixing.

If the resultant ”mixing” rheology is too high for good slurry mixability, then alternative solutions may be necessary. These may include:

- Reducing the C514 concentration to get a lower rheology (while maintaining acceptable free fluid and/ or sedimentation).
- Dry-blending the C514 instead of pre-hydrating.
- Changing the slurry design or using a different mixing method to increase the mixing energy (e.g., batch mix instead of jet mix).

When C514 is dry blended with the cement, the influence of mixing energy on rheology is the same as for other cement slurries.

High mixing energy or time is recommended in this case only to improve the hydration of C514.

14.1.3.Concentration Range

C514 dosage rates vary from 0.2% to 0.6% of dry cement used in the slurry. In order to achieve optimum anti-settling control, each slurry should be tested to determine the proper dosage. C514 should be mixed with the dry cement prior to the addition of water in order to achieve optimum anti-settling control.

14.1.4.Laboratory Procedures

C514 may be dry blended with the cement or it may be pre-hydrated in the mix water. For lab preparation: mix C514 for 5 min in a Waring blender at 4,000 rpm with the mix water prior to pre-hydration of other additives to provide a sufficient hydration of the additive. Antifoam Agent C011 should be added before the addition of other additives.

Free fluid and sedimentation tests:

Apart from the methods proposed in API Specification 10, several test procedures may be used:

At low temperature (<85 degC [185 degF]):

- Simple free-fluid and density-gradient test: After mixing, condition the slurry for 20 min in an atmospheric consistometer at the test temperature. Then pour into a 250 mL graduated cylinder. Seal the cylinder to prevent evaporation and place on a vibration-free surface for 2 h. The volume of free fluid is then measured. The slurry may then be allowed to set. Cut into regular portions and measure density by weighing and immersing in water. The density gradient "d is calculated as the density difference between the top and bottom section.

- *45 angle free-fluid test:* This test procedure is the same as above, except that the cylinder is inclined at 45 degree for the two hours. These are more severe conditions for sedimentation.

At higher temperature 85 degC to 150 degC (185 degF to 300 degF):

- Sedimentation test in curing chamber as per "BP settling test": This test measures sedimentation at high temperature under pressure. After mixing, pour the slurry into a brass tube which can be opened along its length. Completely fill the tube and place it in a curing chamber. Apply 3,000 psi pressure. Increase the temperature up to BHCT and maintain until the slurry normally sets.Cool the cell and release the pressure. Free fluid is estimated as any reduction in height from the top of the set cement to the top of the tube. Settling/sedimentation is determined from the density gradient of the set cement (as explained earlier).

Note: Another simple method to estimate free fluid volume of a slurry at high temperature consists of using a 100 mL graduated cylinder in a high temperature, high-pressure consistometer cell.

Rheological test for low-mixing energy

Where high rheological parameters are obtained from API Specification 10 mixing for a slurry containing pre-hydrated C514, even higher rheology may be expected when mixing with a low-mixing energy (e.g., jet mixer). The laboratory mixing procedure to simulate low mixing energy is as follows:

- Pre-hydrate C514 in the mix water containing antifoam agent for 5 min at 4,000 rpm in the Waring blender.

- Add any other additives to be pre-hydrated and mix for 1 min at 4,000 r pm.

- Continue mixing at 4,000 rpm while adding the cement (or cement blend with additives) within the next 15 s.

- After complete addition of cement, continue mixing at 4,000 rpm for 1 min.

- Measure the rheology of the slurry at mixing temperature. Do not condition the slurry in an atmospheric consistometer.

If possible, the same test should be run at lower mixing energy: i.e., the same time for addition of cement and mixing, but at 2,500 rpm instead of 4,000 r pm.

This test provides the best laboratory estimation of the highest limit reachable when mixing energy decreases.

14.1.5.Compatibility and Influence on Slurry Properties

C524 is compatible with most commonly used Sprint additives. In particular, it has no effect on latex stability in C303 or C020 slurries.

The addition of C524 will mainly change the performance test results which could be attributed to sedimentation. More precisely its effect on slurry properties is the following:

* *Fluid-Loss Control:* C524 has no detrimental effect on fluid-loss control. However, an apparent deterioration of fluid-loss control by the addition of C524 may be observed if the initial "good" fluid-loss rate was caused by severe sedimentation and thus formation of an efficient cake in the test cell.

* *Thickening Time:* No accelerating effect due to C524 has been observed. Sometimes a slight retardation may occur.

* *Rheology:* The viscosity of a cement slurry is increased in a regular and reproducible way by the addition of C524. Often, a linear variation of the plastic viscosity of the slurries with C524 concentration can be observed, especially when slurry density is greater than 15.8 lb/gal. Care must be taken when comparing rheological parameters calculated from measurements with and without C524 as the values obtained for a slurry which sediments may be totally inaccurate. If a turbulent flow slurry is wanted, a balance must be found between rheology and sedimentation. Sometimes this may be difficult or even impossible to achieve. Rheology after low energy mixing must be checked especially for high-density slurries exhibiting high-plastic viscosities (>150 cP) measured by conventional API Fann testing. If necessary the design or the mixing procedure of the job should be adapted.

* It has been observed that C524 may impart some thixotropy to the slurry.

14.1.6.Field Mixing Procedures

C514 may be dry blended with the cement or pre-hydrated in the mix water.

Pre-hydration of C514

The mixing equipment used for pre-hydration of C514 should be clean. In particular, mud contamination could result in a high-viscosity base fluid and lead to problems during mixing with the cement (difficulties to increase the density, higher sensitivity to mixing energy, etc.). The use of Antifoam Agent C010 is preferred to C011. If some salt is used, it must be added after the complete hydration of C514. If the pre-hydration is planned for more than a few hours before mixing. The procedure for pre-hydration of C514 is the following:

* Add C514 to the mix water, plus antifoam through a mud hopper or jet mixer to insure a good dispersion of the C514 powder.

* Circulate at a high rate for 20 min to 30 min (more in seawater) to complete the additive hydration. Pre-hydration of the other additives can then be done according to usual procedure. The sequence of the addition of additives should be the same as that used in the laboratory.

Dry Blend

Standard dry-blending procedures should be followed. Sampling is recommended to check that the blend is homogeneous.

When C514 is dry blended with the cement, care must be taken to provide enough mixing energy/time to allow good additive hydration. Some sedimentation may be observed on samples taken right after the mixer.

Provided enough circulation or mixing is done after this point, the properties of the slurry which is pumped downhole will be as designed.

14.2.C524 Anti-Settling Agent

14.2.1.Summary

Anti-settling Agent C524 is a powder additive designed to prevent sedimentation and/or free-water problems in cement slurries at bottom-hole temperatures below 302 degF. C524 is particularly effective in stabilizing over-dispersed cement slurries.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C524	2.48	0.0483	Non Soluble	Off White

Slurry densities ranging from 12 lbm/gal to 22 lbm/gal have been successfully stabilized using C524. Normal concentrations range from 0.2 % to 0.6 % C524 by weight of cement although concentrations up to 1.5% BWOC can be used, depending on the type of application, the slurry density and the severity of the problem.

C524 can be used in fresh water or seawater slurries. In systems containing more than 5 % NaCl BWOW, its efficiency may be impaired.

C524 is compatible with all Sprint additives and Portland cements. It may be dry blended with the cement, or pre-hydrated in the mix water.

14.2.2.Limits of C524 Use

C524 must not be used at bottom-hole temperatures higher than 150 degC (302 degF). Above this temperature, it undergoes a severe thermal degradation and completely loses its efficiency. No density limit has been identified.

At present, cement slurries ranging from 12 lbm/gal to 22 lbm/gal have been tested. C524 will increase the rheology of a cement slurry. The magnitude of the increase depends on the cement type, slurry design and density. Therefore, the concentration of C524 required to stabilize a particular slurry may be limited by the rheology increase.

14.2.3.Particular Points To Check

Similarly to C514 the same points need to be considered during the job planning phase (Refer to C514 section Particular Points to check).

14.2.4.Concentration Range

Usually 0.1 % to 0.4 % C524 BWOC is enough to obtain good results. In the case of low-density slurries (12.5 lbm/gal to 14.5 lbm/gal), the amount of additive needed is sometimes higher (0.4 % to 1.5 % BWOC).

Each sedimentation or free-water problem is unique so the concentration of C524 to use will depend on many parameters (cement brand and batch, mix water, other additives present, etc.). Thus, it is difficult to issue precise guidelines.

Laboratory testing using the mix water, cement and additives which are used locally, must be carried out to determine the C524 concentration needed.

Concentrations to start a design are usually:

- *In most of the cases:* 0.1 % to 0.3 % C524, where free fluid or sedimentation is not too severe, and with medium to high density (or low density in the presence of C501 or C400).

- *For very severe sedimentation problems:* 0.5 % C524, where more than 20 mm thick cement cake in the Fann cup after rheology measurement exists for instance, or for low-density slurries containing no C501 or C400.

14.2.5.Mix Water

Fresh water, seawater or local rig water (up to a salinity equivalent to seawater) is recommended. At salt concentrations greater than 5% BWOW in the mix water, the efficiency of C524 will be reduced.

Contamination of mix water must be avoided by using clean tanks which are well isolated from other fluids.

14.2.6.Compatibility and Influence on Slurry Properties

The same effects as C514 can also be considered for C524 (Refer to C514 section Compatibility and influence on slurry properties)

14.2.7.Field Mixing Procedures

C524 may be dry blended with the cement or pre-hydrated in the mix water. The same considerations as C514 can be applied (refer to the C514 section Field Mixing Procedure)

15. Special Additives: Strength Retrogression Additives

15.1.Summary

The addition of silica is required when Portland cement systems are exposed to temperatures of 110 degC (230 degF) or above. Silica agents are used to stabilize cement systems for use not only in deep, high temperature wells, but also in systems for cementing geothermal or thermal-recovery wells. The addition of 35 % (BWOC) silica prevents the loss of strength and the increase of permeability within the set cement that would normally occur from strength retrogression.

The C031 silica sand and C030 silica flour agents can be used with most API classes of Portland cement. In this manual section, the strength-retrogression phenomenon is discussed, and data are presented that illustrate how the addition of silica can prevent it. In addition, slurry design guidelines are provided for systems stable to bottom-hole temperatures up to 316 degC (600 degF).

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C030	2.65	0.0453	Non Soluble	White powder
C031	2.65	0.0453	Non Soluble	White powder

15.2.Strength Retrogression

High-temperature wells present special cement system design challenges because the physical and chemical behavior of well cements changes significantly at high temperatures and pressures. Without careful modification of slurry design, the set cement may loose strength and gain permeability, potentially resulting in the loss of zonal isolation.

Portland cement is essentially a calcium silicate material. Upon the addition of water, it hydrates to form a gelatinous calcium silicate hydrate called ”C-S-H gel”, which is responsible for the strength and dimensional stability of the set cement at ordinary temperatures. In addition to C-S-H gel, a substantial amount of calcium hydroxide is liberated.

C-S-H gel is the early hydration product even at high temperatures and pressures, and is an excellent binding material at well temperatures less than about 110 degC (230 degF). At higher temperatures, C-S-H gel is subject to metamorphosis which usually results in decreased compressive strength and increased permeability of the set cement. This phenomenon is called strength retrogression.

The deterioration of the set cement is the result of a conversion of C-S-H gel to a phase called alpha dicalcium silicate hydrate (C2SH). C2SH is highly crystalline and much more dense than C-S-H gel. As a result, a shrinkage occurs which is deleterious to the integrity of the set cement which depicts the compressive strength and water permeability behavior of conventional Portland cement systems cured at 230 degC (446 degF) for up to two years. The initial compressive strength and permeability of these systems were satisfactory, but significant loss of compressive strength occurred within one month. The levels to which strength fell would be sufficient to support the casing in the well. The real problem lies in the severe permeability increases. To prevent interzonal communication, the water permeability of set cement should be no more than 0.1 mD (millidarcy). Within one month, the water permeabilities of the normal-density Class G systems were 10 to 100 times higher than the recommended limit. The permeability of the high-density Class H system was barely acceptable. Notice that the deterioration of the low-density extended cements is very severe.

15.2.1.Stabilized Systems

The strength retrogression problem can be prevented by reducing the bulk lime-to-silica ratio (C/S ratio) in the cement. To accomplish this, the Portland cement is partially replaced by ground quartz. There are two grades of ground quartz: fine silica sand (C031) and silica flour (C030).

The average particle size of C031 is about 100 µm (70 to 200 mesh). C030 has an average particle size of about 15 µm (finer than 200 mesh).

The conversion of C-S-H gel to C2SH can be prevented by the addition of at least 35 % (BWOC) C031 or C030. At this level, a mineral known as tobermorite (C5S5H5) is formed. Fortunately, high compressive strength and low water permeability are preserved. As the curing temperature increases to about 149 degC (300 degF), tobermorite normally converts to xonotlite (C6S6H) and a smaller amount of gyrolite (C6S3H) with minimal deterioration.

With a few exceptions that are discussed later, the addition of less than 35 % (BWOC) C031 or C030 can result in worse cement performance than that of systems containing no added silica.

A critical C/S ratio must be attained to form tobermorite or xonotlite. Insufficient silica will only enhance the stability of C2SH. On the other end of the spectrum, addition of more than 35 % BWOC C031 or C030 usually results in a dilution of compressive strength such as that observed with other extenders. However, at very high temperatures or in highly saline well-bore environments, addition of up to 100 % BWOC C031 or C030 can be advantageous.

15.2.2.Effects of Additives on Stabilized Systems

Silicate extenders such as flyash, bentonite, perlite, etc., can be safely used in silica-stabilized slurries up to about 232 degC (450 degF). Above 232 degC, the use of extenders other than silica (C031 or C030) is not advisable. At these temperatures, bentonite and pozzolans interfere with the chemical processes by which strong cement compounds like xonotlite are formed and maintained.

Non-reactive additives such as powdered coal do not cause cement systems to degrade at elevated temperatures. Expandable cement agents such as C515 and C509 can also be used. Additives that increase the water content of the slurry will decrease the strength and increase the permeability of a silica-stabilized cement at any temperature. This is the result of extending the cement and not of temperature degradation.

15.3.Slurry design

All cements in thermal wells will ultimately be exposed to the high temperatures of the produced fluid. Consequently, the cement used for the surface and intermediate strings must have the same care in design as the cement for the production string. The formations in geothermal wells are often porous or highly fractured. The cements for these wells are usually lightweight cements followed by a tail-in of heavier, stronger cement. Oil wells, which are subject to steam stimulation, generally use an insulating cement to reduce thermal loss to surface formations. Hot dry rock and geo-pressured wells are usually cemented with normal or weighted cements.

In deep wells, the cement slurry is exposed to high pressures, and a significant accelerating effect is observed. Earlier compressive strength development and higher ultimate compressive strength are also observed as curing pressure increases. Therefore, when designing a proper cement slurry composition in the laboratory, care must be taken to perform compressive-strength tests at the anticipated BHP.

The common assumption that high compressive strength and low permeability are automatically linked is false. Water permeability should be measured in the laboratory before a cement system is placed in a thermal well.

In general, the higher the circulating temperature, the higher the sensitivity of Portland cement systems to subtle chemical and physical differences between slurry ingredients. Therefore, all laboratory tests must be performed with samples of the water, cement and additives that will be used during the job.

15.3.1.Concentration

In most cases, about 35 % silica (C031 or C030) weight of Portland cement produces optimum properties. Additional silica is NOT added for pozzolans, extenders or weighting agents that may be present in the slurry. Some extenders such as fly ash and diatomaceous earth contain silica; when these materials are present in a Portland cement slurry, *the minimum required concentration of C031 or C030 is about 20 % BWOC. The addition of 5 % to 10 % silica often results in set cements with lower compressive strength and higher permeability than those containing no added silica.*

15.3.2.Compatibility

C031 and C030 are inert materials with respect to other additives, and are compatible with any API class of cement. The lightweight cements are stable up to 232 deg C (450 degF), but degrade at higher temperatures. While Class A and C cements are not normally used in high-temperature well cementing, they may be used in thermal projects where they will eventually be exposed to high temperatures after they have set.

15.3.1.Choosing Between C031 and C030

When C031 and C030 are used in Portland cement slurries, they have the following general effects on slurry properties:

- *Increased Water Demand:* An additional 10 % water (1.12 gal/sk) is required for C031. The finer C030 requires 12 % additional water (1.34 gal/sk).
- *Slurry Density:* The slight change in slurry weight is easily calculated.
- *Thickening Time:* The change in thickening time due to the presence of C031 or C030 is slight; however, thickening time tests should always be performed before the job. Changes in mill-runs of cements and the use of other additives may have considerable effect.
- *Rheology:* With the recommended additional water, C031 has little effect on either the viscosity or yield point. However, C030 can thicken the slurry significantly, especially in higher-density systems.

As discussed earlier, C031 and C030 are identical chemically. In most cases there are only minor differences in the properties of set cements containing C031 or C030. Initial compressive strengths may be greater when C030 is used, but C031 systems can often catch up over the long term.

In general, C031 is preferred:

- where dust would be a problem, or
- when a dense, low-water slurry is to be prepared.

C030 is preferred for :

- low-density slurries where settling might be a problem.
- Expansion Cement slurries.
- Base slurries for high-temperature foamed cements

• Salt cements containing more than 10 % sodium chloride (C505) by weight of water, and

• Slurries prepared with cements having a high Blaine fineness such as API Class C.

In high-temperature wells where concentrated brines are encountered, silica sand (C031) is not recommended. Concentrated brines inhibit the effectiveness of C031 as a stabilizer in Portland cement. Because of its fine particle size, silica flour (C030) is suitable for such wells, and should always be added in the concentration range of 35 % to 40 %.

15.1.Temperature limitation

If a cement system is required for a well with a bottom-hole static temperature greater than 399 degC (750 degF), silica-stabilized Portland cement systems are not suitable. Under these conditions it is necessary to use high-alumina cements such as Cement Fondu™ and Lumnite™.

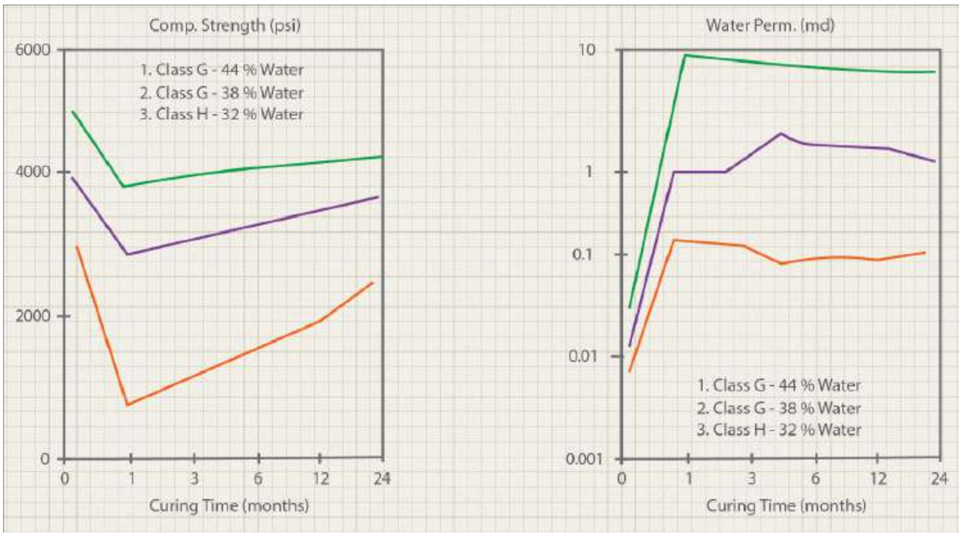


Fig Compressive strength and permeability behavior of neat Portland cement systems at 230 deg C(446 deg F)

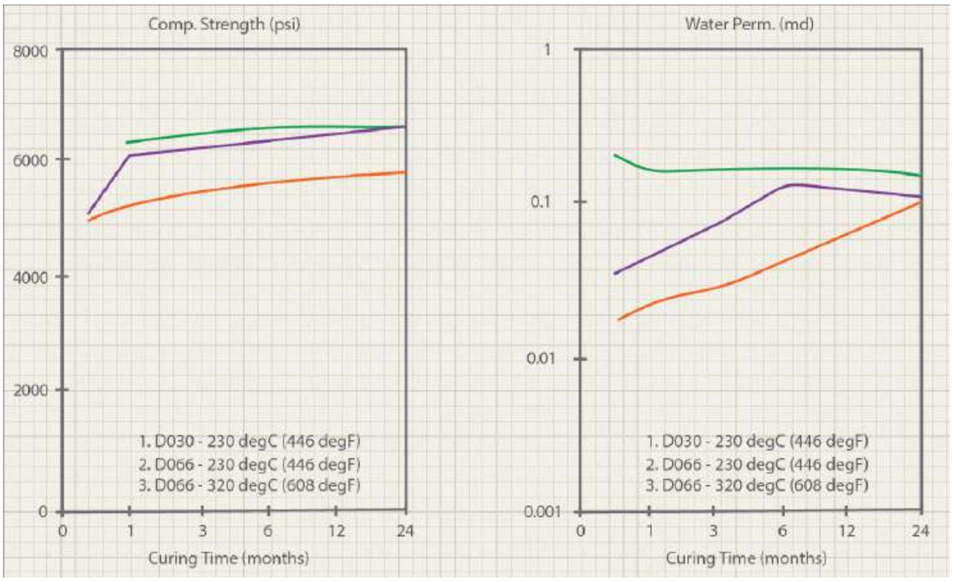


Fig.Compressive strength and permeability behavior of Portland cement stabilized with 35 % silica

16. Special Additives: C505 NaCl Salt

16.1.Summary

Sodium Chloride C505 (NaCl) is primarily used to improve bonding between the cement and the formation across massive salt and/or water-sensitive shale formations.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C505	2.16	0.0556	High	White powder

C505 has a slight accelerating effect when used at low concentrations (up to 10 % BWOW). Between 10 % and 18 % BWOW, its effect is essentially neutral, and thickening times are similar to those obtained with fresh water. Above 18 % BWOW concentration, C505 definitely has a retarding effect.

Sodium Chloride C505 can be added to the mix water or dry blended in the cement system.

16.2.Slurry design

High NaCl concentrations must be used in the slurry in the cases where a string of pipe must be set through a salt zone. A freshwater slurry in contact with a salt formation will dissolve salt from the zone as the slurry sets. This prevents a firm bond of cement to the salt. However, a slurry with C505 will remove less or no salt and will improve bonding with the zone.

The minimum C505 concentration needed for primary cement applications across salt zones is generally considered as 18 % BWOW. Concentrations up to saturation (37 % BWOW) can be used.

When cementing a zone that is sensitive to freshwater-cement filtrate, the inclusion of Sodium Chloride C505 in the slurry should be considered. Some shales contain clays that will swell and sometimes slough in the presence of freshwater filtrates.

Ideally, the C505 content of the slurry should match the salinity of the formation water to prevent swelling and/ or sloughing.

Where this is not known, a 3 % BWOW NaCl solution is used to inhibit clay swelling. For very sensitive clay formations, a low KCl concentration (less than 3 % BWOW) in the mix water has been reported to be very effective. A C505-saturated slurry will minimize the sloughing of most shales.

Studies have shown that the penetration of cement-filtrate water into a core can damage the core permeability. This seems to occur more often in ”dirty” or shaly sandstone for mations. To some degree, a 3 % BWOW NaCl slurry will inhibit the permeability damage that occurs. Fluid-loss control, as provided by Salt Saturated Slurries will also help prevent damage.

16.3.C505 influence and additive compatibility

16.3.1.Thickening Time and Compressive Strength Development

C505 in cement slurries can have either an accelerating or a retarding effect, depending on the concentration. In concentration of 10 % BWOW or less, it acts as an accelerator and improves early strength development. Above 18 %

BWOW concentration, NaCl functions as a retarder. It is not an efficient retarder at high temperatures, but C505-saturated systems (37 % BWOW) can delay strength development for long periods of time at low BHST.

For high-temperature applications, C505 is compatible with retarders C102/C103 and C108.

16.3.2.Fluid-Loss Control

C505 hampers the efficiency of most fluid-loss control additives, especially at concentrations above 18 % BWOW. The most efficient method to provide fluid-loss control in slurries with high NaCl concentrations is to use Salt Saturated Slurries.

For fluid-loss control at high temperatures, C302K and C302 has been found to be particularly useful. For FLAC C304, higher concentrations will be needed at high NaCl concentrations.

16.3.3.Rheology

NaCl has a dispersing effect on cement slurries. Slurries containing salt exhibit rheologies lower than the same slurries with no salt.

The rheology of a salt slurry can be further reduced by using a dispersant. C200 or C201 are normally used, but much higher concentrations (up to 2 % BWOC C200 or 0.5 gal/sk C201) are needed to achieve the same reduced rheology of an equivalent freshwater slurry.

Insufficient dispersant concentrations with high NaCl concentrations will result in very high slurry rheologies.

16.3.4.Expansion

C505-saturated slurries expand slightly after setting. As much as 0.1 % linear expansion has been measured after seven days. Although this expansion is small compared to Expansion Cement Systems (ECS), this property should not be overlooked as a means of cement bond improvement in standard cement systems.

16.3.5.Foaming

Slurries containing high C505 concentrations have very high foaming tendencies, especially when the NaCl is added directly to the mix water. Antifoam Agents like C010 and C012 may be used.

16.3.6.Extenders

The hydration of Bentonite C501 is adversely affected by the presence of NaCl. C505 concentrations greater than 15 % BWOW completely inhibit C501 hydration, so Attapulgite C511 must be used instead.

16.4.Slurry volume calculations

Slurry calculations for insoluble materials like cement, pozzolans, or bentonite are made easily using the absolute volume of the material. When dissolved in water, soluble materials such as sodium chloride or calcium chloride occupy a smaller volume than the absolute volume of the crystals. Once saturation is reached, the slurry volume increase is proportional to the absolute volume of the solid.

16.4.1.Properties of Sodium Chloride Solutions

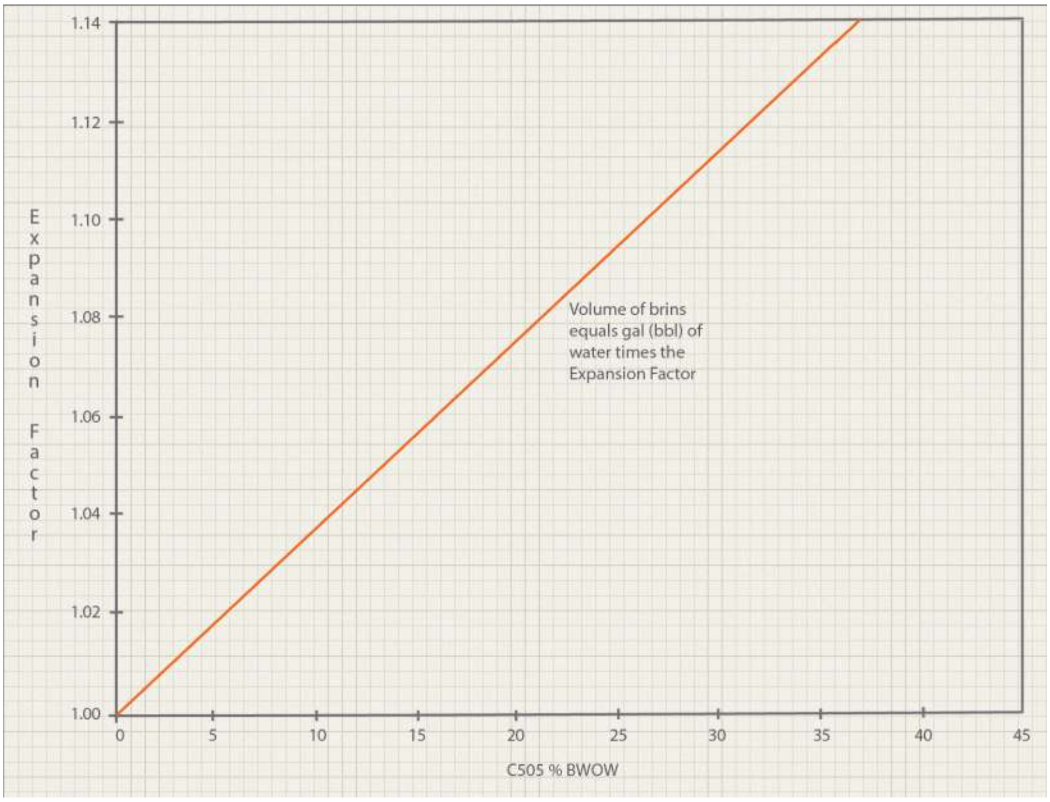
Conventional specific-gravity tables found in chemical handbooks show pounds of NaCl based on the weight of the brine or weight percentage of NaCl. It is important to realize that in cementing, the weight of C505 is based on the weight of fresh water. The handbook values do not apply, and the difference becomes quite appreciable at the higher NaCl concentrations.

The data in Table below are for slurry calculations incorporating C505. They were computed from the table of aqueous sodium chloride solutions found in Lange's Handbook of Chemistry. The term "expansion factor" equals the gallons of brine per gallon of fresh water (or liters of brine per liter of fresh water) for a given C505 concentration. From this table, the Expansion Factor vs Percent C505 by weight of fresh water (BWOW) is plotted in Figure below.

The volume of NaCl solution prepared from a known amount of C505 and a known volume of fresh water, can be calculated by multiplying the water volume by the indicated expansion factor. Because the factor is a linear relationship, it can be shown that C505 has an absolute volume of 0.0453 gal/lbm below saturation. Above saturation, the absolute volume is 0.0556 gal/ lbm, which is equal to the absolute volume of the NaCl crystal.

A C505-saturated solution contains about 37 % salt BWOW at 27 degC (80 degF). This requires 3.1 lbm of C505 per gallon of fresh water.

%C505 BWOW	Specific Gravity	Solution Density lbm/gal	Expansion Factor1 gal/gal
0	0.9966	8.316	1.000
1	1.006	8.37	1.004
2	1.012	8.419	1.008
3	1.019	8.476	1.011
4	1.025	8.525	1.015
5	1.031	8.577	1.019
6	1.037	8.63	1.022
8	1.048	8.716	1.031
10	1.06	8.817	1.038
12	1.072	8.917	1.045
14	1.084	9.016	1.052
16	1.094	9.105	1.060
18	1.105	9.193	1.068
20	1.116	9.287	1.075
22	1.127	9.372	1.083
24	1.137	9.465	1.090
26	1.148	9.548	1.098
28	1.157	9.629	1.106
30	1.168	9.718	1.113
32	1.178	9.797	1.121
34	1.188	9.884	1.128
37	1.202	9.999	1.140



16.4.1.Job Design Data

Example calculation

Find the slurry density and yield of a Class H cement mixed with 38 % water BWOC and 18 % C505 BWOW.

Constants

- Weight of one sack of cement = 94 lbm
- Absolute volume of one sack of cement = 3.59 gal
- Water density at 27 degC (80 degF) = 8.32 lbm/gal
- One cubic foot = 7.48 gal

Calculations

Weight of mix water = 38 % x 94 lbm = 35.72 lbm

Weight of mix water = 35.72 lb / 8.32 lb/gal = 4.29 gal

Weight of C505 = 18 % x 35.72 = 6.43 lbm

From Figure or Table above, the expansion for 18 % C505 BWOW is 1.068.

Note that each linear expansion unit on the graph equals 0.004

Volume of water + C505 = 4.29 gal x 1.068 = 4.58 gal

Additive	Weight (lb)	Volume (gal)
Cement	94	3.59
Water	35.72	-
C505	6.43	4.58
Total	136.15	8.17

Slurry Density = 136.15 lb / 8.17 gal = 16.7 lb/gal

Slurry Yield = 8.17 gal / 7.48 gal/ ft3 = 1.09 ft3 / sk

17. Special Additives: High Compressive Strength Agents

Compressive strength agents work based on the concept of engineered particle size packing. Proper particle size engineering provides the following benefits to a cement slurry.

- Reduced porosity and increase of SVF and therefore reduces free water and fluid loss.
- Reduced cement permeability by plugging cement pore throats thus, providing anti-gas migration properties.
- Reduces rheology due to the “ball bearing” effect caused by the size distribution of different particles.
- Increases the compressive strength of the set cement due to the increase of SVF.

Colloidal Silicates and Micro-Silicates are the primary additives used to improve the compressive strength of cement slurries. In addition to the above mentioned points, colloidal and Micro-silicates can react with calcium hydroxide (CH) during the secondary hydration period in a pozzolanic reaction and therefore, greatly improving the mechanical strength and durability of cement.

HCS Agents Summary

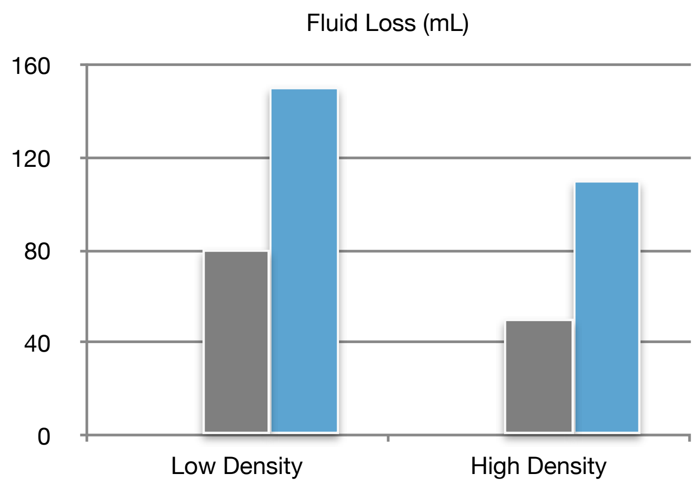
Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
C060	Microblock™	D50 particle size of 0.15 micron. Used to improve compressive strength and slurry stability. Provides Anti-migration properties. Enhances cement bonding.	Accelerates the slurry.	80 - 450	1.42
C351	Liquid HCS Agent	Nano Silicates with 525 sqm/g specific surface area. Used to improve compressive strength and slurry stability. Provides Anti-migration properties. Enhances cement bonding.	• Can lead to slurry viscosification. • Accelerates the slurry.	80 - 450	1.10

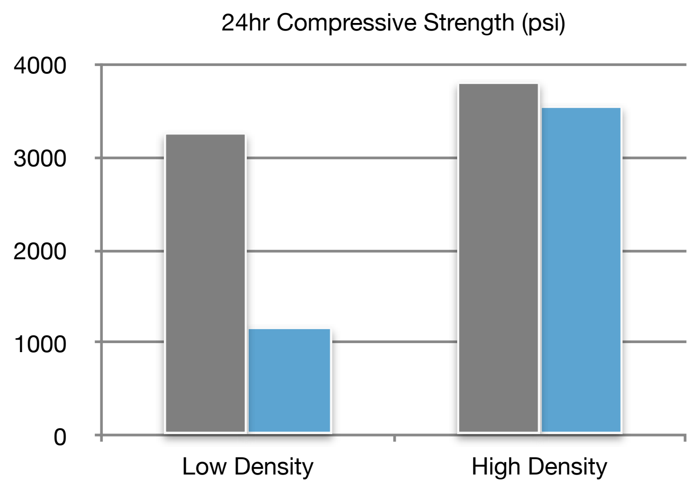
17.1.C060 Multipurpose Liquid Micro-Silica (Microblock™)

17.1.1.Principal Use

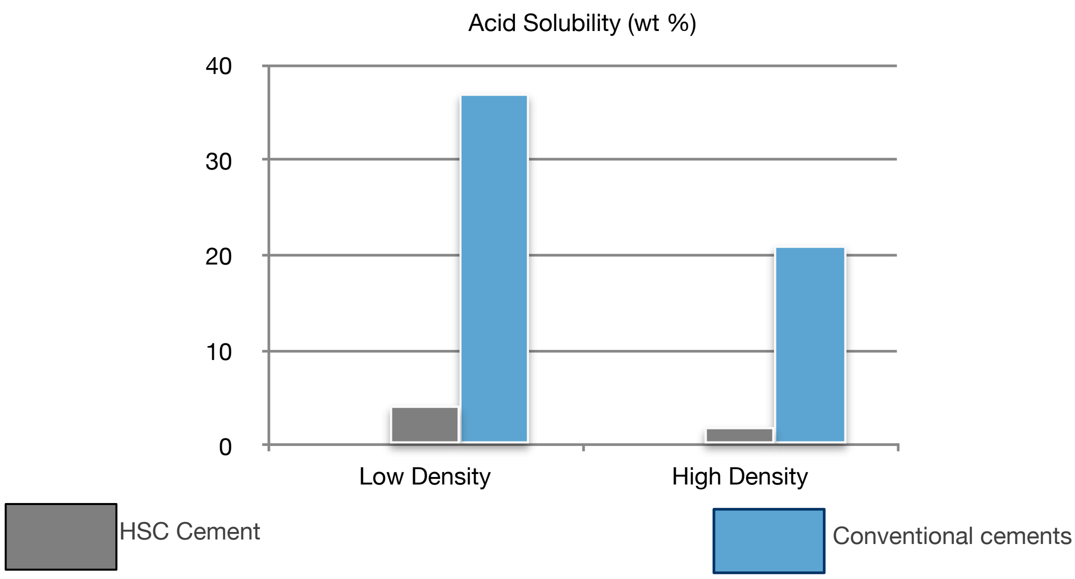
C060 is a mineral composed of ultra fine amorphous glassy spheres of silicon dioxide (SiO_2). The large surface area (21 m2/ g) and high content of amorphous silicon dioxide (89-90% Si02) give C060 superior pozzolanic properties. The micro-silica will react with the calcium hydroxide given off by cement hydration and form more of the calcium silicate hydrate (C-S-H) crystal structure that binds cement, increasing the compressive strength of the set cement. These specific particle characteristics provide C060 with a number of operational benefits such as:

- Zero free water and low fluid loss.
- Low viscosity.
- Early strength development.
- High compressive strength.





- Improved bonding.



- Stable cement slurry as low as 11.00 ppg.

- Corrosion resistance.
- It usually reacts while cement hydrates to give better strength and lower permeability.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C060	1.42	0.0844	52%	4-7	Gray Liquid

C060 increases the compressive strength of set cement more than normal API specifications. High water adsorption combined with the super pozzolanic reaction of the silicon dioxide particles (90%) enhances compressive strength.

The interstitial surface tension created by the C060 and the particle packing in the slurry aids in the suspension of other larger and heavier particles, such as densifiers and silica flour. C060 will prevent sedimentation (settling) in adverse cases such as lightweight cements and horizontal wells cementing and is used to improves performance of set cement.

Another application for C060 is as an additive for gas migration control. With its particle size and excellent suspension, it is a good matrix blocking agent. It is also used for lightweight systems to enhance performance.

17.1.2.Concentration

The usual concentration range 1–4 gal/sk. The chosen concentration must be chosen based on the desired properties (i.e., Compressive strength, free water, gas permeability ,etc…)

17.1.3.Physical Description

- Suspension of micro-silica in water.
- 89-90% amorphous silica
- Particle size 0.15 microns
- Surface Area 21 m2/g

17.2.C351 HCS Agent

17.2.1.Principal Use

The C351 HCS Agent consist of an extremely fine, amorphous non-crystalline type of silicon dioxide of a surface area of around 500 m2/gm. After further processing, C351 is produced as a liquid.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C351	1.1	0.109	15%	10	Clear Liquid

The C351 HCS agent works exceptionally well as a stabilizer, a durability enhancer, an accelerator and a strength developer. It produces extremely stable, fluid loss-free cement slurries without free water. Additionally, at higher temperatures in deep to ultra-deep well cementing applications, C351 enhances early compressive strength.

C351 Colloidal particles interact with the free lime (calcium hydroxide) – created during cement hydration – to create calcium silicate binders. These binders produce a cohesive gel structure that enhances cement density, reinforces the structure between cement grains, and eliminates free water.

Additionally, the low specific gravity of C351 produces lightweight slurries that can be injected more controllably and improves strength and shortens setting times.

The interstitial surface tension created by C351 prevents other solids, including cement particles, from settling. Even when used with other extenders (such as ceramic hollow spheres) to create ultra light weight cement, C351 will help to create high quality, homogeneous cement slurry. The C351 suspension in water is used to improve performance of set cement. It usually reacts while cement hydrates to give better strength and lower permeability.

Another application for C351 is as an additive for gas migration control where, with its particle size and excellent suspension, it is a good matrix blocking agent.

17.2.2.Concentration

A typical concentration of 0.1-0.5 gal/sk. Concentrations up to 1 gps can sometimes be used.

17.2.3.Packaging

55 Gallon Drum.

18. Special Additives: C053 Microfine Cement

18.1.Summary

SPRINT Microfine cementing system allows slurry penetration into narrow gaps without bridging or dehydrating during placement. With this technology, slurry can be injected farther into narrow slots than standard microcement allows. The slurries are resistant to acid and corrosive brine, which allows the cement to seal old perforations, even when future acid stimulations are planned. Microfine Cement has an average particle size of 10 micron vs 12-40 microns for normal class G cement, this allows it to flow in narrow gaps. Additionally, SPRINT microfine cement system eliminates the draw back of conventional class G cement slurries which induce large differential pressure resulting in increased lateral and axial fluid loss which further increases slurry viscosity. SPRINT MFC system has a Low Pv and Yp which helps maintain low placement pressures (typically < 60 cp and 5 lbf/100 sq. ft). This also ensures that the MFC does not exhibit ‘fingering’ compared to conventional class G cement systems having high Yp.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C053	2.94	0.0408	Non soluble/ Low	Grey powder

SPRINF MFC features:

- Remedial solution with pin point accuracy
- Recover the loss of zonal isolation of old wells
- Have high penetration ability
- It repairs well issues when cement won't

18.2.Application of MFC Micro Fine Cement

SPRINT MFC is typically Mixed and used in small quantities not exceeding 10 bbl. they can efficiently help curing the many of the below cases:

- Casing leaks
- Liner tops
- Old perforations
- Channels behind casing
- Fracturing
- Permeable Fracturing
- Squeezing of Gravel Pack

18.3.MFC Micro Fine Cement Slurry Design

SPRINT MFC is typically designed and mixed at a unique density of 14 ppg. GasTIGHT C303 can be added at conc. of 1.5 to 2.5 gps for improved gas tight properties. The MFC system provides an ultra thin effective filter cake of less than 5 mm.

A compressive strength as high as 3800 psi in 24 hours can be obtained. And a 2300 psi at surface temperature is common.

The MFC system can be designed for temperatures ranging from 40 to 320 degF [4 to 160 degC]. The system is also mixed and pumped using existing cement equipment without additional personnel or equipment needs.

19. Special Systems: High Solid Content Systems

19.1.Introduction

19.1.1.Summary

High Solid Content systems (HSC) technology is a method for cementing that involves the utilization of straightforward components in a slurry with reduced water content, applying principles from concrete technology to oilfield applications. The approach focuses on maximizing the packing volume fraction (PVF) within the dry blend used in slurry formulation. The characteristics of both the slurry and the resulting set cement are predominantly influenced by this PVF.

To optimize the PVF of the dry blend, a specific proportion of multiple particle sizes is employed. This strategic combination contributes to enhancing the efficiency and performance of the cementing process.

HSC systems are used for:

- Densities lower than 12.5 ppg and down to 7.5 ppg (LW & ULW)
- Densities higher than 17.0 ppg and up to 23 ppg (HW & UHW)

HSC systems allows the design of a wide range of densities while providing good cement properties:

- Good stability
- Good fluid loss control
- Technically and operationally sound rheology.
- Good compressive strength development
- Lower permeability

19.1.2.Packing Volume Fraction

In the realm of well cementing blends, the concept of Packing Volume Fraction (PVF) assumes a pivotal role in determining the efficiency and success of the cementing design. PVF refers to the proportion of space occupied by solid particles within a given volume of a dry blend used in cement slurry design.

HSC systems, utilizes PVF as a fundamental element in its cement design methodology. The primary objective is to maximize the PVF within the dry blend, improving the properties of both the slurry and the final set cement. The rationale behind this emphasis lies in the understanding that a higher PVF correlates with enhanced packing efficiency, leading to improved cement properties.

Achieving an optimal PVF involves a meticulous balance of different particles sized within the dry blend. This specific particle size distribution is carefully engineered to ensure effective packing, reducing the void spaces between particles.

A perfect arrangement of single sized particles corresponds to a PVF of 0.74 while a random packing corresponds to 0.64. By adding a second particle sized material to the blend (roughly 10 times smaller), the PVF of a perfect arrangement is increased to 0.87.

HSC systems uses an arrangement of multiple particles to achieve PVF values higher than 0.8.

The optimum composition of blends are 55% large, 35% medium, and 10% small. Small sensitivities to these percentages will still provide enhanced PVF and consequently will still provide good cement properties. Each of the particles sizes magnitudes have 8 to 12 multiplier.

19.1.3.High Solid Content Slurries Performance

High solid content slurries provides the following benefits:

- Reduced permeability, porosity and resistance to corrosive fluids.
- Disconnect water content from rheology.
- Providing good fluid loss control ability.
- The slurry and set cement properties result from the dry blend and not the water content.

19.1.4.Laboratory Testing

Variations in densities of hollow microsphere additives (C402/C403/C405/C406) can be considerable from batch to batch. It is important to check the SG of each batch using a gas pycnometer and ensure they are inserted correctly in CemDESIGN before calculating blend quantities. It is not recommended to use Lechatelier flask with blends containing materials with SG less than 1.

Mixing

- For HW and UHW, use standards API procedure.
- For LW and ULW, standard API 12,000 RPM procedure will cause hollow microspheres (C402, C403, etc…) to break. It is mandatory to mix the slurry at 4000 rpm for 5 min 30 s. This corresponds to the same mixing energy without breaking the hollow microspheres.

Bottom hole testing

- For HW and UHW, use standards API procedures.
- For LW and ULW, it is required to crush the cement slurry at the expected maximum downhole pressure for 15 min before performing rheology, fluid loss, sedimentation and free fluids tests.
- It is important to measure the slurry density after crushing and consider it in cement placement simulation software (CemPRO+).

19.1.5.Specific Gravity of Blends

The blend specfiic gravity can be calculated using the below formula:

$$SGb = \Sigma\ SGi \times Vi\ (\Sigma\ vi = 1)$$

where
SGi is the SG of each compound.
Vi is the volume fraction of each compound.

The slurry SVF (solid volume fraction) can then be calculated using the below formula:

$$SGb = [(Ds / 8.33) - 1 + SVF]/SVF$$

and accordingly,

Slurry porosity = 1 - SVF

19.1.6.Blending and QAQC

Refer to the Operation Standard Manual (SAE/TSA/OMN/005), for blending procedures and blend QAQC methods.

19.1.7.Compatibility

HSC systems are compatible with most SPRINT additives such as retarders, dispersants, FLAC, anti-settling and Salts.

19.1.8.Field Mixing

- The NRD (Non-radioactive densitometer) can be reliably used down to 10.5 ppg. Below 10.5 ppg it is recommended to use solid fraction monitors as the blend and water densities are near and therefore considerable fluctuations in the solid/ water ratio will not be detected with the NRD.
- Due to the high solid content, the cement slurry mixing maximum rate will depend on the bulk feed rate. A usual stable rate is 4 bpm.
- If a solid fraction monitor is not available, then the cement slurry must be batch mixed by careful measurement of mix water and volume.

Note: In case of batch mixing, it is important to ensure that the final slurry volume corresponds to the theoretical value. In case of blend segregation, the density can appear to reach the target value before the complete volume is mixed.

- While batch mixing, solid settling or flotation may occur at the beginning due to the high water/ solid ratio. It is important to keep a high shear rate and bring up the density as fast as possible.

19.1.9.Logging Considerations

- It is important to communicate the correct acoustic impedance of the LW and HW cement to the logging company to provide an accurate interpretation of the cement logs. The acoustic impedance can be obtained from the UCA equipment.
- When running a UCA test with LW and HW cements, it is important to select the correct mode in the DAS software. Type A mode must be used for LW and ULW systems. Type C must be used for HW and UHW systems.

19.1.10.Chemicals Storage

- Fine materials can be very reactive and sensitive to humidity. Their effectiveness tends to decrease over storage time. It is important to keep them in a dry cool place and avoid having them as slow moving chemicals.
- Always use punctured or damaged bags as soon as possible.
- Always re-tie and seal bags immediately after use.
- If storage condition is humid, add a bag of hygroscopic substance to each bag of C403 to absorb moisture.

19.2.LightWeight Systems (LW 13.0 - 9.0 ppg)

19.2.1.Additives

Code	SG	Absolute Volume (gal/lbm)	Description	Particle size	Appearance	Max Temp degF	Max Pressure psi
C402	0.75-0.85	0.1598-0.1410	Cenospheres	Large	Tan to gray powder	450	5000
C404	0.89-0.92	0.1347-0.1303	HP LW Agent	Large	White powder	300	-
C517	3.2	0.0375	Class G Cement	Medium	Grey powder	-	-
C403	0.4-0.5	0.2997-0.2398	Hollow Glass Microspheres	Medium	White powder	1149	6000
C406	0.57-0.63	0.2103-0.1903	Hollow Glass Microspheres	Medium	White powder	1149	12000
C410	2.2-2.6	0.055-0.046	Pozzolan Fly Ash	Medium	Tan to gray powder	450	-
C030	2.65	0.0453	Silica Flour	Medium	White powder	450	-
C051	2.2	0.0545	Microsilica	Small	Grey powder	185	-
C052	1.4	0.0856	Liquid Microsilica	Small	Grey liquid	185	-
C053	2.94	0.0408	Microfine Cement	Small	Grey powder	-	-
C029	2.65	0.0453	Microfine Silica	Small	White powder	450	-
C060	1.42	0.0844	Liquid Microsilica	Small	Grey liquid	185	-

19.2.2.Blend Design for LW Systems

Density lb/gal	Large Particle		Medium Particle		Small Particle	
	Additive	% BVOB	Additive	% BVOB	Additive	% BVOB
10.5 to 13.0	C402	55	C517 or C517 + C410	35	C029 or C051*	10
12.3 to 13.0 (HP application)	C404	60	C517	30	C029 or C051*	10
11.0 to 12.3 (HP application)	C404	60	C517 + C406	30	C029 or C051*	10
10.0 to 11.0 (HP application)	C404	60**	C517 + C406	30	C053	10
9.0 to 10.0 (HP application)	C404	60**	C406	30	C053	10
9.0 to 10.5	C402	50	C517 + C403	12 + 23	C053 or C051*	10 - 15

**C052 or C060 can also be used as liquid in the mix water however it must be considered that the active percentage of the liquid C052 and C060 is 52% by weight. This must be taken into consideration when performing slurry calculations on CemDESIGN.*

*** C404 must not be used above 40% BVOB against hydrocarbons bearing zones due to long term cement integrity issues.*

19.2.3.Strength Retrogression

A normal LW cement using C402 as large size material has already a sufficiently high total silica content. Hence C030 is not required when using C402 systems above 110 degC [230 degF]. Tests have shown that there are no observed difference in strength retrogression when C030 is added to a LW system compared to when both C402 and C029/C051/C052/C060 are part of the blend. For high pressure LW systems containing C404, if the BHST exceeds 230 degF then C029 must be used to replace the small material and C030 can partially replace C517 so that the total silica content is at a concentration of 35% BWOC.

19.3.Ultra LightWeight Systems (LW 9.0 - 7.5 ppg)

19.3.1.Additives

Code	SG	Absolute Volume (gal/ lbm)	Description	Particle size	Appearance	Max Temp degF	Max Pressure psi
C402	0.75-0.85	0.1598-0.1410	Cenospheres	Coarse	Tan to gray powder	450	5000
C404	0.89-0.92	0.1347-0.1303	HP LW Agent	Large	White powder	300	-
C517	3.2	0.0375	Class G Cement	Medium	Grey powder	-	-
C403	0.4-0.5	0.2997-0.2398	Hollow Glass Microspheres	Medium	White powder	1149	6000
C030	2.65	0.0453	Silica Flour	Medium	White powder	450	-
C053	2.94	0.0408	Microfine Cement	Fine	Grey powder	450	-
C029	2.65	0.0453	Microfine Silica	Fine	White powder	450	-

19.3.2.Blend Design for ULW Systems

Density lb/gal	Large Particle		Medium Particle		Small Particle	
	Additive	% BVOB	Additive	% BVOB	Additive	% BVOB
9.0 to 8.0	C402	55	C403	30	C029 or C053	15
Below 8.0			C517 + C403	8 - 12 + 80 - 85	C053	8 - 12 (Up to 24% if C517 is not used)
Below 9.0 (HP application)	C404	60*	C406	30	C053	10

** C404 must not be used above 40% BVOB against hydrocarbons bearing zones due to long term cement integrity issues.*

19.3.3.Strength Retrogression

It is highly unlikely to exceed 230 degF with ULW cements due to the C402 and C403 BHP limitations. However, in such cases C029 must be added at a concentration of 35% BWOC. For high pressure ULW systems containing C404, if the BHST exceeds 230 degF then C029 must be used at a concentration of 35% BWOC.

19.4.HeavyWeight Systems (HW 16.0 to 17.5 ppg)

19.4.1.Additives

Code	SG	Absolute Volume (gal/lbm)	Description	Particle size	Appearance	Max Temp degF
C031	2.65	0.0453	Silica Sand	Large	White powder	450
C517	3.2	0.0375	Class G Cement	Medium	Grey powder	-
C030	2.65	0.0453	Silica Flour	Medium	White powder	450
C029	2.65	0.0453	Microfine Silica	Small	White powder	450
C055	2.12-2.3	0.0666-0.0499	Micro Fly Ash	Small	Light grey or tan	450

19.4.2.Blend Design for HW Systems

Density lb/gal	Large Particle		Medium Particle		Small Material	
	Additive	% BVOB	Additive	% BVOB	Additive	% BVOB
16.0 - 17.5	C031	50-60	C517 or C517 + C030	30-40	C029 or C055	5-15

19.4.3.Strength Retrogression

Due to the high silica content present in C029 and C031 in the HW system, the system can be used above 230 degF BHST. For high BHST, always ensure that C029 + C031 = 35 %BWOC.

19.5. Ultra HeavyWeight Systems (UHW above 17.5 ppg)

19.5.1. Additives

Code	SG	Absolute Volume (gal/lbm)	Description	Particle size	Appearance	Max Temp degF
C530	5.1	0.0235	Hematite	Large	Dark red to black	-
C031	2.65	0.0453	Silica Sand	Large	White powder	450
C517	3.2	0.0375	Class G Cement	Medium	Grey powder	-
C030	2.65	0.0453	Silica Flour	Medium	White powder	450
C053	2.94	0.0408	Microfine Cement	Small	Grey powder	450
C507	4.95	0.0243	Micromax	Small	Dark red	-

19.5.2. Blend Design for UHW Systems

Density lb/gal	Large Particle		Medium Particle		Small Particle	
	Additive	% BVOB	Additive	% BVOB	Additive	% BVOB
17.5 to 23.0	C031 + C530	50-60	C517 or C517 + C030	25-40	C029 or C053	5-15
Above 23.0	C530	50-60	C517 or C517 + C030	25-35	C507* or C053	10-15

**C507 can be added to the mix fluid directly.*

19.5.3. Strength Retrogression

C030 must be added at a concentration of 35% BWOC above 230 degF BHST.

20. Special Systems: GasTIGHT Systems

20.1.Introduction to Gas Migration

Annular gas migration has three distinct root causes:

- The hydrostatic pressure in the annulus falls to a level that is less than or equal to the pore pressure of a gas bearing zone.
- Space in the annulus allows gas entry.
- A path is present in the annulus through which the gas can migrate.

All three root causes must be satisfied for annular gas migration to take place. The root causes involve various factors inherent to the cementing process.

SPRINT uses a matrix of assessment to determine the anti-gas migration slurry requirement for short- and long-term isolation.

- For short term slurry requirement, CemPRO+ is used to calculate the gas flow potential at specified depths (For instance, the user will consider the gas flow potential at the bottom and top of the gas bearing zone) and accordingly, determine the slurry properties and testing requirement according to the level of severity.
- For long term slurry requirement, CEMLIFE is used to predict the cement failure mapping to identify slurry mechanical properties requirement and accordingly the cement slurry system to be used.

20.2.Short Term Cement Requirement

The gas flow potential number (ranging from zero to infinity) is calculated by CemPRO+ and then classified as per the below table.

Gas Flow Potential (GFP)	Severity Rating
< 4	Minor
4 to 8	Moderate
> 8	Severe

Depending on the level of severity, the slurry test requirements is established. For instance, severe cases will require additional testing such as shorter critical hydration period and a shorter strength development period. Below are the different criteria used by SPRINT to validate an anti-migration slurry for a specific application.

20.2.1.Fluid Loss Criterion

For all GFP severity ratings, the fluid loss value for an anti-migration slurry must be below 50 ml / 30 min API.

A slurry with high fluid loss values can directly promote gas migration due to:

- Reduction of volume and therefore an associated reduction of the hydrostatic head during cement gelation.
- Increased gelation effects due to reduced water content

- Annular bridging can restrict the transmission of hydrostatic pressure.

20.2.2.Free Fluid Criterion

Although not heavily influential in vertical wells, a free fluid of 0 ml must be ensured for all severity ratings especially for deviated sections.

20.2.3.Cement Shrinkage Criterion

For all severity ratings, a cement shrinkage test must be conducted to ensure no cement shrinkage and thus not allowing a gap for the gas to travel up the annular section.

20.2.4.Pressure Decay Limit Parameter Criterion, PDLP

CemPRO+ provides the user with a critical gel strength vs depth chart. Shall the lowest critical gel strength across the gas zone fall into one of the below PDLP ranges, the corresponding test requirement shall be considered.

PDLP (lbf/100ft2)	Severity Rating
0-50	Very critical
50-150	Critical
150-300	High
300-500	Moderate
>500	Low

The cement slurry must be tested in a static gel strength analyzer (SGSA and in MGSA in moderate and above cases) and must show a critical hydration period (time taken from when the slurry reaches PDLP until 500 lb./100 ft2) of:

- less than 45 min for minor and moderate severity, and
- less than 30 min for high and above cases.

20.2.1.Gas Migration Analyzer Testing

For all GFP greater than 4 (moderate and high severity rating), a gas migration analyzer (Cement Hydration Analyzer CHA) test must be performed.

A gel strength development test is typically run within the test to determine the critical hydration period over which the gas migration test will run.

20.2.2.Cement Coverage

In addition to slurry testing requirements, a mud removal requirement must be achieved while designing the cement job. CemPRO+ provides a 3D displacement efficiency representation of the wellbore. A safe cementing design can then be performed to ensure a good mud removal above the gas zone.

- For all GFP less then 8 (minor and moderate severity rating), it is mandatory to have a minimum of 50 meter of 80% minimum cement coverage above the top of the gas zone.
- And for GFP greater than 8 (high severity rating), it is mandatory to have a minimum of 50 meter of 100% cement coverage above the top of the gas zone.

20.3.Long Term Cement Requirement

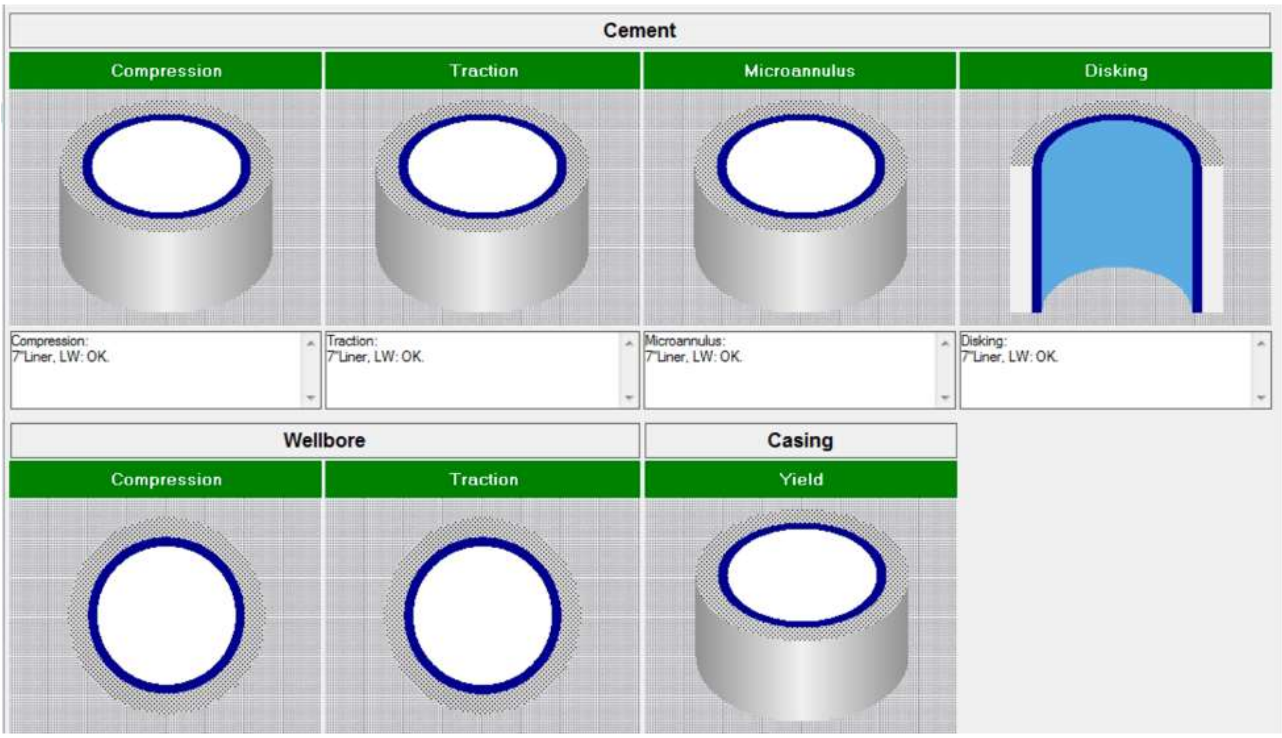
As the wellbore is exposed to pressure and temperature cycles during its life, cement integrity can be compromised due to debonding, compression or tensile failure. Thus, causing gas migration concerns.

SPRINT uses CemLIFE software to predict set cement behavior. This allows to adjust the mechanical and chemical properties of the cement to mitigate failure. The software takes into the following consideration into account:

- Cement, formation, and pipe mechanical and thermal properties.
- Cement expansion.
- Standoff
- Initial state stresses
- Tectonic stresses and orientation
- Wellbore geometry
- Pressure and temperature change profile and duration (Sudden or linear over time)

SPRINT standards mandate the following criteria to be used when simulating any pressure and temperature cycles across cemented gas bearing zone in CemLIFE:

- A maximum micro-annulus limit of 10 micrometers.
- The maximum Mohr-Coulomb stresses shall not exceed 80% of the cement and formation’s respective compressive strengths.
- The maximum axial stresses shall not exceed 80% of the cement and formation’s respective tensile strength (No traction failure).
- The maximum tangential stress shall not exceed 80% of the cement’s tensile strength (No disking).
- The maximum von mises stress shall not exceed 80% of the casing’s yield pressure.



20.4.C303 GasTIGHT Latex Systems for moderate and High Severity

20.4.1.Summary

Latex systems were developed to improve zonal isolation through improved bonding. They improve the cement-to-pipe and cement-to-formation bonds by their fluid-loss control and adhesion properties. Further more, their extremely low permeability when set prevents any fluid movement behind the casing.

Latex systems can be used at BHCT up to 250 degF when C303 is used alone and up to 400 degF with C020 latex stabilizer, provided they can be properly retarded. They can be mixed at slurry densities ranging from 8 lbm/gal to 23 lbm/gal. Fresh water or seawater can be used for mixing. Other water should be tested in the laboratory first since Latex systems can tolerate only a limited amount of salt (especially Magnesium and Calcium).

Whenever a moderate or severe gas migration problem is foreseen, GAS-TIGHT Latex Systems must be used. They should satisfy all requirements set in sections Short Term Cement Requirement and Long Term Cement Requirement. Additional the appropriate minimum concentration must be used in this case and is calculated using CemDESIGN.

20.4.2.Slurry Design

The sealing and bonding capabilities of Latex systems are derived from three intrinsic properties: adhesion, increased solids content, and elasticity when hard.

Latexes are aqueous dispersions of solid polymer particles, including surfactants and protective colloids, which impart stability to the dispersion. Most latexes have film-forming capabilities; thus, when contacted by a gas, or when the particle concentration exceeds a given threshold value, latex particles coalesce to form an impermeable polymer barrier. In a wellbore, the gas first invades the portion of the cemented annulus across the gas zone and contacts the dispersed latex particles in the slurry. The latex coalesces within the pore spaces, blocking further progress up the annulus.

20.4.3.Cement Slurry Composition

Latex systems are primarily composed of neat or certain extended cements, the GASTIGHT Additive C303, Dispersants C200 or C204, Antifoam Agents C010 or C012 and mix water. Retarders, accelerators and weighting agents can be incorporated as required. Above 110 degC [230 degF], Silica Flour C030 or Cement Silica C031 must be included to prevent strength retrogression in conventional cement slurries.

20.4.4.Mix Water

Latex systems are best mixed with fresh water or seawater. Low amounts of salt can be tolerated in the mix water, but their maximum admissible concentration depends on the temperature of application, particularly for Magnesium and Calcium salts. Consequently, any doubtful salt water should be tested in the laboratory prior to field use.

20.4.5.Slurry Density

Any type of unretarded Portland cement (Classes A, B, C, G and H) mixed at their normal density can be used for preparing Latex slurries.

Latex slurries above 14.2 lbm/gal

Latex slurries are easily designed at densities down to 14.2 lbm/gal simply using C514 to keep the slurry homogeneous and prevent the cement particles from settling. In addition to offering logistics advantages, it also helps the mud removal process in making this slurry more viscous than the spacer.

Pozzolan or fly ash cement in latex slurries

For lower densities, blends of Portland cement with Pozzolan or fly ash are the preferred conventional extenders for densities down to 13.0 lbm/gal. Latex additives MUST NOT be used with C501 Bentonite, C400 Sodium Silicate or C051/052 Micro-Silica extenders.

LW and ULW systems

Latex slurries can be designed with additives such as C402 and C403 to obtain LW and ULW GasTIGHT slurries. The only limitation can be an increase in rheologies which can induce additional BHP pressures and therefore rendering the benefits of an ULW slurry

Barite C504 and hematite C500 in latex slurries

Barite C504 is the preferred conventional weighting agent up to 18 lbm/gal. Between 18 lbm/gal and 20 lbm/gal, hematite C500 and Micromax C507 can be used provided the free fluid developed by the slurry is reasonable (less than 3 %). The free-water problem in this case is related to the particle size of the weighting agent, the coarsest material resulting in the highest free fluid. If the maximum particle size is below 100 microns, free fluid should normally be controllable.

20.4.6.Concentration of Additives

GASTIGHT additive C303

The C303 concentration essentially depends on the slurry density and on the type of extender/weighting agent used. It is optimized only on the basis of fluid-loss control. Usually the C303 quantity required to obtain a fluid loss of less than 100 mL/30 min at BHCT will also achieve the other properties of the Latex slurry (improved bonding and low permeability). Normally, this concentration does not depend on the temperature for BHCT below 102 degC [215 degF]. Above this temperature, the C303 concentration sometimes may have to be increased slightly, especially if C102/C103 are used as the retarder.

It is not recommended to use C303 at the threshold concentration, since a slight variation in slurry density can lead to poor fluid-loss control. Therefore, 0.1 gal/sk more than the threshold concentration is preferred.

The minimum concentration of C303 to ensure the anti-migration properties of a latex GasTIGHT system MUST be calculated using the CemDESIGN. A lower concentration is not guaranteed to prevent gas percolation into the cement matrix during the cement gelation phase.

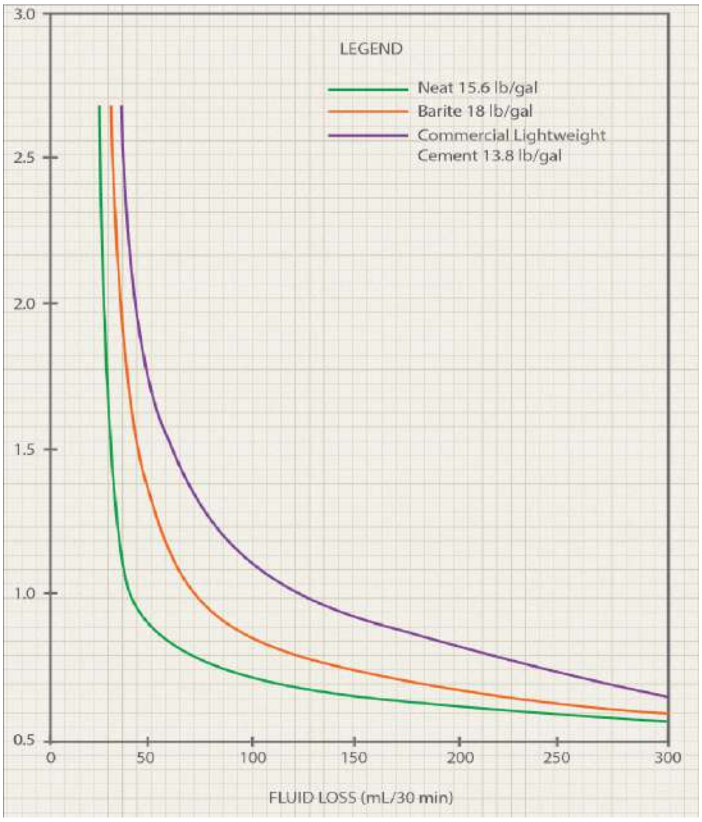


Fig. API fluid-loss at 85degC(185degF)

Antifoam agent concentration

C010 is the recommended cost-effective antifoam agent for use in Latex slurries containing less than 2 % salt BWOW. The required amount of Liquid Antifoam Agent C010 is 0.05 gal/sk.

Antifoam agent should be added to the mix water before adding any other additives.

Retarders

Any retarder can be used to adjust the thickening time.

Accelerators

At low temperatures (below 49 degC [120 degF]), Latex slurries can be accelerated with seawater, C505 (maximum concentration 6 % BWOW) or with C013 (maximum concentration 1 % BWOC).

Latex shelf life

The shelf life of our latex additives is normally 12 months from the date of manufacture. When not stored in the sun and not exposed to more than three freeze/thaw cycles, C303 is stable for at least one year.

When not properly stored, a thick skin at the top of the drums may be observed. This layer has a higher concentration of latex particles due to a slight evaporation that occurs at the air/liquid interface, even in a closed drum.

It is important to keep latex away from freezing conditions as could lead to liquid viscosification and difficulties during mixing.

20.5.C302K GasTIGHT Systems for Low Severity

20.5.1.Summary

C302K GasTIGHT systems can be used at BHCT up to 356 degF. They can be mixed at slurry densities ranging from 8 lbm/gal to 23 lbm/gal. Fresh water or up to salt saturated water can be used for mixing.

Whenever a low gas migration flow potential is foreseen, C302K GAS-TIGHT Systems can be used. They should satisfy all low severity requirements set in sections Short Term Cement Requirement and Long Term Cement Requirement.

20.5.2.Slurry Design

C302K contains water soluble polymers that viscosify the interstitial water of the cement slurry. Because at least a part of gas migration involves the displacement of cement pore water, viscosification of the water tends to limit gas mobility. This approach is also appropriate for fluid-loss control.

20.5.3.Cement Slurry Composition

C302K GasTIGHT systems are primarily composed of neat or certain LW/extended cements, the GASTIGHT Additive C302K, Dispersants C200 or C204, Antifoam/ Defoamer Agents C010, C011 or C012 and mix water. Retarders, accelerators and weighting agents can be incorporated as required. Above 110 degC [230 degF], Silica Flour C030 or Cement Silica C031 must be included to prevent strength retrogression in conventional cement slurries.

20.5.4.Mix Water

C302K systems are best mixed with fresh water or seawater. Although C302K has a high salt tolerance, higher amounts of salt in the mix water will require higher concentrations of C302K.

20.5.5.Slurry Density

C302K can be used from 8 ppg slurries up to 23 ppg. Gelation problems have been encountered with UHW systems in this case the use of C302 instead has been found to be more suitable.

20.5.6.Concentration of Additives

GAS-TIGHT additive C302K

The appropriate concentration will be determined based on the concentration required to achieve a fluid loss below 50 ml/30 min API and ideally a value of 25 ml/30 min API should be achieved.

Antifoam agent concentration

C010, C011 and C012 can be used. The required amount of Liquid Antifoam Agent is 0.02 gal/sk. Antifoam agent should be added to the mix water before adding any other additives.

Retarders

Any retarder can be used to adjust the thickening time.

Accelerators

C302K is compatible with C013 and C505 although higher concentrations of C302K might be required.

20.5.7.Design Examples

Conventional 15.8 ppg GasTIGHT at 104 degF

Density (ppg)	15.8 (1.9SG)	Yield cu,ft/sk	1.164
Mix Water (g/sk)	5.057	Mix Fluid (g/sk)	5.18
Porosity	58%	Batch Mix Time	45 min

Sprint Code	Description	Batch #	Unit	Conc.	Lab concentration	for 1 bbl
C517	Cement Class G	2021-29	sx	1.00	776.38 gm	4.825 sx
C011	Defoamer	1861332203	gps	0.02	1.38 ml	0.096 gal
C302K	GasTight Additive	20190315	%BWOC	0.60	4.66 gm	2.721 lb
C200	Dispersant	2102168	%BWOC	0.70	5.43 gm	3.175 lb
C102	Retarder	BC102-1220-01	%BWOC	0.025	0.19 gm	0.113 lb
H2O					348.59 ml	0.581 bbl

Temperature (degF)	BHCT
Pressure (psi)	1000
API ml/30 min	48
Consistency	**Time (hr:min)**
30 BC	3:15
70 BC	3:30
Time (hr:min)	**Strength (psi)**
12:00	2250
24:00	2970
Rheology	
Pv	110.24
Ty	10.15

11.0 ppg LW GasTIGHT at 104 degF

Density (ppg)	11.0 (1.32 SG)	Yield cu,ft/sk	2.634
Mix Water (g/sk)	9.179	Mix Fluid (g/sk)	9.73
Porosity	49%	Batch Mix Time	60 min

Sprint Code	Description	Batch #	Unit	Conc.	Lab concentration	for 1 bbl
Blend	LW Blend	LW-0621-01	Lb/bbl	100	489.79 gm	287.581 lb
C011	Defoamer	1861332203	gps	0.02	0.61 ml	0.043 gal
C302K	GasTight Additive	20190315	%BWOC	0.40	1.37 gm	0.802 lb
C200	Dispersant	2102168	%BWOC	1.20	4.12 gm	2.405 lb
C351	HCS Agent	VIZA02/126M	gps	0.40	12.18 ml	0.853 gal
H2O					279.58 ml	0.466 bbl

Temperature (degF)	BHCT
Pressure (psi)	1000
API ml/30 min	48
Consistency	**Time (hr:min)**
30 BC	4:07
70 BC	4:36
Time (hr:min)	**Strength (psi)**
12:00	1115
24:00	1850
Rheology	
Pv	114.43
Ty	11.48

9.00 ppg ULW GasTIGHT at 106 degF

Density (ppg)	9.00 (1.08 SG)	Yield cu,ft/sk	6.833
Mix Water (g/sk)	23.386	Mix Fluid (g/sk)	24.25
Porosity	47%	Batch Mix Time	60 min

Sprint Code	Description	Batch #	Unit	Conc.	Lab concentration	for 1 bbl
C517	Cement Class G	2021-47	sx	1.00	132.22 gm	0.822 sx
C053	Microfine Cement	MS-C1801ZEQ0421	%BWOC	45	59.50 gm	34.756 lb
C402	Cenosphere	CS16965VP0319	%BWOC	100	132.22 gm	77.236 lb
C403	HGMS	SZB20170513	%BWOC	28	37.02 gm	21.626 lb
C011	Defoamer	DF4266947130921	gps	0.02	0.23 ml	0.016 gal
C302K	GasTight Additive	FLC20190315	%BWOC	2.00	2.64 gm	1.545 lb
C200	Dispersant	AUB-2102168	%BWOC	1.10	1.45 gm	0.850 lb
C351	HCS Agent	VIZA02-126M	gps	0.60	7.04 ml	0.493 gal
H2O					274.53 ml	0.458 bbl

Temperature (degF)	BHCT
Pressure (psi)	1000
API ml/30 min	46
Consistency	**Time (hr:min)**
30 BC	4:25
70 BC	4:47
Time (hr:min)	**Strength (psi)**
12:00	235
24:00	594
48:00	1371
Rheology	
Pv	101.11
Ty	12.20
Static Gel Strength	
100-500 lbs/100ft2	22 min

20.6.C303N GasTIGHT Systems for Low Severity

20.6.1.Summary

C303N GasTIGHT systems can be used at BHCT up to 400 degF. They can be mixed at slurry densities ranging from 8 lbm/gal to 23 lbm/gal. Fresh water or up to salt saturated water can be used for mixing.

Whenever a low gas migration flow potential is foreseen, C303N GAS-TIGHT Systems can be used. They should satisfy all low severity requirements set in sections Short Term Cement Requirement and Long Term Cement Requirement.

20.6.2.Slurry Design

C303N is a liquid, anionic, grafted-polymer solution. It is a cement fluid loss additive which provides highly effective fluid loss control, particularly at temperatures above 200°F (90°C). C303N may be used in a variety of cement slurry systems due to its dispersible characteristic that imparts a very low rheology. In addition, C303N may be used as a gas migration control additive due to its excellent fluid loss control.

20.6.3.Cement Slurry Composition

C303N GasTIGHT systems are primarily composed of neat or certain LW/ extended cements, the GASTIGHT Additive C302N, Dispersants C200 or C204, Antifoam/ Defoamer Agents C010, C011 or C012 and mix water. Retarders, accelerators and weighting agents can be incorporated as required. Above 110 degC [230 degF], Silica Flour C030 or Cement Silica C031 must be included to prevent strength retrogression in conventional cement slurries.

20.6.4.Mix Water

C30N systems are best mixed with fresh water or seawater. Salt concentrations can be used up to salt saturation.

20.6.5.Slurry Density

C303N can be used from 8 ppg slurries up to 23 ppg. Due to C303N dispersing nature, care must be taken to ensure no settling with LW and HW systems.

20.6.6.Concentration of Additives

GASTIGHT additive C303N

The appropriate concentration will be determined based on the concentration required to achieve a fluid loss below 50 ml/30 min API and ideally a value of 25 ml/30 min API should be achieved. A typical concentration of 0.3 gps will usually achieve the required fluid loss value.

Antifoam agent concentration

C010, C011 and C012 can be used. The required amount of Liquid Antifoam Agent is 0.02 gal/sk. Antifoam agent should be added to the mix water before adding any other additives.

Retarders

Any retarder can be used to adjust the thickening time.

Dispersant

C303N exhibits a dispersing nature and therefore lesser amounts of C200/ C204 are required relative to other GasTIGHT systems.

20.6.7.Design Examples

Conventional 15.8 ppg GasTIGHT at 95 degF

Density (ppg)	15.8 (1.9SG)	Yield cu,ft/sk	1.164
Mix Water (g/sk)	4.765	Mix Fluid (g/sk)	5.18
Porosity	59%	Batch Mix Time	30 min

Sprint Code	Description	Batch #	Unit	Conc.	Lab conc.	for 1 bbl
C517	Cement Class G	1603-2020	sx	1.00	776.31 gm	4.824 sx
C011	Defoamer	1861332203	gps	0.02	1.38 ml	0.096 gal
C300	FLAC	20170808	%BWOC	0.10	0.78 gm	0.453 lb
C200	Dispersant	1905142	%BWOC	0.40	3.11 gm	1.814 lb
C303N	Gas Migration Control Additive	GV8F1644A1	gps	0.25	17.23 ml	1.206 gal
C351	HCS Agent	B 10 19/0005	gps	0.10	6.89 ml	0.482 gal
C102	Retarder	1909065	%BWOC	0.10	0.78 gm	0.453 lb
H2O					328.38 ml	0.547 bbl

Temperature (degF)	BHCT
Pressure (psi)	1000
API ml/30 min	46
Consistency	**Time (hr:min)**
30 BC	4:08
70 BC	4:20
Time (hr:min)	**Strength (psi)**
12:00	1853
24:00	3012
Rheology	
Pv	89.07
Ty	8.65

11.0 ppg LW GasTIGHT at 95 degF

Density (ppg)	11.0 (1.32 SG)	Yield cu,ft/sk	2.661
Mix Water (g/sk)	8.946	Mix Fluid (g/sk)	9.87
Porosity	49%	Batch Mix Time	30 min

Sprint Code	Description	Batch #	Unit	Conc.	Lab conc.	For 1 bbl
C517	Cement Class G	1603-2020	sx	1.00	339.56 gm	2.110 sx
C402	Cenosphere	4190541	%BWOC	44.5	151.11gm	88.266 lb
C011	Defoamer	1861332203	gps	0.02	0.60 ml	0.042 gal
C300	FLAC	20190728	%BWOC	0.20	0.68 gm	0.397 lb
C200	Dispersant	1905142	%BWOC	0.90	3.06 gm	1.785 lb
C303N	Gas Migration Control Additive	GV8F1644A1	gps	0.30	9.04 ml	0.633 gal
C351	HCS Agent	B 10 19/0005	gps	0.50	15.07 ml	1.055 gal
C102	Retarder	1909065	%BWOC	0.15	0.51 gm	0.298 lb
H2O					269.69 ml	0.449 bbl

Temperature (degF)	BHCT
Pressure (psi)	1000
API ml/30 min	49
Consistency	**Time (hr:min)**
30 BC	4:40
70 BC	5:00
Time (hr:min)	**Strength (psi)**
12:00	1178
24:00	1735
Rheology	
Pv	107.18
Ty	7.89

21. Special Systems: CemFLEX & FiberCEM Systems

21.1.C090 CemFLEX Systems

21.1.1.Principal Use

Neat set cements are highly brittle materials which means as soon as the onset of cement failure is reached, macro-cracks may propagate in an unstable manner leading to the destruction of the cement sheath. Neat set cements do not have the appropriate mechanical behavior when the cement sheath is submitted to severe static and dynamic stresses. These stresses can result from the milling, cutting and drilling operations necessary to complete the construction of lateral branches of a multilateral well.

The addition of C090 CemFLEX in the cement slurry improves significantly the mechanical behavior of the set cement in terms of impact resistance, fracture toughness and to a lesser extent tensile strength. The consequence is that CemFLEX system is much harder to drill than any other cement system mixed at the same density which makes of CemFLEX an ideal cement system for kickoff operations.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C090	7.2	0.0166	Non Soluble	Metalic fibers 1 x 5 mm

C090 CemFLEX system is a cement system that exhibits drastically improved mechanical properties in terms of resistance to impact and fracture toughness when compared to conventional cement systems. This is achieved through the post-addition of C090 CemFLEX to very specific base slurries. The aforementioned base slurry MUST be batch mixed.

The unique mechanical characteristics of CemFLEX technology make it the product to recommend for kicking off in hard to very hard formations. CemFLEX technology is the appropriate solution in cases where the set cement is submitted to severe dynamic stresses created by drilling, milling and cutting operations.

The C090 CemFLEX uses the same reinforcement technique as the Sprint's FiberCEM to render the set cement more resitant to impact and improve its long term integrity. However, Sprint CemFLEX additive has a much higher level of shock and tensile strength resistance beside, its strong bonding effect with the cement when compared to FiberCEM. C090 CemFLEX technology can be added to the FiberCEM slurry to improve slurry impact and shock resistance properties and meanwhile combat lost circulation.

The CemFLEX cement technology can be added to any one of the following base slurries:

- CemROCK base slurry.
- Class G cement with suspending agent base slurry.
- Class G FiberCEM base slurry.

The CemROCK base slurry is still considered as the most reliable and the first recommended option for CemFLEX cement applications. The two others are proposed as a complementary solution in case where additional well condition might dictate there use such as lost circulation, lower formation toughness, etc.... Each type of base slurry must comply with specific requirements for suspending the C090 throughout the operation and be qualified as CemFLEX base slurry. No exemption to those requirements can be allowed.

The C090 CemFLEX provide the set cement with the "toughness" needed for cement plug placed in the wellbore to side-track above or to initiate directional drilling operation. The CemFLEX system prevents fissures propagation ensuring the cohesion of the cement sheath even at high deformation (very good post-cracking behavior). Also different tests performed to evaluate the "drillability" of such system have shown that CemFLEX cement is much harder to drill than any other non-reinforced cement.

Note:

Compressive strength is not significantly affected by the addition of C090. However, the drill-ability is as the resistance to failure of the cement matrix when drilling and its toughness are much improved in CemFLEX cement system.

Base slurry should exhibit sufficient compressive strength to ensure that cement systems are inherently strong enough before the addition of C090. Base slurry formulation should ensure fast development of strength under downhole conditions.

21.2.Important Operation Considerations:

- CemFLEX slurry is not commercial for applications other than cement plugs.
- Never pump a slurry containing C090 CemFLEX through restrictions with dimensions less than 18 mm (0.7 in)
- CemFLEX cement slurries are exclusively batch-mixed
- Never take sample of slurry containing C090 CemFLEX using the small sampling ball valves of a blender, batch tank or of a re-circulating mixer. Sample the slurry exclusively from the top of the tank.
- If a fresh water wash is to be used ahead of the CemFLEX slurry then, a viscosified pad spacer should be pumped directly ahead of and behind the CemFLEX slurry in order to prevent dilution of the slurry with consequent fall out of the CemFLEX at the fluid interface. The rheological requirements on the base cement slurry should also be applied to the spacer.
- After having injected CemFLEX cement slurry inside the drill pipe do not halt pumping unless absolutely necessary. Static conditions increase the opportunity for settling of the CemFLEX.

21.2.1.Concentration

Because C090 CemFLEX is chemically inert, CemFLEX cement can be formulated with all base slurries mentioned above with density ranging from 15.8 lb/gal to 25 lb/gal (1,895 kg/m3 to 3,000 kg/m3).

C090 CemFLEX is typically added at concentration from 30-35 lbm/bbl (85 kg/m3 to 100 kg/m3) of slurry.

The principal requirement for the base slurry is to obtain specific rheological properties that provide effective and efficient carrying capacity for the CemFLEX.

21.2.2.CemROCK or Class G With Suspending Agent Base Slurries

A stable CemROCK slurry has enough solids to normally suspend the C090 CemFLEX provided that its rheology at BHCT further meets the following specification:

- Shear Stress (not reading) at 3-rpm or 10-sec gel strength (not reading) higher than 16 lbf/100ft2 (7.7 Pa) , and

- Yield Stress higher than 10 lbf/100ft2 (4.8 Pa) as calculated using the Herschel- Bulkley's model assuming readings affected by slippage at the wall are eliminated.

In case of class G cement with suspending agent, such a rheological requirement is always and systematically obtained, whatever the well and slurry test temperature, by using 0.5 % BWOC C514 anti-settling agent. This provides for a robust system that tolerates changes and variations in retarder and dispersant concentrations without affecting the stability of the CemFLEX cement (with C090).

Sometimes, depending on the other additives in the base slurry, a concentration of C514 slightly lower or higher than 0.5 % BWOC may be used, provided that the rheological requirements are met and slurry stability at BHCT confirmed through a Slurry Sedimentation test.

Table : CemROCK Base Slurry Design

Property	Value
Temperature, degF	160
Density of the base slurry, lb/gal	17
Density of the final slurry, lb/gal	17.6
Cement Class G, % BVOB	40
C031 Silica Sand, % BVOB	50
C051 Micro Silica, % BVOB	10
C011 Defoamer, gal/sk of blend	0.01
C305 FLAC, %BWOB	0.15
C200 Dispersant, %BWOB	0.2
C102 Retarder, %BWOB	0.1
C090 CemFLEX, lbm/bbl of slurry	35
Rheology after mixing at ambient temperature and before addition of C090 CemFLEX	
Plastic Viscosity (cP)	158
Yield Point (Ty)	18
10 Sec Gel Strength	16
Rheology after conditioning (30min) and before C090 addition	
Plastic Viscosity (cP)	169
Yield Point (Ty)	22
10 Sec Gel Strength	19
Thickening time, 100 Bc (hr:mn)	4:35
API Free Fluid, (ml)	0

Table: Class G with Suspending Agent Base Slurry designs

Property	Value Test 1	Value Test 2
Temperature, degF	200	220
Density of the base slurry, lb/gal	16	16.5
Density of the final slurry, lb/gal	16.58	17.08
C305 FLAC, %BWOC	0.25	0.1
C514 Anti Settling Agent, % BWOC	0.5	0.4
C011 Defoamer, gal/sk of Cement	0.02	0.02
C104 Retarder, %BWOC	0.18	0.22
C090 CemFLEX, lbm/bbl of slurry	35	35
Rheology after mixing at ambient temperature and before addition of C090 CemFLEX		
Plastic Viscosity (cP)	120	165
Yield Point (Ty)	20	21
10 Sec Gel Strength	18	19
Rheology after conditioning (30min) and before C090 micro-ribbons addition		
Plastic Viscosity (cP)	135	172
Yield Point (Ty)	28.27	27
10 Sec Gel Strength	22	24
Thickening time, 100 Bc (hr:mn)	5:28	4:56
API Free Fluid, (ml)	0	0

21.2.3.FiberCEM System

FiberCEM class G slurry mixed at a density of 15.8 lbm/gal (1,895 kg/m3) or higher can make acceptable CemFLEX base slurries provided:

- The slurry is well dispersed and is sufficiently fluid.
- The slurry is stable at BHCT, i.e., no sedimentation of the cement (or density difference between top and bottom of test specimen) is apparent in the sedimentation test.
- C080 fibers are added to provide effective suspension of the C090 CemFLEX

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
C080	0.91	0.1334	Non Soluble	Off white fibers 5-10 mm x 2 mm

The recommended concentration of C080 fibers for CemFLEX slurry design is 0.9 lbm/bbl (2.5 kg/m3). This recommended concentration is the minimum at which C090 CemFLEX are effectively suspended while mixing, while pumping as well as in static conditions, provided the original base slurry is already stable. At this concentration of C080 fibers, our equipment is capable to mix and pump such slurry combined with C090 CemFLEX.

Table : FiberCEM Base Slurry Designs

Property	Value Test 1	Value Test 2
Temperature, degF	150	180
Density of the base slurry, lb/gal	15.8	17
Density of the final slurry, lb/gal	16.5	17.6
C300 FLAC, %BWOC	0.4	0.2
C200 Dispersant, % BWOC	0.45	0.4
C011 Defoamer, gal/sk	0.02	0.02
C102 Retarder, %BWOC	0.18	0.24
C080 Fiber, lbm/bbl of slurry	0.9	0.6
C090 CemFLEX, lbm/bbl of slurry	35	35
Rheology after mixing at ambient temperature and before addition of C090 CemFLEX		
Plastic Viscosity (cP)	85	95
Yield Point (Ty)	13	8
10 Sec Gel Strength	11	7
Rheology after conditioning (30min) and before C090 CemFLEX addition		
Plastic Viscosity (cP)	95	102
Yield Point (Ty)	19	16
10 Sec Gel Strength	17	15
Thickening time, 100 Bc (hr:mn)	6:10	5:40
API Free Fluid, (ml)	0	0

21.2.4.Mechanical Properties of the Set Cement

It is very important to understand that when comparing a CemFLEX system to another cement system for Kick-Off Plug operations compressive strength is not the key parameters to concentrate on. What makes CemFLEX system an ideal candidate for such operation is not its compressive strength but its resistance to impacts and its toughness. Unfortunately these two properties cannot be measured in the laboratory using standard cementing equipment and procedures.

The physical and mechanical properties of CemFLEX system are compared to those of the base slurry under the same curing conditions. The measurements include impact resistance, flexural strength, compressive strength and drill-ability. At the end of the curing period, the samples are always kept under water until the measurement is made.

The tests performed showed:

- increase in the resistance to impact by almost a factor of 10,
- increase in flexural strength,
- increase in energy to rupture by at least a factor 1.5,
- prevention of fissure propagation ensuring a cohesion of the cement sheath even at high deformation,

- compressive strength is not much affected by the presence of C090 CemFLEX, and
- considerable improvement in “drillability”. It was demonstrated that CemFLEX cement system is much harder to drill than a non ferroconcrete cement system

21.2.5.Drilling Resistance of CemFLEX Cement System

Yard test where set cements containing or not C090 CemFLEX were drilled with Tricone bit and PDC bit have demonstrated that in the same drilling conditions (bit RPM, WOB...), the ROP is 2 to 3 times lower with C090 CemFLEX at a concentration of 25 lbm/bbl of slurry (70 kg/m3). CemFLEX cement system is much harder to drill than non-reinforced cement.

22. Special Systems: CemMAX Systems

The key objective of primary cementing is to maintain the zonal isolation throughout the lifetime of the well. It has been observed in some situations that the cement was properly placed and provided a good initial hydraulic seal, however, the zonal isolation quality degraded with time. The loss of zonal isolation has been attributed to several reasons including; development of micro-annulus, cement-to-casing decoupling, cement-to-formation decoupling, hydraulic fracturing leading to cement cracks, or cement cracks developed due to exposure to extreme downhole temperature or stresses.

The studies conducted over-time revealed that the changes in downhole conditions can induce stresses that destroys the integrity of the cement sheath. Any damage to the cement sheath shall allow the free flow of the formation hydrocarbons from one zone to another and may significantly compromise well integrity. The cement sheath failure under stress conditions can be associated with the relatively high fluid pressures and temperatures inside the casing during testing, perforating, hydraulic fracturing, or fluid production. Also, other stress condition can result from the tectonic movement of the formation. These stresses, when exerted on the set cement, can lead to the cement sheath failure in the form of radial circumferential cracking of the cement matrix or the de-bonding of cement.

The detailed analysis of the mechanisms leading to failure of the cement sheath revealed that the risk of failure is directly linked to the tensile strength of the set cement and is attenuated when the ratio of tensile strength to Young's modulus is increased.

The Young's modulus usually characterizes the flexibility of material thus, to increase the tensile strength to Young's modulus ratio, the set cement should have a low Young's modulus. Consequently, the industry has recognized the requirement to design a flexible and resilient cement system that has low Young's modulus so that it can withstand the outlined stresses. For any given situation the stresses generated in the cement sheath will be lower for a system that has a lower Young's modulus, thus the risk of failure of a system with a lower Young's modulus is decreased.

SPRINT CemMAX systems have been developed to improve the mechanical properties of the set cement. The mechanical properties are optimized to meet the challenging stresses in the well-bore. These systems offer excellent flexibility and chemical resistance while maintaining lower permeability and good compressive strength. These properties enable the CemMAX systems to resist the stresses and maintain long-term zonal isolation.

These systems also offer the solution to cure the cement sheath failure by introducing the self-healing additives which have a swelling tendency when comes in contact with the hydrocarbon. Hence the fluid migration path can be eliminated without well intervention.

22.1.Cement Sheath Failure Modes

We can avoid the failure of cement sheath over the lifetime of the well by analyzing the different modes of failure. The stresses induced in the well-bore can cause the following types of cement sheath failure:

- Failure in traction and discing (leading to tensile cracking in the cement)
- Failure in compression (leading to the destruction of the cement matrix)
- Cement de-bonding (micro-annulus) from the casing and/or the formation (leading to micro-annulus).

22.1.1.Traction Failure

Cement fails in traction whenever the tensile stresses, generated in the set cement, exceed the tensile strength. This kind of failure is typical for well-bore pressure or temperature increases, when the formation is soft (low Young's Modulus) and/or the cement is rigid (high Young's Modulus).

A pressure increase inside the well-bore has the effect of pushing the casing outwards. In the situations where the surrounding medium is soft, the rock is not rigid enough to contain the push, thus the casing and cement sheath expand outwards. This expansion involves deformation of the cement sheath as it increases in diameter.

Such deformation would stretch the cement creating tensile tangential stresses. A Portland cement has a much higher resistance to failure in compression than in tension. In these circumstances, the cement frequently fails under the tensile stress, showing radial cracks that extend vertically along the well-bore.

Temperature increases will also produce an outward expansion of the casing due to thermal dilation. In situations where the surrounding medium is soft, this expansion may create tensile cracks in the cement.

22.1.2. Failure Under Compression

Cement fails in compression whenever the Mohr-Coulomb Stress generated in the set cement, exceeds the compressive strength. This kind of failure is typical for well-bore pressure and/or temperature increases, when the formation is rigid (high Young's Modulus), or when the cement sheath is present between two casings.

Due to pressure increase inside the well-bore, the casing will be pushed outwards. In the situations where the surrounding medium is hard, the rock is rigid enough to prevent any expansion movement in the radial direction, so the cement sheath becomes squeezed between the casing and the formation. Similarly, when the cement is placed between two casings, then the external casing would be sufficiently rigid to prevent any expansion when the pressure will be increased. Thus, the cement sheath becomes squeezed between the two casings. In these circumstances, the push creates compressive stresses in the cement. If the compressive stresses exceed the cement Mohr Coulomb failure criteria, a failure in compression occurs.

The temperature increase will also produce the effect of pushing the casing outwards, due to thermal dilation. In the situations where the surrounding medium is hard, this push may lead to cement failure in compression.

22.1.3.Cement Debonding (Micro-Annulus)

Micro-annulus occurs when the cement sheath loses its bond with the casing and/or the formation. Micro-annulus typically occurs when there is a pressure decrease or temperature decrease in the well-bore.

A pressure or temperature decrease inside the well-bore has the effect of contracting the casing inwards. If the bond at the casing/cement interface is weak, the casing detaches from the cement, creating a gap.

The properties of set cement are optimized over short or long periods of time by running mechanical and thermal analysis on the CEMLife software module. CEMLife analyzes 3 types of failure modes (traction, compression, micro-annulus) under various temperature conditions and pressure changes. It determines the mechanical properties that the set cement must have to withstand the stresses generated by the changes in downhole conditions. CEMLife software also estimates the size of any micro-annuli that might be formed. The temperature and pressure change cycle along with the mechanical properties (Young's modulus, Poisson's ratio, compressive strength, and tensile strength) of cement, casing, and formation are required as an input to the software.

Once the required properties are known the blend can be designed to meet both the density and the set cement mechanical property requirements.

22.1.4.Design Standards

SPRINT standards mandate the following criteria to be used when simulating any pressure and temperature cycles across cemented gas bearing zone in CemLIFE:

- A maximum micro-annulus limit of 10 micrometers.
- The maximum Mohr-Coulomb stresses shall not exceed 80% of the cement and formation's respective compressive strengths.
- The maximum axial stresses shall not exceed 80% of the cement and formation's respective tensile strength (No traction failure).
- The maximum tangential stress shall not exceed 80% of the cement's tensile strength (No disking).
- The maximum von mises stress shall not exceed 80% of the casing's yield pressure.

22.1.5.Classifications of CemMAX Systems

CemMAX cement systems help ensure lifetime zonal isolation by providing an integral cement sheath that does not degrade throughout life of the well. The systems provide a competent annular pressure seal that prevents hydrocarbon leaks and protects against Sustained Casing Pressure (SCP). They create an effective cement sheath that bonds to the formation and the casing, effectively sealing oil, gas, or water from the well-bore.

These systems use flexible additives to decrease the Young's modulus of the set cement. CemMAX systems may also contain additives to provide expansion of the set cement to minimize the occurrence of micro-annuli. The combination of flexible and expansive additives are used to produce a Flexible Expansive Cement System. Also, swelling additives can be incorporated in the slurry design which will swell when comes in contact with hydrocarbon. It will eliminate the fluid migration path in the set cement thereby ensuring the integrity of cement sheath throughout the life of the well.

Hence CemMAX Systems offer a complete solution to keep the cement sheath integral after the initial cement placement and until the well abandonment. It must be noted that the CemMAX Systems cannot be an alternative to the best practices required during the cement placement.

Based upon their characteristics, the CemMAX Systems are classified in the following sub-systems:

- CemFLEX-R (Flexible Cement System)
- CemEX (Expansive Cement System)
- CemSEAL (Expandable CemFLEX-R System i.e., Flexible Expanding Cement System)
- CemHEAL (Self-Healing Cement System)

We will discuss them in details in the following sub-sections.

22.2.CemFLEX-R Flexible Cement System

SPRINT CemFLEX-R flexible cement system is designed to modify the mechanical properties of the set cement. The flexible particles are added in the slurry to improve its elasticity and ductility. The degree of flexibility can be controlled by the concentration of flexible additive added to the mixture. The stress modeling is performed using the CEMLife software to assess the cement sheath integrity in different modes. Accordingly the slurry shall be designed to achieve the required modulus of elasticity and compressive strength that provides the cement sheath integrity.

Code	SG	Absolute Volume (gal/lbm)	Percentage Activity	pH	Appearance
C303	1.02	0.1162	58%	7.02	Milky white liquid
C310	1.5	0.0799	-	-	Black Powder
C404	0.89-0.92	0.1347-0.1303	-	-	White powder

The flexible particles should meet the following properties:

- Young's modulus: They should be made of a material having Young's modulus of less than 5000 MPa, preferably less than 3000 MPa. The elasticity of the materials selected for these flexible particles should be at least four times greater than that of cement and more than thirteen times that of the silica usually used in oil well cement.
- Average particle size: The average particle size of the flexible particles should be in the range of 100 microns to 400 microns and must not exceed 500 microns. Additionally, they should be isotropic in nature.
- Density: The density of these particles should be around 1.0 SG.
- Solubility: The flexible particles must be insoluble in aqueous medium including saline waters.

Some examples of the materials which satisfy the various criteria cited above are thermoplastics (polyamide, polypropylene, polyethylene etc.) or other polymers such as styrene-divinyl benzene or styrene butadiene.

The flexible properties in CemFLEX-R system are achieved either by the use of C303 Liquid Latex Additive, C310 Crumb Rubber Particles, C404 or the combination of both. We can identify the correct flexible additive based upon the required slurry properties.

22.2.1.C303 Latex

The C303 latex additive is a fine particulate material, therefore, it offers following additional benefits:

- Good compressive strength of the cement system
- Effective cement bonding with casing and formation
- Promote the right angle set properties of the set cement which leads to improved zonal isolation

22.2.2.C310 Flexible Particles

The C310 crumb rubbers are large particles having a D50 of around 150 microns,

CemFLEX-R system can be designed by using these rubber particles for a slurry density up to 17.0 ppg. However, for the higher slurry densities, the utilization of rubber particles only will reduce the slurry ability to achieve the required density. In this case, it is recommended to include C303 latex as well in the slurry design which will also help achieving higher compressive strength and cement bonding.

It must also be noted that the high slurry density makes the required Young's modulus value difficult to achieve while keeping the compressive strength of the slurry at acceptable levels. This is due to the less concentration of cement in the HW blend of the CemFLEX-R system. C310 is thermally stable until 300 degF. Degradation of mechanical properties might be observed towards the high end temperature.

22.2.3.C404 Lightweight Flexible Particle

One of the key advantages of incorporating C404 into well cements is its low density. C404 is inherently lightweight, significantly reducing the overall density of the cement slurry. This characteristic is particularly advantageous when a LW flexible cement is required. By incorporating C404 into the cement matrix, the resulting material exhibits improved flexibility and resilience. C404 is used up to 230 degF

22.2.4.CemFLEX-R Blend Design

The blend design for the CemFLEX-R System is based on the optimized particle packing concept. The mechanical properties of the CemFLEX-R system are controlled by the flexible material, HW, material/LW material and cement blend used and by the solid volume fraction (SVF) used for the slurry design. The mechanical properties are also affected by the bottom hole static temperature (BHST) of the well.

The CemFLEX-R blend is designed for any given slurry density using three different materials as follows:

- Cementitious Particles are used at concentrations from 30 % to 40 % by volume of the blend (BVOB).
- HW, LW and Flexible Particles are used at concentrations from 40 % to 55 % by volume of the blend (BVOB). The large particles fraction should contain at least 20% by volume of blend (BVOB) flexible particles.
- Other Particles are used at concentrations of 10 % to 20 % by volume of the blend (BVOB).

22.2.5.Mechanical Properties of CemFLEX-R

The mechanical properties of a CemFLEX-R system are determined by several parameters:

- Flexible particle concentration – the higher the concentration the lower will be Young's modulus and more flexible would the system be. The flexible particle concentration should be between 20 % BVOB and 55 % BVOB. A minimum concentration of 20 % BVOB is required to give a measurable decrease in Young's modulus.
- Cement type and concentration – the higher the concentration of cement the higher will be Young's modulus. It must be noted that the higher concentration of cement will lead to higher compressive strength as well as Young's modulus. Therefore, it is recommended to keep the cement concentration between 30% and 35% BVOB when using Class G or Class H cement. Below this concentration, the compressive strength may be insufficient and above this concentration, Young's modulus may be too high.
- Solid Volume Fraction – the higher the SVF the higher will be Young's modulus. The SVF of CemFLEX-R systems is typically chosen between 55% and 60%.
- Bottom-hole Static Temperature (BHST) – for bottom-hole static temperatures higher than 110°C (230°F), at least 35% BWOC silica must be added to prevent strength retrogression.

- Density requirement – the blend options are limited by the density of slurry. The CemFLEX-R system with a medium Young's modulus (< 4,000 MPa) can be designed for densities up to around 15 lb/gal using Class G Cement. However, above this density, it becomes difficult to meet the density requirements, whilst keeping the system flexible. At higher densities, the requirement to have enough cement to provide sufficient compressive strength and significant concentrations of weighting agent to control density leads to systems with Young's moduli > 4,000 MPa. Although these systems will still have a lower Young's modulus than conventional cement systems, Young's modulus may not be sufficiently low to prevent cement failure in all cases. In these extreme cases, it is recommended to use systems designed with C053 MFC as discussed below.

22.2.1.CemFLEX-R System With C053 MicroFine Cement

CemFLEX-R Systems designed with C053 Microfine Cement are used when high density and low Young's modulus systems are required. The usage of C053 Microfine Cement offers the following advantages:

- Lower concentrations of C053 Microfine Cement can be used, compared with class G cement, to provide sufficient compressive strength. The lower cement concentration leads to a system with a lower Young's modulus.
- C500 Hematite can be used as the medium sized particle in the CemFLEX-R design. The smaller size of the C500 makes it easier to stabilize.
- As the weighting agent C500 is predominantly the medium sized particle, coarser flexible particles can be used for a given density leading to design a system with a lower Young's modulus.

22.2.2.Effect of Blend on Mechanical Properties

The composition of CemFLEX-R blend has significant effect on the mechanical properties of set cement. The table below presents three different blend designs for a 15.6 lbm/gal density slurry with same SVF.

<table>
<tr><th></th><th>Design 1</th><th>Design 2</th><th>Design 3</th></tr>
<tr><td>C517 Class G Cement, % BVOB</td><td>30</td><td>30</td><td>40</td></tr>
<tr><td>C051 Microsilica, % BVOB</td><td colspan="3">15</td></tr>
<tr><td>C310 Flexible Particles, % BVOB</td><td>30</td><td>41.5</td><td>30</td></tr>
<tr><td>C530 Coarse Hematite, % BVOB</td><td>5</td><td>13.5</td><td>3</td></tr>
<tr><td>C032 Silica Sand, % BVOB</td><td>20</td><td>-</td><td>12</td></tr>
<tr><td>SVF, %</td><td colspan="3">60</td></tr>
<tr><td>Density (lbm / gal)</td><td colspan="3">15.6</td></tr>
<tr><td>Young's Modulus (MPa)</td><td>3,400</td><td>2,300</td><td>4,300</td></tr>
</table>

Design 1 is the base design with coarse hematite and coarse sand used to control density. It is observed in design 2 that using the coarse hematite only to allow a larger volume of flexible particles will reduce Young's modulus. On the other hand, if we increase the cement concentration while keeping the concentration of flexible particle same, then Young's modulus will be increased. Therefore, design 3 has the highest Young's modulus of the three designs due to the high concentration of cement.

It is always recommended to increase density by increasing the weighing agent concentration.

22.3.CemEX Expansive Cement System

CemEX is SPRINT's expansive cement system designed to induce expansion in the cement and to improve its sealing against the casing and the formation. This expansion prevents micro-annuli formation and reduces the potential of fluid migration along the casing annulus. Thereby, improving the primary cementing results and promoting zonal isolation after the cement is set and throughout the early life of the well.

C603 and C605 are mid and high temperature expansion additives used in the formulation of the CemEX cement system. Both additives induce expansion in the early life of the set cement. The extent of the expansion depends on ;

- the concentration of the expansion additive,
- the CemEX blend design,
- the solid volume fraction (SVF) of the blend, and
- the bottom-hole static temperature (BHST).

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C603	3.35	0.0357	Low/ Insoluble	Tan powder
C605	3.19	0.0375	Low/ Insoluble	Brown powder

22.3.1.Mechanism Of Micro-Annulus Formation

One of the main causes of the loss of zonal isolation is the formation of micro-annuli. An inner micro-annulus between the casing and the cement can be created by the radial displacement of the casing resulting from the decrease of temperature or/and pressure in the well-bore (either due to the change in mud weight or surface pressures after the cement is set). Also, an outer micro-annulus between the cement and the previous casing and/or the formation can be generated due to the cement bulk shrinkage.

This micro-annuli can decrease the well efficiency due to fluid and gas migration to the surface or to other zones. It might also allow the intrusion of formation water which may cause higher pipe corrosion, scale build-up, increased disposal cost, pollution problems, and uneconomical production.

The formation of micro-annuli can be avoided by using C603 or C605 expansion additives. Both additives have been specifically designed to prevent post-setting cement shrinkage and improve bonding between the cement/formation and cement/casing with time as the expansion takes place.

In an oil well cementing, there are two micro-annuli cases to consider; 1) one when the radial displacement of the casing occurs prior to the cement expanding and 2) the other when the displacement occurs after the expansion has ended. The latter case, may occur for an intermediate casing, when the mud weight is decreased during the drilling and cementing of a subsequent casing (perhaps several weeks after the intermediate casing has been cemented).

22.3.2.Effect of Cement young's Modulus on the Ability of Expansion to Close Microannulus

Consider a case where the mud weight is decreased to drill the next section after the completion of the cementing job. Let's also assume that a micro-annulus of 38 microns was generated by this decrease in pressure and that the Young's modulus of the surrounding formation was 7,000 MPa.

The figure below shows the effect of cement Young's modulus on the ability of CemEX cement expansion to close this micro-annulus.

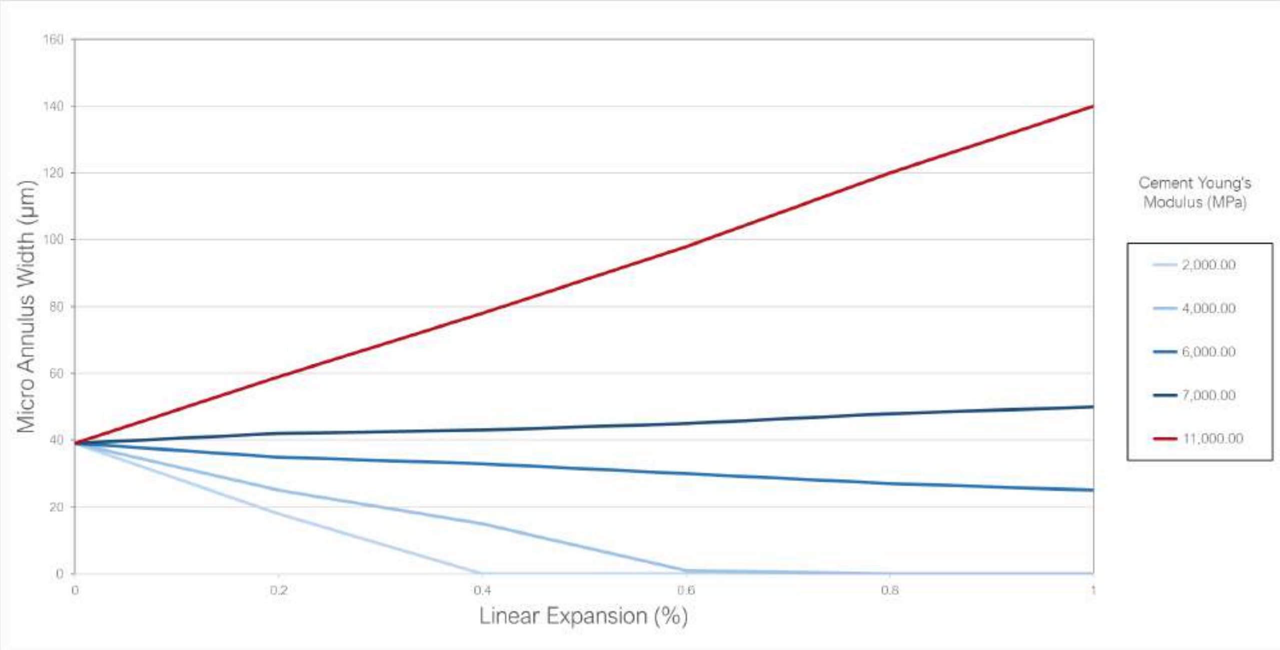


Fig-Effect of Cement Young's modulus on the ability of expansion

In the figure, we have plotted the size of the micro-annulus as a function of the amount of linear expansion and of Young's modulus of the cement. It is clear from the graph that:

- When the cement Young's modulus is much lower than the rock Young's modulus, the linear expansion required to close the micro-annulus would be less. This is because cement, in this case, will be more flexible than the surrounding formation, therefore, more of the expansion will be directed inwards and closing the micro-annulus.
- When the cement Young's modulus is close to that of the surrounding formation Young's modulus, the amount of linear expansion is ineffective to close the micro-annulus.
- When the cement Young's modulus is higher than the surrounding formation Young's modulus, the micro-annulus increases in size as it is easier for the cement to expand outwards and deform the rock than to expand inwards and deform itself. This outwards deformation of rock will lead to an increase of micro-annulus.

Therefore it can be concluded that Flexible Expanding Cement System will work best in hard rock formations (formations having Young's modulus higher than the cement), which are able to constrain the expansion forces of the expanding cement. As a result, the cement expansion can be directed inward and a good hydraulic seal is achieved on both sides of the cement sheath (casing and formation). In such case, the cement must always be more elastic (have a lower Young's modulus) than the surrounding rock to ensure good bonding to the inner casing.

22.3.3.MT Expansion Additive C603

C603 expansion additive is SPRINT's cement expansion additive used with Portland cement in primary casing/liner jobs and in remedial cementing. It is a dry, yellow, free flowing inorganic powder that helps the elimination of micro-annulus and gives expansive stress property to the Portland cement.

The C603 cement expansion has been verified in slurries at temperatures up to 170°F. It also provides good bonding between the formation and the casing provided that an effective mud displacement is achieved.

The C603 expansive agent is designed to produce most of its expansive effect after the cement is set. While the cement is still liquid, C603 does not induce any expansion or alter the properties of the cement slurry.

Furthermore, for practical reasons, it will often be desirable that the expansion in the set cement be limited to a maximum of 2% under the temperature and other conditions to which the cement is exposed. The C603 induced expansion should allow a maximum increase of 1.1 to 1.5 times the original radial stress level in the set cement.

Concentration: C603 is normally premixed with the Portland cement and its normal concentration varies from 5 to 30 percent by weight of cement. The C603 expansion properties are measured using a special strain-gauged expansion cell. Expansion has been verified in slurries at temperatures up to 170°F. Other cement properties such as thickening time, compressive strength, free water) can be measured using conventional API cement tests.

22.3.4.HT Expansion Additive C605

C605 is a high-temperature expansion additive that can help eliminate fluid intrusion and gas migration during cementing. These problems are often caused by the formation of micro-annuli in the cement column due to poor cement bonding. The C605 applicable temperature range is 200°F to 400°F. The addition of C605 into the cement slurry provides multiple benefits. Some of these benefited are listed below:

- Provides early expansion of the set cement
- Provides improved bonding for better zone isolation
- Prevents cement volume losses due to shrinkage
- Reduces pipe corrosion and scale build-up due to migrating formation water
- Helps prevent the formation of micro-annuli
- Provides a positive seal to the pipe and formation
- Helps prevent gas migration in the well-bore
- Helps prevent costly squeeze work
- Helps prevent water cutting of oil and gas
- Compatible with all API classes of cement and other additives
- Has little effect on viscosity or thickening time

Furthermore, for practical reasons, it will often be desirable that the expansion in the set cement be limited to a maximum of 2% under the temperature and other conditions to which the cement is exposed. The C603 induced expansion should allow a maximum increase of 1.1 to 1.5 times the original radial stress level in the set cement.

Concentration : C605 is normally added to the mix-fluid and the normal concentration of C605 varies from 1 to 10 percent by weight of cement. The C605 expansion properties are measured using a special strain-gauged expansion cell. Expansion has been verified in slurries at temperatures up to 400°F. Other cement properties such as thickening time, compressive strength, free water) can be measured using conventional API cement tests.

C605 is not reactive below 200°F/93°C, it strictly should not be used below this temperature.

22.3.5.Measurement of Linear Expansion of Cement

The linear expansion of the cement matrix can be measured using the annular expansion molds and should be checked under actual well conditions for each slurry design. The measurements must be carried out up to the point where a plateau is reached or at least the expansion curve has a downward curvature. The linear expansion of the cement, as measured in these cells under static downhole conditions, must not exceed 2 %.

Equipment:

The linear expansion properties of the cement slurries are measured using annular expansion molds. A mold consists of a:

- bottom plate,
- a split expandable ring with two attached pins and
- a top plate.

The expandable ring is placed between the two plates. When the cement sets and expands, the diameter of the expandable ring will expand and the distance between the attached pins will increase.

Procedure:

- The test slurry is poured into the large hole in the top plate of the mold. It must be noted that the mold should be fully filled.
- Tap the mold while filling the slurry. Keep on pouring the slurry until excess slurry exits the small hole of the top plate.
- After filling the mold, place it in either a water bath or in a pressurized curing chamber.
- Once the cell is filled, the initial distance (L_1) between the two pins on the split expandable ring is measured with a micrometer as a zero-reading.
- After curing the mold, the distance (L_2) between the two pins is measured with the micrometer.
- Calculate the linear expansion with the following formula: EXP_{LIN} (%) = 100 x (L_2 – L_1) / (3.1416 x D) where,
- EXP_{LIN} (%) is the linear expansion of the cement slurry measured in percentage
- L_1 is the micrometer measurement before test curing (zero-reading)
- L_2 is the micrometer measurement after curing
- D is the inner diameter of the expandable ring

22.3.6.Slurry Designs for CemEX System

The slurry design for an Expansive Cement System depends on the following items.

Concentration of the expansion additive

The concentration of C603 and C605 is expressed as % BWOC. The typical concentration range varies from;

• C603: 5 to 30 percent by weight of cement

• C605: 1 to 10 percent by weight of cement

For conventional systems around 15.8 lbm/gal density, the typical concentration of C603 is around 5 % BWOC . However, it must be remembered that for other systems the concentrations may be significantly different. For conventional extended systems the required concentration will be higher as there will be less cement in the system and more expansion agent will be required due to the lower SVF.

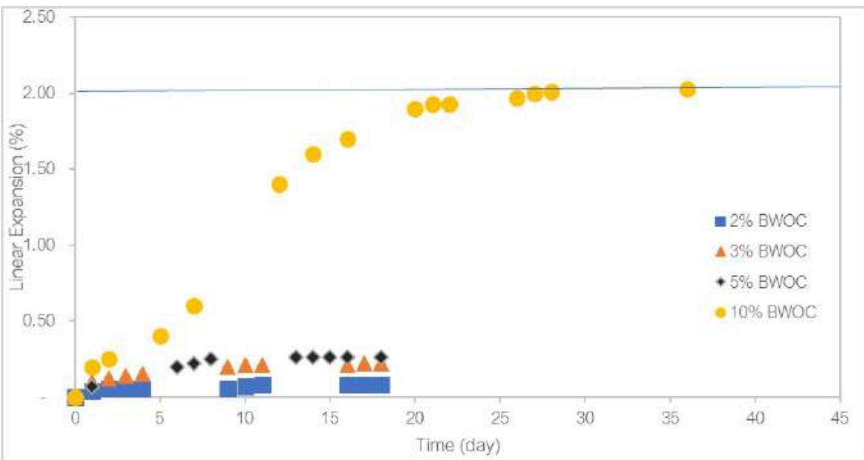
The design for 16.4 lbm/gal CemEX system with a varying concentration of C603 Expansion Additive is given below in Table 1.

The linear expansion data have been generated using annular expansion molds. In all cases, the linear expansion of each slurry design must be confirmed with annular expansion molds until a plateau is reached

Table 1 – Slurry designs and rheological properties with different concentration of C603 for slurry density 16.4 lbm/gal

		Design 1	Design 2	Design 3	Design 4	Design 5
C603 Expansion Additive MT	% bwoc	1	2	3	5	10
C400 Sodium Silicate	gps	-	-	-	0.09	
C201 Liquid Dispersant	gps	0.045		0.05	0.06	0.07
C011 Defoamer	gps	0.03				
C102 Retarder	% bwoc	0.29		0.31	0.45	0.6
SVF (porosity)	% (%)	45 (55)				45.5 (54.5)
PV surface	cP	42	38	52	51.5	66.9
YP surface	lbf / 100 ft^2	6	3	5	5	6.5
PV @ 170 deg F	cP	24	27	30	33.9	79.2
YP @ 170 deg F	lbf / 100 ft^2	17	24	22	1.6	6.5
10' gel strength	lbf / 100 ft^2	38	41	80	20	35
Free Fluid	mL	2	0	0.5	3	0
Thickening Time	hh:mm	4:10	4:00	4:00	5:10	4:30

The degree of expansion increases with an increase in C603 concentration (see Figure 1 and Figure 2). The corresponding designs are shown in Table 1 and Table 2.



Linear expansion of cement slurries with different concentration of C603 vs time. Slurry density is 16.4 lbm/gal, BHST is 170 deg F

Table 2 – Slurry designs and rheological properties with different concentration of C603 for slurry density 14 lbm/gal and 170 deg F

		Design 1	Design 2
C603 Expansion Additive MT	% bwoc	5	10
C501 Bentonite	% bwoc	5	5
C102 Retarder	% bwoc	0.45	
C011 Defoamer	gps	0.03	0.05
SVF (porosity)	% (%)	32 (68)	33 (67)
PV surface	cP	21.9	22.8
YP surface	lbf / 100 ft^2	27.4	26.1
PV @ 170 deg F	cP	7.9	8.9
YP @ 170 deg F	lbf / 100 ft^2	9.4	10.7
10' gel strength	lbf / 100 ft^2	15	14
Free Fluid	mL	4	3.5
Thickening Time	hh:mm	6:20	4:00

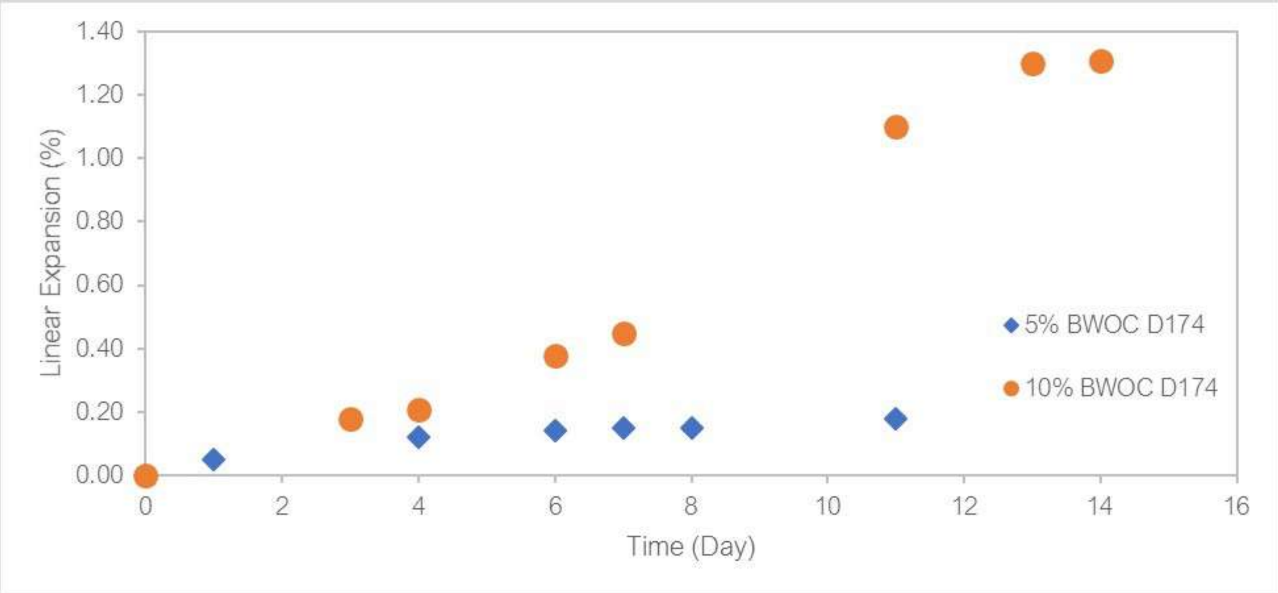


Fig 2 – Linear expansion of cement slurries with different concentration of C603 vs time. Slurry density is 14 lbm/gal, BHST is 170 deg F

Temperature

The temperature has a significant influence on the degree of expansion, as the reactivity of the expanding additive and the whole cement system is affected. In general, the higher the temperature, the more reactive, and hence the more expansive the system.

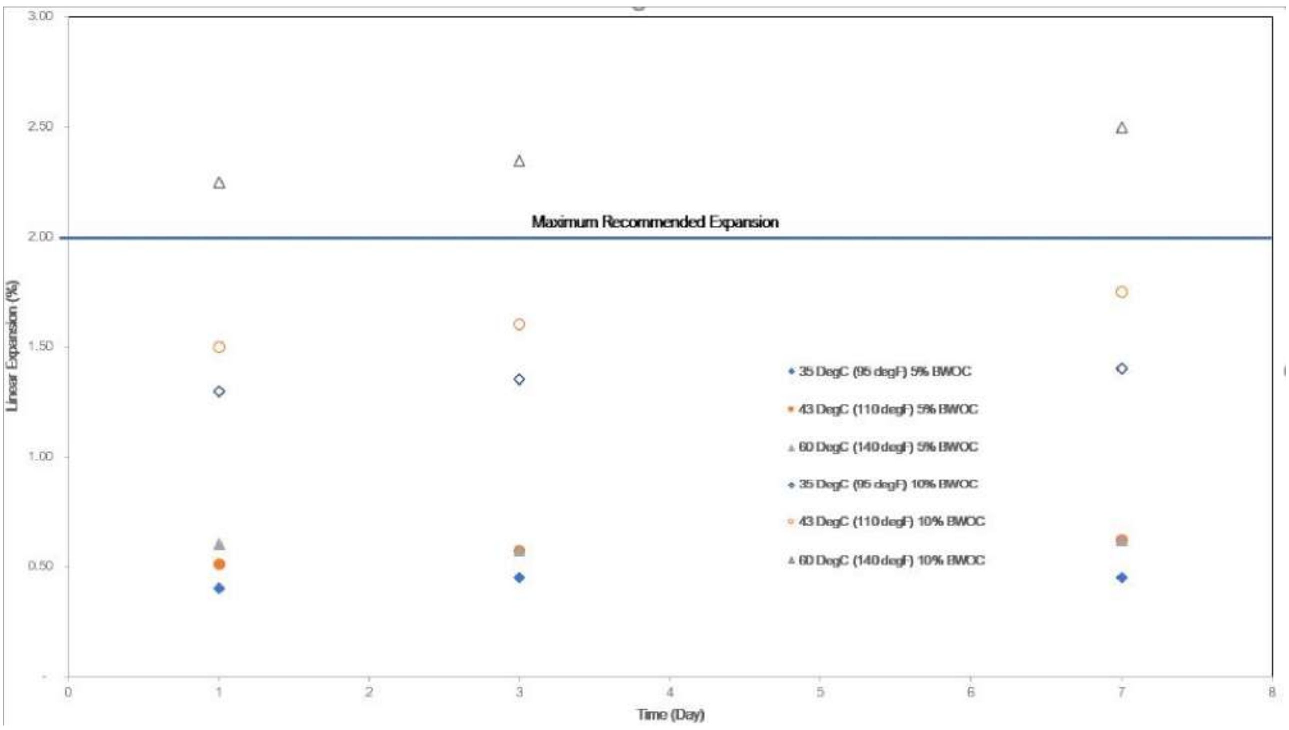


Fig-Influence of temperature on degree of expansion. Density 16 lbm/gal with 5 % BWOC C603, and 16.1 lbm/gal with 10 % BWOC C603

The performance of C603 has been demonstrated in a temperature range between 80 degF and 170 degF. C603 can also be used at temperatures down to 50 degF and in this case, the expansion reaction rate and degree of expansion are significantly decreased.

C603 should not be used at higher temperatures than 170 degF, since it will hydrate prior to the complete cement hydration (eliminating its expanding capability). For wells with temperatures above 170 degF BHST the use of the high temperature expanding additive C605 is recommended. The applicable temperature range of C605 is from 200 deg F up to 400 degF

Rheology

The addition of C603 alters the slurry rheology. It may increase the viscosity and gel strength of a slurry and the design must be adjusted accordingly. This effect is intensified with increasing temperature and density. Small amounts of C400 may help to decrease the viscosity of the cement slurry and reduce any gelation.

On the other hand, C605 Expansion Additive HT has not shown any adverse effect on the slurry rheology. However, it is recommended to carry out the laboratory testing prior to the field use.

Thickening Time

C603 expansion additive MT decreases the thickening time of the expanding cement systems: the higher the concentration of C603, the shorter the thickening time. However, the thickening time can be controlled by increasing retarder concentration.

The C605 expansion additive HT has not shown an accelerating effect on the slurry. However, laboratory testing is recommended with the field water and chemical samples which will be used in the job execution.

22.3.7.Storage

The C603 and C605 are hygroscopic in nature. Therefore, bags that are opened should be kept well sealed. Otherwise, the powder will lose its fineness of grain.

23. Special Systems: CemPROTECT Systems

23.1.Introduction

SPRINT CemPROTECT Acid Soluble Cement system is a particular blend of cement that has a controllable setting time with the capability to dissolve in diluted HCl acid. CemPROTECT system provides low viscosity and acceptable compressive strength, thus making it an excellent slurry for work-over operations and temporarily abandon/protect pay zones. SPRINT CemPROTECT can be used as a temporarily plugging of extremely fractured limestone producing zones at the near well-bore area. Unlike common lost-circulation materials (LCMs), it can be easily removed / dissolved with hydrochloric acid (HCl), resulting in minimal formation damage. Although CemPROTECT-I and CemPROTECT-II cement systems are 70 to 90% soluble in acid, the structure of the cement fully disintegrates into small fines and generates a lot of CO2 gas which eases flowing back the particles out of the well during cleanup. Moreover, the SPRINT CemPROTECT-III is 100% soluble and typically a 2"x2"x2" cube will fully dissolve in 2-3 hours.

When used as a plug, acid-soluble cement can be designed to develop good compressive strength. without jeopardizing its solubility in HCl.

CemPROTECT systems are unique blends of different cementitious materials that can be used in a wide range of temperature from 30˚F to 350˚F for CemPROTECT-I and CemPROTECT-II and upto 200 Deg F for CemPROTECT-III. Different formulation of ASC systems can be designed to achieve the required compressive strength, acid solubility, short setting time and right angle set for any particular application.

Sprint developed three different formulation of CemPROTECT slurry system being; 1) CemPROTECT-I, 2) CemPROTECT-II and CemPROTECT-III. More information regarding each system is provided in the following sections.

Key Features:

- Reliable and consistent slurry performance
- Lower rheological parameters resulting in easy placement via conventional techniques
- Wide temperature range starting from 30F up to 350F.
- Batch mixed and pumped by conventional methods
- Acid solubility of minimum 70%, total recovery>99%
- Cost effective

23.1.1.Application

Conventional Cement solubility in acid has proven to be a problem in the field and has recently been confirmed by laboratory testing. Traditional views have held that acid will react with cement for only a short period of time until it forms a protective skin which inhibits the acid attack. However, field experience has shown that a large percent (> 75%) of secondary squeeze cement jobs were breaking down after a HCl-HF acid stimulation. Further, 17% of primary cement jobs developed zonal isolation problems after a HCl-HF acid treatment of the producing perforations….HCl-HF acid, the most destructive acid tested, showed a 96% dissolution of a 2x2x2 in. (5.1x5.1x5.1 cm) cement cube when immersed in a stirred solution of 12-3% HCl-HF acid at 190 deg F. Finally, the data indicates that the major factors that effect the reaction rate are HF acid volume to cement surface area and acid shear rate at the cement/acid interface. (J.L. Brady et Al.Cement Solubility in Acids. 1989)

Capitalizing on this research, SPRINT further investigated the addition of a high acid soluble agent to the cement slurry to maximize its solubility not only on HCl-HF acid but also in pure HCl. This solubility property in HCl helped using the CemPROTECT to provide a temporary cure for lost circulation across production zones, as well as to be used for temporary isolation plugs. When used as a plug, acid-soluble cement develops good compressive strength. Unlike common lost-circulation materials (LCMs), it can be easily removed with hydrochloric acid (HCl), resulting in less potential formation damage.

In recent developments of unconventional gas reservoirs, there has been a move towards drilling horizontally to increase formation contact with the objective to increase production. A longer horizontal extension gives greater formation contact. However, these extended laterals must be cemented which has caused constraints on optimal reservoir production. Studies have indicated that conventional cements are one of the primary causes resulting in reduced fracture initiation.

CemPROTECT Acid-soluble cements have been advocated for use in unconventional gas reservoirs as a means to reduce the rate of inefficient fracture initiations. The logic behind using acid-soluble cement was based on field study examinations completed in 2005. These studies indicated that more than 25% of cemented horizontal laterals experienced fracture initiation problems compared to 4% for un-cemented horizontal laterals. In acidizing acid-soluble cement in the area of strategically placed clusters, conditions approaching open hole are obtained similar to that of un-cemented horizontal laterals. Cement remaining between clusters provides sufficient zonal isolation for well bore stability.

23.2.CemPROTECT-I

SPRINT CemPROTECT-I slurry system uses various grades of CaCO3 calcium carbonate and cement mix to produce a 70 to 90% acid soluble set cement structure. The system is soluble in HCl acid and the remaining insoluble components of 10% are easily recovered out of the well during flow back. The C055 CemPROTECT-I cement slurries can be used for a wide range of temperatures. This slurry system is compatible with most of the Sprint cementing additives. It can be used for temporarily cementing across producing formations.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C513	2.7	0.0445	Non soluble/ Low	White powder (Fine, medium or coarse)

Although CemPROTECT-I and CemPROTECT-II cement systems are 70 to 98% soluble in acid, the structure of the cement fully disintegrates into small fines and generates a lot of CO2 gas which eases flowing back of the particles out of the well during cleanup.

The C055 slurry has low rheology, high ultimate compressive strength and can be used for temperatures up-to 350 F. The optimum Slurry density is 14.2 ppg however it can be designed for much lower densities and similarly for high densities up-to 16 ppg with slight effect on acid solubility.

Below are typical designs for a 15 ppg CemPROTECT-I slurry using UCN cement and 100% BWOC CaCO3. These designs are provided as a guideline and actual testing is required to confirm final slurry properties and additives concentrations.

Table: 15.0 ppg CemPROTECT-I

Sprint Code	Description	Unit	Slurry 1 - Conc. @ 150 Deg F	Slurry 2 - Conc. @ 200 Deg F	Slurry 3 - Conc. @ 250 Deg F	Slurry 1 Lab conc. @ 150 Deg F	Slurry 2 - Lab conc. @ 200 Deg F	Slurry 3 - Lab conc. @ 250 Deg F
C517	Class G Cement	Sx	100	100	100	363.67 gm	363.47 gm	362.8 gm
C513	$CaCO_3$	% BWOC	100	100	100	363.67 gm	363.47 gm	362.8 gm
C300 / C305	FLAC FLuid Loss Additive	% BWOC	0.25	0.25	0.25	0.91 gm	0.92 gm	0.92 gm
C514	Anti settling agent	% BWOC	0.30	0.20	0.35	1.09 gm	0.72 gm	1.27 gm
C102 / C104	Retarder	% BWOC	0.10	0.14	0.35	0.36 gm	0.50 gm	1.27 gm
C011	Defoamer	gps	0.02	0.02	0.02	0.64 ml	0.65 ml	0.65 ml
Water						350.42 ml	350.42 ml	349.42 ml

Table :15 ppg CemPROTECT-I : Slurry Yield and Porosity

Density (ppg)	15.0	Yield cu,ft/sk	2.48 / 2.65
Mix Water (g/sk)	10.853	Mix Fluid (g/sk)	10.87 / 10.86
Porosity	59% / 58%	Batch Mix Time	-

Table : Slurry Rheology and Static Gel Strength

RPM	Fann readings Slurry 1		Fann readings Slurry 2	
	80 F	150 F	80 F	190 F
300	39	27	30	37
200	29	22	21	27
100	19	17	13	17
60	14	14	9	13
30	10	10	6	9
RPM	Fann readings Slurry 1		Fann readings Slurry 2	
	80 F	150 F	80 F	190 F
Pv	30.90	17.70	26.17	30.53
Ty	7.52	9.82	3.71	6.50
10 sec Gel	6	10	3	5
10 min Gel	19	20	32	14

Table: Slurry Consistency

Consistency	Slurry 1 - Time (HH:MM)	Slurry 2 - Time (HH: MM)	Slurry 3 - Time (HH: MM)
30 Bc	4:34	2:29	4:02
70 Bc	5:13	3:41	4:08

Fig. 15 ppg ASC-I Slurry Consistency at 250 Deg F Table 13.15 CemPROTECT-I Compressive Strength

Slurry 3 - Compressive strength (psi)	Time (HH:MM)
50	2:51
500	5:06
803	12:00

23.3.CemPROTECT-II

CemPROTECT-II system is based on Acid Soluble Agent-II M519 system developed to give higher and faster ultimate acid solubility and recoverability. When, magnesia enters the cement matrix, makes it more vulnerable to acid attack. Due to this reactivity (rate of dissolution of cement) is very high as compared to CemPROTECT-I. CemPROTECT-II cements are mostly recommended for low permeability formations where recovery of cementation materials is a serious challenge.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
M519	2.96	0.0405	Non soluble/ Low	White powder

The slurry has low rheology, high ultimate compressive strength and can be used for temperatures up-to 350 F. The optimum Slurry density is 14.2 ppg however it can be designed for much lower densities and similarly for high densities up-to 16 ppg with slight effect on acid solubility.

M519 is typically added to class G cement at a concentration of 100-150% BWOC. This ratio is provided as a guideline and actual testing is required to confirm final slurry properties and additives concentrations based on the actual sample of M519 and cement used on the job.

CemPROTECT-II has a controllable rheological properties based on the size of particles used. It also develops high early compressive strengths and final compressive strength compared to CemPROTECT-I.

CemPROTECT-II can be used for temperatures up to 350 deg F. However, care should be taken while selecting optimum retarder.

23.4.CemPROTECT-III

23.4.1.Summary:

SPRINT CemPROTECT-III is a unique blend of M520 and M512 (Activator) that dissolves in acid (diluted HCl). The CemPROTECT-III can be mixed at densities between 10 to 12 ppg.

Code	SG	Absolute Volume (gal/lbm)	Solubility	Appearance
C508	1.73	0.0694	High	White or off white powder
M512	2.32	0.0517	High	White granular powder
M520	3.58	0.0334	Non soluble/ Low	White powder

It exhibit low viscosity, sufficient compressive strength (500-700 psi), and provides a right angle set profile for improved lost circulation cure in gas environment. Thus making it excellent production zone temporary cure for lost circulation across gas zones. The system is highly efficient in curing extremely fractured limestone and sandstone production zones. The CemPROTECT-III can be designed for temperatures up to 200 deg F.

The CemPROTECT-III is comprised of materials that can completely disintegrate in the presence of HCl, making CemPROTECTIII completely non damaging to the formation.

By Mixing the M512 (Activator) brine solution with M520 (Acid Soluble Agent-III) powder, the product so obtained is used as fast curing cement for losses during drilling. The additives react according to the following reaction mechanism.

Table Chemical Reaction

$5MgO + MgCl_2.6H_2O + 7H_2O$	======>	$5Mg(OH)_2{\cdot}MgCl_2{\cdot}8H_2O$
$5\ MgO + 1\ MgCl_2 + 13\ H_2O$	======>	$5Mg(OH)_2.MgCl_2{\cdot}8H_2O$

SPRINT CemPROTECT thickening time is highly sensitive to density e.g. T.T. considerably increases with the decrease of density and shortened when increased. Similarly, it is highly sensitive to temperature e.g. T.T. considerably increases with the decrease of temperature and shortened when increased. The below matrix provides the recommended density for each slurry designed temperature range.

Moreover, the higher the density the more compressive strength is achieved on the account of thickening time. A 13 ppg CemPROTECT-III system at 125 deg F, provides +/-30 min pumping time and 2200 psi compressive Strength after 24 hours.

While an 11.5 ppg at the same temperature will provide +/-1:45 min T.T. and +/- 400 psi after 24 hours.

Table : CemPROTECT-III Density Matrix

	Thickening Time		
Temperature range	**1:00 hr**	**1:30 hr**	**2:00 hr**
70 - 100 Deg F	12 ppg	12 ppg	11.5 - 12 ppg
	Thickening Time		
100 - 125 Deg F	12 ppg	12 ppg	11.5 - 12 ppg

125 - 150 Deg F	12 ppg	11.5 - 12 ppg	11.5 ppg
150 -175 Deg F	12 ppg	11.5 - 12 ppg	11 - 11.5 ppg
175 -200 Deg F	11.5-12 ppg	11.5 ppg	11 ppg
200-225 Deg F	11.5 ppg	11 ppg	11 ppg

It should be noted that increasing slurry density will not highly affect the percentage of solubility of CemPROTECT-III in HCl.

The CemPROTECT-III can transform from fluid to solid within few minutes. Due to this short transition time (30 BC - 100BC), the development of compressive strength is very quick as compared to conventional cements. This property of CemPROTECTIII makes it a good choice for curing loss circulation problem in highly fractured and vogus producing formations.

23.4.1.Retardation:

The main retarder used in the formulation of the CemPROTECT is Sprint C508 HT retarder. It is used typically in concentrations from 1 to 15% bwoc.

Below included are some typical formulations for the CemPROTECT-III at various temperatures. It should be noted that testing using fresh samples used on the job should be conducted prior to any CemPROTECT-III job execution.

Table : 11.5 ppg CemPROTECT-III Formulation at 125 Deg F and 1:30 T.T.

Sprint Code/Type	Description	Unit	Concentration
M520	Acid Soluble Agent III	Sx	100
C300/C305	FLAC	%BWOC	0.30
C011	Defoamer	gps	0.02
C508	Retarder	%BWOC	1.0
C200	Dispersant	%BWOC	0.5
Base Fluid			
M512	Acid Soluble Activator III	BWOW	23%
Water			

Table : 11.5 ppg CemPROTECT-III Formulation at 175 Deg F and 1:40 T.T. & 850 psi CS @ 12 hr

Sprint Code/Type	Description	Unit	Concentration
M520	Acid Soluble Agent III	Sx	100
C300/C305	FLAC	%BWOC	0.50
C011	Defoamer	gps	0.02
C508	Retarder	%BWOC	10.0
C200	Dispersant	%BWOC	0.50
Base Fluid			
M512	Acid Soluble Activator III	BWOW	25%
Water			

Table : 11.5 ppg CemPROTECT-III Formulation at 175 Deg F and 4:15 T.T. & XXX psi CS @ 12 hr

Sprint Code/Type	Description	Unit	Concentration
M520	Acid Soluble Agent III	Sx	100
C300/C305	FLAC	%BWOC	0.50
C011	Defoamer	gps	0.02
C508	Retarder	%BWOC	12.0
Sprint Code/Type	**Description**	**Unit**	**Concentration**
C200	Dispersant	%BWOC	0.50
Base Fluid			
M512	Acid Soluble Activator III	BWOW	25%
Water			

Table : 11.5 ppg CemPROTECT-III Formulation at 225 Deg F and 0:30 T.T. & XXX psi CS @ 12 hr

Sprint Code/Type	Description	Unit	Concentration
M520	Acid Soluble Agent III	Sx	100
C300/C305	FLAC	%BWOC	0.50
C011	Defoamer	gps	0.02
C508	Retarder	%BWOC	15.0
C200	Dispersant	%BWOC	0.50
Base Fluid			
M512	Acid Soluble Activator III	BWOW	25%
Water			

Table 13.31 11.5 ppg CemPROTECT-III Formulation at 225 Deg F and 0:50 T.T. & XXX psi CS @ 12 hr

Sprint Code/Type	Description	Unit	Concentration
M520	Acid Soluble Agent III	Sx	100
C300/C305	FLAC	%BWOC	0.50
C011	Defoamer	gps	0.02
C508	Retarder	%BWOC	20.0
C200	Dispersant	%BWOC	0.50
Base Fluid			
M512	Acid Soluble Activator III	BWOW	25%
Water			

24. Gunk Plugs

The use of a gunk plug or squeeze may be considered if conventional LCM pills and cement plugs are unsuccessful in reducing or curing formation losses. The traditional gunk plug or squeeze involved dispersing Bentonite in diesel oil and spotting the resulting gunk plug across the thief zone.

The gunk squeeze involves closing the annular BOP and squeezing the gunk plug into the thief zone in an attempt to cure the formation losses. This gunk plug procedure should not be used for curing losses in the reservoir section due to resultant formation damage.

The gunk plug or squeeze will only be effective if the exact location of the thief zone is known, which can be determined by running logs (e.g. well-bore temperature log), and the diesel spacers must be large enough to prevent Bentonite hydration before the gunk pill has left the drill string.

A gunk plug can be formulated using any mineral or synthetic base oil, as the primary function of the oil is to prevent hydration while displacing a concentrated suspension of Bentonite down the drill string to the thief zone.

Bentonite Diesel Oil slurries can be useful in the following situations:

- They can assist in controlling severe mud loss in areas where conventional LCM ineffective.
- They can be helpful in vugular and cavernous thief zones

NB: Bentonite Diesel Oil slurry contamination with water or water based mud MUST be avoided in the pump lines as it will hydrate and form a dense plastic plug which will plug the lines. It is crucial to check the quality of the diesel available on site and ensure that there is no water contamination.

24.1.Bentonite, Cement, Polymer Gunk Plug

A slurry that consists of bentonite, cement or polymers mixed into an oil. Water downhole interacts with the bentonite, cement or polymers to make a sticky gunk.

24.1.1.BDO Gunk Plug Formulation:

Sprint Code/Type	Description	for 1 bbl
C011	Defoamer	0.2 - 0.25 gal
C501	Bentonite (Mixed in 20 min)	200 - 300 lb
Diesel		39 gal

24.1.2.BDOC Gunk Plug Formulation:

Commonly Used 12.4 ppg Density Gunk Plug using Class G cement, Bentonite and Diesel

Sprint Code/Type	Description	for 1 bbl
C517	Cement Class G	200 - 250 lb
C011	Defoamer	0.2 - 0.25 gal
C501	Bentonite (Mixed in 20 min)	100 - 150 lb

Diesel		29 gal

Mixing Ratios (Slurry: H2O)	Observation after mixing	Observation after 30 minutes
1:2	Viscous fluid	Gelling after ~ 15 - 25 min
1:1	Highly Viscous	Gelling after ~ 10 -15 min

Pv	70.57
Ty	31.98
10 sec Gel	20
10 min Gel	23

24.1.1.12.0 Ppg Density Gunk Plug Using Light Weight Blend , Bentonite and Diesel (Low Final Compressive Strength)

Sprint Code/Type	Description	qty
Blend	Light Weight Blend (C517 = 249 lb/bbl + C402 = 37 lb/bbl (21%BWOC))	250 - 300 lb
C011	Defoamer	0.2 - 0.25 gal
Diesel	Diesel	27 – 28 gal
C501	Bentonite (P.H. for 20 min)	50 lb

Mixing Ratios (Slurry: H2O)	Observation after mixing	Observation after 30 minutes
1:1	Viscous	Gelling after ~ 15 - 20 min

24.2.Gunk Plug Squeeze Procedures

The procedure for a typical bentonite diesel oil / gunk plug (25 bbls used as example, It is recommended that plastic plug volume shall equal, or be greater than, the hole volume below the loss zone) and squeeze when mixed at the cement unit is as follows:

1. Flush the cement pump and associated lines with base oil to remove all traces of water.
2. Make sure the cement mixing tank is clean and dry.
3. Fill the cement mix tank with 25 bbl base oil.
4. Switch on the mix tank agitator.
5. Add 300 ppb Bentonite to form a concentrated suspension in base oil (this can be a split of Bentonite and Cement).

NB: check pumpability and rheology of the oil based mixture in the lab.

6. Keep circulating the mix tank to disperse and suspend the Bentonite.
7. Pull string 100-150 ft above the loss zone. The distance could be more, say 300-500 ft, depending on the situation.
8. Pump 10 bbl base diesel oil spacer from the displacement tank into the drill string.
9. Pump the gunk plug pill from the batch tank into the drill string.
10. Pump 10 bbl base diesel oil spacer from the displacement tank into the drill string.
11. Displace the Bentonite Diesel Oil Cement pill to bit at 6-7 bpm with mud.
12. With BDOC pill at bit, close annular bop ram.
13. Squeeze BDOC pill into open hole, with 3-4 bpm on drill string side, and pump mud at 1-2 bpm down the kill line and annulus.
14. After displacing (bentonite oil diesel) half the plug, reduce the pump rate by half.

NB: The gunk plug may or may not be squeezed by pressure into the zone.

15. Normally, shall BDOC pill works, you will see squeeze pressure increase.
16. Monitor pressure closely to avoid shocking the well.
17. After displacing 3/4 of the plug, attempt a ‘hesitation squeeze pressure’ with 100-500psi.
18. Under displace plug by one barrel.
19. After achieving the squeeze pressure, bleed back pressure.
20. Open annular preventer and pull out of hole to previous casing shoe to displace any remaining BDOC pill in the drill string into open hole. A wiper plug can be used to clean the inner drill pipe as well.

NB: The inner drill pipe will have layers of cement sheath build-up, depending on number of pills pumped. It is very important to make sure that the drill pipe is clean, before conducting any cement job to avoid the float equipment being plugged up by cement sheath during a cement job. Maximize the use of foam wiper plug while circulating the drill string clean.

21. Then POOH
22. Allow 8-12 hrs set time. Depending on the BHST/BHCT, it is required to wait on cement to set around 12-hr prior to continue drilling.
23. Close the annular blowout preventer and squeeze the gunk pill into the thief zone.
24. Pull up into the casing shoe and maintain pressure for approximately 4 hours.

Gunk slurry will follow the path of least resistance which is the way to the losses zone and will plug the thief zones

In case the gunk slurry will remain in the annulus, the drill pipes will not be stuck since the set plug has no yield, compressive nor tensile strength

During the squeeze, the base oil is pushed into the thief zone and the Bentonite is then hydrated by water from the water-based mud, which will form a thick, putty-like material that is designed to seal the thief zone.

24.3.Squeezing

It has been proven in the field that the hesitation squeeze method is more effective than running squeeze method in curing TOTAL losses.

The hesitation squeeze method allows the dehydration of small quantities of cement into the fractures of formation. This procedure involves the intermittent application of pressure (at a rate of 0.25 to 0.5 bbl/min), separated by an interval of 10 to 20 minutes for pressure leak-off due to filtrate loss to the formation.

The initial leak-off is normally fast because there is no filter cake. As the cake builds up and the applied pressure increases, the filtration periods become longer and the difference between the initial and final pressure becomes smaller, until at the end of the job when pressure leak-off becomes negligible.

The slurry volumes necessary for this technique are usually much less than those required for a running squeeze

A loose formation normally requires a long hesitation period to begin building squeeze pressure. A first hesitation period of 30 minutes or more is not unreasonable. A much shorter initial hesitation period (possibly 5 minutes) is normally sufficient for tight formation.

24.4.Disadvantages

- For medium losses, the gunk slurry requires to be squeezed to reach the formation matrix which can be possible only when the annulus is full otherwise it will rise up through annulus.
- If gunk slurry in the annulus cannot be circulated out, cleaning with bit is required.

25. Well Washes

25.1.Summary

Washes are preflushes with a density and a viscosity very close to that of water or oil. Consequently, they can easily be pumped in turbulent flow. They act according to the mechanisms of mud dispersion, tangential erosion of mud layers, and leaving the casing and formation surfaces water-wet for optimal cement bonding. When WBMs are used, the simplest wash is fresh water. However, for more efficient mud thinning and dispersion, chemical washes that contain dispersants and surfactants are more commonly used.

Washes Summary

Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
WW100	Wellwash 100	Fresh and salt water.		80 - 450	0.96
WW200	Wellwash 100	Fresh and salt water.		80 - 450	0.95

25.2.WW100 WellWash 100

WellWashes are water-based fluids with low viscosities and densities (much like water) and are very easy to get into turbulent flow. They are the preferred fluid for turbulent flow washes.

Code	SG	Absolute Volume (gal/lbm)	pH	Appearance
WW100	0.96	0.1249	3.1	Clear or yellowish

The WellWash is premixed in a tank but can also be mixed on short notice by adding the products to the displacement tanks in the field as the water is being added.

Product	WW - WBM	WW - WBMF	WW - OBM	WW - OBMF
Water	41.5	41.25	41.25	41
WW100	0.5	0.5	0.5	0.5
S560 OSR		0.25		0.25
S281			0.25	0.25
Fluid Loss Control	No	Yes	No	Yes
Water/Oil base mud	Water	Water	Oil	Oil

The mixing order for chemical washes is:

- begin with water
- add WW100
- add S560 if required and agitate the mixture well
- add S281 last, just before pumping fluid into the well.

Table WellWash 100 Naming Convention

Sr. #	Fluid Description	SPRINT CODE	Comments
1	AQUEOUS - NON WEIGHTED CHEMICAL WASH	WW100	Water Base Mud
2	WASH FOR WELLS WITH OIL BASE MUD WITH SURFACTANT	WellWash 100 O	O = Oil Based Mud
3	WASH FOR OIL BASE MUD WITH SURFACTANT AND MUTUAL SOLVENT	WellWash 100 OM	O = Oil Based Mud M= Mutual Solvent
4	WASH FOR SALT SATURATED WELL WITH SALT SATURATED WATER BASE MUD	WellWash 100 S	S = Salt Saturated Water Based Fluid
5	WASH FOR SALT SATURATED AND OIL BASE MUD WITH SALT SATURATED BASE FLUID AND SURFACTANT	WellWash 100 OS	O = Oil Based Mud S = Salt Saturated
6	WASH FOR SALT SATURATED AND OIL BASE MUD WITH SALT SATURATED BASE FLUID, SURFACTANT AND MUTUAL SOLVENT	WellWash 100 OSM	O = Oil Based Mud S = Salt Saturated Water Based Fluid M= Mutual Solvent

25.3.WW200 WellWash 200

WW200 provides similar performance to WW100 however provides an additional benefit in that it meets offshore environmental requirements (OSPAR), while WW100 does not.

Code	SG	Absolute Volume (gal/lbm)	pH	Appearance
WW200	0.95	0.1199	3.1	Amber Liquid

The WellWash is premixed in a tank but can also be mixed on short notice by adding the products to the displacement tanks in the field as the water is being added.

Product	WW - WBM	WW - WBMF	WW - OBM	WW - OBMF
Water	41.5	41.25	41.25	41
WW200	0.5	0.5	0.5	0.5
S560 OSR		0.25		0.25
S281			0.25	0.25
Fluid Loss Control	No	Yes	No	Yes
Water/Oil base mud	Water	Water	Oil	Oil

The mixing order for chemical washes is:

- begin with water
- add WW200
- add S560 if required and agitate the mixture well
- add S281 last, just before pumping fluid into the well.

Table WellWash 200 Naming Convention

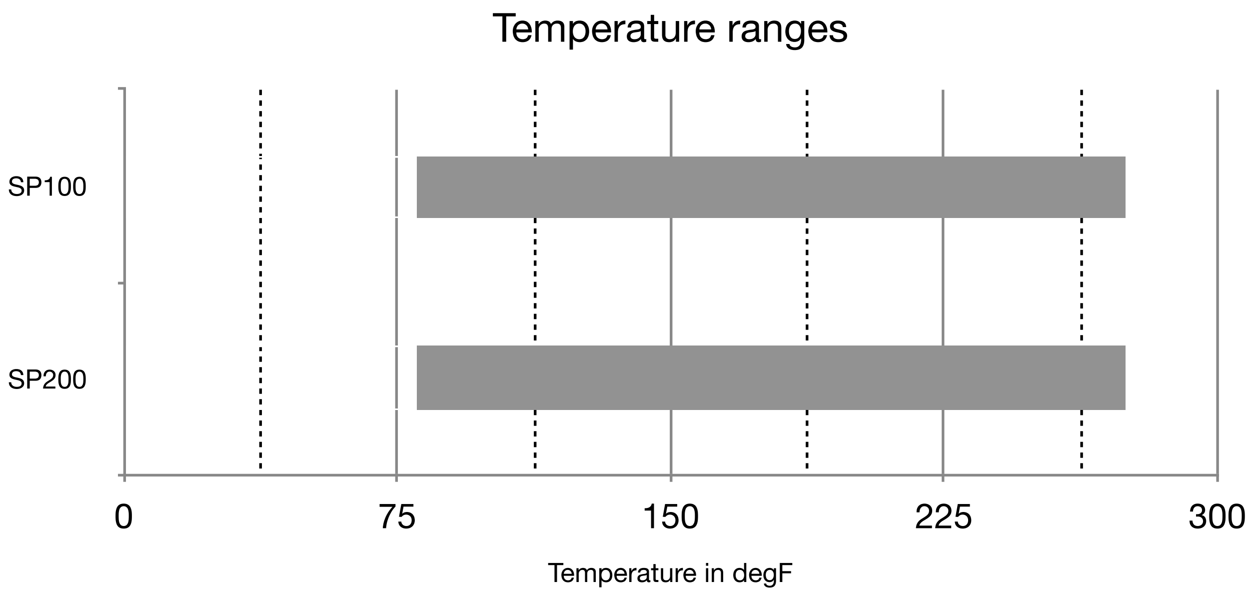
Sr. #	Fluid Description	SPRINT CODE	Comments
1	AQUEOUS - NON WEIGHTED CHEMICAL WASH	WW200	Water Base Mud
2	WASH FOR WELLS WITH OIL BASE MUD WITH SURFACTANT	WellWash 200 O	O = Oil Based Mud
3	WASH FOR OIL BASE MUD WITH SURFACTANT AND MUTUAL SOLVENT	WellWash 200 OM	O = Oil Based Mud M= Mutual Solvent
4	WASH FOR SALT SATURATED WELL WITH SALT SATURATED WATER BASE MUD	WellWash 200 S	S = Salt Saturated Water Based Fluid
5	WASH FOR SALT SATURATED AND OIL BASE MUD WITH SALT SATURATED BASE FLUID AND SURFACTANT	WellWash 200 OS	O = Oil Based Mud S = Salt Saturated

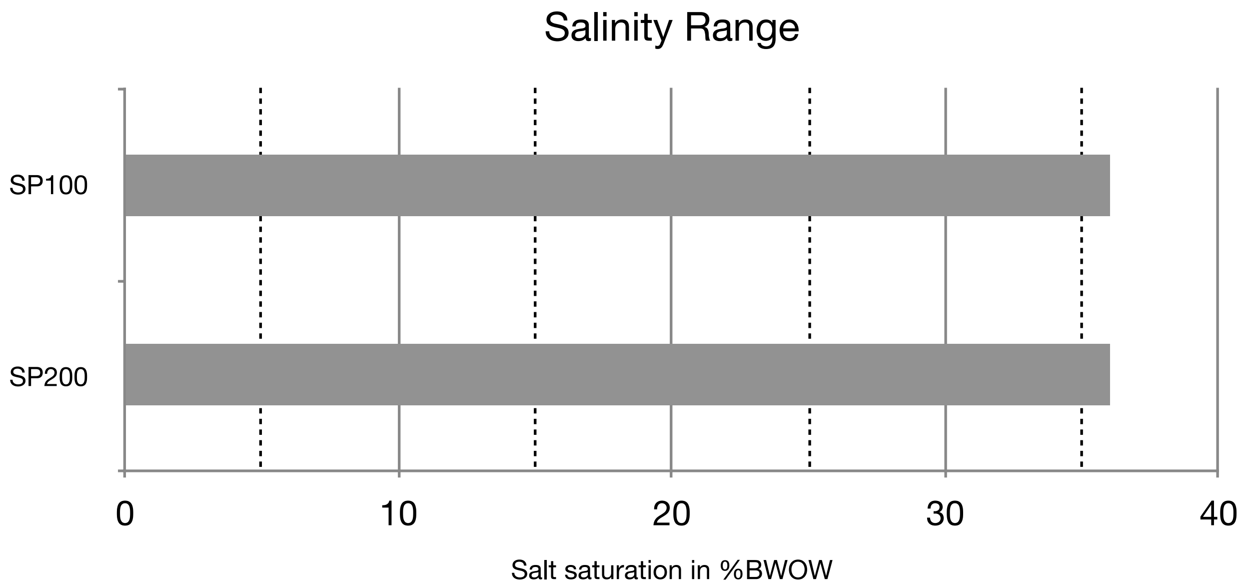
6	WASH FOR SALT SATURATED AND OIL BASE MUD WITH SALT SATURATED BASE FLUID, SURFACTANT AND MUTUAL SOLVENT	WellWash 200 OSM	O = Oil Based Mud S = Salt Saturated Water Based Fluid M= Mutual Solvent

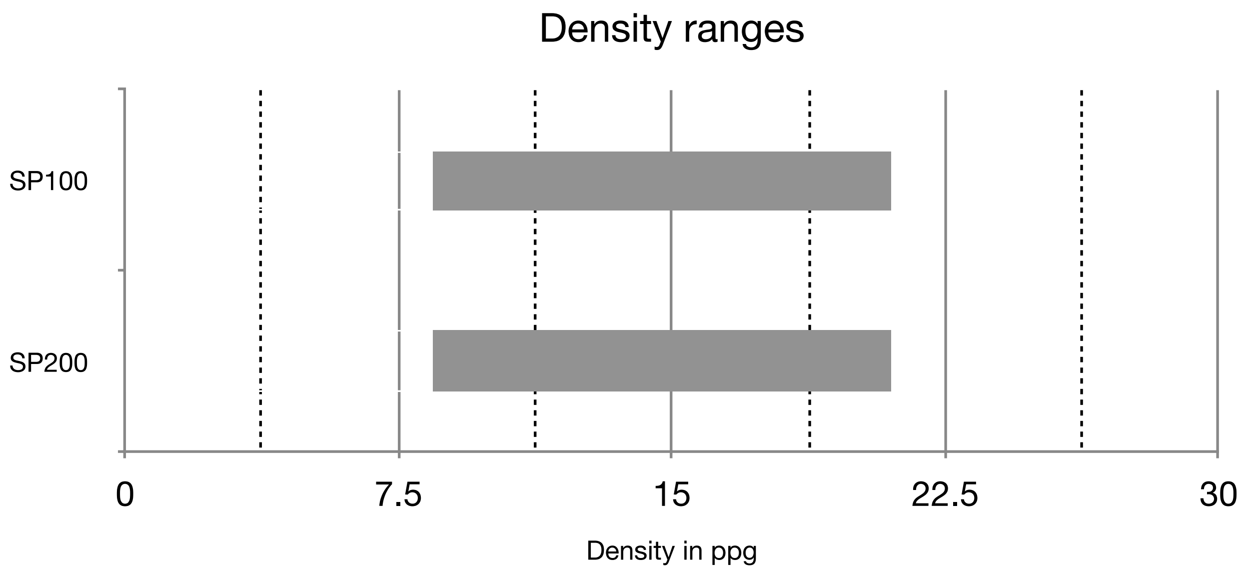
26. Spacers

Spacers Summary

Code	Description	Application	Limitations	BHCT Range (deg F)	Absolute Density (SG)
SP100	CemBOND Spacer	Fresh and salt water spacers.	• Decreased efficiency with higher salt content.	80 - 275	2.36
SP200	WellSHIELD Spacer	Biodegradable additive suitable for reservoir sections. Used for fresh and salt water spacers. Suitable for cementing during expected or existing losses.		80 - 275	1.8


Temperature ranges
SP100
SP200
0
75
150
225
300
Temperature in degF


Salinity Range
SP100
SP200
0
10
20
30
40
Salt saturation in %BWOW


Density ranges
SP100
SP200
0
7.5
15
22.5
30
Density in ppg

26.1.SP100 CemBOND Spacers

26.1.1.CemBOND Spacer SP100

The main advantage of SP-100 is its good fluid loss control at low and high temperatures. It is efficiently used up to 275 degF BHCT. The filter cake which develops helps to greatly reduce the fluid leak off into formations where the mud cake has been mechanically removed by centralisers or scratchers.

Ideally, the spacer should be more dense and more viscous than the mud but lighter and less viscous than the cement slurry. The spacer can be displaced in laminar or turbulent flow depending on the temperature and pipe configuration. A minimum of 500 ft. of annular fill of spacer should normally be used ahead of the cement, and pipe movement should be attempted where possible to help achieve maximum mud removal.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
SP100	2.36	0.0508	Non Soluble/ Partially Soluble	Off White

26.1.2.Mixing Procedure

To achieve the required density, barite or Calcium Carbonate is added as the weighting material.

The usual concentration range is 3.5 lbs/bbl to 14 lbs/ bbl for weighted spacers . Higher concentrations may be used depending on the application and design requirement. Laboratory tests should be run with the available weighting agents. Concentrated salt water inhibits the hydration of the spacer, and poor properties may result. Sea water can be used although the hydration time is slightly longer and fluid loss tends to rise.

The addition of a water wetting surfactant, at 2 to 3 U.S. gals. per barrel of spacer, will give a fluid which will emulsify oils, and hence help remove oil based muds from pipe and formation face. With oil based muds, it is good practice to assess the compatibility of the mud, cement and spacer under down-hole conditions prior to running the cement job.

Depending on the temperatures expected downhole, the polymer concentration can be altered to achieve the desired rheology and fluid loss control. A hydration time of 20 minutes should be allowed while circulating SP-100 in the tank before adding any weighting material

26.1.3.Weighting Agents

The type of weighting agent can be selected as per the below table guidelines

Density (ppg)	Weighting Agent
< 11.5 ppg	$CaCO_3$
Between 11.5 and 16 ppg	Barite
> 16 ppg	Hematite

26.1.4.Surfactants

Adding surfactants (S280, S281, S282) to the spacer makes it compatible with oil-based muds. S281 is the preferred surfactant due to its non-ionic nature which renders it compatible with other additives.

26.1.5.Required Properties of Spacers

The required properties of spacers are:

- Compatibility with the drilling fluid and the cement slurries in the well. C200 can be used to solve compatibility issues with WMB.
- Stability and suspending properties even at high temperatures, to avoid allowing the weighting agent to drop out of suspension.
- Controllability, so the density and rheology properties are the same in the lab and in the field.
- Provision of good fluid loss control, since it will be used across permeable pay zones.
- Environmentally safe and easy to handle in the field.

26.1.6.Composition and Field Mixing Order of Spacers

For spacers to work properly, they must be both blended in the correct concentrations and mixed in the correct order. The field mixing order for spacers is:

- Clean tanks and lines before mixing. Dirty lines and tanks can contaminate the fluid, making it less effective.
- Add fresh or brackish water once the lines and tanks are clean.
- Take a one-gallon sample of the water before any other chemicals or additives are mixed with it.
- Add the anti-foam agents at a concentration of 0.1 to 0.2 gal/bbl after the sample is taken.
- Add the spacer blend through the hopper and allow to pre-hydrate for 20 minutes to one hour.
- Check the viscosity of the mix using a MARSH funnel.
- Alter the rheology of CemBOND spacer by adjusting the concentration of the gelling agent, if necessary.
- Add salt through the hopper, if necessary. Circulate salt, if added, in the mix water for about 30 minutes to dissolve crystals completely.
- Add necessary weighting agents through the hopper after any added salt has completely dissolved. Check the density of the fluid because the specific gravities of some weighting agents vary (Different weighting agents are used depending upon the density required).
- Add surfactants to make the mix compatible with oil-based environments just before pumping. The type and concentration of the surfactants (S280, S281 and S282) depend on lab tests and the type of drilling fluid used.
- Take a sample of the spacer and check for density and rheology when everything has been mixed.

26.1.7. CemBOND Naming Convention

Sr. #	Fluid Description	SPRINT CODE	Comments
1	CemBOND SPACER (Weighted or nonweighted)	SP100	Water Base Mud
2	CemBOND (Weighted or nonweighted) FOR WELLS WITH OIL BASE MUD WITH SURFACTANT	CemBOND O	O = Oil Based Mud

3	CemBOND (Weighted or nonweighted) FOR OIL BASE MUD WITH SURFACTANT AND MUTUAL SOLVENT	CemBOND OM	O = Oil Based Mud M= Mutual Solvent
4	CemBOND (Weighted or nonweighted) FOR SALT SATURATED WELL WITH SALT SATURATED WATER BASE MUD	CemBOND S	S = Salt Saturated Water Based Fluid
5	CemBOND (Weighted or nonweighted) FOR SALT SATURATED AND OIL BASE MUD WITH SALT SATURATED BASE FLUID and SURFACTANT	CemBOND OS	O = Oil Based Mud S = Salt Saturated Water Based Fluid
6	CemBOND (Weighted or nonweighted) FOR SALT SATURATED AND OIL BASE MUD WITH SALT SATURATED BASE FLUID, SURFACTANT AND MUTUAL SOLVENT	CemBOND OSM	O = Oil Based Mud S = Salt Saturated Water Based Fluid M= Mutual Solvent

26.2.SP200 WellSHIELD Spacer

26.2.1.Summary

WellSHIELD is a shielding spacer system that helps prepare the well-bore for cementing. WellSHIELD spacer is a superior product that helps minimizing losses when pumped ahead of the cement slurry. The spacer system forms an impermeable shield on the formation face, mitigating lost circulation issues before cement enters the annulus. WellSHIELD forms a shield against the formation and helps reduce fluid invasion, meanwhile reduces cement losses and formation damage. WellSHIELD also allows safe operations slightly above the frac gradient to handle the typical high equivalent circulating density (ECD) near the end of the displacement in wells where the fracture gradient has traditionally limited the design of the cement job.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
SP200	1.80	0.0863	Non Soluble/ Partially Soluble	Off White

WellSHIELD can be used in fragile and fractured formations, when circulating drilling fluid is an issue, in wells where pre-job simulations show final ECD near or above the frac gradient or when the capability to mix on-the-fly with a weighted spacer is preferred. It is efficiently used up to 275 degF BHCT.

WellSHIELD rheology can be easily adjusted which enhances hole cleaning and mud removal prior to cement placement.

WellSHIELD is biodegradable and environmentally compliant for use in all areas; PLONOR listed for North Sea use, HMCS Category P, OCNS Group E and passes the North America 96-hr LC50 bioassay mysid shrimp.

26.2.2.Concentration:

WellSHIELD should be used at an ideal concentration of 15 lb/bbl of mix water. (One sack of spacer concentrate yields 3 barrels of spacer).

Higher concentrations can be used to increase the YP for optimized displacement efficiency or during high pressure differentials.

It might be required to reduce the SP200 from the ideal concentration to optimize rheological hierarchy between spacer/cement. In such cases, the SP200 minimum recommended concentration for LCM applications can be calculated in CemDESIGN.

WellSHIELD LC1k, LC3k or LC4k should be added to WellSHIELD spacer at concentrations of 10-30 lb/bbl to case losses are due to natural fractures or for wellbore reinforcement.

Note: LC3k is NOT recommended to be added to the WellSHIELD spacer if pumped in 7” and 5” liners or through float collar and shoe not equipped with flapper type valves (such as puppet or dart valves) unless a slot bridging test is performed.

The WellSHIELD calculator can be found on CemDESIGN calculator and should be used by both lab and operations as a guideline for initial testing to provide the required rheology.

26.2.3.Field Mixing Procedures

1. Add required volume of clean mixing water to a clean pit or batch mixer.
2. WellSHIELD spacer should be slowly added through a mixing hopper or jet mixer. Shear for at least an additional 5 minutes after all the spacer has been added.
3. WellSHIELD LC1k, LC3k or LC4k (if required) should be slowly added and sheared for at least an additional 5 minutes after all product is added.
4. Slowly add the weighting material (if required). Shear for at least an additional 5 minutes after all the weighting material has been added.
5. Check density and adjust. Weight should be little high if surfactants are required and have not yet been added.
6. Shut down all potentially air entraining mixing equipment and add surfactants (if required) as close to the starting of spacer pumping. Confirm density and adjust if required. Gentle agitation is recommended.

As an alternative, the WellSHIELD spacer system can be pneumatically blended with the weighting material and mixed on the fly through the cementing head.

26.2.4.Surfactants

Adding surfactants (S280, S281, S282) to the spacer makes it compatible with oil-based muds. S281 is the preferred surfactant due to its non-ionic nature which renders it compatible with other additives.

26.2.5.WellSHIELD Naming Convention

Sr. #	Fluid Description	SPRINT CODE	Comments
1	WellSHIELD SPACER (Weighted or nonweighted)	SP200	Water Base Mud
2	WellSHIELD (Weighted or nonweighted) FOR WELLS WITH OIL BASE MUD WITH SURFACTANT	WellSHIELD O	O = Oil Based Mud
3	WellSHIELD (Weighted or nonweighted) FOR OIL BASE MUD WITH SURFACTANT AND MUTUAL SOLVENT	WellSHIELD OM	O = Oil Based Mud M= Mutual Solvent
4	WellSHIELD (Weighted or nonweighted) FOR SALT SATURATED WELL WITH SALT SATURATED WATER BASE MUD	WellSHIELD S	S = Salt Saturated Water Based Fluid
5	WellSHIELD (Weighted or nonweighted) FOR SALT SATURATED AND OIL BASE MUD WITH SALT SATURATED BASE FLUID and SURFACTANT	WellSHIELD OS	O = Oil Based Mud S = Salt Saturated Water Based Fluid
4	WellSHIELD (Weighted or nonweighted) FOR SALT SATURATED AND OIL BASE MUD WITH SALT SATURATED BASE FLUID, SURFACTANT AND MUTUAL SOLVENT	WellSHIELD OSM	O = Oil Based Mud S = Salt Saturated Water Based Fluid M= Mutual Solvent

26.3.SP300-1k WellSHIELD LC1K

26.3.1.Summary

WellSHIELD LC1k lost circulation additive is added to the WellSHIELD shielding spacer systems to remediate against moderate, complete and total losses. WellSHIELD LC1k is formulated to prevent losses with fracture sizes of 1,000 microns and permeability's up to 3500 darcies. The WellSHIELD LC1k beside enhancing the WellSHIELD spacer system's effectiveness when losses are problematic, it can help the system Withstand differential pressures >1000psi. SP300-1K can be used up to 400 degF BHCT.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
SP300-1K	1.46	0.0821	Non Soluble/ Partially Soluble	Coarse, brown powder

WellSHIELD LC1k is typically used during partial to total lost circulation where fracture sizes of 1,000 microns were experienced. It can also be used in high permeability formations, unconsolidated and fractured formations when losses were observed during the drilling phase.

WellSHIELD LC1k is biodegradable and environmentally compliant for use in all areas; PLONOR listed for North Sea use, HMCS Category P, OCNS Group E and passes the North America 96-hr LC50 bioassay mysid shrimp Concentration:

WellSHIELD LC1k should be added to WellSHIELD spacer at concentrations of 10-30 lb/bbl to control pre-existing loss situations. The SP300 minimum recommended concentration for LCM applications can be calculated in CemDESIGN.

26.4.SP300-3k WellSHIELD LC3K

26.4.1.Summary

WellSHIELD LC3k lost circulation additive is added to the WellSHIELD shielding spacer systems to remediate against moderate, complete and total losses. WellSHIELD LC3k is used to prevent losses in formations with fracture sizes of 3,000 microns. The WellSHIELD LC3k is used during partial to total lost circulation where fracture sizes of 3,000 microns were experienced. It can also be used in high permeability formations, unconsolidated and fractured formations when losses were observed during the drilling phase. SP300-3K can be used up to 400 degF BHCT.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
SP300-3K	1.5	0.0799	Non Soluble/ Partially Soluble	Coarse, brown powder

The WellSHIELD LC3k beside enhancing the WellSHIELD spacer system's effectiveness when losses are problematic, it can help the system Withstand differential pressures >1000psi.

WellSHIELD LC3k is environmentally compliant for use in all areas; PLONOR listed for North Sea use, HMCS Category P, OCNS Group E and passes the North America 96-hr LC50 bioassay mysid shrimp Concentration:

For seepage losses the WellSHIELD recommended treatment ranges from 10-30 lb/bbl. However for severe lost circulation the recommended treatment concentration is 30-50 lb/ bbl. The SP300 minimum recommended concentration for LCM applications can be calculated in CemDESIGN.

Note: LC3k is NOT recommended to be added to the WellSHIELD spacer if pumped in 7" and 5" liners or through float collar and shoe not equipped with flapper type valves (such as puppet or dart valves) unless a slot bridging test is performed. Instead,SP300-4k should be used.

26.5.SP300-4k WellSHIELD LC4K

26.5.1.Product Specifications:

LC4K is a lost circulation additive which is added to WellSHIELD spacer systems to remediate against complete and total losses. LC4K is formulated to prevent losses with fracture sizes of 4,000 microns.

Code	SG Range	Absolute Volume (gal/lbm)	Solubility	Appearance
SP300-4K	1.25	0.0821	Non Soluble/ Partially Soluble	Coarse, brown powder

26.5.1.Application:

- Used during total lost circulation where fracture sizes between 10 to 4,000 microns
- Used in high permeability formations, unconsolidated and fractured formations when losses were observed during the drilling phase.
- SP300-4K is used as an alternative to SP300-3k in small restriction cement jobs such as 7" liners or smaller due to its more fibrous nature.

26.5.2.Advantages:

- Improves the WellSHIELD spacer system's effectiveness when losses are challenging
- Effective in sealing a wide range of fracture widths in all types of formations
- Withstand differential pressures > 1200 psi
- Compatible with downhole accessories.

26.5.3.Treatment Recommendations:

- For seepage losses recommended treatment ranges from 10-20 lb/bbl.
- For severe lost circulation recommended treatments of 25-40 lb/ bbl.
- The SP300 minimum recommended concentration for LCM applications can be calculated in CemDESIGN.

27. Slurry Design and Calculations

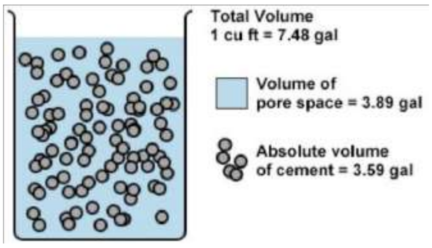
This section will introduce you to parameters, which are important for slurry calculations.

- Bulk volume and absolute volume
- Slurry Calculation Parameters
- API Water Requirement

27.1.Absolute Volume

The absolute volume is the total space taken by only the material, whereas the bulk volume is the total volume of the material and void space.

These can be measured experimentally by adding a volume of water to a dry material without causing an increase in bulk volume. The amount of water added is subtracted from the bulk volume, which results in the absolute volume.



When a dry material occupies a space, it does not completely pack solid within that space. There are void spaces as well as dry material in the given space.

The total volume of material and void space is the bulk volume. If water is added to a bulk volume, the volume does not immediately change because the water is initially replacing the air and filling the void spaces.

For example, a container with 1 ft3 volume will hold one sack of dry cement. The bulk volume of that sack of cement is 7.48 gal. For standard oilfield cement, 3.89 gal of water can be added to the container before overflow.

Therefore, the absolute volume of the cement is 3.59 gal (7.48 gal - 3.89 gal = 3.59 gal).

27.2.Slurry Calculation Parameters

Absolute volume is used to determine all the important slurry calculations, including

- slurry yield
- slurry density
- water requirement

If the cement composition and one of these slurry parameters are known, the other parameters can be calculated, and the slurry can be completely defined. It is important to remember that 1 ft3 of cementing material has an absolute volume of 3.59 gal and that 1 gal of water weighs 8.33 lbm.

27.3.Slurry Yield

Slurry yield is the ratio of the volume of slurry produced to an equivalent sack when cement and additives are mixed with water. Slurry yield is usually expressed in cubic feet per sack of cement (ft3/sk). This measurement is reached by dividing the total volume of

slurry in gal/ sk by the cubic foot conversion (7.48 ft3/gal).

One sack of cement (with a weight of 94 lbm) is 1 ft3. 4.97 gal of water is equal to 0.66 ft3. So, when 1 sack of cement is mixed with 0.66 ft3 of water, an expected result would be 1.66 ft3 of slurry. However, the slurry yield of a neat 15.8 lbm/gal Class G cement slurry is only 1.15 ft3/sk.

The reason for this reduced yield is that the dry cement is composed of cement particles with air between the particles, or the bulk volume. When water is initially added to the cement, it displaces the air without changing the volume.

The volume of bulk cement less the volume of water that displaces air is called the absolute volume.

Volume of Bulk Cement - Volume of Water that Displaces Air = Absolute Volume

The yield when water is mixed with cement is determined by the absolute volume of the cement, not its bulk volume.

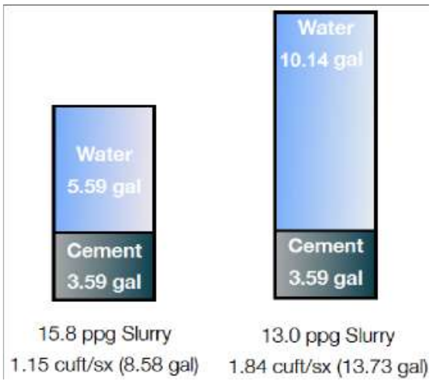
27.4.Slurry Density

Slurry density is the weight of 1 gal of the liquid slurry. It is measured in lbm/gal.

27.5.Water Requirement

The water requirement for a slurry is the amount of water needed to hydrate the dry cement and additives to create a pumpable liquid.

27.6.API Water Requirements



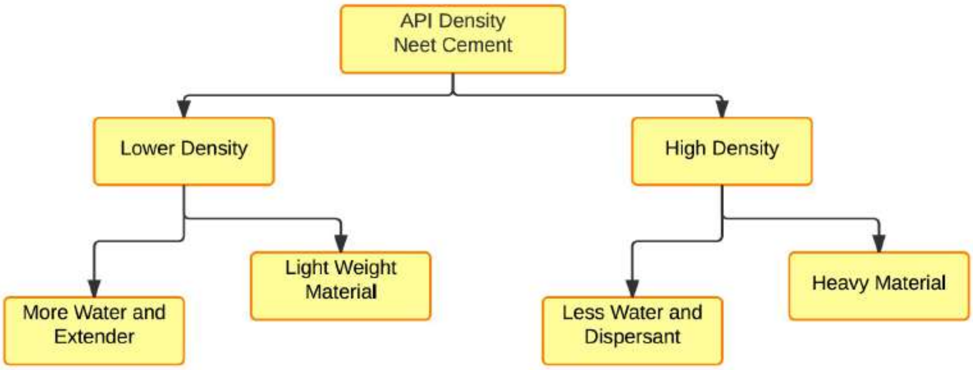
Cement slurries should always have the density specified by the American Petroleum Institute (API). While density can be changed by simply adding or reducing the water-to-solid ratio from the API standards, the effect can be high viscosity (unpumpable slurry) if water is reduced, or excessive free water if the water is increased. Therefore, density should only be changed by using the appropriate additives.

The appropriate ways to both increase and reduce the API slurry density of neat cement can be as follows: Density can be lowered by either

- adding water and extenders
- adding lightweight material

Density can be increased by either

- using less water with a dispersant
- using heavier material



Changing the water-to-cement ratio has the most dramatic effect on Density

Lower density slurries are used when the hydrostatic pressure on the well-bore is above the fracture gradient of the formation. By reducing the density of the slurry, the hydrostatic pressure exerted by the slurry is also reduced.

Extenders, like C501 bentonite, can be used with increased water to make a lower density slurry, but this will also lower the compressive strength of the cement.

Lightweight material, like C402 Light Spheres, is more expensive but has a greater compressive strength than added water and extenders.

Extenders also increase the yield of the slurry. For the same number of cement sacks, there is more slurry volume. This condition makes an extended slurry economically favorable. Therefore, even if formation breakdown is not a concern, it is common to pump an extended lead and then a neat tail slurry.

27.7.Absolute Volume Calculations

Absolute volume is used to determine the slurry calculations of density, yield, and water requirement. It is important to realize that if the class of cement and one other parameter are known, then the other two parameters can be determined.

27.7.1.Calculation of Neat Cement Slurries

Here are examples of calculating neat cement slurries.

Example of Class G Mixed to API Specs

Material	Weight	Abs Vol	Volume
Class G	94.00	0.0382	3.59
H2O (44%)	41.36	1 / 8.33	4.97
Total	135.36		8.56

yield of a class G cement mixed to API specifications. In this example, all calculations are based on:

- one sack of cement which weighs 94 lbm and has a volume of 3.59 gal/sk, and
- water required by API specifications, which is 44% by weight of the cement (BWOC) or 41.36 lbm, and has a volume of 4.97 gal/sk.

The combined volume of one sack of class G cement and the API-specified amount of water is 8.56 gal/ sk.

The density can be determined by dividing the total weight by the total volume

Similarly, the yield can be determined by dividing the total volume by the conversion to cubic feet (7.48 gal/ft3).

Yield = Total Volume / Conversion to ft3 8.56 gal/sk / 7.48 gal/ft3 = 1.144 ft3/sk

Since this slurry is mixed to API specifications, the water required is based on the percentage of water API specifies (4.97 gal/ sk).

Material	Weight	Abs Vol	Volume
Class G	94.00	0.0382	3.59
H2O	8.33*x*	1 / 8.33	*x*
Total	94 + 8.33*x*		3.59 + *x*

where x = gal/sk H2O

Instead of mixing to API specifications, suppose the slurry must be mixed to a density of 15.5 lbm/gal. Then, both the yield and the amount of water required will change. This table shows the information needed to calculate the new yield and water requirement amounts.

Given the density of 15.5 lbm/gal, use algebra to solve for the amount of water required. Simply give the volume of water the value of x and solve for x.

Density = Total Weight / Total Volume

15.5 lbm/gal = (94 + 8.33x) lbm/sk / (3.59 + x) gal/sk

15.5 (3.59) + 15.5x = 94 + 8.33x

55.645 + 15.5x = 94 + 8.33x

15.5x - 8.33x = 94 - 55.645 7.17x = 38.355 x = 5.35 gal/sk

In this example, 5.35 gal of water are required for each sack of cement.

Once the water requirement is determined, yield can be determined.

Yield = Total Volume / Conversion to ft3

(3.59 + x) gal/sk / 7.48 gal/ft3

(3.59 + 5.35) / 7.48

8.94 / 7.48 = 1.195 ft3/sk

If you now plug the volume of water into x and solve the density equation, the accuracy of the math can be checked. If the calculated density equals the given density (15.5 lbm/gal), then the math has been performed correctly. If the calculated density does not equal the given density, then the math has been performed incorrectly and should be recalculated.

Water Weight: 8.33x = 8.33 (5.35) = 44.57 lbm/gal

Total Weight: 94 + 44.57 = 138.57 lbm/gal

Total Volume: 3.59 + 5.35 = 8.94 gal/sk

Density = Total Weight / Total Volume

138.57 lbm/sk / 8.94 gal/sk = 15.5 lbm/gal

Example of Class G with 5.05 gal/sk Water Required

Material	Weight	Abs Vol	Volume
Class G	94.00	0.0382	3.59
H2O	42.07	1 / 8.33	5.05
Total	136.07		8.64

If the volume of water per sack is given, density and yield can be determined for a cement slurry that does not follow API specifications. In this example, the volume of water is 5.05 gal/sk. The calculations are performed in exactly the same manner as previously, except that the water value is not determined from API specifications. This table shows the information needed to calculate the density and yield.

To determine the density, divide the total weight by the total volume.

Density = Total Weight / Total Volume

136.07 lbm/sk / 8.64 gal/sk = 15.75 lbm/gal

To determine the yield, divide the total volume by the conversion to cubic feet (7.48 gal/ft3).

Yield = Total Volume / Conversion to ft3

8.64 gal/sk / 7.48 gal/ft3 = 1.16 ft3/sk Example of Class G with Yield of 1.06 ft3/sk

Material	Weight	Abs Vol	Volume
Class G	94.00	0.0382	3.59
H2O	8.33*x*	1 / 8.33	*x*
Total	94 + 8.33*x*		3.59 + *x*

where x = gal/sk H2O

If the yield is given, density and water requirements can be determined. This table shows the information needed to calculate the density and water requirements if the yield is 1.06 ft3/sk. where x = gal/sk H2O

If the yield is 1.06 ft3/sk, use algebra to solve for the amount of water. Simply give the volume of water the value of x and solve for x.

Yield = Total Volume / Conversion to ft3

1.06 = (3.59 + x) gal/sk / 7.48 gal/ft3

1.06 (7.48) = 3.59 + x

7.93 = 3.59 + x 7.93 - 3.59 = x

x = 4.34 gal/sk

In this example, 4.34 gal of water are required for each sack of cement.

Once the water requirement is known, the density formula can be used to determine the density.

Density = Total Weight / Total Volume

(94 + 8.33x) lbm/sk / (3.59 + x) gal/sk

(94 + 8.33 (4.34)) / (3.59 + 4.34)

(94 + 36.15) / 7.93

130.15 / 7.93

16.41 lbm/gal

27.7.2.Calculation of Slurries With Additives

Just as with neat cement, calculations with additives are based on one sack of cement. If dry additives in concentrations less than 1% by weight of cement (BWOC) are used, these additives are sometimes disregarded in absolute volume calculations because their effect is negligible.

Liquid additives are always included in calculations because even small amounts can affect the water requirements of a slurry. Solid additives are treated as extra weight, not as part of the sack of cement.

The only exception to this is when a cement blend consisting of a percentage of cement and a percentage of pozzolan (flyash) is used. In this case, an equivalent sack weight is determined.

Here are the calculations of density, yield, and water required for class H cement with 3% C013 Calcium Chloride (BWOC) mixed to API specifications.

Material	Weight	Abs Vol	Volume
Class H	94.00	0.0382	3.59
C013	2.82	0.0687	0.194
H2O (38%)	35.72	1 / 8.33	4.288
Total	132.54		8.072

Density = Total Weight / Total Volume

132.54 lbm/sk / 8.072 gal/sk = 16.42 lbm/gal

Yield = Total Volume / Conversion to ft3

8.072 gal/sk / 7.48 gal/ ft3 = 1.079 ft3/sk

Water required = 4.288 gal/sk

27.7.3.Additives Requiring Additional Water

When these solid additives are used, they require additional water be added to the slurry:

- C501 Bentonite
- C511 Attapulgite
- D502 Gilsonite Extender

- C031 Silica Sand
- C504 Barite
- C030 Silica Flour

C501, bentonite, requires 5.3% (BWOC) additional water for each 1% of dry blended C501 added.

C502, gilsonite, requires an additional 1 gal of water for each 25 lbm of C502 added.

C031, silica sand, requires 0.286% (BWOC) additional water for each 1% of C031 added. This is 10% additional water for a 35% mix of C031.

C504, barite, requires an additional 0.024 gal of water for each 1 lbm of C504 added.

C030, silica flour, requires 0.343% (BWOC) additional water for each 1% of C030 added. This is 12% additional water for a 35% C030 mix.

Calculations with Additives Requiring Additional Water.

Material	Weight	Abs Vol	Volume
Class A	94.00	0.0382	3.59
C501	1.88	0.0454	0.085
H2O	94 (0.46 + 2(0.053)) = 53.204	1 / 8.33	6.387
Total	149.08		10.062

This table shows the information needed to calculate the water requirement, density, and yield for a class A cement with 2% C501 mixed to API specifications.

Notice the weight of the water. The Class A cement slurry has a 46% (BWOC) water composition with 5.3% water added for each 1% of C501 added. Therefore, the water required is 6.387 gal/sk.

Here are the density and yield calculations:

Density = Total Weight / Total Volume

149.08 lbm/sk / 10.062 gal/sk = 14.82 lbm/gal

Yield = Total Volume / Conversion to ft3

10.062 gal/sk / 7.48 gal/ft3 = 1.345 ft3/sk

27.7.4. Calculations With Liquid Additives

When working with liquid additives, there is a difference between "mix water" and "mix fluid." Mix water refers to the actual water used to mix the slurry, while mix fluid refers to the total volume of liquid (water and liquid additives) used.

The values given in the Data Handbook are labeled mix water but should be thought of as mix fluid (total liquid), as liquid additives substitute for part of the water. The density of the additive and the water are not the same. In fact, the slurry is no longer API.

Material	Weight	Abs Vol	Volume

Class H	94.00	0.0382	3.59
C303	17.09	0.117	2.0
C201	3.08	0.0973	0.3
C101	2.00	0.100	0.2
H2O	8.33*x*	1 / 8.33	*x*
Total	116.17 + 8.33*x*		6.09 + *x*

where x = gal/sk H2O

This table shows the information for a class H cement blended with 2 gal of C303 per sack, 0.3 gal of C201 per sack, and 0.2 gal of C101 per sack at a density of 16.5 lbm/gal.

Since the density of 16.5 lbm/gal is given, solve for x to find the water requirement.

Density = Total Weight / Total Volume

16.5 lbm/gal = (116.17 + 8.33x) lbm/sk / (6.09 + x) gal/sk

(16.5 (6.09)) + 16.5x = 116.17 + 8.33x

100.485 + 16.5x = 116.17 + 8.33x

16.5x - 8.33x = 116.17 - 100.485 8.17x = 15.685 x = 1.92 gal/sk

In this example, 1.92 gal of water are required for each sack of cement.

After the water requirement is determined, yield can be determined.

Yield = Total Volume / Conversion to ft3

(6.09 + 1.92) gal/sk / 7.48 gal/ ft3

8.01 / 7.48 = 1.071 ft3/sk

Here's the total mix fluid calculation for a class H cement blended with 2 gal of C303 per sack, 0.3 gal of C201 per sack, and

0.2 gal of C101 per sack at a density of 16.5 lbm/gal.

Total Mix Fluid = Total Volume of Liquid (Water + Liquid Additives)

= 1.92 (H2O) + 2.0 (C303) + 0.3 (C201) + 0.2 (C101) = 4.42 gal/sk

27.7.5. Calculations With Salt (NaCl)

Since common rock salt (or NaCl) dissolves rapidly in fresh water (up to its saturation point of 37.2% by weight of water), it increases the mix water volume of the slurry. Because saturation is measured by weight of water (BWOW), salt is added to mix water by weight of water (not by weight of cement). This is the only dry additive treated in this fashion.

Since most water soluble additives are mixed in small concentrations, their effects on slurry properties are negligible. However, C505 (salt) is mixed at very high concentrations, so its effect must be taken into consideration when performing absolute volume calculations.

The absolute volume factor used for C505 is different when dealing with a non-saturated solution or a saturated solution. This is because after saturation, some of the salt comes out of solution. The saturation point of salt is generally considered to be 37.2%.

However, if the ambient temperature is high or low, the saturation point will increase or decrease, respectively. This is not normally a problem unless you are in an extremely cold or hot climate. There are temperature charts available to allow for this correction. Both absolute volume factors are given in the Data Handbook.

This table shows the information needed to calculate the water requirement, yield, and C505 requirement for a class H cement with 37.2% C505 (BWOW) mixed at a density of 17.3 lbm/gal.

Material	Weight	Abs Vol	Volume
Class H	94.00	0.0382	3.59
C505	0.372 (8.33*x*)	0.0556	0.17*x*
H_2O	8.33*x*	1 / 8.33	*x*
Total	94 + 11.43*x*		3.59 + 1.17*x*

Since the density of 17.3 lbm/gal is given, solve for x to find the water requirement.

Density = Total Weight / Total Volume

17.3 lbm/gal = (94 + 11.43x) lbm/sk / (3.59 + 1.17x) gal/sk

17.3 (3.59) + 17.3 (1.17x) = 94 + 11.43x

62.107+ 20.241x = 94 + 11.43x

20.241x - 11.43x = 94 - 62.107 8.811x = 31.893 x = 3.62 gal/sk

In this example, 3.62 gal of water are required for each sack of cement.

After the water requirement is determined, yield can be determined.

Yield = Total Volume / Conversion to ft3

(3.59 + 1.17 (3.62)) gal/sk / 7.48 gal/ ft3

(3.59 + 4.24) / 7.48

7.83 / 7.48 = 1.046 ft3/sk

To determine the amount of C505 required, plug the volume of water into x and solve.

C505 weight = 0.372 (8.33x)

0.372 (8.33 (3.62))

0.372 (30.15) = 11.21 lbm/sk

C505 volume = 0.17 (3.62) = 0.6154 gal/sk

To check your calculations, make sure your density is equal to the given density of 17.3 lbm/gal.

Density = Total Weight / Total Volume

(94 + 11.43x) lbm/sk / (3.59 + 1.17x) gal/sk

(94 + 11.43 (3.62)) / (3.59 + 1.17 (3.62))

(94 + 41.3766) / (3.59 + 4.2354)

135.3766 / 7.8254 = 17.3 lbm/gal

28. Chemicals Safety

Handling a cementing material can cause a health hazard. Knowing if a hazard is present, what it is and taking the necessary precautions is the key to personal safety. This holds true not only for cementing materials but for all chemicals. The mechanisms for communicating personal safety information during chemical handling are:

- Material Safety Data Sheets (MSDS)
- Standardized labeling

In addition to personal safety, safe chemical handling includes maintaining a quality environment. Procedures for handling chemical spills, waste disposal and shipping fall under this category.

This manual section is not intended to cover all aspects of material safely. Much of this information is available in other literature and will therefore be referenced. Only the key points will be discussed to provide the reader with a general overview.

28.1.Material Safety Data Sheet (MSDS)

The Material Safety Data Sheet (MSDS) is the main information source on material safety. For each chemical stored or handled within Sprint, an MSDS is available. This includes Sprint-coded products as well as chemicals supplied by an outside vendor.

The MSDS is the first information source on material safety to be updated, and is updated the most frequently. By referring to MSDS, you are assured to get the most current information available. For each chemical, MSDS contain:

- Physical data,
- Fire and explosion hazard data,
- Reactivity hazards,
- First aid procedures,
- Handling precautions,
- Spill and disposal procedures,
- Toxicology,
- Special precautions and additional information,
- Shipping information.

An outside-source MSDS may look different than Sprint MSDS; however, they both contain the same type of safety and health information.

28.2.Labels

All containers of hazardous chemicals are labeled. The label contains the basic safety and health information necessary for personal safety. This information corresponds with the detailed information in the respective MSDS.

The labels on containers from outside sources may look different from a label on a Sprint container. Although different in appearance, they both contain the same type of safety and health information.

29. Well Preparation

29.1.Introduction

Well preparation prior to cementing consists of:

- completely cleaning and stabilizing the wellbore and drilling mud
- running the casing in the well at an acceptable rate with the correct casing hardware
- conditioning the drilling mud.

Proper well preparation is the first of many steps required to achieve a successful cement job. Failure to do so limits the effectiveness of all other efforts.

Since well preparation is performed by the rig under the direct supervision of the operator's representative on location, its implementation can only be influenced via the recommendations included in the job design and the communication of the information presented in this manual section.

29.2.Cleaning & Stabilizing

The objective of cleaning and stabilizing the well-bore and drilling mud is to:

- move immobile mud located in washouts
- mobilize and remove settled cuttings
- remove any entrained gas from the drilling mud
- achieve maximum mud-circulation efficiency. Fluid calipers can be used to confirm this.
- reduce gel strength and yield point to aid mud removal.

This is achieved by:

- wiper trips, including pipe movement (rotation and reciprocation), during and after logging
- circulation during wiper trips until mud properties are acceptable (no entrained gas and stabilized solids content)
- mud circulation at regular intervals (every 1000 to 3000 ft) while running casing.

Regular mud circulation while running casing removes the filter cake that has collected around the collars, scratchers and centralizers. It also prevents the accumulation of cuttings and other solids and breaks the mud gel strength, which could cause excessive pressures when circulation is resumed after the casing has been completely run.

29.3.Running Casing

To have the casing correctly placed in the well means not only incorporating the required casing hardware while it is being run, but also minimizing formation damage during the running operation.

Prior to running the casing, we should ensure that the number of centralizers and their placement will conform to the design, and the scratchers and their proper placement are strongly recommended, even if someone else is supplying this casing hardware.

For two-stage cement jobs using a non-latching first-stage plug, a rubber seal-off plate must be secured to the top internal surface of the landing collar before the collar is attached to the casing. This plate provides the hydraulic seal when the plug is bumped and the casing is pressured up (two-stage cementing equipment is discussed in Equipment Requirements).

When the number of centralizers recommended in the job design appears excessive, the operator may raise concerns over the possibility of the casing becoming stuck. This concern is addressed during the job design using the Running Force option in the Centralizer calculator of the program. For the worst condition (when the casing bottom reaches total depth), the hook load to pull the casing and the hook load while lowering the casing (a negative value means the casing is stuck) are calculated.

Scratchers are strongly recommended to help remove immobile mud in the well-bore. They are effective only when used in conjunction with pipe movement during well circulation and cementing operations.

There are two types of scratchers, one for casing rotation and the other for casing reciprocation. Both scratcher types use wires or cables to help remove the mud.

For jobs using casing reciprocation, the spacing between the scratchers must be less than the reciprocation stroke length to ensure complete mud disturbance.

Casing being run into a well exerts surge pressures within the well-bore, with the maximum pressure occurring when the casing bottom reaches total depth. The magnitude of the surge pressure is directly related to the casing running speed: the greater the running speed, the higher the surge pressure. In some cases, excessive casing running speeds can induce formation fracturing.

Maximum surge pressures are exerted when the casing string contains standard float equipment. Casing strings containing automatic fill-up or differential fill equipment instead of standard float equipment reduce the surge-pressure effect.

29.4.Drilling-Mud Conditioning

With the casing in place, the final stage of well preparation before starting the cement job is to condition the drilling mud to improve its mobility. Conditioning the drilling mud means reducing the rheology (plastic viscosity, yield point) and gel strength of the drilling mud to the minimum possible while circulating the well and reciprocating or rotating the casing.

The degree to which these mud properties are reduced is ultimately decided by the customer representative, in consultation with the mud engineer.

Drilling fluid is conditioned to:

- reduce gel strength,
- reduce or optimize the yield point (the resistance to initial fluid flow) and
- plastic viscosity (the tangential shearing force in excess of the yield point value required to induce a unit rate of shear),
- reduce solids in the fluid (cuttings) to less than 6% of the total volume, and

• achieve mud flow all around the casing.

One responsibility of the Sprint representative on the job is to check that:

• the final mud rheology is acceptable based on the mud rheology used for the cement-job design

• the mud-circulation rate during mud conditioning exceeds the Minimum Mud-Circulation Rate stated in the job design

• the mud-circulation and pipe-reciprocation rates during mud conditioning comply with the rates recommended in the design

If any of the above points are not in compliance, then Sprint representative should make every effort to convince the customer representative to make sure they are acceptable mud rheology is when the actual plastic viscosity and yield point are equal to or preferably less than those used in the cement-job design. A potential consequence of unacceptable mud rheology, if the job is executed as per design, would be incomplete mud removal.

Once the proper mud conditioning has been achieved, the well should be circulated at least one full (calipered) hole volume prior to cement-job commencement.

29.5.Displacing Mud from the Annulus

The final step in the process of mud removal is to displace the mud from the annulus and replace it by the injection of cement slurry.

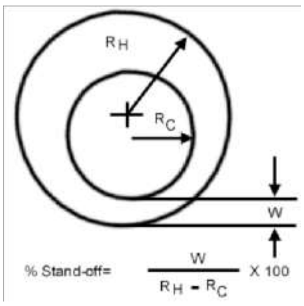
Casing standoff is the ratio of the smallest annular gap to the average annular gap between two pipes with different diameters if one is completely centered within the other. Casing standoff should be over 70% before cement is pumped.

Both reciprocation (up and down motion) and rotation (circular motion around an axis) of the casing should be taken into account and allowed for, if possible. If reciprocation occurs, as the casing moves up, the relative pump rate in the annulus decreases (swab pressure); as the casing moves down, the relative pump rate increases (surge pressure). This effect can create pressures different from those calculated for stationary casing.

29.6.Criteria for Mud Removal

Drilling the hole correctly with good drilling fluid properties and mud removal is of primary importance to complete an in gauge and stable hole. The criteria for effective mud removal are:

• A well-centralized casing. A standoff of 100% is ideal. A minimum standoff of no less than 70% is acceptable.



• The casing in motion, if possible, throughout the job, from the start of circulation to the end of displacement. This motion can be reciprocation or rotation. If motion is possible, use scratchers to help scrape filter cake off the wall and to help move any thick, gelled mud.

• Use of both top and bottom wiper plugs. More than one bottom plug is recommended.

• Use of pre-flushes (Well washes and spacers) to separate the slurries from the drilling fluid and to perform efficient hole cleaning. The cement (heavier than mud) has a tendency to channel in the mud in the casing. The same applies to the mud -spacer interface. Cement contamination while traveling down a casing can be very dramatic and can completely ruin the cement job.

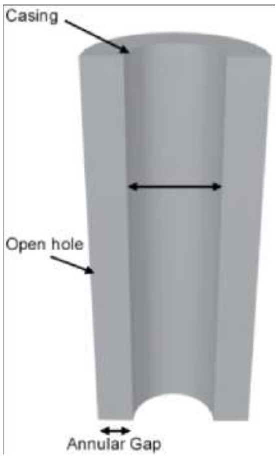
- Achievement of turbulent flow for the most effective mud removal. If turbulent flow cannot be achieved, Laminar Flow (LF) is the second choice.

Effective mud removal is greatly influenced by the geometry of the well-bore in which the casing is run. Effective mud removal is influenced by:

- Angular gap standards
- Sloughing
- Flow from the formation into the well-bore
- Flow regime
- Effects of temperature
- Mud filter-cake in the well-bore
- Mud circulation
- Caliper log and mud circulation
- Mud circulation efficiency

Annular Gap Standards

The industry standard for the total gap between the casing and the well-bore is 1.5 in. The minimum standard annular gap is 0.75 in. An annular gap of less than 0.75 in. results in a cement sheath that is too thin and, therefore, very fragile and that could be shattered by drilling-induced vibrations or the impact of perforating.



For example, the total gap between a 9-5/8 in casing and its standard hole size of 12.25 in is 1.31 in (12.25 in – 9.625 in = 2.62 in.

The annular gap = 2.62 in/2 = 1.31 in). This gap ensures a good sheath of cement around the casing.

The gap between a 7-in casing and its natural hole size of 8.5 in is 0.75 in (total gap = 8.5 in - 7.0 in = 1.5 in; annular gap = 1.5 in/2 = 0.75 in, the minimum acceptable size).

Sloughing

The open hole should be stable with no sloughing. If the formation is caving in, rocks from the underground formations could block the flow of fluids in the annulus with disastrous consequence for the cement job.

The hole should be as uniform as possible even if it is greater than the drilled hole. A uniform hole can be effectively cleaned out, but caves in the well-bore contain gelled mud that is not removed by the spacers, preventing a good cement job.

Flow from the Formation Into the Well-bore

There should be no flow from the formation into the well-bore. The well must be perfectly under control before cementing is initiated with no fluid losses or intake. If there are losses, part or all of the cement slurry could be lost. If formation fluids (water, oil, or gas) are allowed to enter the well-bore during a cement job, the

• Cement slurry will be contaminated by the formation fluids

• The cement will not set properly

• A blow-out situation may develop.

Flow Regime

The casing is centered in the hole. The ideal standoff is 100%. Sprint requires that it is not less than 70%. An ideal standoff ensures that fluids flow equally all around the casing.

Fluid velocity (ft/sec or ft/min) is always higher on the wide side of an eccentric annulus than on the narrow side. The fluid flowing in an eccentric annulus takes the path of least resistance and flows through the wide side, where friction pressure is reduced.

Without careful attention to flow regime, a channel of drilling mud can remain in an eccentric annulus after the fluid displacement process is completed. Such a channel can make the entire cementing job ineffective.

Effects of Temperature

Accurate bottom-hole static temperature (BHST) and bottom-hole circulating temperature (BHCT) are necessary to determine accurate placement time of both lead and tail slurries.

Errors in placement time can result in premature setting or over-retardation of the slurry.

The static temperature at the top of the cement should be higher than the bottom-hole circulation temperature (BHCT) at total depth to ensure that the cement sets up as quickly at the top as at the bottom. The result is a more effective cement job.

Mud Filter-cake in the Well-bore

The mud filter-cake in the well-bore should be thin and impermeable. It should not be gelled or unconsolidated. A thin filter-cake is not moved by the fluids passing by it, nor does it contaminate the slurry or greatly affect the results of the cement job. Gelled or unconsolidated filter-cake, however, can contaminate the slurry and result in a poor cement job.

Mud Circulation

Take care to ensure that there is no lost circulation into the well-bore. Lost circulation can result in the slurry entering the formation instead of filling the annular gap.

The ideal well-bore has an in gauge diameter hole. The closer the hole to the gauge, the easier turbulent flow is to achieve. The more uniform the hole, the less volume of fluid is required to complete each phase of mud removal.

The mud is conditioned to ensure that all mud is movable and, therefore, can be removed.

The Caliper Log and Mud Circulation

The entire volume of the hole must be in circulation to effectively displace the mud from the casing and the well-bore.

Use fluid calipers with the caliper log to determine how much of the mud in the hole is in circulation. If parts of the hole are not in circulation, then mud is not removed and the cement slurry by-passes those sections of the well-bore.

The caliper log procedure is simple and is performed as often as possible.

The most important step is to run a *BGT log (borehole geometry tool, or multi-arm caliper) to determine the difference between the actual open hole volume and the total hole volume.*

Mud Circulation Efficiency

After the caliper log is run and the casing is on bottom, the well is circulated at the expected maximum cementing rate. At this time, mud circulation efficiency is determined. The steps in determination of mud circulation efficiency are:

- Drop markers or tracers at staged intervals during circulation. The markers can be colored fluids or objects (like rice) that can be easily seen when they return to the surface.
- Monitor the returning fluids for markers as the well is circulated.
- Determine the volume of fluid circulated to return each marker from the pump rate and time. This volume should be reasonably close to the total hole volume determined by the caliper log.
- Increase the pump rate and repeat the calculations if the circulated volume and caliper log volume are very different. As the pump rate increases, the volume of fluid should increase.

29.7.Flow Regimes

29.7.1.Turbulent Flow

Turbulent flow is the best flow regime to remove drilling fluid, based on both experiments and statistics. When formation features and other considerations make it impossible to reach turbulent flow, laminar flow is used. Turbulent Flow Displacement

For a fluid to be in turbulent flow, it must be pumped above a minimum flow rate, i.e., the critical flow rate.

The fluid particles move in a swirling, randomized motion, which aids in the removal of a cuttings bed in highly deviated holes.

The critical flow rate of a given fluid depends on four factors:

- The rheology of the fluid (i.e., the thinner the fluid, the easier it goes into turbulent flow).
- The centralization of the casing or casing standoff (i.e., the better centralized the casing, the easier the fluid goes into turbulence all around the casing).
- The annular gap or clearance between the casing and the hole size (i.e., the smaller the gap, the easier the fluid will go into turbulence).
- The fracture gradient of the formation.

The fracture gradient of the formation is an indirect factor, but it must be taken into account. If the pressure required to achieve turbulent flow is higher than the fracture gradient of the formation, the formation may rupture, and losses of fluid will result.

Fluids appropriate for use as pre-flushes are WellWashes and CemBOND-T spacers. Water, diesel oil, or base oil can also be used. There are minimum requirements for the use of washes and spacers. The requirements for the use of washes and spacers are:

- Contact time in turbulent flow must be at least 10 minutes. When well conditions are favorable (e.g., the casing can be rotated, good mud properties, etc.) contact time can be dropped but never below 5 minutes.
- All fluids pumped must be compatible with both the drilling fluid in the well and the slurries to be pumped.

- The cement slurry properties must be optimized. In other words, the yield point (the resistance to initial fluid flow), and plastic viscosity (the tangential shearing force in excess of the yield point value required to induce a unit rate of shear), must be reduced without causing sedimentation or free water.
- Fluid loss should be controlled.
- All fluids must be designed to water-wet the casing and formation.

29.7.1.Laminar Flow

Laminar flow (LF), is the alternative flow regime when turbulent flow is not possible. Laminar flow tends to occur in the low flow regimes in the annulus; therefore, most drilling fluids exhibit laminar flow.

Rules for the Well Cleaning in laminar flow

For a displacement to be considered in effective laminar flow, four conditions must be met to prevent channeling and/or fluid contamination during cement placement. The four conditions for a displacement to be considered in LF are:

1. The displacing fluid must have a density 10% higher than the fluid being displaced.
2. The Minimum Pressure Gradient must be satisfied for all fluid involved (i.e., there must be flow all around the casing).
3. The displacing fluid must exert a friction pressure gradient 20% higher than the fluid being displaced.
4. The differential velocity criteria (also called the interface stability criteria) should always be used during job design. The differential velocity criterion is easier to achieve when standoff is good to very good. Conditions for achieving the differential velocity criteria include:
    - minimizing the velocity difference between the displaced and displacing fluids to establish a flat interface. The sum of the gravitational force and the friction force of the displacing fluid in the wide side of the annulus must be greater than that of the fluid being displaced in the narrow side of the annulus.
    - maintaining the annular flow rate below a certain value. When the displacement rate is too high, the displacing fluid tends to bypass the fluid to be displaced rather than displacing it uniformly around the annulus.

Viscous Spacer for LF pumping process.

A viscous spacer, the CemBOND-L, has been developed to meet the criteria of the LF regime. This spacer has an adjustable viscosity based on changing the concentration of SP102 in the spacer. When pumping WB-L, a minimum of 500 feet in the annulus or 60 bbl must be used; 20 to 40 bbl of WellWash should be used ahead of the spacer to start to disperse the drilling fluid.

29.8.Eccentric Annulus Flow Regimes

29.8.1.Laminar Flow in an Eccentric Annulus:

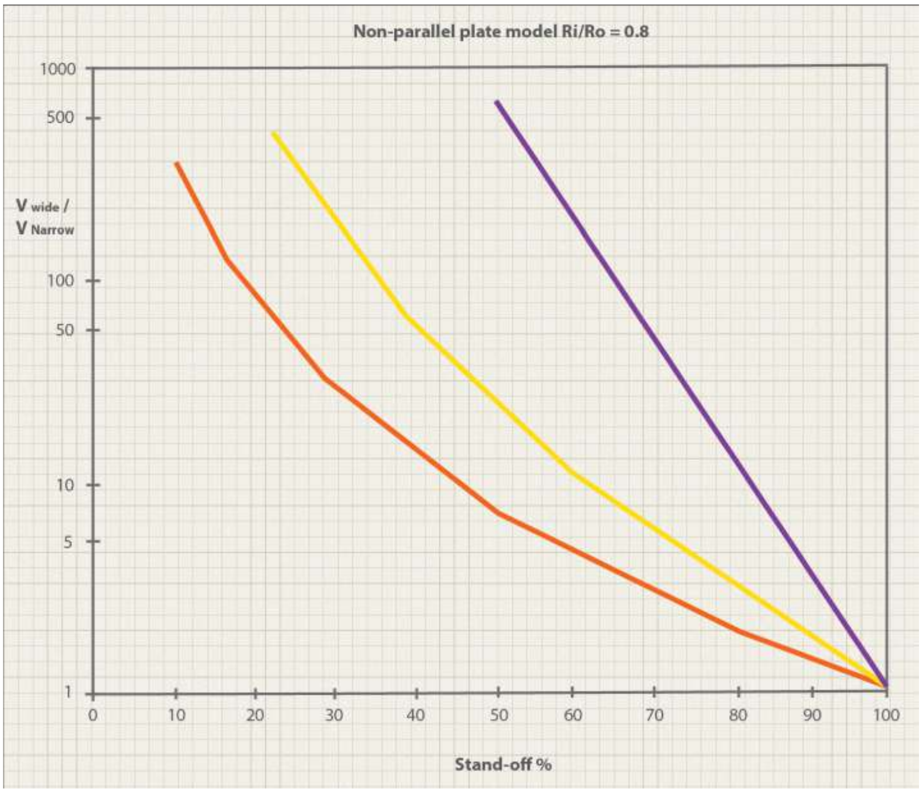


Figure above gives the ratio of velocity in large and small pipe vs. standoff in laminar flow fluids

Laminar flow is generally associated with low rates and orderly patterns of flow, such as found in the annular regions of a well bore and with fluid movement in uniform layers. In laminar flow, the flow rate/flow pressure relationship is a function of the viscous properties of the fluid (ref. Rheology Module).

This graph plots the ratio of the velocity in the large pipe over the velocity in the small pipe versus the standoff. A fluid with an N value of 1 and standoff of 70% has a velocity in the larger pipe 50 times higher than the velocity in the smaller pipe, illustrating the importance of having as high a standoff as possible in laminar flow.

The graph also illustrates that as the fluid deviates from a Newtonian fluid (N=1), the effects of standoff decrease, but are still very important. For example, for a fluid with an N value of 0.2 and a standoff of 60%, the velocity ratio between the large diameter pipe and the small diameter pipe is five, i.e., the fluid flows five times faster in the larger pipe.

29.8.2.Turbulent Flow in an Eccentric Annulus

Turbulent flow occurs at high flow rates and results in erratic, random flow patterns. The flow rate/flow pressure relationship is governed by the inertial forces of the fluid (ref. Rheology Module).

For the same fluid in turbulent flow through the two pipes, the velocity in the larger pipe is 1.64 times the velocity in the smaller one, and the Reynolds number is 3.28 times greater.

• Velocity
$$\frac{\Delta P}{\Delta L} = \frac{0.241 \times \rho^{0.75} \times \mu^{0.25}\left(\frac{V_1 \pi D_1^{\,2}}{4}\right)^{1.75}}{D_1 4.75}$$
$$= \frac{0.241 \times \rho^{0.75} \times \mu^{0.25}\left(\frac{V_2 \pi D_2^{\,2}}{4}\right)^{1.75}}{D_2 4.75}$$
if $D_2 = 2D_1$
$$V_2 = 1.64 V_1 (\text{for } 67\%)$$
• Reynolds number
$$Re_2 = \frac{\rho V_2 D_2}{\mu} = \frac{\rho 1.64 V_1 2 D_1}{\mu} = \frac{3.28 \rho V_1 D_1}{\mu}$$
$$Re_2 = 3.28\, Re_1 (\text{For } 67\%)$$

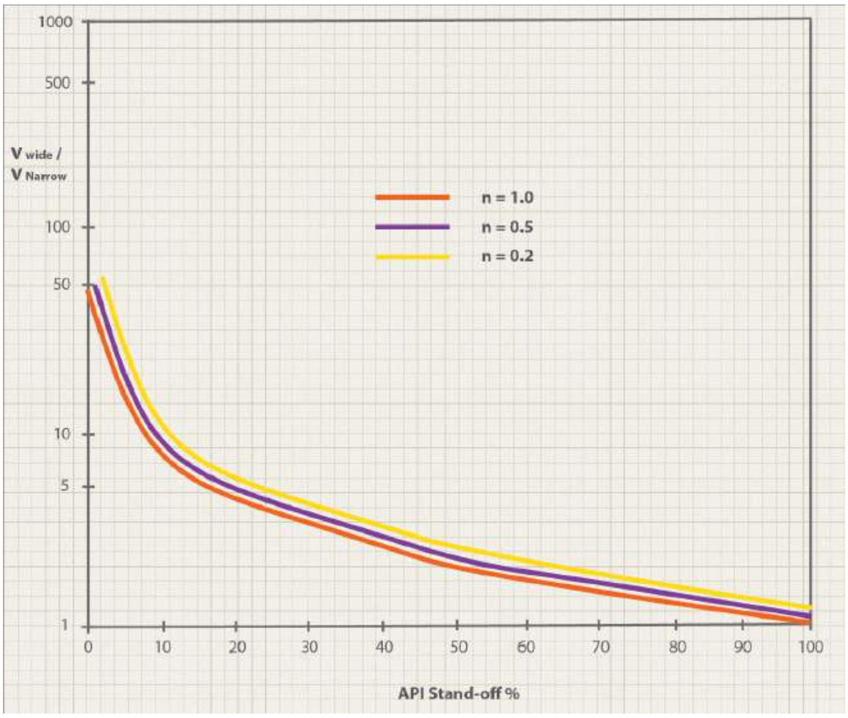


Figure above gives the ratio of velocity in large and small pipe vs. standoff in turbulent flow fluids

This graph illustrates the same relationship for turbulent flow as previously illustrated for laminar flow. Notice that there is very little difference between the fluid characteristics of Newtonian and non-Newtonian fluids. For any fluid in turbulent flow, the effect of standoff becomes very significant when standoff is below 20%. This is the primary reason turbulent flow is the preferred flow regime.

29.8.3.Standoff

As previously discussed, standoff is the ratio of the smallest annular gap to the average annular gap between two pipes with different diameters, if one is completely centered within the other.

The graph illustrates the ratio of flow rate necessary to achieve turbulent flow in an eccentric annulus compared to the flow rate necessary to achieve turbulent flow in a concentric annulus.

Above 75%, there is little difference in the flow rate ratio.

Down to 35%, the flow rate ratio changes almost linearly to about five times faster on the wide side than on the narrow side.

Below 35% standoff, the flow rate ratio starts to increase exponentially.

There are two ways to increase standoff from casing:

- Drill perfectly straight holes.
- Use centralizers on the casing.

Perfectly straight holes are rarely possible or desired, so centralizers on the casing are used extensively.

30. Cementing Data & Design Checklist

30.1.1. Well Data Checklist

Client :		**Field Name :**	
Total Depth :		Well Name :	
Land / Offshore :		Country / Province :	

30.1.2. Surface Casing Checklist

Surface Casing	
Size:	
Depth:	
OH size:	
BHST:	
Lead Slurry Density:	
Tail Slurry Density:	
Stab in Shoe/collar?	
Surface Losses?	
Losses Depth:	
Average No of LC Plugs per section:	
Average volume for each plug:	
Losses per hr prior to start of cement job	

30.1.3.Intermediate Casing

Intermediate Casing	
Size:	
Depth:	
OH:	
BHST:	
Mud Density:	
Min. Frac Gradient:	
Max. Pore Pressure:	
Lead Slurry Density:	
Tail Slurry Density:	
DV Tool ? and depth if any? Losses?	
Losses depth:	
•depth 1:	
•depth 2:	
•depth 3:	
Average No of LC Plugs per section: Average volume per plug:	
Losses per hr prior to start of cement job	
High pressure zone?	
HP zone Depths:	
•depth 1:	
•depth 2:	
•depth 3:	
Average Cement Squeezes per section:	
Average Volume per Squeeze:	

30.1.4.Production Casing / Liner

Production Casing / Liner	
Size:	
Depth:	
OH:	
BHST:	
Mud Density:	
Min. Frac Gradient:	
Max. Pore Pressure:	
Lead Slurry Density:	
Tail Slurry Density:	
Liner Top depth if any:	
Losses or high Pressure Zone ?	
Losses per hr prior to start of cement job	
Average No. of Cement plugs or Squeezes per section:	

30.1.5.Liner Cementing Checklist

Liner Cementing Checklist				
Category	**Description**	**Checked**	**Value**	**Comments**
Cement Slurry	Use Fracture and Pore Pressure Gradients to check Flow Potential of Well.			
	Cement slurry design Temperature:			
	Use CemPRO+ temperature simulations for slurry design			
	For 5 in liners and smaller sizes use BHSqT for all depths			
	Identify Zones of interest (Production zones, gas zones, losses zone, etc…)			
	Lab mixing is compliant to 5API in TightHoles			
	Lab slurry agitation duration in lab matches field agitation time			
	Slurry fluid loss < 50 ml/30min			
	Thickening time > 4 hrs and check 24 Hrs Compressive strength at top of liner			
	Cement-Spacer Compatibility test conducted at 25:75 / 50:50 / 75:25			
	Cement-Spacer fluid loss test conducted at 25:75 / 50:50 / 75:26			
	Pv < 90 cp			
	Ty greater than 5 lb/100ft2 and less than 12 lb/100ft2			
Spacer	Fluid loss of spacer < 50 ml/30min			
	Spacer complying to design rule for weighting agent and density			
	Mud-Spacer Compatibility test conducted at 25:75 / 50:50 / 75:25			
	Mud-Spacer fluid loss test conducted at 25:75 / 50:50 / 75:26			
	1.4 Pv Mud <= 1.2 * Pv Spacer <= Pv Cement			
Placement	Liner hanger clearance is > 60% of the cross section area			
	Run CentraDESIGN for centralization with actual BGT Log and centralizers data			
	70% Stand-off is achieved in the recommended CentraDESIGN program.			

	Simulate Pumping Rates, Pre-Flush Volumes and Rheologies to Optimizes Displacement Efficiency (avoid inducing losses and / or causing well control situation)).			
	For liners where it is planned not to set Liner Hanger Packer, Check the well stability when cement slurry gels up and its hydrostatic head reduces to water head equivalent.			
	For muds with oil content Wash and Spacer shall leave formation water-wet by incorporating Water Wetting Surfactant and Mutual Solvent as needed			
	Physically Confirm WellWash volume pumped from surface.			
	Physically Confirm Spacer volume pumped from surface.			
	Physically Confirm Slurry volume pumped from surface.			
	Physically Confirm Displacement volume pumped from surface.			
	Mixing time matches or less then lab slurry mixing time			
	Pumping time matches lab slurry agitation time			
	Run CemPRO Mud Removal simulation using actual Hole caliper.			
	Cementing Simulation is run using actual hole diameter and fluids properties			
	Operator have a copy of the simulation on location			

30.1.6.Coiled Tubing Cementing Checklist

Coiled Tubing Cementing Checklist				
Category	**Description**	**Checked**	**Value**	**Comments**
Cement Slurry	Use Fracture and Pore Pressure Gradients to check Flow Potential of Well.			
	Cement slurry design Temperature shall be equal to BHST			
	Identify Zones of interest (Production zones, gas zones, losses zone, etc…)			
	Lab mixing is compliant to 5API in TightHoles			
	Lab slurry agitation duration in lab matches field agitation time			
	Slurry fluid loss < 50 ml/30min			
	Thickening time > 6:30 hrs and check 24 Hrs Compressive strength at top of plug			
	Cement-Spacer Compatibility test conducted at 25:75 / 50:50 / 75:25			
	Cement-Spacer fluid loss test conducted at 25:75 / 50:50 / 75:26			
	Pv < 70 cp			
	Ty greater than 5 lb/100ft2 and less than 9 lb/100ft2			
Spacer	Fluid loss of spacer < 50 ml/30min			
	Spacer complying to design rule for weighting agent and density			
	Mud-Spacer Compatibility test conducted at 25:75 / 50:50 / 75:25			
	Mud-Spacer fluid loss test conducted at 25:75 / 50:50 / 75:26			
	1.4 Pv Mud <= 1.2 * Pv Spacer <= Pv Cement			
Placement	Bull Nose Nozzle is used at bottom of the BHA			
	For muds with oil content Wash and Spacer shall leave formation water-wet by incorporating Water Wetting Surfactant and Mutual Solvent as needed			
	Physically Confirm WellWash volume pumped from surface.			
	Physically Confirm Spacer volume pumped from surface.			
	Physically Confirm Slurry volume pumped from surface.			

	Physically Confirm Displacement volume pumped from surface.			
	Mixing time matches or less then lab slurry mixing time			
	Pumping time matches lab slurry agitation time			
	Cementing Simulation is run using actual pipe and hole diameter and fluids properties			
	Operator have a copy of the simulation on location			

31. Primary cementing

Primary cementing is the placement of a cement slurry into the annulus between the casing and the formation exposed to the well-bore (open hole) or previous casing.

The most important objective of primary cementing is to provide zonal isolation(that is, to prevent communications between the different zones in a well). In addition, the cement provides support for the several casing strings run in a well.

Another objective for primary cementing is to protect the casing from plastic (e.g.,salt) formations or corrosive formation fluids (e.g., waters containing sodium ,calcium, magnesium, or dissolved CO_2). Without cement for support, the plastic-formation will deform, or creep, and may collapse or shear the casing. Also, underground corrosive waters can destroy the integrity of the steel (of the casing) in a few years, which results in unwanted fluid migration during production, or, worse, premature loss of the well.

Finally, primary cementing is done to protect the borehole from collapsing (otherwise known as caving in), especially across plastic, water-sensitive, or unconsolidated formations.

31.1.Casing Running Objectives

Casing is placed down the well-bore from the surface to:

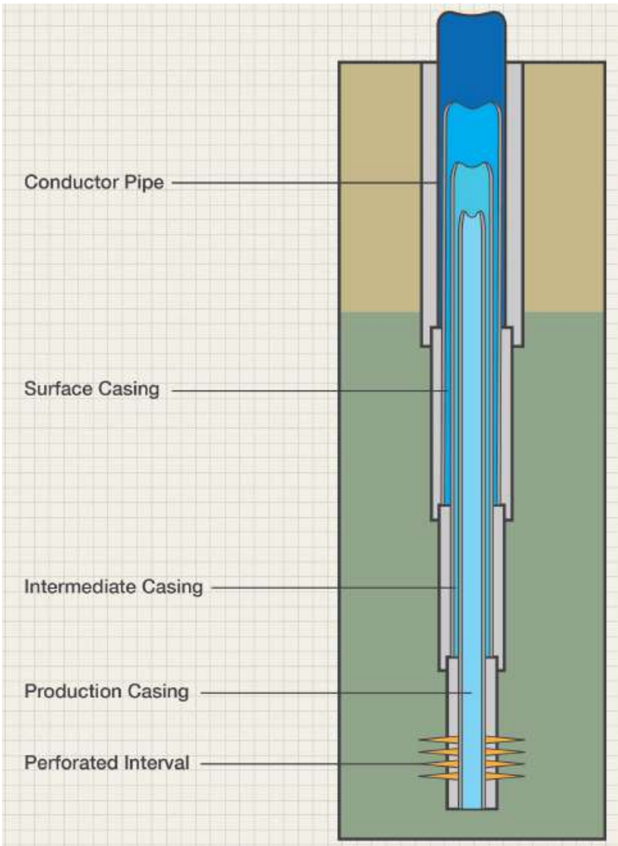
- separate the open hole from the formation.
- prevent the well-bore from caving in.
- allow the flow of fluids both in and out of the well-bore.

The size of the casing depends on

- the depth of the well.
- the size of the open hole.
- the drilling objective.
- the expected hydrostatic and formation pressures.
- the type of completion once the well is drilled.

Of these, the hydrostatic and formation pressures are the most important to avoid bursting or collapsing of casing.

Depending on the size and type of casing to be cemented, different methods of cementing may be used. To understand these methods, it is important to learn about the various types of casings.



31.2.Types of Casing Strings

- conductor casing

- surface casing
- intermediate casing
- production casing
- liners.

31.3.Conductor Casing or Pipe

Conductor casing is the largest casing run in a hole. Its size ranges from 30 in. down to 16 in. in diameter. Its primary purpose is to:

- prevent washout under the rig
- provide elevation for the flow nipple to allow mud flow-back to the rig tanks.

Conductor casing is usually set at shallow depth, running from between 30 to 200 ft, with 100 ft being the most common.

This shallow, large casing is often driven into the ground through the use of a pile or pile hammer, and often does not require cementing. If cementing is done, plugs are not used. Cement is pumped until it returns to the surface; then, displacement fluid is pumped until 40 to 80 feet of casing is left full of cement. Neat cement with an accelerator is normally pumped in to reduce the waiting-on-cement (WOC) time at low temperature. Because plugs are rarely used, slurry contamination can occur in both the pipe and the annulus. For this reason, cement is often seen reaching the surface long before it is expected. This is called channeling, or fingering. To avoid contamination inside the casing, the through-tubing, or through-drill pipe or stabin cementing method is performed. Conductor casing is not always API standard, so extra care must be taken when pumping to avoid exceeding the burst or collapse pressure on the casing during the job. This means that pumping must be done very carefully, with the job carefully recorded.

Conductor casing can be either welded or threaded. Usually, the larger sizes (20 to 30 in.) are welded, while the smaller sizes (16 to 20 in.) are threaded.

Because formations at the surface are unconsolidated, there are usually large washouts, which lead to excess volumes of 100% to 200% being pumped.

The drilling of these surface holes has a large impact on the size of the holes. Drilling with too much hydraulic horsepower (too fast of a flow rate) will result in an oversized hole.

Normally, the blowout preventers (BOP) are not connected at this stage, so care must be taken to avoid lost control of the well (which could be the result of a strong water flow). In wells where over-pressured formations are likely to be encountered, the BOPs are installed.

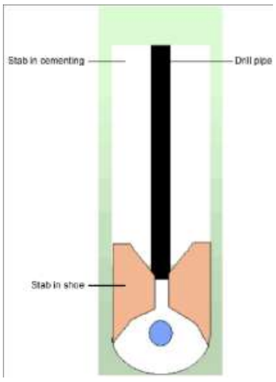
It is also quite common to face a problem with shallow freshwater zones (Artesian wells), which can produce at very large flow rates and can endanger the drilling rig as the ground below gets washed away.

31.3.1.Conductor Cementing Methods:

This section will describe these two cementing methods:

- through-drill pipe, or stab-in, cementing
- outside cementing.

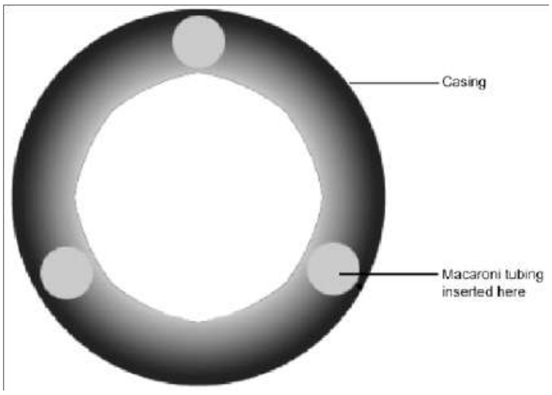
Through-Drill pipe or Stab-In Cementing:



There are three important reasons for using the through-drill pipe, or stab-in method of cementing:

1. The stab-in tube, or pipe, greatly reduces contamination and channeling of the cement while traveling down within the casing.
2. Displacement volumes (and, therefore, job time) are reduced. For example, 400 ft of 26-in. casing would require 223 bbl, while 400 ft of 5-in. Drill-pipe would require only 7 bbl.
3. You can continue mixing and pumping until you have good cement at the surface, ensuring a good cement job at the end of displacement. Usually, this technique is used for casing sizes larger than 13 3/8-in. outer diameter (OD).

Outside Cementing



Since the conductor casing is cemented in weak, or unconsolidated, formations, losses may occur, or estimated excess volumes may not have been enough. This causes the top of the cement to be too low. In these cases, “top jobs,” or outside cementing, may be required to bring the top of the cement to the surface.

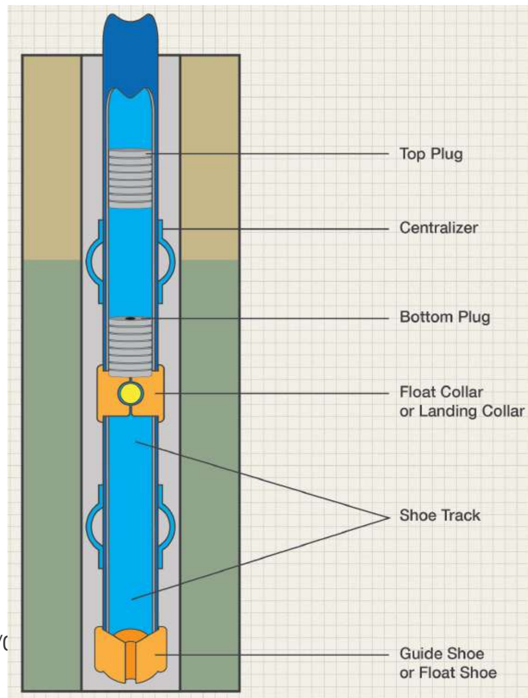
Top jobs are run using small-OD tubing called macaroni tubing (usually between 1- and 2 1/2-in. OD). Depending upon job requirements, two, three, or four strings of tubing can be run into the annulus. The usual maximum

depths for top jobs is between 250 and 300 ft.

Generally, the "macaroni" pipes are left cemented in place. If not, they are lifted out as the cement is placed. This is a dangerous and difficult operation; therefore, Sprint employees should never get involved in this operation.

It is recommended that the macaroni tubing be rotated around the casing to ensure constant distribution of the cement.

31.4.Surface Casing



Surface casing is run to protect freshwater formations from contamination by formation or drilling fluids. This type of casing serves to case off unconsolidated or lost-circulation zones near the surface and is used to support subsequent casing strings.

Additionally, surface casing provides primary pressure control by supporting the blowout preventers (BOP). A typical BOP consists of four distinct parts:

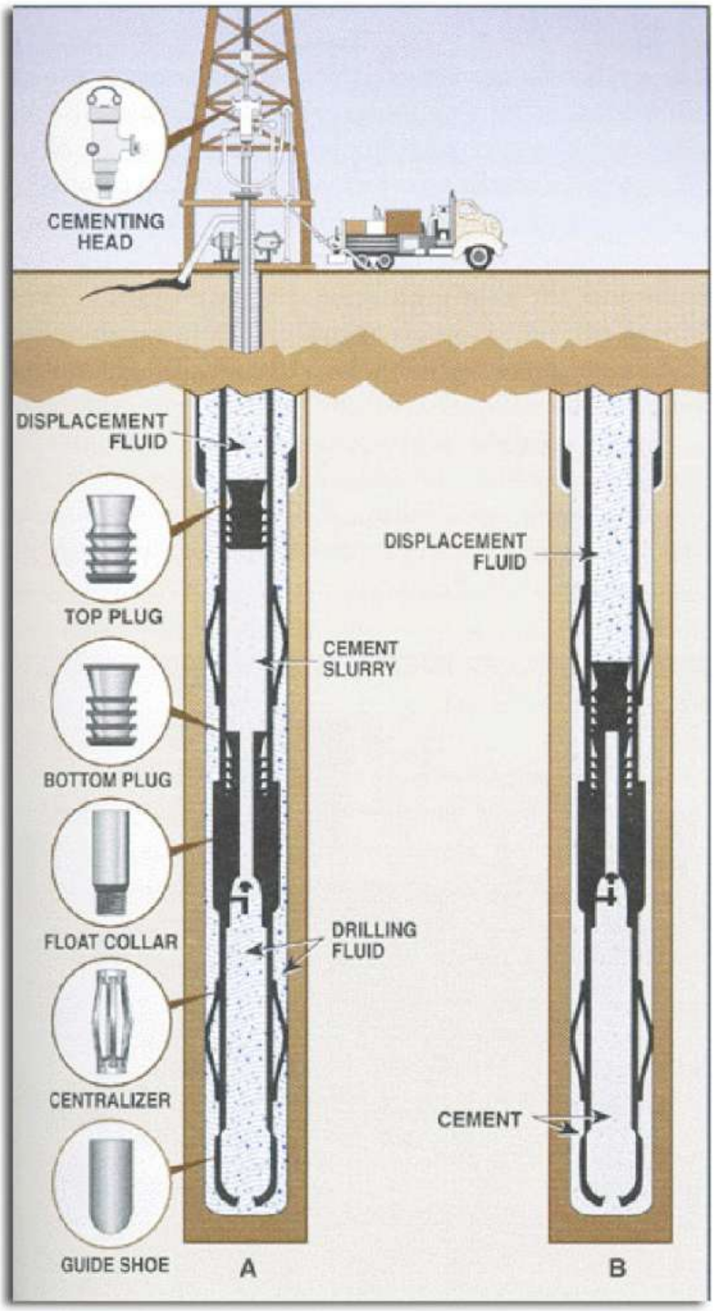
- The first is called an annular preventer, or Hydril. It is designed to seal off the annulus around most sizes and shapes of pipe. It is mounted at the very top of the stack of BOPs.
- Below the Hydril is the pipe ram. The purpose of the pipe ram is

to completely seal the annulus around the pipe, while allowing flow to continue through the pipe. Unlike the Hydril, which adjusts to various sizes of pipe, the pipe ram is designed for one specific OD of pipe. If, during drilling, the pipe size changes, the rams in the pipe ram must be changed to match the new size of pipe.

- Below the pipe ram is the blind ram. The blind ram is designed to seal the hole.
- Below the blind ram is the shear ram. The shear ram is equipped with a knife-like blade that cuts the pipe. This should only be employed as a last resort, since the drill-string will be lost down hole when it is sheared.

If the BOP is closed, well fluids can be pumped out through the choke line, and surface fluids can be pumped down hole through the kill line. BOPs are not used on larger casing sizes (greater than 20 in.), as shallow formations rarely have high pressures. Also, the size of the BOP for these casings may be too large to even fit under the rig.

Typical casing sizes range from 9-5/8 to 20 in., with 13-3/8 in. being the most common. Surface casing is threaded casing run to depths of 100 to 3,000 ft (or more). The depth of the surface casing is limited in part by the weight restrictions of the rig and the types of zones deeper in the well.



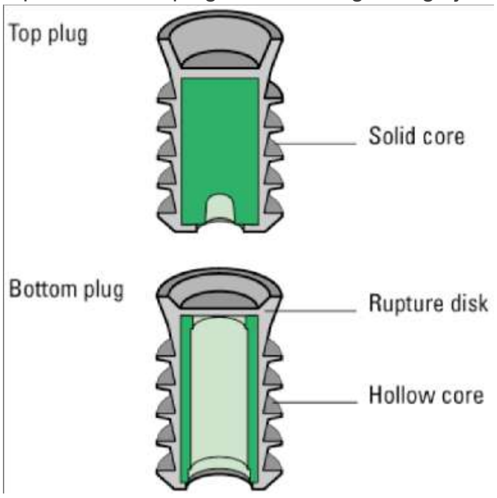
31.4.1. *Surface Casing Cementing Methods*

When cementing surface casing, an excess (additional volume of slurry) is usually used to provide for unknown hole volumes. This excess can range from 50 to 100%, or even more.

As in conductor casings, the through-drill pipe method of cement placement is preferred to

- reduce rig time (jobs are performed faster).
- save on cement quantity (the slurry is mixed and pumped until it appears at surface and then the job is stopped).
- ensure higher-quality jobs by reducing the channeling and contamination in the casing

Top and Bottom plugs used in single stage jobs



Lightweight, extended lead slurries (bentonite or silicate extended slurries) ensure that a high yield are generally used for surface-casing cementing. These slurries keep costs low and give a lower density, which means less chance of losses.

Neat-tail slurries are used to provide maximum compressive strength at the shoe. In addition, accelerators are used in the tail slurry to reduce waiting on cement (WOC) time. Before the drilling can resume, the cement must have a compressive strength of at least 500 psi. The faster the cement reaches this value, the less rig downtime.

Normally, the lead slurry is pumped until it returns to the surface; then, the tail slurry is pumped. A good rule of thumb is for the tail slurry to usually be between 25% and 30% of the length of the cement column (i.e., the length of the casing to be cemented).

If, for example, the casing were 3,000 ft, the tail slurry would be between 750 ft and 900 ft.

31.5. Intermediate Casing

Intermediate casing (sometimes called the "long string") is used to separate the well into the following workable sections:

- isolated lost-circulation zones
- salt sections
- over-pressured zones
- heaving shales
- other downhole or surface conditions that would make further drilling difficult or dangerous.

Sizes and depths can vary from one operator to another, from one field to another, and even from one well to another in the same field. Some typical casing sizes are

- 13-3/8 in.

- 10-3/4 in.
- 9-5/8 in.

The setting depths range from around 3,000 ft down to 15,000 ft. Intermediate casing normally is not used in shallow wells of less than 3,000 ft.

31.5.1.Intermediate Casing *Cementing Methods*

Intermediate casings can be cemented to the surface or to some point within the previous casing shoe (depending upon the client's requirements, formation-fracture pressures as determined by a leak-off test at the previous casing shoe, etc.). Some clients may even prefer to leave some open hole uncemented to allow for re-injection of cuttings and other drilling wastes.

If the interval to be cemented is very long and low-fracture pressure formations exist, the casing may be cemented in several stages. When cementing intermediate casing, the following casing accessories are used

- shoes
- collars
- centralizers
- plugs, etc.

The number one objective of a cementing job is to provide zonal isolation. To provide zonal isolation, all the drilling fluid must be removed from the annulus and replaced by cement, both in the open hole and in the previous casing. To efficiently remove the mud, the following are required

- pre-flushes (washes and spacers)
- centralizers, for good centralization
- casing movement (both reciprocating and rotational)
- well-engineered displacement rates.

Typically, large cement volumes are used, since the depths are great and the casing size is large. Often, clients will have logged this part of the well, and caliper logs are available to calculate the volume of required slurry more accurately.

Even with caliper log readings, excess slurry of at least 10% over the caliper hole size should be run to compensate for errors in measurement.

Note: Two-armed caliper logs give a less accurate reading of open hole volume than four-arm calipers.

The volume of cement required often makes cost an important issue in intermediate cementing.

The type of cement slurries used depends on the conditions that exist downhole. Typically, extended-lead and neat-tail slurries are used. Retarders are added to control thickening time. Fluid-loss agents and other additives are added to the slurries, depending on downhole conditions.

In some cases, specialized slurries may have to be used to control salt zones or gas migration, and lightweight slurries may be used for weak zones, etc.

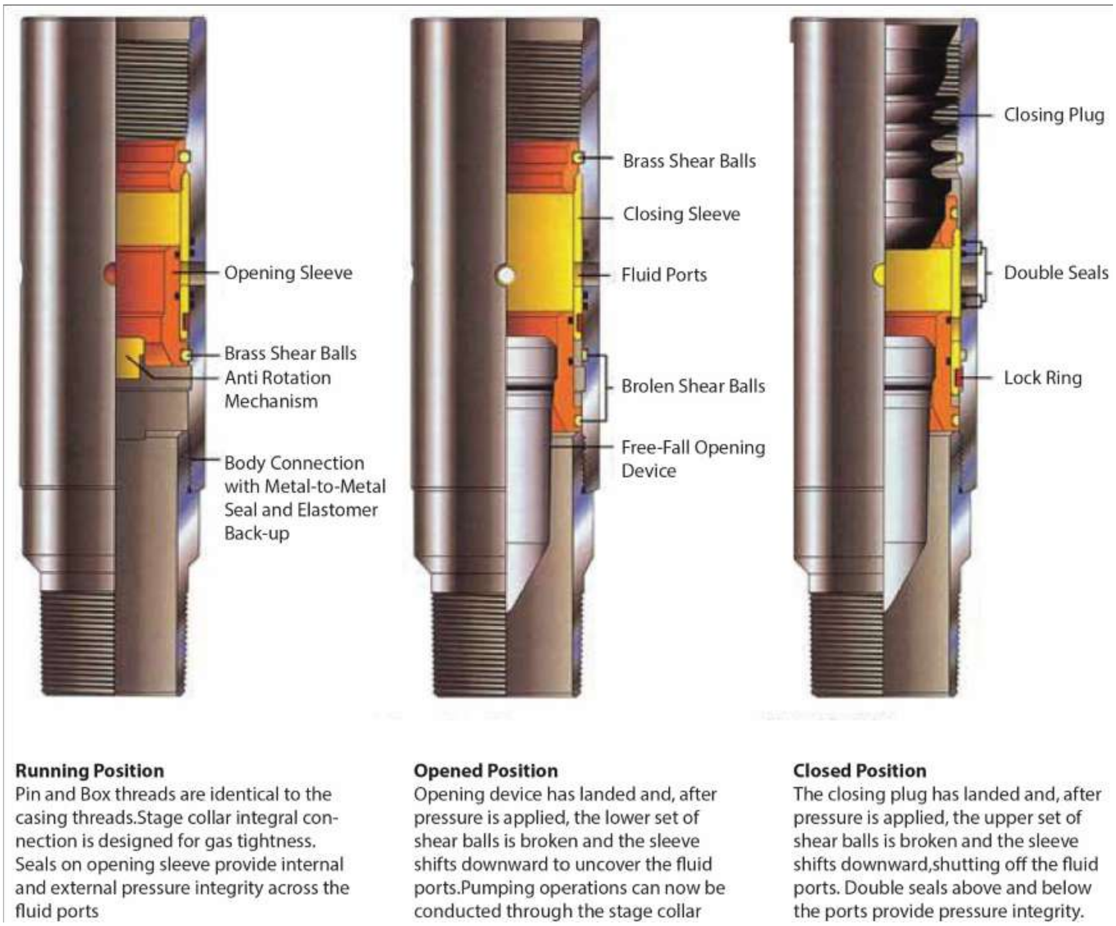
Two-Stage Cementing

Two-stage cementing is a technique in which a special type of collar (called a stage collar) is placed as part of a casing string.

This collar allows ports or holes to be opened, and circulation can be performed through them.

This technique is very useful for isolating two problem-zones within one open-hole section (for example, a high-pressure zone and a low-fracture pressure zone). It is also useful for reducing the hydrostatic pressure in the well when a weak formation exists: the first-stage cement is pumped and left to set before the second stage is cemented.

DV tool set



This picture is showing the two-stage tool

This technique can be used to reduce cement wastage in a well where only the bottom and an upper portion of the casing are to be cemented. With two-stage cementing, some part of the hole can be left uncemented. It is important to be certain that the portion of the hole that remains uncemented has no corrosive fluids or plastic formations that can damage casing.

Two-stage cementing is also used on long casing string. Basically, it is like doing two primary-cement jobs back-to-back, the stage collar being just another shoe higher up in the hole.

Two-stage cementing is also used on many applications when a weak zone that cannot support a heavy column of cement is encountered in a well. In such a case, the stage collar is located just above the weak zone.

One serious disadvantage of two-stage cementing is the absence of a bottom cementing plug on the second stage. This can result in extremely bad contamination of the slurry as it travels inside the casing.

31.6.Production Casing

Production casing is normally run across the pay zones. Since different zones may have different pressures, the water or gas in these zones may slow down or even stop the production of oil from the pay zone if not properly isolated. It is also used to provide a protective housing for the subsurface production equipment when the well is completed (for example, submersible pumps).

Production casing can also be used to cover worn or damaged intermediate casings. Depths and sizes vary considerably, as in the case of intermediate casings, but the most common sizes are:

- 4-1/2 in.
- 5 in.
- 7 in.
- 9-5/8 in.

Clients usually maintain casings sizes as a set from the beginning of the well to the end (in other words, conductor casing: 30 in.; surface casing: 20 in.; intermediate casing: 13-3/8 in. and 9-5/8 in.; and production casing: 7 in.).

Production casing can be run as a complete string from total depth (TD) to surface, or only from TD to 300– 500 ft inside the previous casing. Production casing that does not run to the surface is called a production liner.

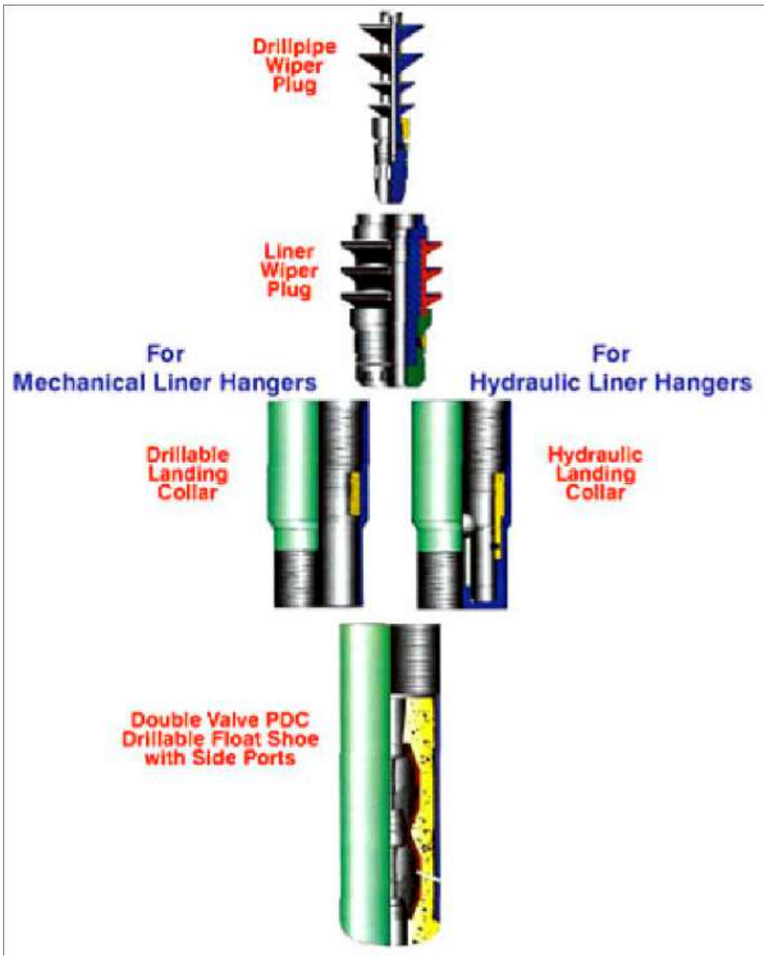
31.7.Liners

Unlike casing, which runs to the surface, liners are strings that are not run to the surface, but are hung off inside the intermediate casing (300–500 ft inside is quite common). Here's a typical liner and liner hanger inside the intermediate casing.

Liners are run to save on the amount of casing required. Since casing can be the most expensive part of a well, reducing several thousand feet of casing in a deep well can save a great deal. Also, in deep wells where the intermediate casing is already small (for example, 7 in.), a liner allows production from lower zones with standard production equipment.

Care should be taken when cementing liners because the annular clearances are small, and rates and pressures are usually restricted to avoid over-pressuring the well and causing losses. Note that the burst/collapse pressures listed in the Field Data Handbook assume casing in air. To measure conditions on the casing downhole, the pressure of fluids in the casing and annulus must be taken into account.

Additionally, since the liner hanger and packer are activated by pressure, excessive pressure in the casing can cause premature setting of the liner hanger and/or packer.



31.8.Casing Specifications

For a particular size and type of casing to be considered acceptable for running into an oil well, it has to meet certain requirements that have been set up by the American Petroleum Institute (API). These requirements include:

- OD
- weight
- grade
- collapse and burst (or internal yield) pressures
- thread type. Standards

With the OD and weight of a casing given, the inside diameter (ID) and the internal capacity can be determined.

Grade L80 corresponds to a steel with a yield point of 80,000 psi. This value is then used to determine the collapse and burst pressures, as well as the tension the casing will stand before it goes from elastic to the plastic region and becomes permanently deformed.

Some clients run tapered strings, where the casing size changes or where different weights of one size casing are used. This is done to reduce cost.

The types and sizes of casings used are based on downhole conditions:

- formation pressures

- maximum hydrostatic and pumping pressures during the cementing operation
- expected maximum pressure during the life of the well, depth, etc.

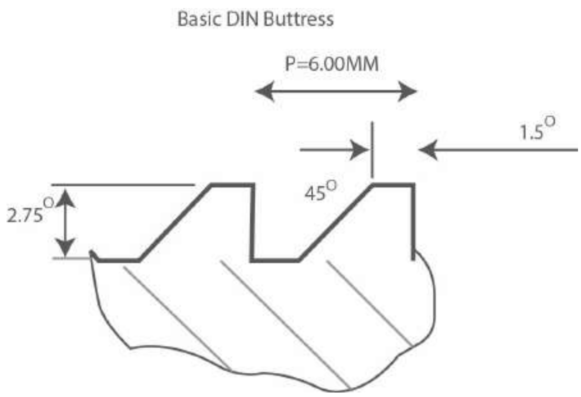
The types and sizes of casings used are also influenced by surface conditions (for example, how much the rig can lift). These factors determine the burst and collapse pressures and tensile loadings that the casing will have to stand. Thread Types

Thread types include:

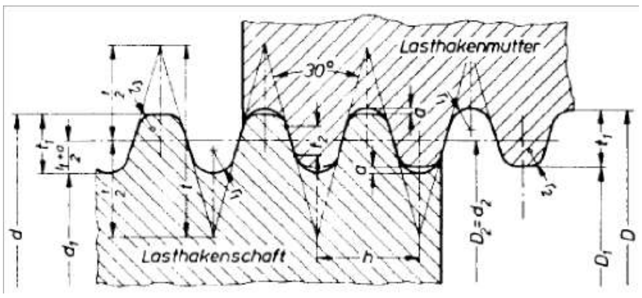
- buttress
- 8-round
- VAM
- HYDRIL.

31.8.1.Buttress and 8-Round Threads

Buttress and 8-round are the oldest and most popular types of threads. Both rely on sealing on the threads themselves. The buttress is a development over the 8-round API thread, making it easier to screw the two pieces together.



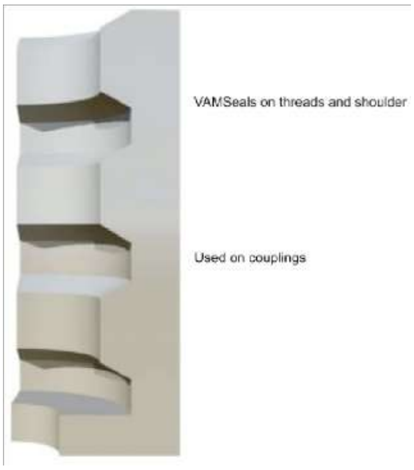
Buttress Thread



8 Round Thread

31.8.2.VAM Threads

VAM threads are used mainly for production strings and are quite popular, although they are not recognized as API-type threads. VAM threads have the ability to seal on the thread (similar to a buttress thread) and also on the shoulder in the coupling. A newer type, called the NEW VAM, has recently appeared in the field. It has a shorter length of thread and a better sealing area in the shoulder. Buttress threads can be used with VAM threads, but not with NEW VAM.



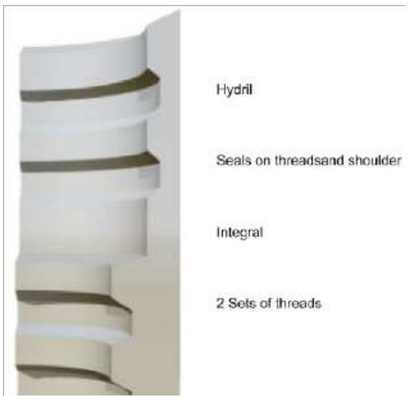
VAM Threads

31.8.3.HYDRIL Threads

A HYDRIL-type thread is a special type of thread that is integral with the casing (that is, it is machined into each side of the casing), making this type of thread very expensive. HYDRIL threads have three sealing areas:

- on the shoulders
- on the middle shoulder.
- on the threads

This type of thread is quite rare in the oil field. You will find HYDRIL threads on special projects, such as high-pressure gas re-injection wells. Whenever rig-up is done, special care must be taken to ensure that the correct threaded connections are used in crossovers and connections for the cement heads, swages, etc.



HYDRIL Threads

31.9.Primary Cementing Job Procedures

Cementing job procedures include

- pre-job procedures
- job procedures
- post-job procedures.

Good centralization is the key to a successful cement job; therefore, it is important for the cementing supervisor to ensure that the correct number and type of centralizers specified in the design are actually run on the job. In some situations this is not a problem, since the cementer is normally present at the rig site before the casing is run. It may also be the responsibility of the cementer to check the casing jewelry, including float shoes and collars. There are cases, however, where the engineer arrives on location after the casing has been run.

31.9.1.Pre-Job Procedures

Pre-job procedures include

1. The first thing to do upon arrival on location is to meet with the company man and review the job calculations with him. Verify that no changes have been made to the planned job design.
2. Next, the lines and equipment should be rigged up. MR1 is required on all the equipment, including priming the units and pressure-testing the lines.
3. Check that all the products and materials have arrived correctly.
4. A pre-job safety and organization meeting must be held with everyone who will be involved in the job:
    - the customer representative
    - the Sprint personnel
    - the rig crew.
5. After the meeting, start preparing the different mix-fluids, spacers, and washes. (You must get the go-ahead from the company representative before starting to prepare any fluids at the well site. That will cover you should the job be called off for any reason.) The company man may want you to wait until the casing is on bottom and the well is circulated to avoid lost products, if the casing cannot get to the bottom. If this is the case, make sure everything is ready to go, including correct water volumes in the tanks.
6. Collect the compulsory samples of fluids.

31.9.2.Job Procedures

The job starts when the company man gives the go-ahead.

1. The first task is to test the lines again in the presence of the company representative. It's very important that both the company man and the Sprint engineer in charge agree on the maximum pressure and rates for the job that will begin.
2. Contingency plans must be drawn should the execution not go as planned. The plugs are then loaded into the cement head in the correct order. The company representative must witness and acknowledge that the plugs are correctly loaded at this stage.

3. It is strongly recommended that you run two bottom plugs. The objective is to prevent the contamination of the slurries and spacers while traveling down in the casing. You should ensure that the slurry is always pumped in sandwiched between the bottom plug and the top plug. The contamination is worse with large-size casing, and the density differential between the cement and the mud is critical. It's very important that you do everything correctly to prevent this contamination.

4. The pre-flushes (washes/spacers) are then pumped in the proper sequence.

5. After the pre-flushes have been pumped, the bottom plug is dropped by the operator.

6. The cement slurries are mixed and pumped at the correct density.

7. When all of the slurry has been pumped, the top plug is dropped by a Sprint employee, and displacement can start.

8. Displacement is done at the specified rate. The volume that can be pumped above the calculated displacement volume should be defined prior to the job, and an agreement should be reached with the company man to avoid misunderstandings, or a major operational failure, at this critical moment.

9. When the top plug reaches the bottom plug, the top plug is bumped with the agreed pressure. Always check the returns to make sure that the float equipment is holding. If there is a constant return flow after about four or five barrels of return fluid, the float equipment is leaking, which means cement slurry is returning in the casing. When this happens, pump the returned fluid back into the well to push the plug back onto the float collar, but don't allow the pressure to build up in the casing above the pressure at the end of displacement. Then, you should install a pressure sensor close to the cement head, and close the line. If the plug is not bumped once the theoretical mud volume has been pumped, you, in agreement with the company man, need to pump a volume of mud no more than half the shoe-track capacity.

31.9.3.Post Job Procedures

The end of the job can be as important as the rest of the operation and can leave a good or bad impression on the client.

1. When the job is completed, equipment and lines must be washed up. The wash-up should be performed to the waste pit of the rig. No water or oil or mud spills should be thrown on the client's location, even with approval from the company man. The location should be left in as good or better condition than when you arrived.

2. After washing up, all equipment should be rigged down. A MR1 must be done on all equipment at this time. This helps to prepare for the next job and identifies potential difficulties that might arise in the future.

Finally, all the paperwork should be completed and either signed by the client or left with him.

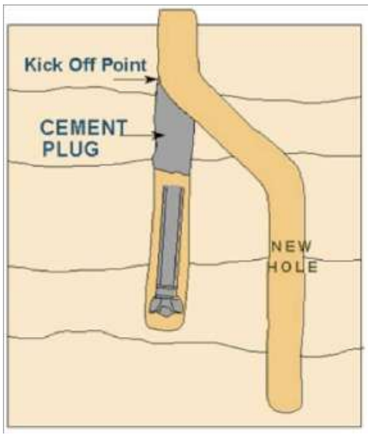
32. Plug Cementing

32.1.Type of Cement Plugs

Setting a cement plug in a well is a common oilfield operation that involves a relatively small volume of cement slurry. Cement plugs are used for a variety of purposes, including

- sidetrack and directional drilling (whipstock plug)
- plugging back a depleted zone
- lost circulation
- abandonment
- a test anchor

32.1.1.Sidetrack and Directional Drilling



During directional-drilling operations, it may be difficult to achieve the correct angle and direction when drilling through a soft formation. It is common practice to set a "kick-off plug" across the zone to achieve the desired course and target.

Also, when tools, drill-string, etc. are lost in the hole during drilling, it is often more economical to sidetrack around the non-retrievable equipment rather than "fish" it out. Slurries used for these plugs are often of a higher compressive strength and shorter time is needed to wait on the cement to set (therefore less stand-by time for the rig).

These properties can be achieved using conventional cementing technology by an increased density and depending on the temperatures, may contain an accelerator.

32.1.2.Plug Back Depleted Zones

Depleted zones may require isolation to prevent the possible migration of liquid or gas from productive intervals. Isolation may also be required to protect a low-pressure zone in the open-hole before completion of an upper interval. If the depleted or low-pressure zone is not isolated, a large loss in production can result. Production will go to this zone rather than to surface.

32.1.3.Lost Circulation

Loss of drilling fluid can be stopped by setting a properly formulated slurry across the thief zone. A thief zone is any formation that cannot support the hydrostatic pressure of the fluid in the well; as a result, drilling fluid in the well flows into the zone rather than being circulated. Using a lighter (less dense) drilling fluid is not an option in most cases. Although the cement slurry may be lost to the thief zone, if properly formulated it will harden and consolidate the weak formation.

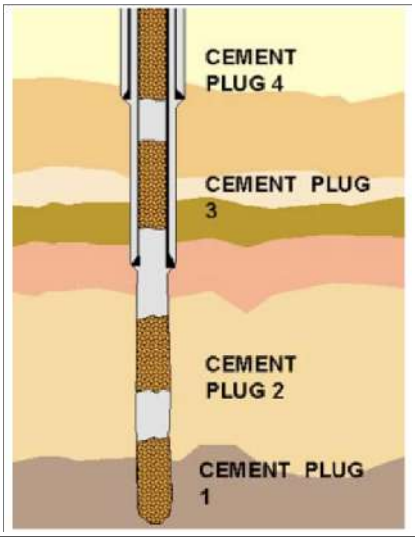
A cement plug can also be set on top of a zone to protect or isolate it from being fractured under the hydrostatic pressure that might develop during the cementing of a casing string. This is called a plug back prior to a casing job.

Lost-circulation additives are very often included in cement slurries to prevent or limit losses to the formation. These slurries are often desired to have a high rheology or even to be thixotropic (gelling when in a static state and then liquefying when subjected to agitation). This property also inhibits losses.

32.1.4.Abandonment Plugs

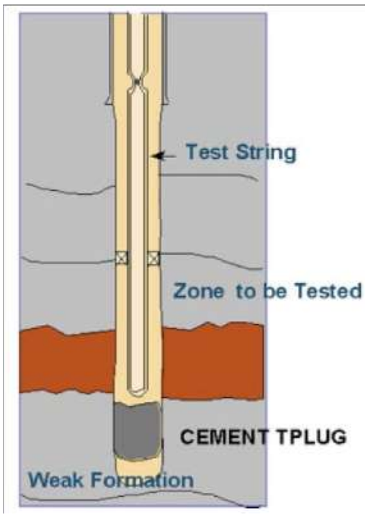
A dry hole (no commercial pays) is usually abandoned by setting cement plugs at various depths to prevent zonal communication or any migration of fluids (gas or liquid) that might pollute underground, freshwater sources or cause pressure communication between intervals. Depleted zones or formations are also plugged when they are abandoned.

In most countries today, oil and gas well operators and service companies are compelled to precisely follow abandonment procedures dictated by government authorities.



32.1.5.Test Anchor Plug

When a soft or weak formation exists in an openhole below a zone to be tested, and it is impractical or impossible to place a sidewall anchor or a bridge plug, a cement plug can be placed to provide the necessary support for the test. This plug is called a test anchor.



As an example, if an injection test was to be done, the weaker formation would break down first. So, a proper test could not be completed without isolating the weaker zone. If the zones of interest were in an open-hole section, it would be difficult to get a bridge plug to set or seal properly.

32.2.Plug Placement

Three common techniques for placing cement plugs are

- the balanced-plug method
- Enhanced balanced plug method
- the two-plug method

32.2.1.Balanced-Plug Method

The most commonly used cement plug placement method is the balanced-plug technique. In this method, tubing or drill-pipe is run in the hole to the desired depth for the plug base.

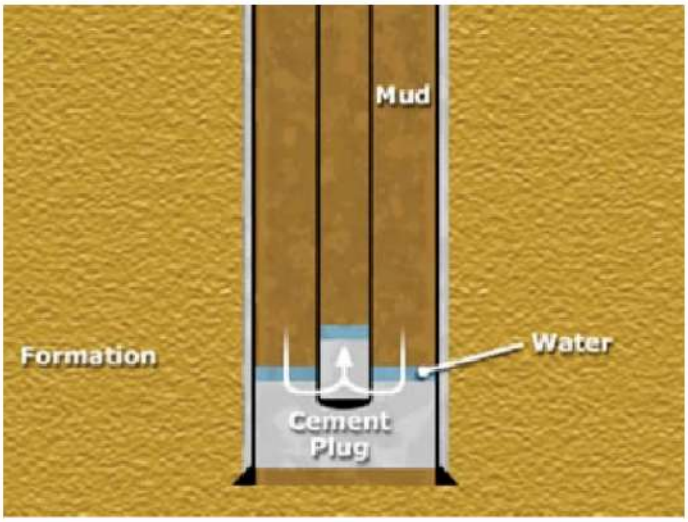
Washes and spacers are pumped ahead and behind the slurry to avoid contamination of the cement by mud. The slurry is often batch-mixed for more consistent density and rheology control. A uniform density is essential to have a balanced plug and to have correct slurry properties.

The volumes of washer and spacer are placed so that their heights in the annulus and in the drill-pipe or tubing are the same. Displacement is completed to the depth of the calculated plug top inside the pipe. It is common, however to slightly under displace the plug (by usually one or two barrels) to avoid spilling flow back when breaking connections when pulling the pipe after placement. This allows the plug to reach hydrostatic balance.

After the plug is balanced, the pipe is slowly pulled out above the desired top depth of the plug, and any excess cement is circulated out of the hole. The height to pull above the plug depends on:

- the operator
- the type of plug
- the type of circulation.

If you do not pull some distance above the plug, and you circulate down the tubing or with a high rate, the top portion of the cement plug could be contaminated due to jetting effects.



Reverse circulation (down the annulus and up the tubing) is sometimes done on a lost circulation plug. This limits jetting and greatly reduces the volumes needed to pump for bottoms up (fluid at the bottom of the pipe to surface).

Care must be taken while circulating, especially for a lost-circulation plug. If the surface pressure is not monitored and controlled, the formation could break down and the plug will be lost to the formation.

On plugs where placement of the top of the plug is not critical, it is common to pull the drill-pipe one or two stands above the top of cement before circulating.

Note: When setting a balanced plug, it is imperative that the operator circulate the well completely. The drilling fluid must be clean and of the same weight through out the well and in the pits. If a slug of heavy mud is pumped in the tubing to balance the well prior to the job, this slug will be in the annulus and will make the well out of balance at the end of the job. The operator must be aware of how important proper circulation, prior to the plug job, is to the success of the job.

Here is the balanced-plug job procedure to circulate and balance the well (normally done by the operator):

1. The treating lines are tested.
2. Washes and spacers should be pumped ahead of the cement slurry to ensure proper mud removal.
3. The cement slurry should then be mixed and pumped.
4. Spacers and washes should be pumped behind the cement slurry to prevent contamination by displacement fluids, and to get the proper balance.
5. The calculated amount of displacing fluid should be pumped. Normally, the plug will be under-displaced by 0.5 to 1.0 barrels to assure that the spacer or displacement fluid does not contaminate the inside of the plug.
6. After displacement is completed, the return lines to the displacement tank on the unit should be opened, and the cement plug should be allowed to balance itself either by return flow or vacuum.
7. The drill-pipe or tubing should then be slowly pulled a safe distance above the plug.
8. Excess cement should be reverse circulated out, if this will not result in pressure damage to weak formations.
9. Finally, the drill-string is pulled out of the hole, and sufficient WOC is allowed before operations are resumed in the hole.

32.2.2.Enhanced Balanced Plug Method

The conventional balanced cement plug method is effective in situations where a constant ID is used throughout. In a situation where the cement plug is placed with a tapered string a problem arises during pulling out of hole as the cement plug will not longer be hydrostatically balanced. During pulling out of the cement plug, the cement begins to exit from the cement stinger into the annulus and the cement plug itself, once the volume of mud in the tubular with the larger ID flows into the stinger with the smaller ID, it causes the fluid height inside the string to increase substantially causing an unbalanced hydrostatic situation and therefore leading to plug contamination and lower TOC .

To counter this issue, the spacer behind and displacement volumes must be calculated by balancing the fluids above the cement at the TOC depth (with string outside the cement). PlugPRO can compute the enhanced balanced plug method automatically by ticking the “with under-displacement vol” in the operation tab.

Due to metal displacement, an air gap will occur during POOH which will affect the displacement volume calculations. The air gap will be equal to the metal displacement volume + the calculated under-displacement volume calculated previously to hydrostatically balance the plug. Two scenarios could arise:

- If a trip tank is available and native fluid is automatically filling the annulus during POOH, volume calculations shall not consider the air gap.

• If a trip tank is not available and the well is not being automatically filled, an air gap will definitely be present and the displacement volume shall be calculated based on that level.

PlugPRO can consider air gap calculations by unticking “annulus filled by native fluid during POOH” depending on the situation.

32.2.3.Two-Plugs Placement

The two-plug method uses a special tool to set a cement plug in a well at a calculated depth. Unlike other methods, the two-plug method:

- provides positive indication at the surface, when slurry arrives downhole.
- allows accurate determination of displacement volume and helps ensure a good cement job each time.
- limits mud contamination of the slurry more than the other methods of plug cementing.

The tool consists of:

- a bottom-hole sub installed at the lower end of the drill-pipe.
- a bottom wiper plug (sometimes called a dart).
- a top wiper plug.
- a rupture disk or sliding sleeve to allow circulation past the bottom plug.

the two-plug method procedure is:

1. The bottom plug is pumped ahead of the cement slurry to isolate the cement from the mud.
2. The shear pin connecting the dart to the plug is broken by increased pump pressure, and the plug is pumped down through the tail pipe. (In other arrangements, the dart and not the plug is pumped through the tail pipe.)
3. The top plug is pumped behind the cement slurry to isolate the cement from the displacement fluid. Increased surface pressure is observed when the plug arrives at the seat.
4. The drill-pipe is then pulled up until the lower end of the tail pipe reaches the calculated depth for the top of the cement plug.
5. The shear pin between the sub body and the sleeve is broken by increased pressure, which allows the sleeve to slide down and open the reverse circulation path.
6. Excess cement is then circulated from the hole.

If, during the process, the tail pipe becomes stuck in the cement, an increase in pull will break the tail pipe and free the drill pipe. This is possible due to the aluminum or fiberglass material used in the tail pipe.

The two-plug method has three primary advantages over other methods of plug cementing:

- The top and bottom plugs provide isolation ahead and behind the cement, reducing contamination of the slurry by drilling fluids and other fluids.
- The wiper action of the plugs cleans the drill-pipe from the surface all the way to the tail pipe.
- The fact that there is a pressure bump when the plug lands gives a positive surface indication of slurry placement.

32.3.Plug Job Design

This section on job design will include

- overview
- slurry volume
- slurry properties
- cement plug failure
- keys to successful cementing.

The design of a plug-cement job starts with the definition of the objective. Setting a plug for lost circulation is quite different from setting a plug to abandon a depleted zone or to plug back a well. In addition, there are a number of considerations that must be taken into account to design a well. These considerations include:

- the purpose of setting the cement plug
- the type of drilling fluid
- the deviation
- the depth at which the plug will be set
- the type of formation across which the cement will be placed
- the density of the slurry to be used
- the bottom-hole static temperature (BHST)
- the volume of slurry to be pumped.

These considerations affect:

- method of placement,
- the type of slurry to be used
- the properties of that slurry.

The purpose of the plug will determine the preferred method of placement, and the method of placement will determine the slurry properties that must be prepared.

Among the slurry properties that must be addressed are:

- Rheology
- Thickening time

- Any mud contamination that may exist and the effect it will have on the slurry (that is, compatibility tests)
- Density
- Compressive strength
- Lost circulation control
- Fluid loss control.

It is also important to determine:

- Whether pipe centralization and rotation are necessary
- How much time must be spent waiting on cement (WOC).

32.3.1.Slurry Volume

Slurry volume varies depending upon:

- The type of plug to be placed
- The method used to place it.

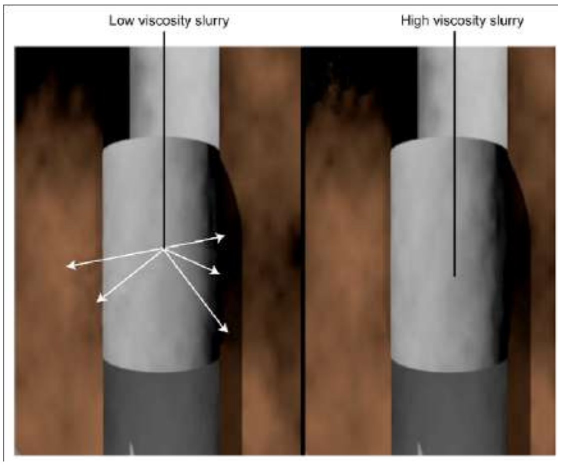
Additionally, certain plug operations, like well-abandonment plugs, have volumes dictated by government regulations.

Other plug operations, like whipstock or kickoff plugs, require large slurry volumes to be effective. The plug must have a considerable length to:

- reduce the effects of contamination
- ensure adequate plug to get kicked off on the first attempt when an expensive drilling rig is over the hole

Small slurry volumes must be used in other applications so that hydrostatic pressure will not damage lower, depleted, or weak zones.

32.3.2.Slurry Properties



The three most important properties of any slurry are:

- rheology
- compressive strength
- thickening time.

If a cement job is going to be effective, each of these parameters must be designed to meet the needs of the specific application .

Rheology

The rheology of a cement slurry affects both:

- viscosity
- gel strength.

For a lost-circulation plug:

- High rheology is preferred for losses into highly fractured zones with large fractures.
- Low rheology is preferred for losses into zones with micro-fractures or fissures and also for coiled-tubing applications.

Compressive Strength

Compressive strength is less important for lost-circulation applications, but is critical for plug cementing applications where compressive strength much higher than 500 psi are required.

It is important to note that, while small amounts of contamination have a significant effect on the compressive strength, larger concentrations (at or above 50%) can destroy the compressive strength of a slurry almost completely.

Thickening Time

Early compressive strength depends heavily on thickening time. Rig time can be saved with proper slurry design by reducing WOC. Slurries must be designed for a thickening time in accordance with:

- well conditions
- job procedures
- a reasonable safety factor.

While thickening time must be enough for placement, between one and a half and two hours is normal. In addition, WOC should be between 12 and 24 hours. It's important that the operator knows the WOC so drilling is not started prematurely.

Choice of retarder can have a strong influence on compressive strength development. A retarder showing rapid strength development is preferred.

32.4.Plug Cementing Tools and Techniques

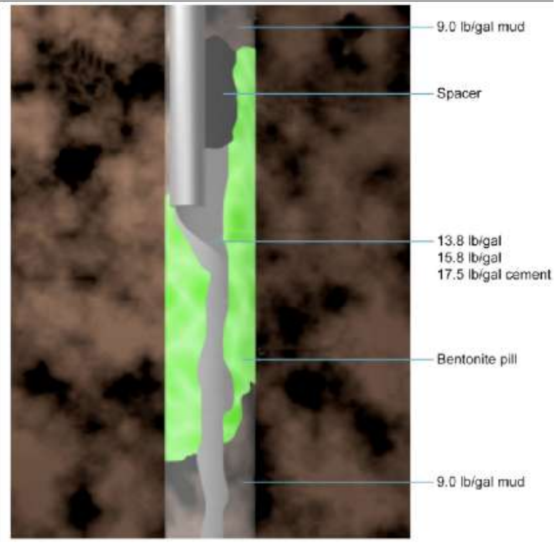
This section will address:

- diverter tool use
- reverse circulating excess cement

32.4.1.Diverter Tool

The diverter tool is used on the end of the work-string to redirect the flow of the cement so that there is no downward jetting action. Downward jetting action of the cement can cause the cement to jet through the viscous pill or mud, contaminating the cement and causing it to fall below the desired location of the plug.

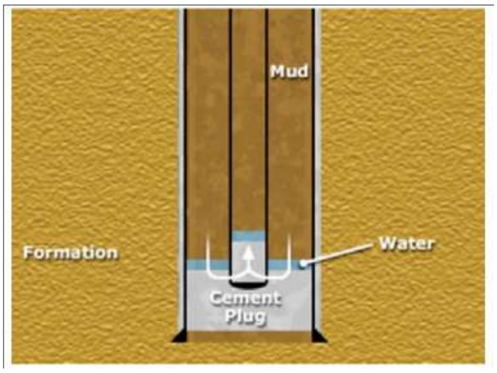
In conjunction with the diverter tool, the drill-pipe must be centralized to ensure complete mud removal from the cemented area. This graphic shows a centralized drill-pipe with a diverter tool and the location of the various fluids when the cement is placed.



This graphic shows the effect of jetting on the viscous gel pill when a diverter tool is not used. The jetting action of the cement breaks the pill, and the cement falls through the gel and mud. The result is that no cement remains at the placement location.

Additionally, bad centralization/standoff can cause poor mud removal. In this case, some mud remains behind the drill-pipe and is not removed. This mud contaminates the cement and results in a failed cement job.

32.4.2.Reverse Circulating Excess Cement



To ensure that the correct top of cement (TOC) is achieved in an open-hole (especially where the hole size is unknown), it is common practice to place excess cement into the hole. When the cement is placed, the drill pipe is run into the hole to the desired top of cement, and the excess slurry is reverse circulated out.

Reverse circulation is preferred to conventional circulation, since conventional (bottom up) circulation takes a longer interval of time, and the slurry could set before all of the slurry is circulated out. This could result in stuck drill pipe.

Alternatively, and probably more common, reverse circulation is well above the desired top of cement. After the desired WOC time, the top of cement may be dressed off by drilling. This also allows the strength of the cement to be determined.

When circulating a well, the fracture-pressure safety limits must be considered. Reverse circulation tends to apply more pressure on the formation than does direct circulation. This condition exists because, normally, there is much more friction pressure created in the drill-pipe than in the annulus.

32.5.Cement Plugs Calculation

When you are in the field, you will perform all calculations as accurately as possible (using as many decimals as needed). However, the final results of your calculations must be rounded (to the closest unit or half unit in general). This process also must take into account the size of the number to be rounded: a few hundred barrels displacement can be rounded to an entire number of barrels, whereas a few gallons of additive must be measured accurately.

Plug Height with Tubing (Drillpipe) Lcmt = Vcmt / (Cann + Ctbg) where

Vcmt = Cement slurry volume (ft3/ft)

Cann = Annular capacity (ft3/ft)

Ctbg = Tubing capacity (ft3/ft)

Plug Height without Tubing (Drillpipe) Lcmt = Vcmt / Ccsg where

Vcmt = Cement slurry volume (ft3/ft)

Ccsg = Casing capacity (ft3/ft)

Displacement Volume to Balance Plug

Vp (bbl) = {(Depth to bottom of tubing. - Lcmt) ft x Ctbg (bbl/ft)} - Wb (bbl)

where

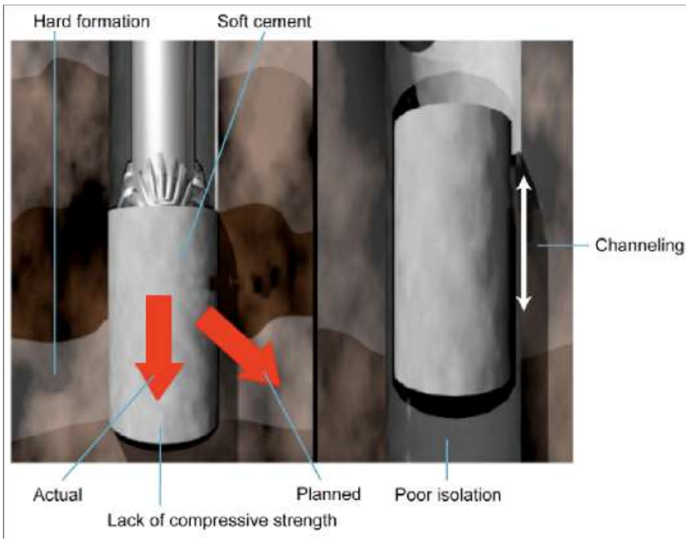
Wb = Water behind (bbl) = Wa x (Ctbg / Cann)

Remember, it is preferable to under-displace (0.5 to 1 bbl).

Well Control Calculation during Cement placement and drill pipe POOH

Simulator must be used to ensure well control requirement is meet during the complete process of plug placement taking in to effect the swabbing action of the DP while POOH.

32.6.Cement Plug Failures



The most common reason for cement plug failure is contamination of the plug by mud during displacement. This in turn, results in insufficient compressive strength, as shown on the table on the previous screen.

Evaluation of past plug-cementing failures has shown that common reasons for failure are:

- a lack of compressive strength (especially in sidetracking applications)
- poor isolation (especially in plug back or abandonment)
- the placement of the plug at the wrong depth (in all plug applications)
- not using an adequate slurry volume
- the sinking of the cement to the bottom of the hole (in all plug applications)
- the loss of the slurry to a thief zone (in lost-circulation applications).
- well control failure during cement placement or while POOH.

Another common reason is a failure to provide sufficient WOC for the cement to set. This is sometimes the result of an inaccurate bottom hole static temperature, which affects the time it takes for the cement to set.

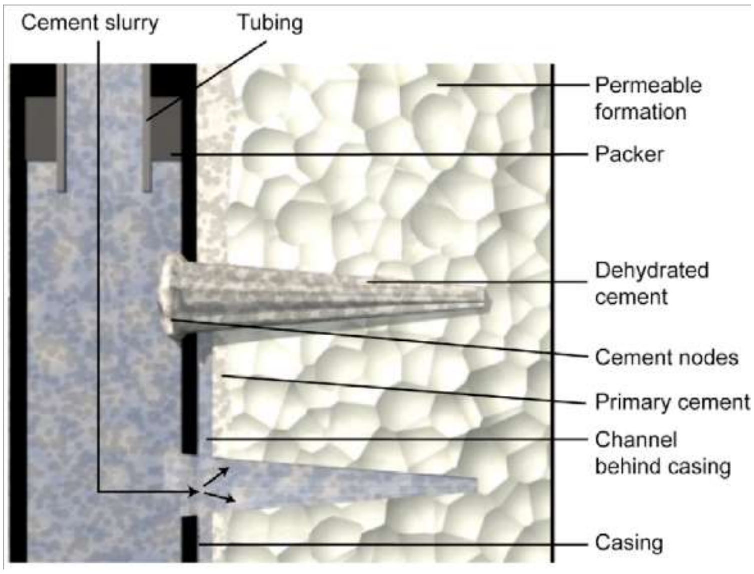
Another common reason for failure is cement contamination during displacement and pulling out of the hole (POOH). This can be the result of contamination in the annulus or as the result of overbalanced displacement. If the pipe is pulled out of the cement too quickly, a swabbing effect can contaminate the plug as well.

32.7.Keys to Successful Plug Cementing

To ensure successful plug cementing it is important that certain guidelines be followed:

- Place the plug in a soft formation.
- Use ample volumes of cement, especially in sidetracking applications.
- Use a tail pipe through plug-back intervals.
- Use centralizers with tail pipes where the hole is not excessively washed out.
- Use a two-wiper plug system for positive indication of slurry depths.
- Circulate the hole sufficiently before running the job. A mud with a low yield point and low plastic viscosity should be used, but with sufficient weight to control the well.
- Run a high-viscosity pill that is compatible with the mud ahead of the cement to make an artificial bottom to prevent the cement from sliding down the hole.
- Use spacers and washes to combat the effects of mud contamination during placement of the slurry. Densified cements with a dispersant can also be useful.
- Finally, it is critical that ample time be allowed for the cement to set. A perfectly placed cement slurry can fail if WOC should be 12 hours, but actual WOC is only 8 hours. Always ensure sufficient WOC for the cement to set. If the plug is tagged and is soft, pull up and wait an additional 8 hours. This is better than drilling out and having to set another plug.
- If the plug is still soft, leave 50 ft of the plug as a bottom for the next plug.

33. Squeeze Cementing



Remedial Squeeze cementing covers different techniques of slurry placement to

- repair and/or complete a previous cement job.
- plug and seal casing leaks.
- seal depleted or non-productive zones.

Squeeze cementing is often called squeeze cementing because of the manner in which the cement is placed into the well-bore. Before remedial cementing is done, the possible benefits and harm to the well must be considered.

Because remedial cement jobs are expensive, the client must have a serious need for the corrections that the remedial cement job represents for it to be of value. Since remedial cement jobs involve placing cement under pressure, the well can easily be damaged.

When the slurry is forced against the permeable formation, the solid particles filter out on the formation face while the aqueous phase (cement filtrate) enters the formation matrix. A properly designed squeeze job causes the resulting cement filter cake to fill the openings between the formation and the casing. The slurry placement may be done either above or below the fracture pressure of the zone, depending on the type of job.

This graphic below shows the placement of a remedial cement slurry into a set of two casing perforations. The perforations are filled up with cement slurry, and the slurry dehydrates and hardens, resulting in plugged perforations.

33.1.Remedial Squeeze Objectives

33.1.1.Primary Cement Job Repair

A faulty primary cement job may be the result of

- channeling, which leaves pockets or channels of mud behind the casing through which communication can occur.
- low top of cement when zonal isolation (the main objective) is not achieved.
- a poor cement bond.

Two situations may exist behind the casing:

- The mud channel to be repaired is against a permeable formation and, during the squeeze job, the cement filter cake will fill the void.
- Circulation is established between two sets of perforations, and a circulation squeeze is performed to replace the mud occupying the channel with cement.

To be successful in either operation, the squeeze pressure must remain below the fracture pressure to prevent damage to permeable intervals or the possible opening of other flow paths for the slurry.

The identification of a poorly cemented zone is one matter, but squeezing must also be considered to improve the bond. Perforating a cemented casing is a difficult decision to make, because there is no guarantee that fluid can be forced through the perforations. The general rule is: unless you are absolutely sure that there is a liquid behind the casing, you do not perforate the casing and squeeze.

33.1.2.Zonal Isolation

Poor zonal isolation may be the result of insufficient mud removal which can cause

- mud channeling.
- micro-annulus formation.
- cement contamination.

Another cause of poor zonal isolation could be the result of bad slurry design. Bad slurry design may result in a slurry that has

- excessive settling or free water.
- premature dehydration (caused by poor fluid loss control).
- a long thickening time (resulting in poor compressive strength).
- gas migration problems.

Poor zonal isolation may also be the result of lost circulation during the primary cement job that results in an inadequate amount of cement at the desired depth in the annulus.

Squeeze cementing can solve these problems by placing a cement plug at the desired depth to create zonal isolation.

Non-productive or depleted zones must be isolated to prevent the loss of production. Zones responsible for loss of fluid are often referred to as "thief" zones because they steal fluid. Squeeze cementing is an effective way to seal off these zones. It is normally the lowest zone of interest. Therefore, the squeeze job is performed using a cement retainer technique to provide a mechanical barrier after the squeeze operation.

33.1.3.Casing Leaks

Casing and liners can begin to leak after being placed downhole. In some cases, this is the result of the corrosive nature of well fluids acting on the casing or liners, but it can also be caused by pipe being separated by a fault movement of the earth around it.

Squeeze cementing can place a cement sheath around the damaged casing and prevent further leakage.

When dealing with old and corroded casing, more damage will probably result from the application of the treating pressure and packer-generated stresses. In some cases, it may be advisable to pull the old casing (if possible) and run a new string. Squeeze treatments performed on old wells with corroded casing often fail after a short period of time because corrosion creates new holes in the casing.

33.2.Squeeze Cementing Design Parameters

A successful squeeze job depends on the proper design of the cement slurry to meet the specific conditions of the well.This includes:

• permeability of the formation.

• bottom-hole static temperature.

• formation pressure (can be either an active or a depleted formation).

• fracture gradient.

• hydrostatic pressure.

Critical properties of the slurry include:

• fluid loss control (to provide proper fluid loss rate according to the formation permeability). • viscosity (depends upon the type of problem to solve: fissures, tiny annulus, etc.)

• free water.

• compressive strength.

• thickening time.

• density.

33.3.Remedial Cement Theory

The rate at which filter cake is deposited depends on:

• formation permeability.

• differential pressure applied during the job.

• time over which the pressure is applied.

• rate at which the slurry loses filtrate (related to the amount of fluid loss control agents used in the slurry).

The below table shows the effects of the fluid loss rate on the final result of the squeeze.

Fluid Loss Rate	Effect
>800 ml/30 min.	Dehydrated slurry can completely bridge the casing and prevent perforations below this point from being squeezed.
About 150 ml/30 min.	Large nodes of dehydrated cement can build up and prevent further injection of slurry into the zone.
About 50 ml/30 min.	small node may form in the casing at the end of the squeeze job. In this case, the perforations are efficiently plugged with dehydrated cement. This is the best result possible.
<15 ml/30 min.	A too little fluid-loss rate will not allow enough filter cake to build up. In this case, the perforations may remain partially open and exposed to formation pressure.

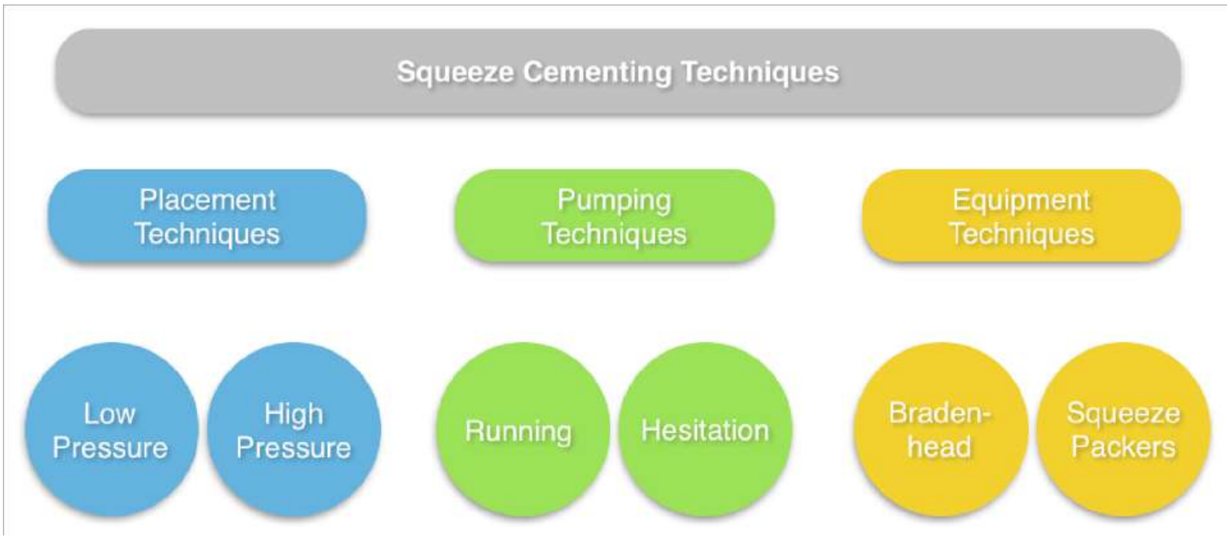
It is important to understand that the fluid loss rate depends on different factors:

• the fluid loss control of the slurry (depends on the amount of FLAC* used).

• the ability of the formation to let the filtrate in is proportional to the relative permeability (to filtrate) of the rock.

• the differential pressure applied during the squeeze operation.

When squeezed against low-permeability formations, slurries with low fluid loss rates dehydrate slowly and tend not to bridge as they are forced along openings or channels. The duration of the operations may be excessive. Against a high-permeability formation, a slurry with a high fluid-loss rate dehydrates rapidly. Consequently, the well-bore may become plugged by filter cake and the channels, which otherwise would have accepted cement would be bridged off.



Some fluid must remain with the slurry for the correct hydration reactions to occur. Therefore, slurries exhibiting low fluid loss rates are best suited for squeezing formations with high permeabilities and vice versa.

The ideal squeeze slurry should be tailored to the formation to control the rate of cake growth (and fluid loss), and allow a uniform filter cake to build up over all permeable surfaces which, after curing, forms an almost impermeable solid. A properly designed slurry will leave only a small node of cement filter cake inside the casing.

To adjust the fluid loss value of the slurry to properly work with the formation conditions, a fluid loss control agent (FLAC* additive) is used.

33.4.Squeeze Cementing Techniques

Squeeze cementing techniques are divided into three main categories:

- placement
- pumping
- equipment.

Placement Techniques

Placement techniques refer to the pressure with which the slurry is placed in the zone of interest. This can be done at either low or high pressure.

33.4.1.Low-Pressure Squeeze

The aim of a low-pressure squeeze is to fill the voids, channels, or perforation cavities with dehydrated cement. The cement volume is generally small, because no slurry is actually pumped into the formation. An accurate control of the bottom-hole pressure (hydrostatic pressure + applied surface pressure) is essential, as excessive pressure could result in formation breakdown.

An injection test must be performed to determine the maximum squeeze rate without exceeding the fracture pressure. This helps to determine

- the need of cleaning the perforations, channels, etc.
- the necessity to apply the high-pressure squeeze technique.

The maximum squeeze pressure normally equals 300 to 500 psi below the established fracture pressure of the formation.

Low-pressure squeeze has a higher success rate than the high-pressure squeeze. Therefore, it should be the preferred method whenever possible.

33.4.2.High-Pressure Squeeze

The high-pressure squeeze technique is used when low-pressure squeeze will not accomplish the job objectives. This is used mainly in cases of

- Isolated channels behind the casing not being directly connected to the perforations.
- Small cracks or micro-annuli that may allow the flow of gas but do not allow the passage of a cement slurry.
- Plugged perforations or impossibility of removal of plugging fluid or debris that is ahead of the cement slurry or inside the perforations.

In high-pressure squeezing, cement slurry placement behind the casing is accomplished by breaking down the formation at or close to the perforations at pressures above the formation fracture pressure and injecting the cement slurry into the zone.

In high-pressure squeezing, slurry volumes are usually relatively high because the created fractures have to be filled with cement slurry. As a special precaution, a wash or weak acid should be pumped ahead of the slurry to minimize the pump rates required to initiate the fractures.

Note: High pump rates can lead to large fractures with unpredictable orientations. These fractures cannot be controlled and the formation can be seriously damaged.

Fluids ahead of the slurry are displaced into the fractures, allowing the slurry to fill the desired spaces. Further application of pressure dehydrates the slurry against the formation walls, leaving all channels (from fractures to perforations) filled with cement filter cake. A properly executed high-pressure squeeze should leave the cement as close to the well-bore as possible.

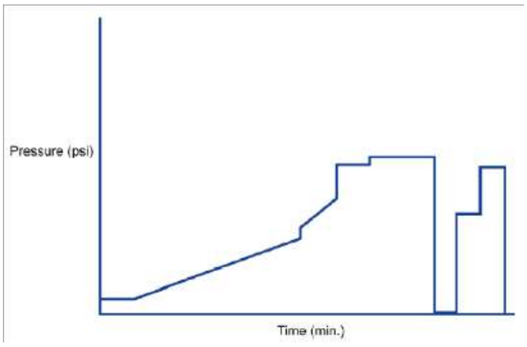
33.5.Pumping Techniques

Pumping techniques refer to how squeeze pressure is attained. This can be done:

- continuously (called a running squeeze).
- intermittently (called a hesitation squeeze).
- circulation squeeze.

33.5.1.Running Squeeze

The Figure below shows a typical graph for a Running squeeze pressure vs. Time



Typical applications of a running squeeze include:

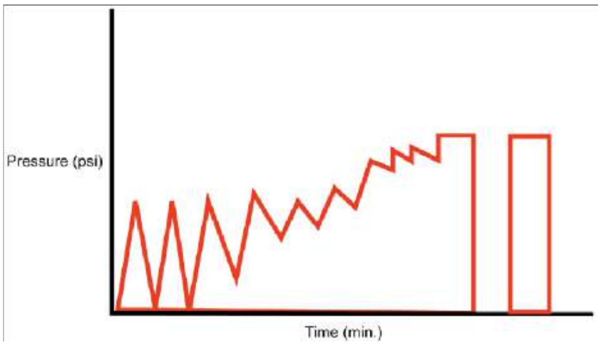
- salt water flows.
- casing shoes.
- liner tops.
- lost circulation zones.

In these cases, it is generally necessary to exceed the formation fracture pressure to inject the slurry. A running squeeze entails the continuous pumping of cement slurry until final squeeze pressure is attained (which may be above or below the fracture pressure). Rapid dehydration is desirable to limit the fracture extension and achieve a good hydraulic seal in the near well-bore area. For this reason, a cement slurry used for a high-pressure squeeze normally has a high fluid loss value.

When the final pressure remains constant, the job is ended. The volume of slurry injected is usually large. Volumes ranging from 10 to 100 bbl are common.

33.5.2.Hesitation Squeeze

The Figure below present a typical Hesitation squeeze pressure vs. time graph



Typical applications of a hesitation squeeze include:

- long intervals or multiple zones

- voids or channels
- wells with low reservoir pressure
- pay zones or near pay zones
- naturally fractured formations.

The hesitation squeeze technique involves the intermittent application of pressure at a rate between 0.25 and 0.5 bbl/min., at 10- to 20-minute intervals, until final squeeze is attained.

The relatively small amount of filtrate lost from the slurry makes continuous pumping (running squeeze) impractical, if not impossible, with conventional field equipment. During a hesitation squeeze, the initial leak-off is usually very high, but it decreases as filter cake builds up.

A hesitation squeeze usually involves a much smaller slurry volume than a running squeeze. Hesitation time depends on the type of formation. This could range from 30 minutes or more at the beginning of the squeeze (no cement filter cake yet) or for loose formations, to 5 minutes in tight formations. Time must be considered in determining the thickening time of the slurries to be pumped during the job.

33.5.3.Circulation Squeeze

The circulation squeeze method is generally used to repair relatively large voids (channels) behind the casing. To fill the void with slurry, two intervals have to be perforated (at the top and the bottom of the void) and a cement retainer is set between these sets of perforations.

Circulation through the bottom perforations, up the void, and out the top perforations has to be established first with water or acid. The interval is circulated with a wash fluid to ensure a good cleanup, and the cement slurry is then circulated behind the casing. No pressure buildup, other than the increase of the hydrostatic, occurs during the job as cement slurry flows up the annulus.

Once the placement is completed, the stinger is released from the cement retainer preventing slurry to flow back.

After slurry placement into the void is completed, additional slurry is usually placed on top of the cement retainer to cover the top perforations. This slurry is squeezed into the top perforations to seal them off.

The cement retainer tool is strongly recommended for this type of job because there is a risk that some of the cement slurry will fall and set on top of the tool. Then, it would be impossible to retrieve any conventional squeeze packer due to the minimal clearance between the packer and the inside of the casing. The cement retainer should be set as close as possible to the top perforations to minimize the amount of tubing below the top perforations.

Please, refer to LinkedIn article http://better-cementing-for-all.org/suicide-squeeze-risky-still-valid-choice for more aspects of the circulation squeeze

Over-displace, It is important for the success of the job not to over-displace. This means some cement slurry (minimum 1 bbl above the top of the zone) has to be left inside the casing at the end of the job. This will ensure that the perforations or voids will be totally covered by cement so no washout with the displacement fluid can occur. It is essential to accurately monitor the different volume of fluid pumped downhole.

33.6.Equipment Techniques:

Equipment/Application techniques refer to how the squeeze pressure is applied. This can be achieved by using either by:

- Bradenhead Squeeze using the blowout preventers (BOP).
- Downhole packers and retainers.
- Coiled Tubing.

33.6.1.Bradenhead Squeeze Technique

The Bradenhead squeeze technique does not involve the use of any downhole isolation tools. This technique is normally used during low-pressure squeezes when there are no doubts concerning the capability of the wellhead and casing to withstand the squeeze pressure. This is not recommended for old casing, especially when it is corroded or damaged, because it may crack or break under pressure.

When there are open perforations below the zone, it is necessary to protect these perforations. A bridge plug, or retrievable bridge plug (RBP) protected by a sand plug, may be required to isolate perforations further downhole. A viscous pill may be needed to support the slurry column when there is a deep cellar and a high density differential between the slurry and work over fluid.

The typical job procedure for a Bradenhead squeeze will be as follows:

1. If necessary, isolate any open perforations below the zone of interest using a bridge plug, an RBP, and/or a sand plug.
2. Run open-ended drill-pipe or tubing (tailpipe might be used) in hole to 10 ft below the bottom of the zone.
3. Close BOP rams.
4. Perform injection test to confirm injection rate and pressure.
5. Open BOP rams and spot the required volume of cement in front of the perforations.
6. Pick up tubing above slurry to balance plug (at least one tubing joint above).
7. Close BOP rams and reverse out any excess cement.
8. Perform squeeze with chosen pumping technique.
9. Open BOP rams.
10. Wait on cement (WOC).

Note: It is essential that no part of the work-string be left in the balanced plug during the application of the squeeze pressure. Otherwise, plugged or stuck tubing may result. The Bradenhead placement method is very popular because of its simplicity. No packer is required and all tubulars are clear of cement before any squeeze pressure is applied.

33.6.2.Squeeze Tool Technique

The main reason for using squeeze tools is to isolate the casing and wellhead while pressure is applied downhole. This technique can be subdivided into two methods: the retrievable tools method and the drillable tools method. In any case, the squeeze tool setting depth will depend on the:

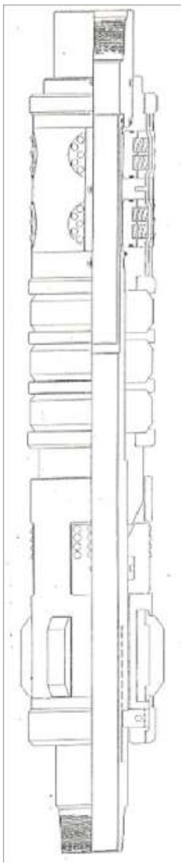
- length of the interval to be treated.
- location of the casing collars.
- quality of the set cement behind the casing (Cement Bond Log).

33.6.3.Retrievable Tools

Retrievable packers can be set and released many times, thus providing more flexibility than drillable packers. They normally have a bypass valve to allow the circulation of fluids while running in the hole and when the packer is set.

The main disadvantage of retrievable packers is that the pressure has to be bled off at the end of the squeeze to unset the packers. If the dehydration process is not properly performed, the cement slurry might flow back to the casing.

The RBP (retrievable bridge plug) can be run in the hole with the packer and retrieved after the cement has been drilled out. To prevent the settling of cement over the releasing mechanism, frac sand is placed on top of the retrievable bridge plug before the job (20 to 40 ft3).



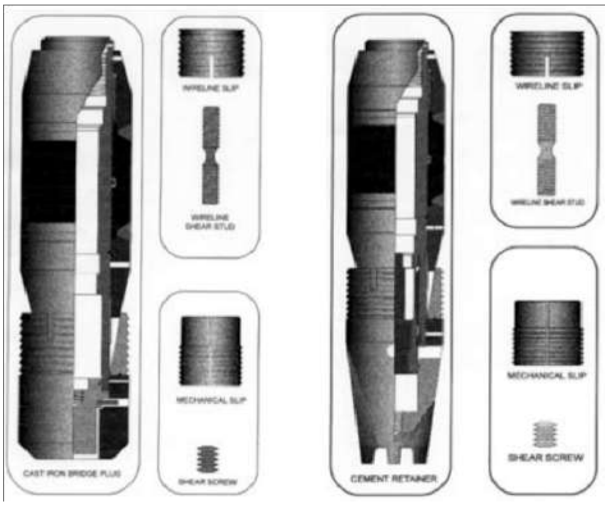
33.6.4.Drillable Tools

Drillable cement retainers are used instead of retrievable packers for the following purposes:

- to provide effective slurry staging during a hesitation squeeze when the formation is highly fractured and will not support a high cement column.

- to prevent back flow when partial or no cement dehydration is expected.
- to isolate the treated area from pressures during the reverse circulation of excess cement from the tubing.
- when a high negative differential pressure may disturb the cement cake just after the squeeze job. • when potential communication with upper perforations makes the use of a packer a risky operation.

The cement retainer and the drillable bridge plug is the same tool which can be converted to fulfill either function. The main difference is that the bridge plug does not contain ports to flow through. They can both be set by wireline or tubing.



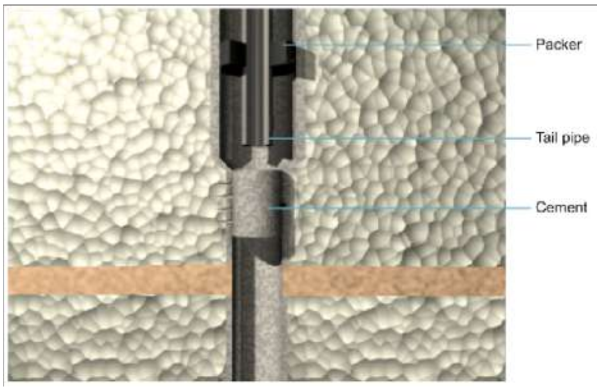
When set by wireline, very accurate setting depths are common. If the zone to squeeze must first be perforated, then the cement retainer can be set immediately after perforating at a minimal additional cost. However, the stinger (the tool which physically connects the tubing to the cement retainer and opens and closes the ports on the cement retainer) must be later run in the well on the end of the tubing.

When set by tubing, the stinger is already connected to the tubing/ cement retainer and the wireline setting cost is avoided.

Because the cement retainer isolates the squeezed perforations, a cement squeeze on perforations above the cement retainer can be performed without delay.

Note: When cement retainers and/or bridge plugs need to be removed, they can only be drilled out.

33.6.5.Packer With a Tailpipe Squeeze



A packer with a tailpipe squeeze involves the use of a retrievable packer to isolate the upper part of the casing and the wellhead from the squeeze pressure.

A squeeze job using a packer with a tailpipe is similar to a Bradenhead squeeze job. The only difference is that a packer is used to isolate the annulus, not the BOP stack (which can be considered as a packer on surface). Instead of closing and opening the BOPs, the packer bypass is set to close and open. In both cases, a cement plug is first spotted and then the squeeze is performed.

Here's the job procedure for a packer with a tailpipe squeeze:

1. Isolate any open perforations below the zone of interest using a bridge plug, an RBP, and/or a sand plug.
2. Run drill-pipe or tubing with packer and tailpipe (bottom of tailpipe might be used) in hole to 10 ft below the bottom of the zone (tailpipe length should be about twice the height of the cement plug).
3. Set the packer and close the bypass.
4. Perform injection test to confirm injection rate and pressure.

5. Open the bypass and spot the required volume of cement in front of the perforations.

6. Pick up string above slurry to balance plug (at least one tailpipe joint above).

7. Close BOP rams and reverse out any excess cement.

8. Open the BOP rams, set the packer, and close the bypass.

9. Perform squeeze with chosen pumping technique.

10. Open the bypass and unset the packer.

11. While waiting on cement (WOC), the string and packer are retrieved from the well and preparations are made to drill out the set cement.

33.6.6.Packer Without a Tailpipe Squeeze

The packer without a tailpipe squeeze technique (also called a suicide squeeze) involves the continuous pumping and injection of slurry into a zone. A retrievable packer (without a tailpipe) is used to isolate the casing and wellhead above.

This technique is considered to be very risky due to the possibility of cementing the packer in the hole because of U-tubing and setting of the slurry. This method is used primarily to squeeze off

- short intervals where the use of tailpipe is not applicable; and
- casing leaks when repetitive operation has to be considered.

It is not advisable to use it to squeeze off channels behind casing because of the possibility of communication between the zones or channels.

A running squeeze technique is recommended when squeezing without a tailpipe:

Here is the job procedure for a packer without a tailpipe squeeze:

1. Isolate any open perforations below the zone of interest using a bridge plug, an RBP, and/or a sand plug.

2. Run in hole with packer to setting depth.

3. Set packer.

4. Perform injection test to confirm injection rate and pressure.

5. Open packer bypass.

6. Pump water ahead, cement slurry, and water behind.

7. Displace until slurry is one barrel to the end of the tubing.

8. Close packer bypass.

9. Perform squeeze into zone until final squeeze pressure is reached, or until the maximum slurry volume is utilized ("hesitating" if there is no pressure buildup).

10. Open packer bypass and close BOP rams.

11. Reverse out the tubing volume 1.5 times to clean tubing and packer.

12. Open BOP rams and close packer bypass.

13. Re-apply squeeze pressure and WOC (wait on cement).

33.6.7.Cement Retainer Squeeze

The cement retainer squeeze technique is similar to using a packer without a tailpipe. However, it uses a drillable isolation tool (the cement retainer) instead of a retrievable packer.

The cement retainer can be set very close to the zone to squeeze by wireline or other mechanical means.Therefore, the risk of cement contamination is minimized.

Squeeze pressure is trapped below the tool by a control valve in the cement retainer. The tubing, casing, and wellhead are protected from the applied squeeze pressure. Also, pressure can be left on the zone after the squeeze is performed. The main advantage, compared to the packer without tailpipe, is that the operation is safer (no need to retrieve the tool).

Here is the job procedure for a cement retainer squeeze (after the cement retainer has been set either mechanically or by wireline):

1. Run in hole with tubing and stinger.
2. Sting into the retainer and perform an injection test to confirm injection rate and pressure.
3. Sting out of retainer.
4. Pump water ahead, cement slurry, and water behind.
5. Displace until slurry is 1 barrel to the end of the stinger.
6. Sting into retainer.
7. Perform squeeze into zone until final squeeze pressure is reached, or until the maximum slurry volume is utilized ("hesitating" if there is no pressure buildup).
8. Sting out of retainer.
9. Reverse out the tubing volume 1.5 times to clean tubing and stinger.
10. Pull the string out of the hole while WOC.

33.6.8.Coiled Tubing Squeeze

The coiled tubing squeeze technique is used to squeeze off depleted or water/gas zones in a producing well without the use of a rig or retrievable tools.

It involves spotting the cement slurry across the zone using coiled tubing, then picking up above the TOC and applying squeeze pressure. The slurry left in the well-bore is then contaminated and reversed out before cement is set.

A coiled tubing squeeze has the advantage of reduced cost because no rig is required to run into the hole. In addition, coiled tubing offers an accurate placement of the slurry in the well-bore and minimizes the contamination.

Slurry design is very critical for the success of the job because the fluids are being pumped through the coiled tubing. This leads to very long job times, high shear rates, and subsequent shortened thickening time.

Here's the job procedure for a coiled tubing squeeze:

1. Run in hole with coiled tubing below the zone.
2. Close the BOP rams and perform an injection test to confirm injection rate and pressure.
3. Spot a viscous pill of gel or heavyweight mud below the zone.
4. Spot the cement slurry while slowly picking up the coiled tubing to follow the increasing level of slurry in the casing.
5. Close rams and apply squeeze pressure until squeeze-off pressure is attained.
6. Bleed-off pressure and open BOP rams.
7. Circulate contaminant (borax solution or MUDPUSH* spacer) while slowly running the coiled tubing to the bottom of the zone to dilute the slurry.
8. Circulate out the contaminated slurry and the pill until the tubing and well-bore are clean. Under normal conditions, reversing out cannot be performed because the coiled tubing is always used with a check valve at the end.
9. Wait on cement (WOC).

33.7.Cement Squeeze Misconception

The Cement Slurry Enters theFormation Matrix

The mix water and dissolved substances (called the cement filtrate) only penetrate the pores, while the solids accumulate at the formation face and form the filter cake. It would require a permeability higher than 100 darcies for the cement grains to penetrate a sandstone matrix. The only way for a slurry to enter a formation is through fractures and large holes (vugs).

High Pressure During or at the End of the Squeeze is the Indication of a Good Job

- If the formation fracture pressure is exceeded, the control of the slurry placement is lost and the slurry enters unwanted areas. Once created, a fracture may extend across various zones and open unwanted channels of communication between previously isolated zones.
- All the perforations are not "taking" cement filtrate at the same rate. If the fluid loss value is too high, nodes may be created in the casing that will isolate the lower part of the zone giving open perforation.

Two Zones are Isolated by Introducing a Horizontal "Pancake" of Cement Between Them

This theory is not strictly valid because fractures formed during high-pressure squeezing will almost always be vertical (the possibility of horizontal fractures exists only at very shallow depths of less than 2,000 ft).

33.8.Squeeze Calculations

33.8.1.Terminology

Here are some common terms and equations for understanding the squeeze calculations.

Squeeze Pressure

Squeeze pressure is defined as the pressure exerted on the zone during the squeeze job. It should not exceed the fracture pressure for a low-pressure squeeze. Squeeze pressure is the sum of surface pressure (psi) and hydrostatic pressure due to fluids in the tubing and across the zone (psi).

Hydrostatic Pressure (HP)

HP (psi) = Density (ppg) x Depth (ft) x 0.052

This is only true for a vertical well where true vertical depth (TVD) and measured depth (MD) are the same. In a deviated well, use TVD instead of depth:

HP (psi) = Density (ppg) x TVD (ft) x 0.052

Frac Pressure (FP)

FP (psi) = Fracture Gradient (psi/ft) x Vertical Depth to top of perforations (ft)

Initial and Final Squeeze Pressures (IP and FSP)

Initial squeeze pressure refers to the BHP (Bottom-hole Pressure) at the beginning of the squeeze job, while final squeeze pressure refers to the BHP at the end of the job.

Here are some guidelines for determining the final squeeze pressure:

1. Squeeze Pressure < Formation Fracture Pressure
2. Squeeze Pressure > Formation Reservoir Pressure
3. Final Squeeze Pressure is
   - high for low-permeability formations and
   - low for high-permeability formations
4. Final Squeeze Pressure ~ Initial BHP + 500 psi

Maximum Allowable Surface Pressure (MASP)

MASP = FP - HP - Pressure Safety Margin (psi)

Where

FP = Fracture Pressure

HP = Hydrostatic Pressure

Burst and Collapse Pressure of Tubulars

Burst and collapse pressures of the tubulars (drill-pipe, tubing, and casing) should be checked at the design stage of the squeeze job. Generally, these values are high and well above the maximum squeeze pressure applied during the job.

However, when dealing with old or corroded pipe, it is important to check that tubulars are able to handle the maximum pressures. This might be a limiting factor that will define the maximum pressure that can be applied during the job. Here are some guidelines:

- Annular BHP above packer < Casing Internal Burst Pressure.

- Squeeze Pressure - Annular BHP above packer < Casing Collapse Pressure.
- Squeeze Pressure - Annular Pressure < Tubing Burst or Collapse Pressure.

It is important to remember that pressure is transmitted through the fluids without any need for the fluid to be displaced. As soon as surface pressure is applied, it is simultaneously applied down the inside of the entire tubing length. It also travels up in the annulus if no tool is used, such as the Bradenhead squeeze, or if the packer bypass is not closed.

33.8.2.Procedure for Calculations

Here is the standard procedure for the calculations:

1. Determine all needed capacities for the following:
   - tubing and/or drill-pipe.
   - annulus.
   - casing.
2. Perform calculations for slurry volume, cement plug displacement, water ahead and behind, etc. This specific step was covered in the Cement Plug section.
3. Calculate the Maximum Squeeze volume.
4. Calculate the Hydrostatic Pressure (HP) at the beginning of the squeeze.
5. Calculate the Hydrostatic Pressure (HP) at different critical steps of the squeeze job (only for cement retainer and packer without tailpipe).
6. Calculate the Hydrostatic Pressure (HP) at the end of the squeeze.

33.8.3.Examples

Suppose a client is interested in squeezing off a casing leak at 8000 ft in an old casing. The leak is identified by running a Packer and RBP in tandem. To save time, the client wants to run the squeeze job with

- 3 1/2-in., 12.95-lb/ft N80 tubing.
- 9 5/8-in., 47-lb/ft C95 casing.
- 7,500-ft packer setting depth.

The client wants to use

- 45 bbl of neat slurry with 15.8-ppg density.
- 5 bbl of fresh water ahead of the cement slurry.
- 5 bbl of fresh water behind the cement slurry.

The well is full of brine with 9.5-ppg density and the frac gradient of the formation behind the casing leak is 0.8 psi/ft. This information is used to determine:

- capacities.
- when to close the packer bypass.

- maximum squeeze volume.
- hydrostatic pressures.
- frac pressure and MASP.
- surface pressure.
- burst and collapse pressures.

Capacities

Example data:

- 3 1/2-in., 12.95-lb/ft N80 tubing.
- 9 5/8-in., 47-lb/ft C95 casing.
- 7,500 ft packer setting depth.
- 45 bbl of neat slurry with 15.8-ppg density.
- 5 bbl of fresh water ahead of the cement slurry.
- 5 bbl of fresh water behind the cement slurry.
- brine with 9.5-ppg density.
- frac gradient of 0.8 psi/ft.

Here is the tubing, annular, and casing data from the Tubing and Casing Data Handbook:

Tubing, Annular, & Casing Data		
C_{tbg}	0.04125 ft^3/ft	0.00735 bbl/ft
C_{ann}	0.3442 ft^3/ft	0.0613 bbl/ft
C_{cas}	0.4110 ft^3/ft	0.0732 bbl/ft

Excess is only calculated in the open-hole section of the plug. This is normally calculated on the slurry volume to cover the height in the open-hole with no drillpipe in the hole. However, it may be calculated on the height and volume of cement in the annulus with the drillpipe in the hole. It depends on the operator and how they wish to do it.

When to Close the Packer Bypass (or Sting in the CR)

Example data:

- 3 1/2-in., 12.95 lb/ft N80 tubing.
- 9 5/8-in., 47 lb/ft C95 casing.
- 7,500 ft packer setting depth.
- 45 bbl of neat slurry with 15.8 ppg density.
- 5 bbl of fresh water ahead of the cement slurry.
- 5 bbl of fresh water behind the cement slurry.

• brine with 9.5-ppg density.

• frac gradient of 0.8 psi/ft.

D1 = Displacement to close packer bypass (or sting in CR) = 4 bbl.

D1 = Vtbg - Vcmt -Vb - 1 bbl.

D1 = (7,500 ft x 0.00735 bbl/ft) - 45 bbl - 5 bbl - 1 bbl = 4.125 bbl => 4 bbl.

where

Vtbg = Volume of tubing (bbl).

Vcmt = Volume of cement slurry (bbl).

Vb = Volume of water behind (bbl).

Maximum Squeeze Volume (MSV)

Example data:

• 3 1/2-in., 12.95 lb/ft N80 tubing.

• 9 5/8-in., 47 lb/ft C95 casing.

• 7,500 ft packer setting depth.

• 45 bbl of neat slurry with 15.8-ppg density.

• 5 bbl of fresh water ahead of the cement slurry.

• 5 bbl of fresh water behind the cement slurry.

• brine with 9.5-ppg density.

• frac gradient of 0.8 psi/ft.

• D1 => 4 bbl.

Maximum squeeze volume = 81.5 bbl

MSV = Vtbg + Vcas - (Wb + D1 + 1 bbl)

MSV = (7500 ft x 0.00735 bbl/ft) + {(8,000 – 7,500) ft x 0.0732 bbl/ft)} – (5 bbl + 4 bbl + 1 bbl) MSV = 81.725 bbl => 81.5 bbl where

Vcas = Casing volume between packer (CR) and top of zone

Hydrostatic Pressures

Calculating the hydrostatic pressure should occur at the start and the end of the squeeze, and also at different critical points during the squeeze. Every time a change occurs in the length of a column of fluid, or when water ahead moves from tubing to casing, the overall hydrostatic pressure changes.

Generally, there are five different steps. However, in real life, the steps depend upon the job that is run. Some steps have a significant effect on the hydrostatic pressure, others do not. The job should guide the choice of selecting the different steps.

Step 1: Hydrostatic pressure at start of squeeze = 5,907.4 psi

Fluid	Position C =Casing, T= Tubing	Density (ppg)	Volume (bbl)	Length(ft)	H.Pressure (psi)
Brine	T	9.5	4+1.125	5.125/0.00735 = 697.3	697.3 x 9.5 x 0.052 = 344.5
Water Behind	T	8.34	5	5 / 0.00735 = 680.3	680.3 x 8.34 x 0.052 = 295
Cement Slurry	T	15.8	45	45/ 0.00735 = 6122.4	6122.4 x 15.8 x 0.052 = 5030.2
Water Ahead	C	8.34	1.125	1.125 / 0.0732 = 15.4	15.4 x 8.34 x 0.052 =6.7
Brine	C	9.5	35.5	500-15.4 = 484.6	484.6 x 9.5x 0.052 = 239.4
Total	-	-	-	-	5915.8

Step 2: Hydrostatic pressure with water ahead inside the casing = 5,916 psi

Fluid	Position C =Casing, T= Tubing	Density (ppg)	Volume (bbl)	Length(ft)	H.Pressure (psi)
Brine	T	9.5	4	4/0.00735 = 544.2	544 x 9.5 x 0.052 = 268.8
Water	T	8.34	5	5/0.00735 = 680.3	680.3 x 8.34 x 0.052 = 295
Cement Slurry	T	15.8	45	45/0.00735 = 6122.4	6122.4 x 15.8 x 0.052 = 66.4
Water Ahead	T	8.34	153.1 x 0.00735 =1.125	7500-(544.2 + 680.3 + 6122.4) = 153.1	153.1 x 8.34 x 0.052 = 66.4
Brine	C	9.5	500 x 0.0732 = 36.6	500	500 x 9.5 x 0.052 = 247

Fluid	Position C =Casing, T= Tubing	Density (ppg)	Volume (bbl)	Length(ft)	H.Pressure (psi)
Total	-	-	-	-	5907.4

Step 3: Hydrostatic pressure with all cement slurry out of the tubing = 4,074.7 psi

Fluid	Position C =Casing, T=Tubing	Density (ppg)	Volume (bbl)	Length(ft)	H.Pressure (psi)
Brine	T	9.5	4 + 46.125	7500 - 680.3 = 6819.7	6819.7 x 9.5 x 0.052 = 3368.9
Water Behind	T	8.34	5	5 / 0.00735 = 680.3	680.3 x 8.34 x 0.052 = 295
Cement Slurry	C	15.8	500 x 0.0732 = 36.6	500	500 x 15.8 x 0.052 = 410.8
Total	-	-		-	4074.7

Step 4: Hydrostatic pressure with water behind inside the casing = 4,089.3 psi

Fluid	Position C =Casing, T =Tubing	Density (ppg)	Volume (bbl)	Length(ft)	H.Pressure (psi)
Brine	T	9.5	4 + 51.125	7500	7500 x 9.5 x 0.052 = 3705
Water Behind	C	8.34	5	5 / 0.0732 = 68.3	68.3 x 8.34 x 0.052 = 29.6
Cement Slurry	C	15.8	500 x 0.0732 5 = 31.6	31.6 / 0.0732 = 431.7	431.7 x 15.8 x 0.052 = 354.7
Total	-	-	-	-	4089.3

Step 5: Hydrostatic pressure at end of squeeze = 3,952.5 psi

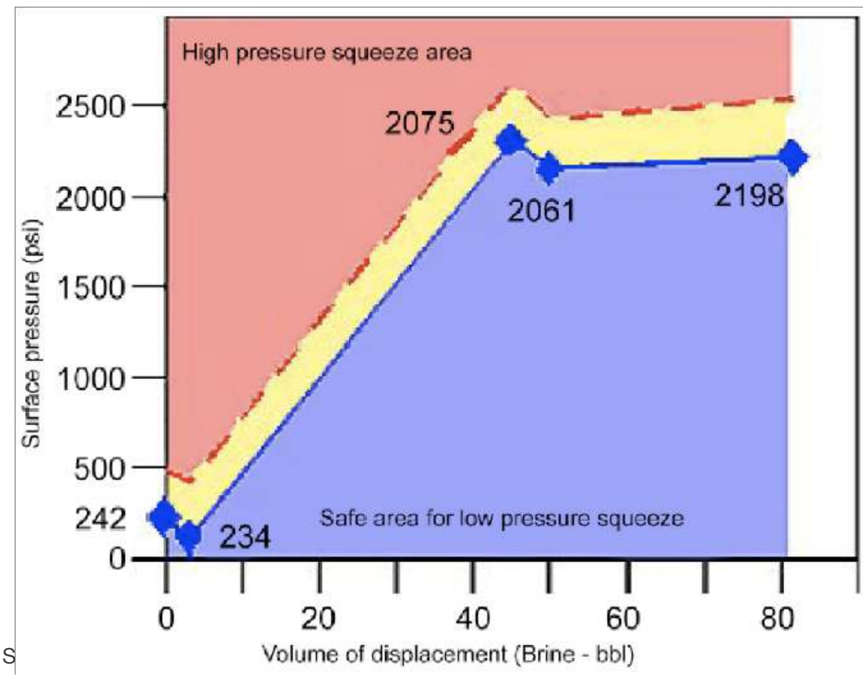
Fluid	Position C =Casing, T =Tubing	Density (ppg)	Volume (bbl)	Length(ft)	H.Pressure (psi)
Brine	T	9.5	4 + 51.124(a)	7500	7500 x 9.5 x 0.052 = 3705

Fluid	Position C =Casing, T =Tubing	Density (ppg)	Volume (bbl)	Length(ft)	H.Pressure (psi)
Brine	C	9.5	418 x Cc = 30.6(b)	500 - (68.3 + 13.7) = 418	418 x 9.5 x 0.052 = 206.5
Water Behind	C	8.34	5	5 / 0.0732 = 68.3	68.3 x 8.34 x 0.052 = 29.6
Cement Slurry	C	15.8	1	1 / 0.0732 = 13.7	13.7 x 15.8 x 0.052 = 11.3
Total	-	-	-	-	3952.5
	a) Tubing Volume filled with brine b) Casing volume filled with brine				

Frac Pressure and MASP

Stage	Volume Squeezed (bbl)	Frac Pressure (psi)	Hydrostatic Pressure (psi)	Safety Pressure (psi)	MASP (psi)
Start	0	6400	5908	250	242
Step 2	1.125	6400	5916	250	234
Step 3	46.125	6400	4075	250	2075
Step 4	51.125	6400	4089	250	2061
End	81.725 (1)	6400	3952	250	2198

Surface Pressure Chart



The Surface Pressure Chart shows three different domains:

1. The Safe Area for Low Pressure Squeeze is the area in which a low-pressure squeeze is performed.
2. The High Pressure Squeeze Area is the area in which a high-pressure squeeze is performed.
3. The Safety Margin Area for Low Pressure Squeeze is the area defined at 250 psi.

Burst and Collapse Pressures

From the Tubing and Casing Data Handbook:

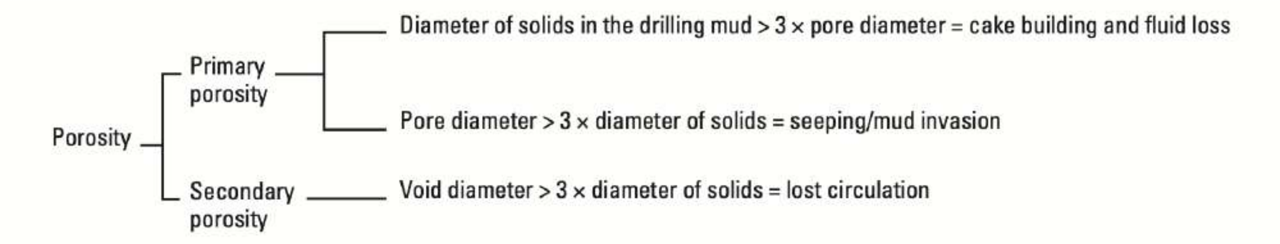
- 9 5/8-in., 47-lbm/ft casing (C95) has a burst pressure of 8,720 psi.
- 3 1/2-in., 12.95-lbm/ft tubing (N80) has a burst pressure of 15,000 psi.

Both are well above the maximum applied pressure for a low pressure squeeze.

34. Lost Circulation

34.1.Introduction

Lost circulation (or lost returns) is defined as the total or partial loss of drilling fluids or cement slurries into highly permeable zones, cavernous formations, and fractures or fractures induced during drilling or cementing operations (Goins, 1952). Lost circulation must not be confused with fluid loss. Fluid-loss process is more related to primary porosity, whereas lost circulation can occur in formations with both primary and secondary porosities. Lost circulation is a problem that is best attacked before performing the cement job. Therefore, the treatment of lost circulation during drilling is included in the following discussion. Lost circulation can be an expensive and time-consuming problem. During drilling, this loss may vary from a gradual lowering of the mud level in the pits to a complete loss of returns. To effectively solve lost circulation with the correct technique, it is necessary to know the severity of the losses, the type of lost circulation zone, and the drilling history of the well just before the losses occurred.



34.1.1.Loss Of Circulation Formation Types

1. Coarsely permeable unconsolidated formations such as sand, pea gravel and some coarse gravel beds, shell beds and reef deposits.
2. Vugular and cavernous formations such as; reefs, limestone, chalk and dolomite formations.
3. Fissures or fractures, both natural and induced.

Three major types of losses are discussed below: these are seepage losses, moderate loss and severe or complete loss of returns. In each of these sections we will describe the nature of the loss and recommended ways to resolve the problem.

34.2.Seepage Losses (1–10 Bbl/Hr [1.5 M^3 to 15 M^3/Hr])

Seepage takes the form of very slow losses. Sometimes the losses can be in the form of filtration to a highly permeable formation, an extreme case of fluid loss. Seepage losses can also be confused with the volume of cuttings removed at the surface. One must not confuse these two completely different occurrences. If seepage losses are suspected, the bit must be pulled off bottom and the mud volumes checked with and without circulation. All mixing equipment and nonessential solids removal equipment should be turned off and baseline values recorded.

Once it is established that fluid is being lost, one must decide whether to tolerate or cure this situation. Depending on the cost of the drilling fluid, rig time, or both, one might decide to continue drilling with seepage losses. If formation damage or stuck pipe are potential problems, one should attempt to cure the losses before proceeding with drilling.

34.3.Partial Losses (10–100 Bbl/Hr)

Partial losses are more voluminous than seepage losses; therefore, the fluid cost becomes more crucial in the decision to drill ahead or combat the losses. Drilling with partial losses can be considered if the fluid is not expensive and the pressures are within operating limits.

34.4.Severe or Total Losses (Above 100 Bbl/Hr)

When severe losses are encountered, regaining full circulation is mandatory. This can be accomplished by pumping a lower-density fluid down the annulus (drilling mud, water, or other lightweight fluid) and monitoring the volumes required to fill the well. If the well becomes stable, one then calculates the hydrostatic pressure required to fill the well. If losses persist, one begins spotting conventional lost circulation material (LCM) pills and progresses to plugs if conventional treatments are unsuccessful. Owing to the reduction of hydrostatic head, the well must be monitored closely at all times for influx of fluids. It may be possible in some areas to continue drilling if the fluid cost is low and pressures are manageable.

In case of total losses, the return flow stops immediately. Treatment begins by spotting conventional LCM pills and progresses to plugs if conventional treatments are unsuccessful.

An underground blowout occurs when a fluid or gas flows from one zone into an upper weaker or hydraulically fractured zone. This is usually indicated by unstable surface-pressure readings. This phenomenon is probably the most serious lost circulation condition. Not only is there a loss of fluid, but a dangerous well-control situation also exists. Casing placement is critical to avoid total losses.

34.5.Classification of lost circulation zones

Lost circulation occurs by one of two mechanisms.

- Natural losses. Whole fluid or cement is lost to formations that are highly permeable, unconsolidated, fractured, cavernous, or vugular.
- Induced losses. The mud or fluid is lost because excessive induced pressure hydraulically fractures the formation.
- It is common to classify lost circulation zones into five categories.
- Unconsolidated formations
- Highly permeable/low-pressure formations (depleted zones)
- Natural fractures or fissures
- Induced vertical or horizontal fractures
- Cavernous and vugular formations

Seeping losses can occur with any type of lost circulation zone when the mud solids are not sufficiently fine to seal the formation face. Partial losses frequently occur in highly permeable gravels, small natural frac- tures, or as a result of fracture initiation. Complete losses are usually confined to long gravel sections, large natural fractures, wide induced fractures, or cavernous formations.

34.5.1.Unconsolidated Formations

Coarse, unconsolidated formations can have a sufficiently high permeability for whole mud or cement slurry to invade the formation matrix (10–100 D). For whole mud or cement slurry to be lost, the average particle size of solids in the mud or cement slurry must be less than or equal to one-third the size of the formation opening (Barkman and Davidson, 1972). These losses are normally confined to shallow wells or surface holes. Rates of loss can vary from seepage to total losses. In the event that losses are total, it is sometimes common practice to continue drilling if a sufficient supply of water is available and there are no environmental or well-control concerns.

One reason for preventing shallow mud losses is that unconsolidated formations may wash out, forming a large, unstable cavity that could collapse from the over- burden and rig weight. In some areas, it may be more common to drill with air, mist, and foamed or aerated muds to prevent losses. Unconsolidated formations are typically found at shallow levels and normally consist of sands or gravel; however, they can also occur in shell beds or reef deposits.

34.5.2.Highly Permeable or Depleted Formations

To permit the penetration of whole mud or cement slurry, the formation permeability must be greater than 10 D; however, significant seepage losses can occur in lower-permeability consolidated sandstones. Producing formations in the same field or general vicinity may cause subnormal (depleted) formation pressure because of the extraction of formation fluids. Loss of mud to these formations requires that the passages be sufficiently large and connected to allow entry of whole mud and that the mud pressure must exceed the formation pressure. Seepage losses to severe losses can often lead to differentially stuck drillpipe. Such depleted reservoirs are found at any depth.

34.5.3.Natural Fractures or Fissures

Hard, consolidated formations may contain natural fractures that take mud when penetrated by the drillstring. The overburden must be self-supporting for a horizontal fracture to exist, but this is not the case for a vertical natural fracture. To widen a horizontal fracture, the overburden must be lifted. Vertical fractures will propa- gate when the fracture pressure is exceeded. A sudden loss of returns in hard, consolidated formations often indicates the presence of natural fractures.

34.5.4.Induced Fractures

If the borehole pressure exceeds the formation parting pressure, open fractures will be created, permitting the loss of mud or cement. There are three typical circumstances when this can occur.

- An immovable mud ring may develop in the annulus owing to fluid loss. The resulting circulating-pressure increase may initiate a hydraulic fracture.
- When one is drilling through an undercompacted formation, typically found offshore, fractures can occur.
- When one is drilling from a mountaintop, the overburden pressure is low, and fracturing occurs easily.

Well irregularities, high mud weight, and rough handling of drilling tools may also help induce fractures.

Simpson et al. (1988) suggested that lost circulation caused by fracture initiation is more common when using oil-base instead of water-base mud. They believed this arises from the failure to consider the compressibility of the oil under downhole conditions. They also observed that induced fractures do not “heal” readily when OBM is present.

When partial losses occur with WBM, an accepted practice is to let the hole “soak.” The mud is allowed to rest in the hole. The resulting mud filtration allows the fractures to be filled with mud solids and often permits full circulation to be restored with no mud-weight reduction. However, filtration from OBM is often too slow to be helpful. Once fractures are initiated with an OBM, fracture extension can be expected until the borehole pressures are reduced or the fracture openings can be sealed.

34.5.5.Cavernous and Vugular Formations

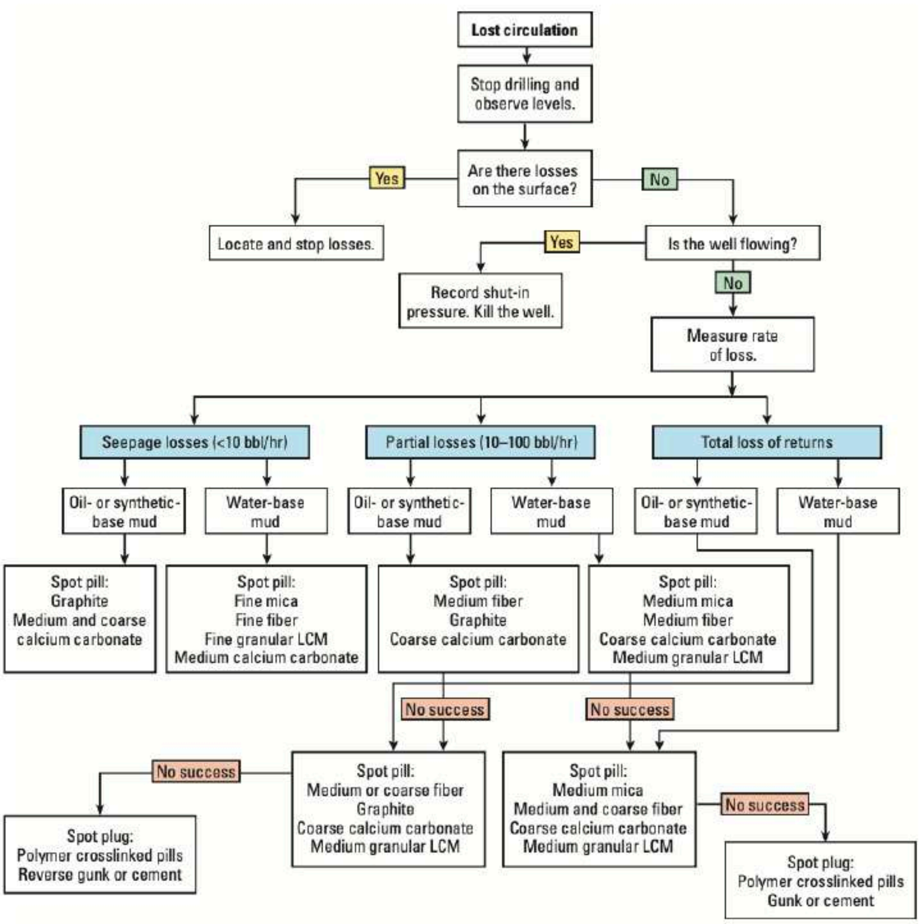
Large voids or caverns are sometimes encountered when drilling through certain limestone and dolomite formations as well as the soluble caprock of salt domes. Sudden and complete losses are typical of this type of zone.

34.5.6.Lost Circulation While Drilling

It is possible to classify the available lost circulation solutions into three main categories:

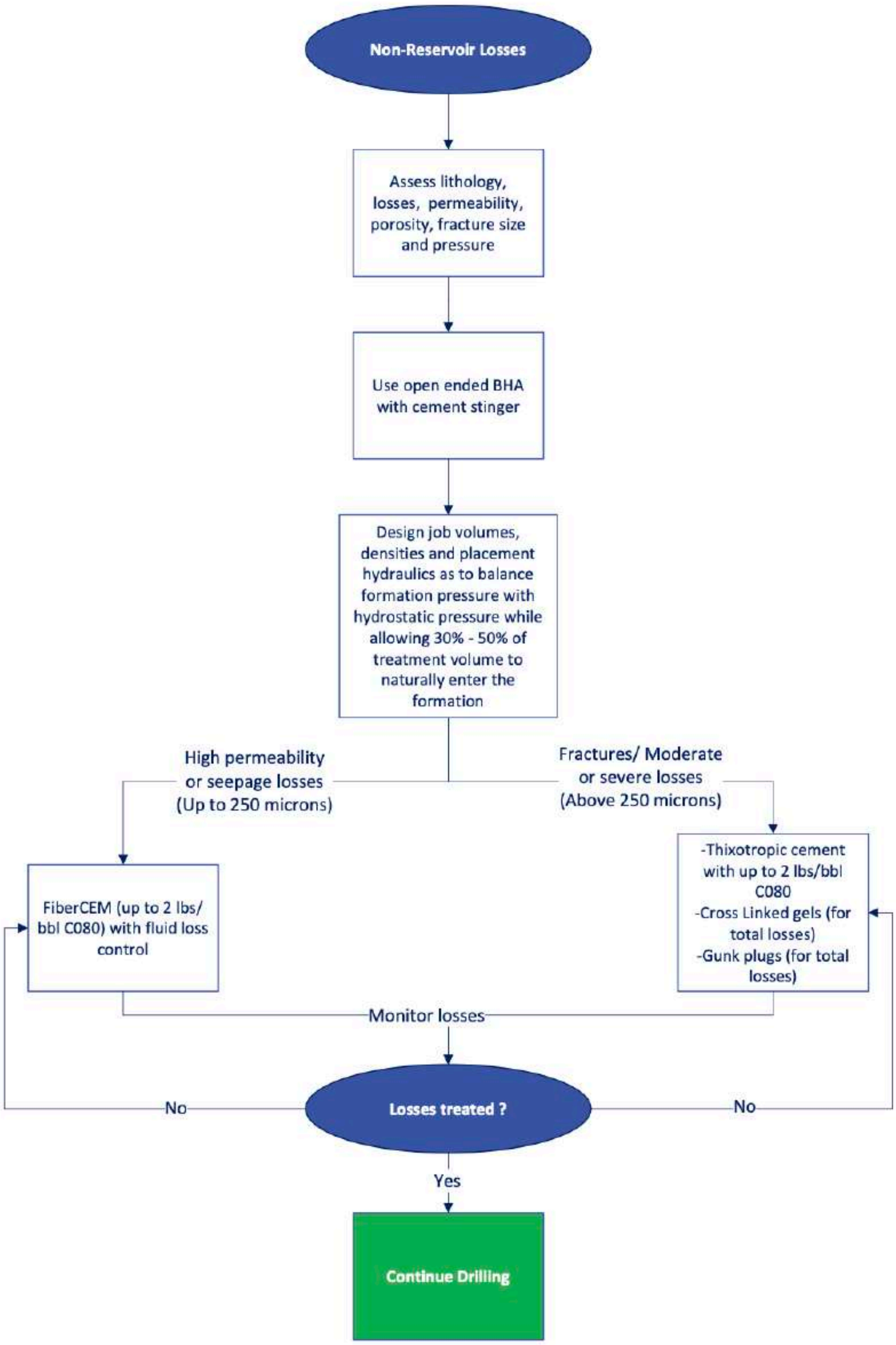
- bridging agents in the drilling fluid (CaCO3, Graphite, Mica, Flakes, LCMs)
- surface-mixed systems (Cement, polymer gels,…)
- downhole-mixed systems. (Cross linked gels, gunk plugs)

The figure shows a lost circulation decision tree to address lost circulation problems.

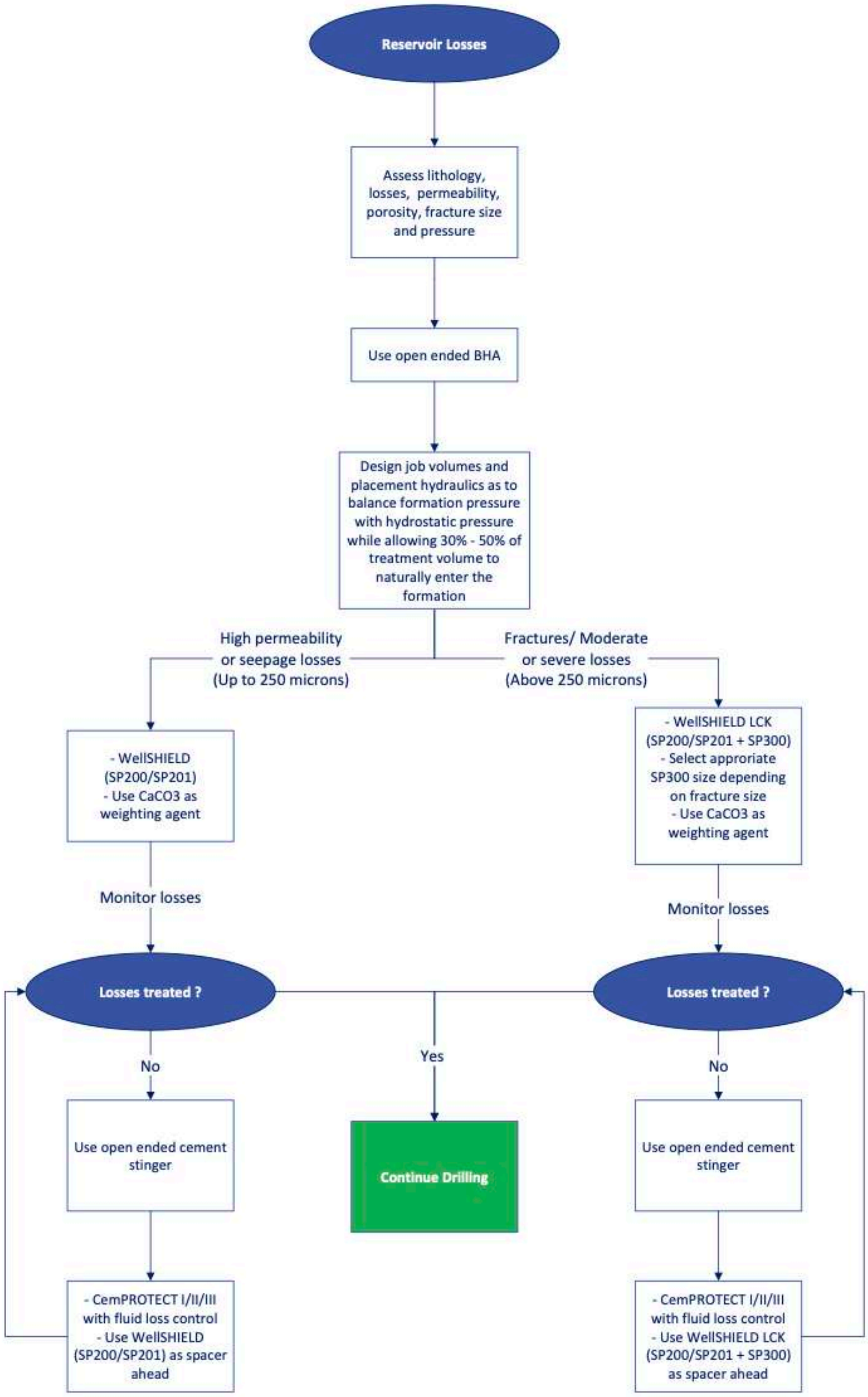


34.6.SPRINT Systems and Decision Tree for Lost Circulation

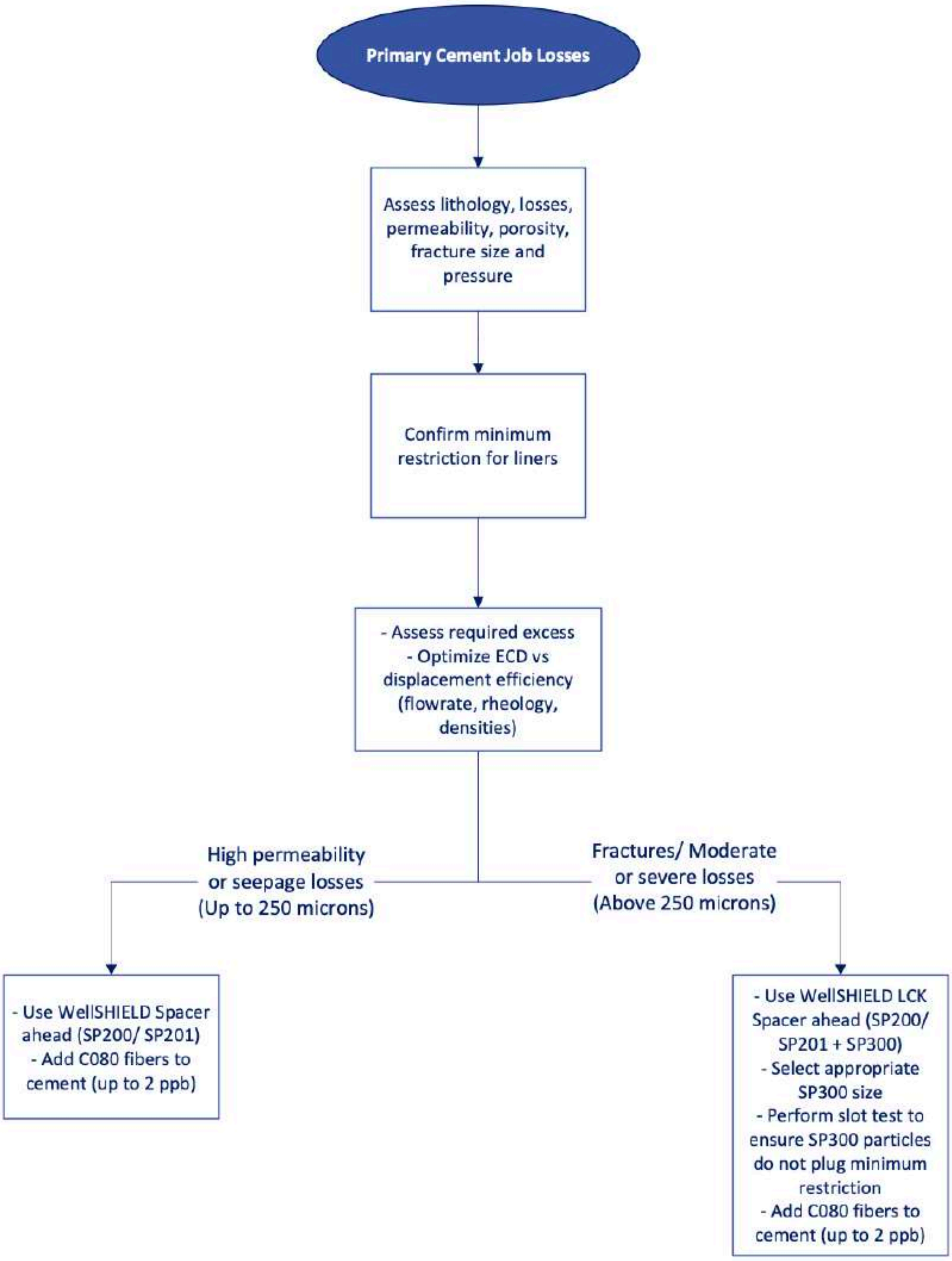
34.6.1.Non-Reservoir Zones



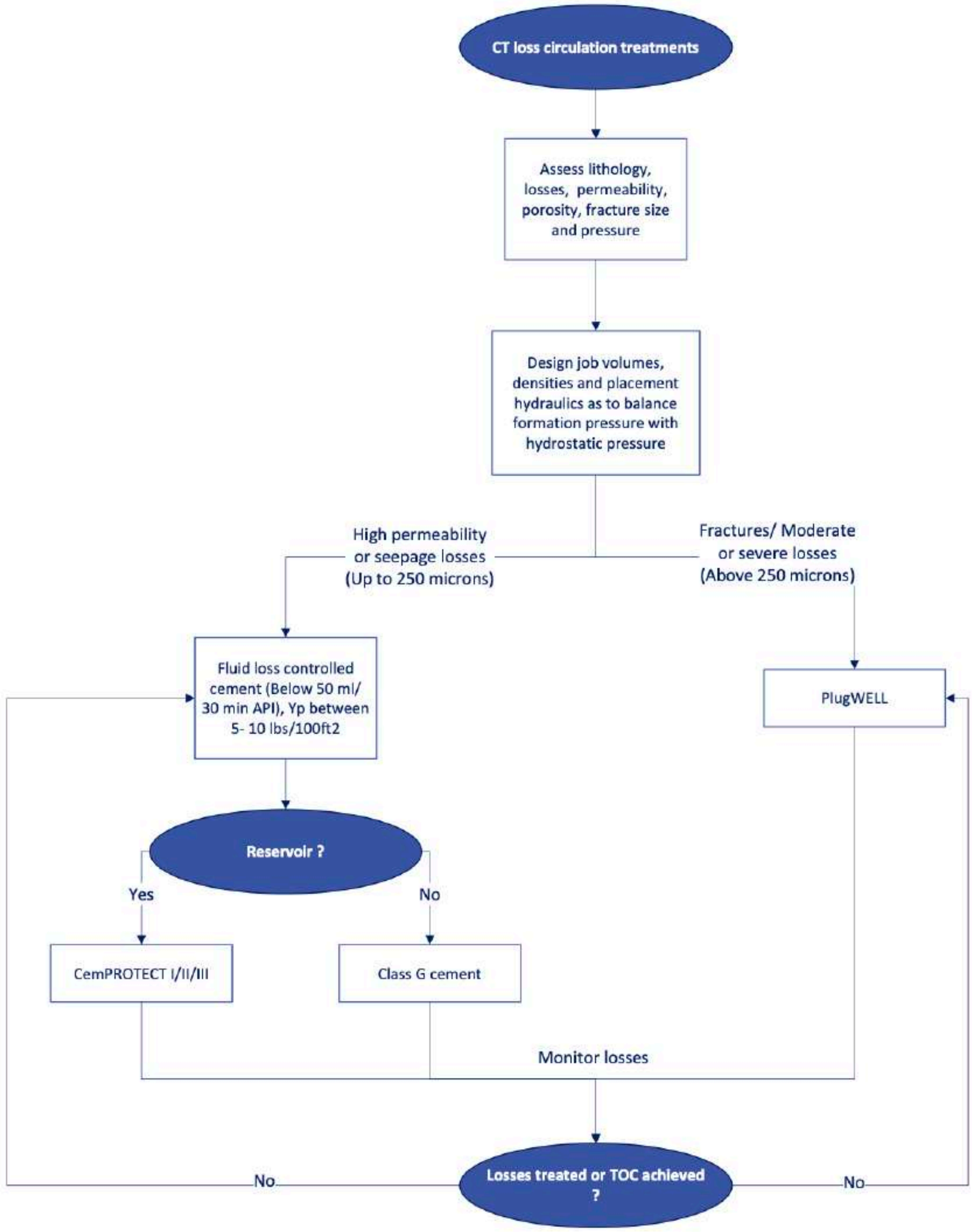
34.6.2.Reservoir Zones



34.6.3.Losses During Primary Cementing



34.6.4.CT Lost Circulation Treatments



35. Cementing Temperature

35.1. Introduction

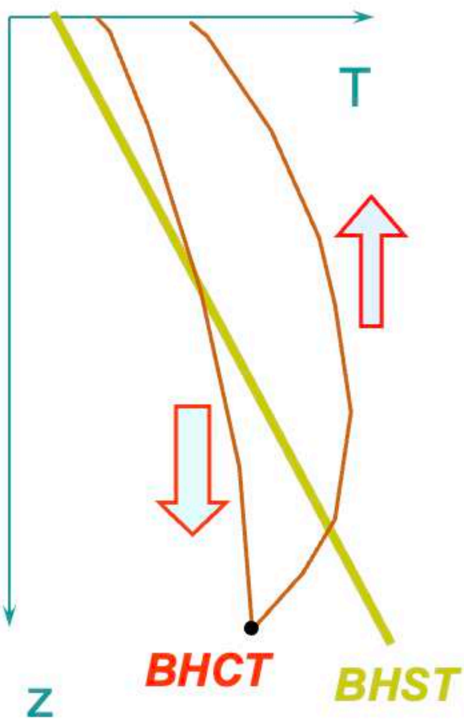
Accurate prediction of the bottom hole temperature (BHT) during the cementing process is of paramount importance. BHT directly influences the setting and curing of cement, and any deviation from the desired temperature range can lead to severe consequences, including compromised well integrity, increased operational costs, and potential environmental risks.

- Inaccurate estimation of the bottom hole temperatures can lead to:
- Extended WOC time and tagging soft cement.
- Creation of a micro-annuli or failure of the cement sheath if well operations resume before the cement has set.
- Flash setting of cement (if the actual circulating temperature is higher than predicted).
- Changes to the cement properties due to the sensitivity of some the cementing additives.
- Gas percolation problems. A change in job temperature from the lab test conditions can affect the right angle set behaviour and extend transition time of the cement, allowing more time for gas to enter the annulus.

It is therefore of the utmost importance to accurately select the design temperature.

35.2. Bottom Hole Static Temperature vs Circulating Temperature

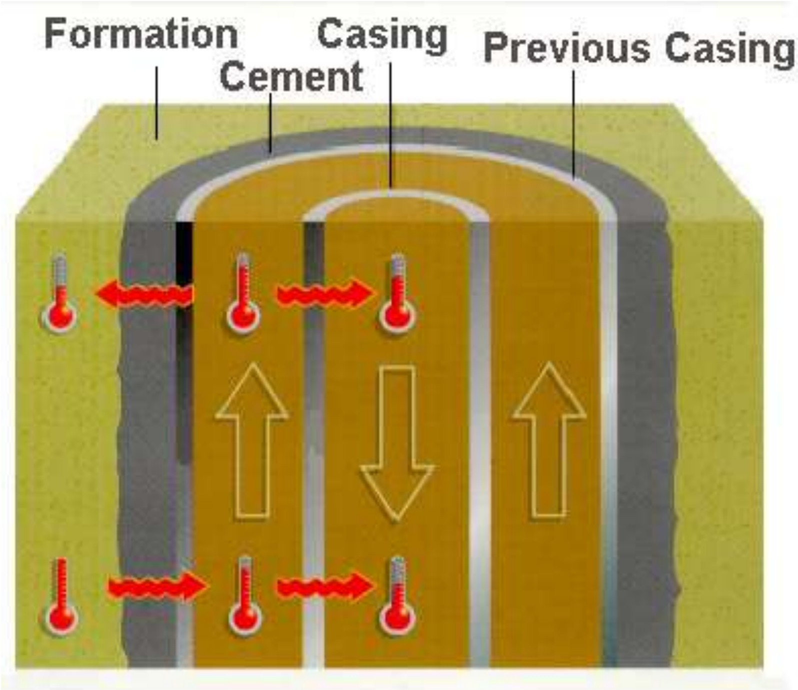
When mud is circulated in the wellbore, heat exchange occurs between the fluid and the formation. At the lower zone (bottom of the hole), heat is transferred from the formation to the annulus fluid. In the upper zone, the heat is transferred from the annular fluid to the formation.



Two processes govern the heat transfer in the well:

- Heat diffusion by conduction to the formation.
- Conductive-Convective heat transfer through the casing, drill pipe wall and annulus.

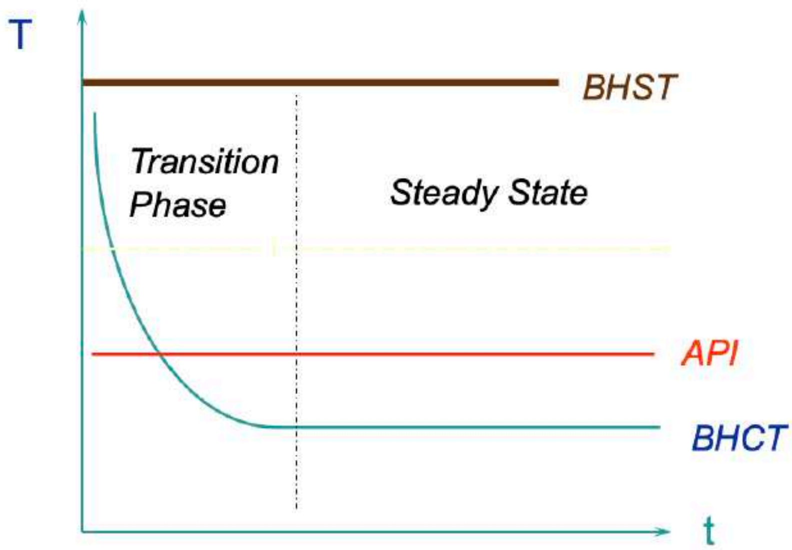
At the bottom of the graph the temperature will continue to increase even after it has passed the float shoe. It is important to notice that the maximum circulation temperature is not at TD, but is continued to be heated by the formation (lower zone), which in turn is transmitted to the formation (upper zone). This heat transfer process continues up to surface.



When mud circulation begins after a static condition, the bottom hole temperature rapidly falls to reach an asymptotic value called bottom hole circulating temperature (BHCT). This temperature is not the maximum temperature for the fluid.

CemPRO+ gives the API value or it can be looked up in the API Schedules. The API measurements do not however handle a number of variations on BHCT, e.g. variation of BHCT vs. time as shown below.

In the graph the fluid is in thermal equilibrium once fresh fluid has been pumped downhole and it reaches its steady state value. Note that if you change the fluid parameters such as rheology, or the pumping rate the BHCT asymptote will also change accordingly. The rates of change of temperature to BHCT will also vary according to the type of fluid pumped, i.e.: It will be different between mud, slurry or spacer.



35.3.API Schedule

Using temperature measurements from 66 wells, API developed a method for predicting the bottom-hole temperature. Field data were obtained from wells drilled with water and oil-based mud using wells with depths ranging from 7,750 ft to 24,850 ft. Temperature sensors were placed near the end of the drill string on a cleanup trip before running the casing and measuring temperature. The static time, before measurement, ranged from 24 to 138 hours with an average of 37.7 hours. The average circulating time was 6.7 hours.

Different field measurements have revealed the tendency for API schedules to over predict the BHCT, especially for high temperature well.

The API method does not account parameters such as: rate, inlet temperature, lithology, circulating time, well deviation and fluid characteristics.

$$PBHCT = 80°F + \left[\frac{\left((0.006061xTVDxPsTG) - 10.095) \right)}{(1 - 0.000015052xTVD)} \right]$$

Where:

PBHCT: predicted bottom-hole circulating temperature

PsTG: Pseudo Temperature Gradient

TVD: True Vertical Depth

Note that the API tables have to be used with caution, and only in certain applications. The tables will only differentiate between three modes of cementing, squeeze, plug and primary cementing. However, the user of the schedule will need to make sure that he/she has satisfied ALL of the conditions that are stated at the beginning of the API schedule manual:

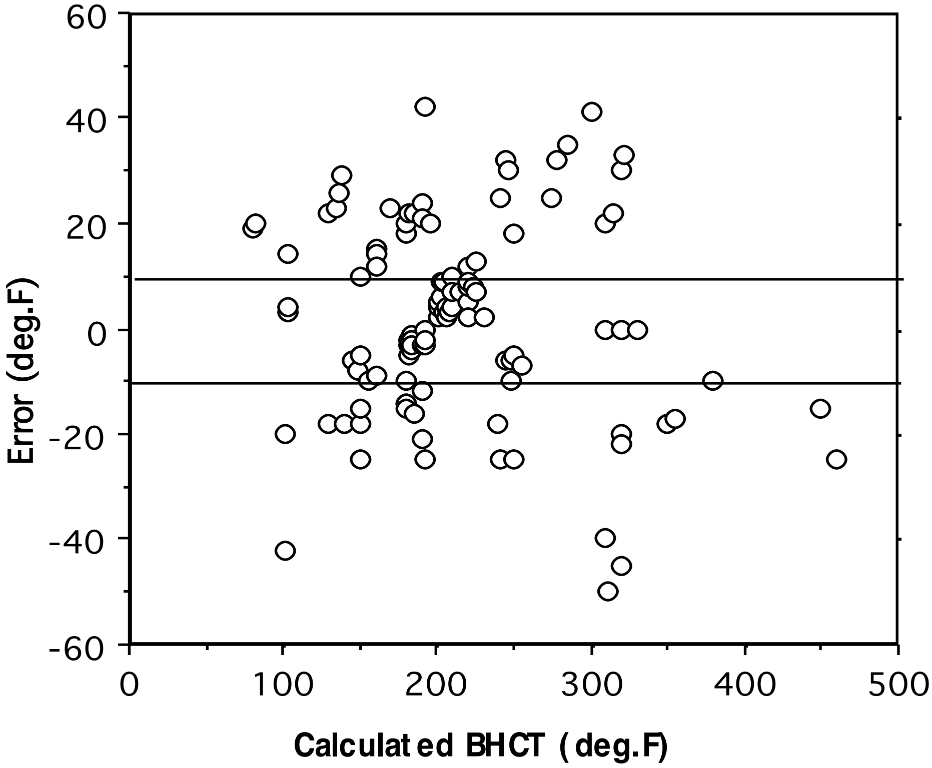
- Depths greater than 10,000 ft and shallower than 22,000 ft.
- Seabed depth greater than 250 ft.
- Surface temperature of 80 degF.
- Maximum gradient of 1.9 degF/100 ft

Below are the limitations of the API schedule:

- No Geothermal Wells
- No Surface variable conditions
- No fluid properties differentiation
- Single Point Geothermal Profile
- Rock Properties are neglected
- Time scaled parameters not taken into account
- Basic Well Geometry is assumed in all the schedules

Due to the above reasons, the API schedule is the least preferred method for estimating BHCT and is not allowed by most of the operators.

Errors between measured BHCT and API calculations



35.4.CemPRO+ Placement Temperature Simulator

CemPRO+ allows the prediction of circulating temperature based on fluid flow and heat transfer laws in order to minimize the risk with temperature. It also takes into consideration the physical parameters of fluids and materials which were not considered in the API correlations. CemPRO+ temperature simulator is the preferred method for estimating the BHCT and is mandatory to use for laboratory cement testing. It is worth noting that PlugPRO is also equipped with the same temperature simulation capabilities.

CemPRO+ features:

- Transient and steady-state solution
- Calculate temperature profile in annulus and casing over time.
- Calculating the temperature profile vs time of the first and last bbl of cement.
- Handle multiple fluids.
- Handle offshore conditions
- Default thermal properties for tubulars, formation lithology and fluids depending on composition.
- Horizontal and deviated wellbore.
- Shut-in time and pre-cementing well circulation is considered.

35.4.1.CemPRO+ Inputs

Fluids:

- Composition
- Rheology
- Flow rate

Wellbore:

- Well trajectory and configuration
- Open hole caliper
- Previous casings and cements

Casing:

- Configuration
- OD and weight

Formation:

- BHST
- Lithology

Off Shore:

- Air gap
- Sea bed depth
- Sea water density
- Riser or returns to sea bed
- Riser dimensions
- Sea temperature profile vs depth
- Mud Line Temperature

35.5.Determination of Static Temperature

Different methods are available to determine BHST and temperature gradient:

- Wireline logging
- Horner plot technique
- Offset well data
- PWD temperature data

• Others field measurements…

35.5.1.Wireline Logging

A critical point in determining an accurate cementing/drilling temperature is the bottom-hole static temperature (BHST). In general, the BHST is taken from the temperature log after the well has been in a static condition for a certain period.

This graph uses temperature measurements taken specifically to establish the API thickening-time schedules. For an average static time of 24 hours, the difference between the log temperature and the static temperature is less than 10 degF. The minimum static time prior to measurement should be 24 hours for a valid static temperature.

If a temperature measurement is taken before 24 hours static time has elapsed, a correction factor must be applied to the log temperature, I.e. it must be ensured that the fluid and the formation are both in thermal equilibrium.

It is also important that the logging speed is not too fast, as this will give a false reading of the BHST.

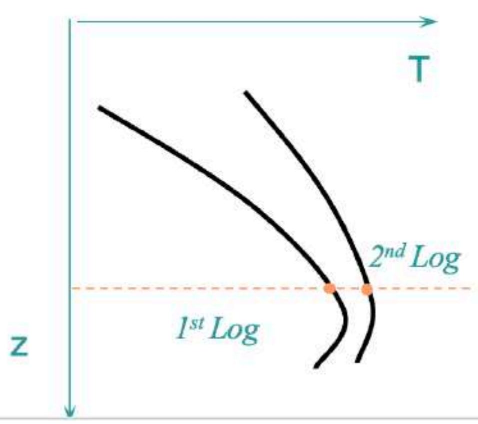
Sometimes the WL temperature reading is only given at the bottom of the well.

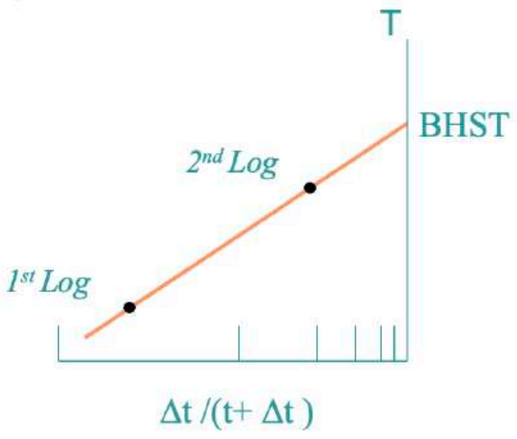
35.5.2.Horner Plot Method

The recorded downhole temperature is not the true static downhole temperature. Due to cooling effects while circulating, the recorded temperature is lower than true static formation temperature.

The Horner technique for estimating static down-hole temperature uses temperature recorded while logging and extrapolation methods similar to those used in determining static bottom-hole pressure.

The Horner plot method is used when there is not time to wait for 24 hrs to use the wireline technique. Normally two wireline runs are performed, first one after 6 hours and a second after 12 hours. This produces two points of BHST plotted on a log scale. From this plot BHT could be extrapolated to a time ratio of unity to give the BHST (i.e. in 24 hours). This produces accurate results. If the BHCT is known this can be used in the graph as the zero





35.5.3.MWD/LWD Tools

MWD-LWD record temperatures while drilling, however data can not be used (directly) as the BHCT for cementing designs:

• Drilling process creates additional heat at the bit (~10 degF).

• High injection temperature (mud pit).

- Different fluid rheological and thermo-physical properties.
- Different wellbore configuration (drill pipe versus casing).
- High flow rates.

36. Extended Leak Off Test Procedure

The extended Leak-Off Test is performed to determine Frac Initiation Pressure and Fracture Reopening Pressure as well as other formation fracturing related information.

The below procedure is typical to an eXtended Leak-Off Test (XLOT) for determining Frac Initiation Pressure and Fracture Reopening Pressure. These steps can vary slightly based on well conditions.

1. Drill 3 to 5 m inside the new formation (below the casing shoe).
2. Circulate the well with mud and ensure the well is full of homogeneous mud to surface.
3. Ensure that the pumping unit pressure sensor and barrel counter are calibrated.
4. Connect Orion DAS to display pressure and volume vs time plot.
5. Conduct Post Job Safety Meeting (PJSM).
6. Disconnect top drive and connect testing lines to the rig floor.
7. M/U crossover to the drill pipe.
8. R/U pumping lines and ensure mud feed line to the cement unit is rigged up and functional.
9. Pressure test the pumping line to 1.5 time the maximum expected surface pressure or to low/high pressure 300/5000 psi.
10. Close the pipe ram and BOP and ensure previous casing annulus is open.
11. Start the XLOT test.
12. Start pumping through drill string at slow constant rate between 0.25 to 0.5 bbl/min. Record the pressure and volumes. It is vital to maintain a fixed pumping rate throughout the whole duration of the test.
13. Pressure will increase linearly until LOP (Leak off Pressure). At this point the slope of the pressure graph will decline.
14. Continue pumping until FBP (Formation Breakdown Pressure) is reached. This is seen as a drop in pressure.
15. Continue pumping at the same rate. The pressure will then stabilize to a constant pressure. This will represent the FPB (Fracture Propagation Pressure).
16. Stop the pump and observe the ISIP (Initial Shut in Pressure).
17. Keep monitoring the pressure decline until it stabilizes. The stabilized pressure is the FCP (Fracture closure Pressure).
18. Bleed off the well-bore pressure and record returned volume in the displacement tank.
19. Another cycle of well-bore pressurization (steps 10 to 17) is required to confirm the FRP (Fracture Reopening Pressure).
20. Close the BOP and start pumping at a fixed rate between 0.25 and 0.5 bbl/min.

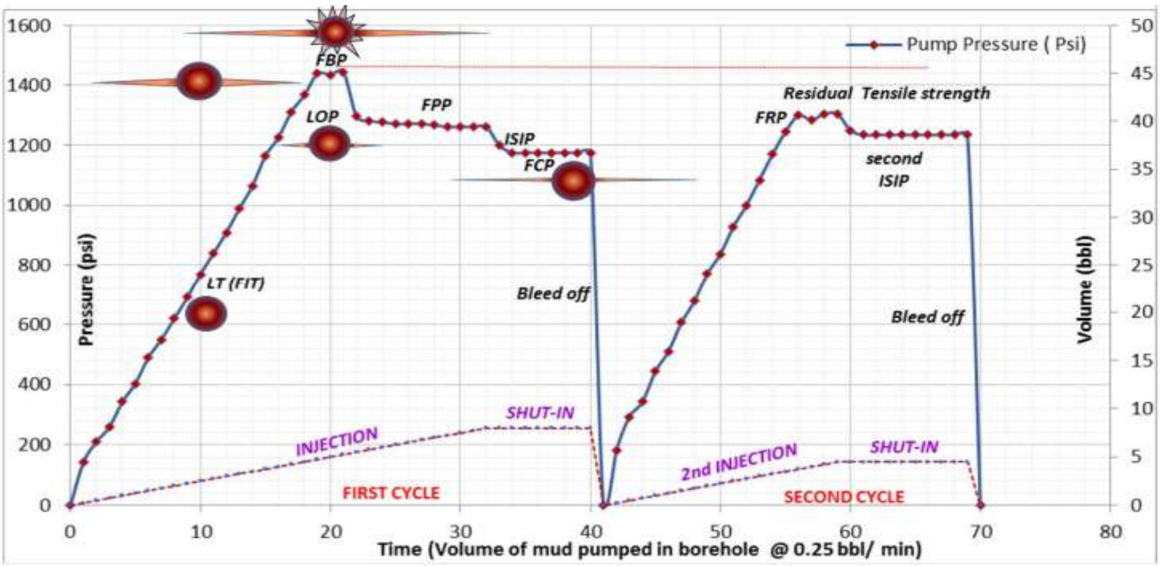
21. The FRP can be observed as a reduction in pressure and a change in pressure slope. Continue pumping at the same rate for 1 to 2 minutes until a pressure drop is observed (Residual Tensile Strength).

22. Shut in the pump and record the pressure (ISIP 2).

23. Continue monitoring the pressure. Once the pressure is stable, record the final pressure.

24. Bleed off the well-bore pressure and record returned volume in the displacement tank.

25. Refer to figure 1 on the next page for an example of XLOT test.

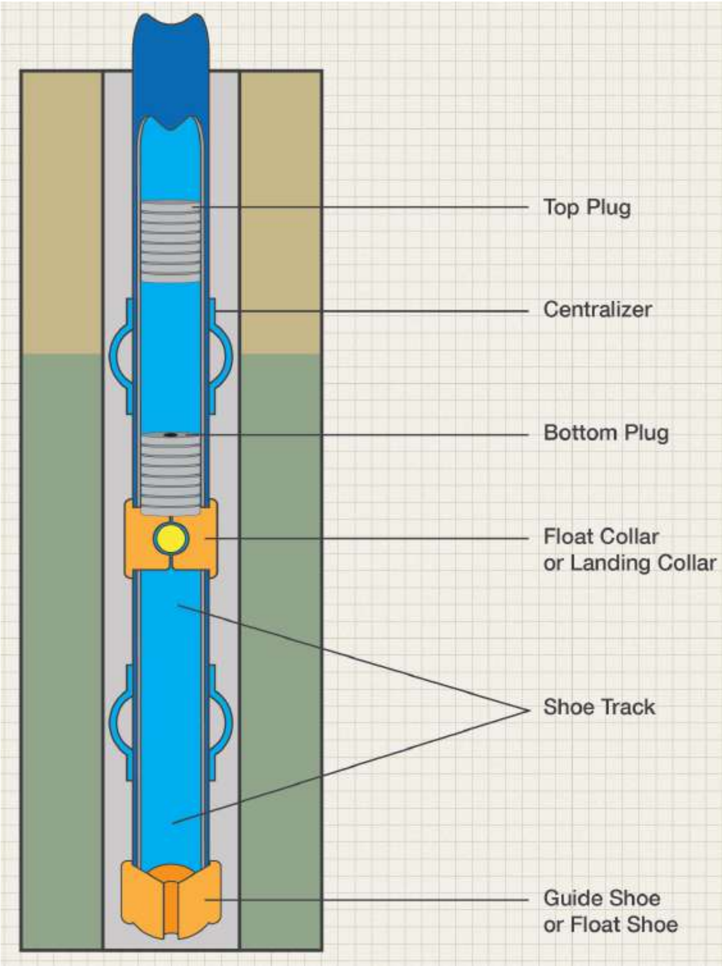


37. Casing hardware tools

Casing hardware consists of all the devices attached to the casing, including the following:

- shoes
- collars
- baskets
- centralizers
- scratchers
- plugs.

These devices are used either in single or multi-stage cementing.



37.1.Shoes

Shoes are attached to the bottom end of casing to make easier to run the casing into its final planned depth. In each case, the shoe has a solid, rounded end that can more easily follow the borehole than open, flat-edged casing can.

This different types of shoes are:

• guide shoes

• float shoes

• stab-in shoes.

37.1.1.Guide Shoes

Guide shoes have inner parts made of drillable materials, such as cement and aluminium's. These inner parts are designed for ease of drilling out when the casing is set. The aluminum guide shoe is most often used with liners, or where ease of drilling out is a prime concern. Cement-filled guide shoes have the advantage of being more resistant to impact.

Both aluminum and cement-filled guide shoes can be equipped with down jets, which force fluid into the well-bore ahead of the shoe to keep the borehole clean and passable during the run in.

37.1.2.Float Shoes

Float shoes have all of the advantages of a guide shoe, but also provide the additional advantage of a check valve to prevent flow back. The disadvantage of a float shoe is the time it takes to run in hole (RIH). Since fluid cannot enter the casing from below, running the casing in hole must be stopped and the casing filled from the top.

RIH time can be reduced by using an orifice fill shoe. Once total depth (TD) is reached, a ball can be dropped or another method can be used to activate the float valve. Different manufacturers and models are activated in different ways.

When running casing with check valves, it is especially important to determine the correct speed for running casing to avoid surge effects. Since no fluid enters the casing from the well-bore, the fluid in the well-bore displaced by the casing can create significant pressures down hole, which can result in the formation fracturing.

Also, if there is no fill-up of the casing, a large differential pressure can be obtained between the mud in the annulus and the air in the casing. This differential pressure could possibly cause the casing to begin to float or collapse.

The check valve in a float shoe can be a

• flapper type

• ball type

• dart type.

The flapper-type check valve provides a better seal and is often used in situations where small hydrostatic differences are expected.

The ball-type check valve does not seal as well as the flapper-type check valve, but ball-type check valves are much cheaper and, therefore, more common.

Float shoes use an automatic fill-up feature the bottom. This reduces the surge effect, but the buoyancy of the casing is reduced, so the use of automatic fill-up devices is limited by the capacity of the rig to support the weight of the casing. When TD is reached, pressure is applied to the valve, which causes it to act like normal float equipment.

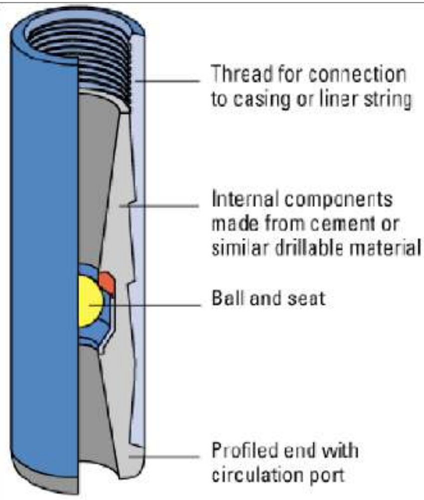
As mentioned earlier, the pressure may be applied by different techniques.

The flapper-type valves often have a sliding sleeve that is moved by dropping a ball down the casing at surface. This ball catches on the sleeve and moves it, which releases the flapper valve. By applying added pressure (which is hard to see at the surface), the ball is pushed on through the sleeve, or there may be ports around the sleeve to allow flow in this position.

Another type of float is the Sure Seal type. This float works much like the Grant Check Valve. A spring holds a dart-type valve in the closed position unless there is pressure to compress the spring and allow flow (only in one direction).

In the automatic-fill float valve, this spring is held in the partially open position by a set of retaining wedges.

Once the casing is in position, a given flow rate will create pressure on these wedges and break them, which releases the spring and makes the float perform like a normal check valve.



Ball Type

The differential fill-up is an alternative to the automatic fill-up. The differential fill-up has two valves. The bottom valve remains open while running in hole. The top valve has a top and bottom end with a smaller bottom side, so that less pressure is required to push it down and open it. Usually, the diameter of the top side is 10% to 20% greater than the bottom side, so if the fluid pressure differential exceeds 10% to 20%, the valve opens, and fluid can enter from the annulus.

When the pressure falls below 10% to 20% differential, the valve closes and fluid cannot enter the casing from the annulus. When TD is reached, a ball is dropped. It passes through the top valve and seats on the bottom valve, which makes it a conventional float shoe. This system keeps the casing 80% to 90% full while running in the hole.

37.1.3.Stab-In Shoes

With the stab-in method of cementing, the cement and other fluids are injected through the drillpipe, rather than through the casing.

Since the inside diameter (ID) of the drillpipe is so much smaller than the inside diameter of the casing, the amount and cost of materials is reduced considerably.

Suppose you are doing a surface job and want to bring cement to surface. Rather than running 50% to 100% excess, as is normal, with a stab-in system, you can pump cement until cement returns to surface, and then start displacement. Only the volume of the drillpipe will return to surface. (This volume at surface depths is not normally significant.)

By using a stab-in system, you ensure cement-to-surface without running large excess amounts and time required to complete the job. Again, displacement volumes are greatly reduced, so the pumping time is greatly reduced.

In addition, since the cement is less exposed to mud in the casing, contamination of the cement is greatly reduced. The surface area contact between fluids is much less in the smaller ID of the drillpipe.

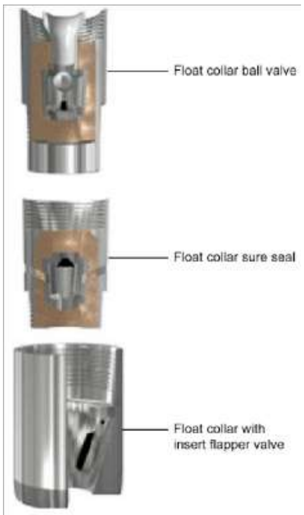
The typical stab-in shoe is like a conventional float shoe with the addition of a stinger-drill connection of a specific size at the top (called the nipple). When the stab-in shoe reaches TD, a stinger (drillpipe) is run in and connected to the nipple. Cement and other fluids are then run through the drillpipe and into the shoe.

37.2.Collars

This section will address the following types of collars:

- float collars.
- stab-in collars.
- stage collars.

37.2.1.Float Collars



Float collars are used to reduce contamination around the shoe by separating the shoe from the float. Float collars function exactly like float shoes except that they are placed in the casing one to three joints above a guide shoe. The length of the shoe track, or joint (as it is often called), depends on the situation and operating guidelines of the client.

When using both a collar and a shoe, some common sense must be used. For instance, it is useless to run a differential fill shoe and a float collar, because the cement and displacement fluid interface can become intermixed. This contaminates the last portion of cement.

Even with the top plug, some contamination exists. The amount of intermixing is limited, but the plug scrapes filter cake, gelled drilling fluid, etc., off the casing walls, and pushes this in behind the cement slurry. If there is any leakage around the plug, some displacement fluid could also follow the slurry.

The shoe itself has no appreciable volume, so without the casing between the collar and shoe, the contaminated slurry, etc., is pushed into the annulus around the shoe. This condition could create what is called a "wet shoe."

When drilling is continued, the shoe does not have solid cement around it, so it unscrews with the drilling process. The shoe falls to the bottom of the hole, and a plug must be set to drill around the shoe, which can result in a lot of lost rig-time and additional jobs.

37.2.2.Stab-In Collars


Stab-in float collar

Here is a typical float collar with a stab-in ball valve. Like a float collar, the stab-in collar is located one to three joints above the shoe and protects the shoe from contamination during stab-in cementing procedures. Whether a stab-in shoe or a stab-in collar is used, the effect is to

- reduce excess cement.
- avoid contamination.
- reduce job time.

You should note that if a stab-in shoe is used with no collar, displacement measurement is critical. Normally, displacement is cut short by 10 to 15 feet from the end of the drill-pipe. This prevents the situation discussed earlier with the "wet shoe." The drill-pipe is then stung out of the nipple, and the cement left in the drill pipe is circulated out the well.

A drill-pipe wiper plug with a snap latch prevents over-displacing of the drill-pipe and gives positive indication of when the drilling is complete.

37.2.3.Stage Collars

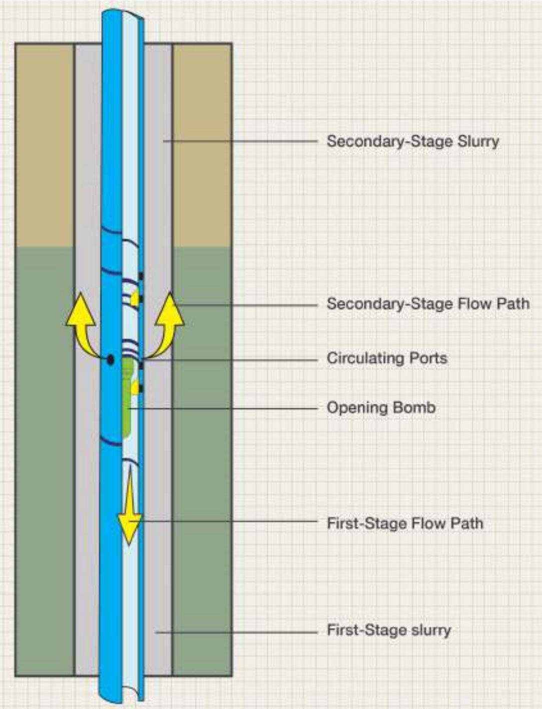
Stage collars are also used when multi-stage cementing operations are required. These collars are placed on the casing at desired depths for cementing. Stage collars' components are:

Stage collar components

- sleeves
- ports
- shear pins, which allow for controlled flow of fluid.

A stage collar is used in two-stage cementing. (For more information on two-stage cementing, refer to that module.) Two-stage cementing is performed to

- reduce the possibility of breaking down a weak formation
- minimize cement contamination
- reduce costs by reducing the quantity of cement and time required to complete the job



When the stage collar is first run into the hole, the lower sleeves cover the ports, which forces the fluids (mud, washes, and spacers) through the end of the stage collar and into the casing below. The first cement stage is done as a normal cement job. The collar plays no role other than being a point to which the top of cement may be brought, as well as the type of top plug to be used for the first stage.

When the first stage is complete, an opening bomb is dropped. After waiting an allocated time (which depends on the density of the fluid in the casing, weight of the bomb, and the deviation of the well), pump pressure is placed on the bomb.

Note: With highly-deviated and horizontal wells, the opening bomb procedure is modified. Normally, 1,000 to 1,500 psi shears the pins in the sleeve and opens the ports for the second stage. If the 1,000 to 1,500 psi pressure does not open the sleeves, additional fluid pressure or mechanical pressure (pushing with drill-pipe [DP]) can be used to open the ports. Additional fluid pressure should be used to the point of the casing burst pressure. Should these efforts fail, the casing can be perforated above the stage collar; however, this method is not recommended and should only be used as a last resort.

The bomb seals the end of the stage collar, so fluid is forced through the ports on its side. When the second stage is complete, the top plug for this stage lands on another sliding sleeve. This sleeve has a larger ID than the one in which the opening bomb lands. When the second-stage top plug seats, a pressure of 1,000 to 1,500 psi above the displacement pressure will normally shear the pins and move the sleeve. This sleeve seals the ports.

37.2.4.ECP (External Casing Packer)

Sometimes baskets or external casing packers (ECPs) are located above the stage collar to keep cement from falling down the annulus. The ECP is hydraulically set and works best inside previous casing because of the known, uniform diameter. If an ECP is used in an open hole, a caliper log of the hole should be run to determine the size and shape of packer required.

37.2.5.Three-Stage Cementing

A three-stage cementing operation is similar to a two-stage operation, except that an extra stage collar is added. In this case, the inside and outside diameters of stage collars, plugs, and bombs are very important to ensure that the bombs and plugs pass through upper collars and stop at the appropriate collar.

37.3.Baskets and Centralizers

37.3.1.Baskets

Cementing baskets are flexible devices that expand to fill the annulus of the casing or the open hole. The basket is placed on the casing or drillpipe just below the stage collar, or above any point where a weak formation is a concern. As the basket opens, it keeps part of the hydrostatic force off the area below it, so that cement can be forced up the annulus and won't fall down into the wellbore.

37.3.2.Centralizers

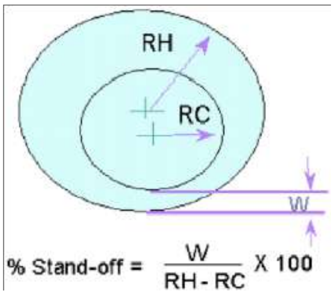
Centralizers are the key to a successful cement job; therefore, it is important for the Engineer In-Charge to ensure that the correct number and type of centralizers specified in the design are run on the job. In some situations this is not a problem, as the Engineer is normally present at the rig site before the casing is actually run. It may also be the responsibility of the equipment operator to check the casing jewelry, including float shoes and collars. There will be cases where the engineer arrives on location after the casing has been run.

Centralizers are placed on casing or drillpipe to improve the standoff between the pipe and previous casing, or the open hole. *Types of Centralizers*

There are two basic types of centralizers:

- Bow type: These are flexible centralizers that can compress or flex to meet the changing diameter of an open-hole. When choosing the correct centralizer for a job, the maximum (commonly referred to as max) and minimum (commonly referred to as min) outside diameters (OD) of the centralizer must fit with the max and min inside diameters (ID) of the well. The min diameters are of special interest, because the casing could become stuck if the centralizer is too big.
- Rigid type: These are fixed OD centralizers. These centralizers are used in cased hole or in open hole operations. If used in open hole, there must be a very accurate caliper available, as the rigid centralizer will not compress for any narrow sections.

37.3.3.Centralization and Standoff



Standoff is defined as the relationship between the narrowest distance from the inner pipe's OD to the outer pipe's ID (called W) and the difference between the casing radius and the well-bore radius. Standoff is expressed in percentages. If the standoff is 100%, the distance from the inside of the well-bore to the outside of the casing is exactly the same everywhere.

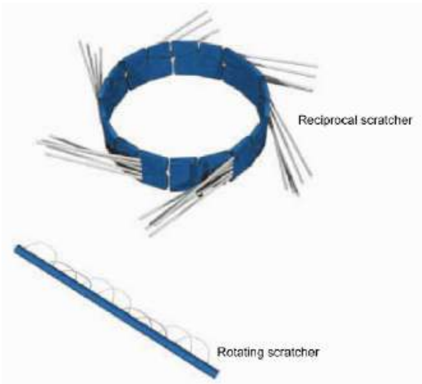
If the standoff is 0%, then the casing is touching the well-bore on one side, and good cementing is impossible. Sprint recommends a standoff of at least 70%. The API standard requires a minimum standoff of 67%.

When standoff is a problem, centralizers can be used to move the casing away from the wall of the wellbore and into a more centralized location.

37.4.Scratchers and Stop Collars

37.4.1.Scratchers

Scratchers are used to aid in the removal of drilling fluid filter cake. They also aid in breaking up gelled drilling fluid.



There are two types of scratchers:

- rotating scratchers
- reciprocal scratchers.

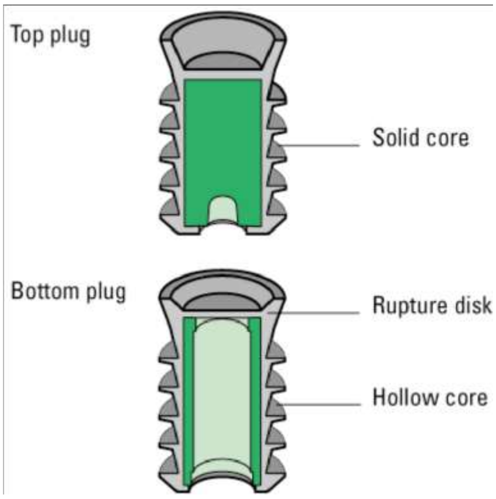
Rotating scratchers attach around the casing and scrape mud and filter cake from the inside of the previous casing and well-bore as the casing turns.

Reciprocal scratchers perform the same function, but while the casing is moving up and down.

37.4.2.Stop Collars

Stop collars are used in conjunction with centralizers or other casing hardware to limit the amount of allowable vertical travel along the pipe. (The vertical travel is of concern if any pipe reciprocation is being done).

37.5.Plugs



Plugs serve several functions during a cementing operation. Plugs are used to

- separate various fluids (e.g., cement from displacement fluid).
- wipe the inside walls of the casing to aid in mud removal.
- provide a surface indication of slurry placement by increasing pressure on the surface when the plug seals (this is called "bumping").

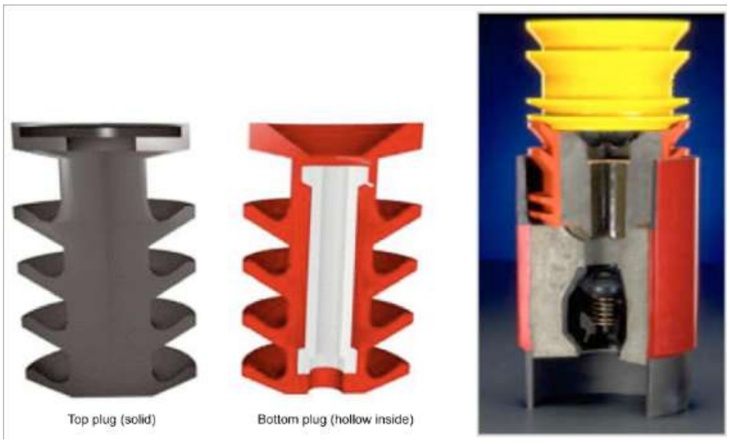
37.5.1.Top Plug

Top plugs are used to separate the cement from the displacing fluid, which is usually drilling fluid. Top plugs also provide a positive indication of the end of displacement. When the top plug stops down hole, an increase in pressure is recorded on the surface and displacement is complete. This pressure increase is called "bumping" the plug.

Unregulated bump pressures can:

- cause plug failure
- burst casing in severe instances (the only way to collapse the casing would be to build a very high pressure and then bleed it off very quickly, momentarily lowering pressure inside the casing with the higher hydrostatic pressure outside the casing).

Pumping is, therefore, slowed as displacement nears an end, so that the bump pressure can be limited to no more than 500 to 1,500 psi. The exact bump pressure depends on the conditions and operating policies of the client.



Note that the top plug is solid and often colored black.

37.5.2.Bottom Plug

The bottom plug is hollow and often colored red. Although these color distinctions are common, you should not rely on the colors to tell them apart. Before launching a plug, it should be examined to determine whether it is a top plug (solid) or a bottom plug (hollow). The bottom plug will have a rubber diaphragm that is soft to the touch. This diaphragm prevents fluid from flowing through the plug while in transit, but will easily burst when the plug reaches the float equipment.

An entire cementing job and well can be ruined by misplacement of plugs, so care in launching the correct plug at the correct time is essential. If the top plug is dropped first, the entire string of casing may be filled with cement, depending on the slurry volume. If the rig is not able to lift the casing string and cement, the well is ruined. It would be easier to drill an entirely new well than to drill out a casing string of cement.

Bottom plugs are used to remove the mud that is ahead of the pref-lushes and cement. They prevent cement and spacers from falling through the lighter fluids ahead of them. This occurrence is particularly serious in large casings.

Additionally, bottom plugs wipe the casing wall clean from mud cake, scale, rust, and other debris. Debris is pushed ahead of the bottom plug and out of the casing. If a bottom plug is not run, this debris is pushed ahead of the top plug. As a result, the debris is pushed into the casing between the float collar and the float shoe (i.e., the shoe track) and possibly out into the formation.

As the bottom plug moves into these areas, it displaces the cement ahead of it and makes a good cement job very difficult, if not impossible.

38. Exception and Job Approval Procedure

38.1.Introduction

Technical proposal approval system is establish to define the approval process for all technical documentations/ Proposals submitted to any and all clients.

our aim is to provide technically correct and effective solution to client and avoid any miscommunication or technically wrong information delivered to client/Operations, which can lead into catastrophic failure or damage to equipment, personnel and reputation of Sprint Oil & Gas Services. to achieve this, different approval levels are defined so we can share the expertise and experience between the different levels of the technical team.

This shall ensure that we do provide client with best technical solution and proactively identify any erroneous information in technical documents to minimize the chances of failure.

38.1.1.Objective

To develop a system or process to improve the quality of our technical solutions, and to avoid any damage to Capex, personnel or company reputation due to any erroneous information delivered in technical documents.

38.1.2.Scope

This Approval process is applicable to all cementing locations at all times.

38.2.Implementation and Responsibility

To implement this process, all Jobs are categorized under 1) Routine, 2) Critical and 3) exceptions jobs.

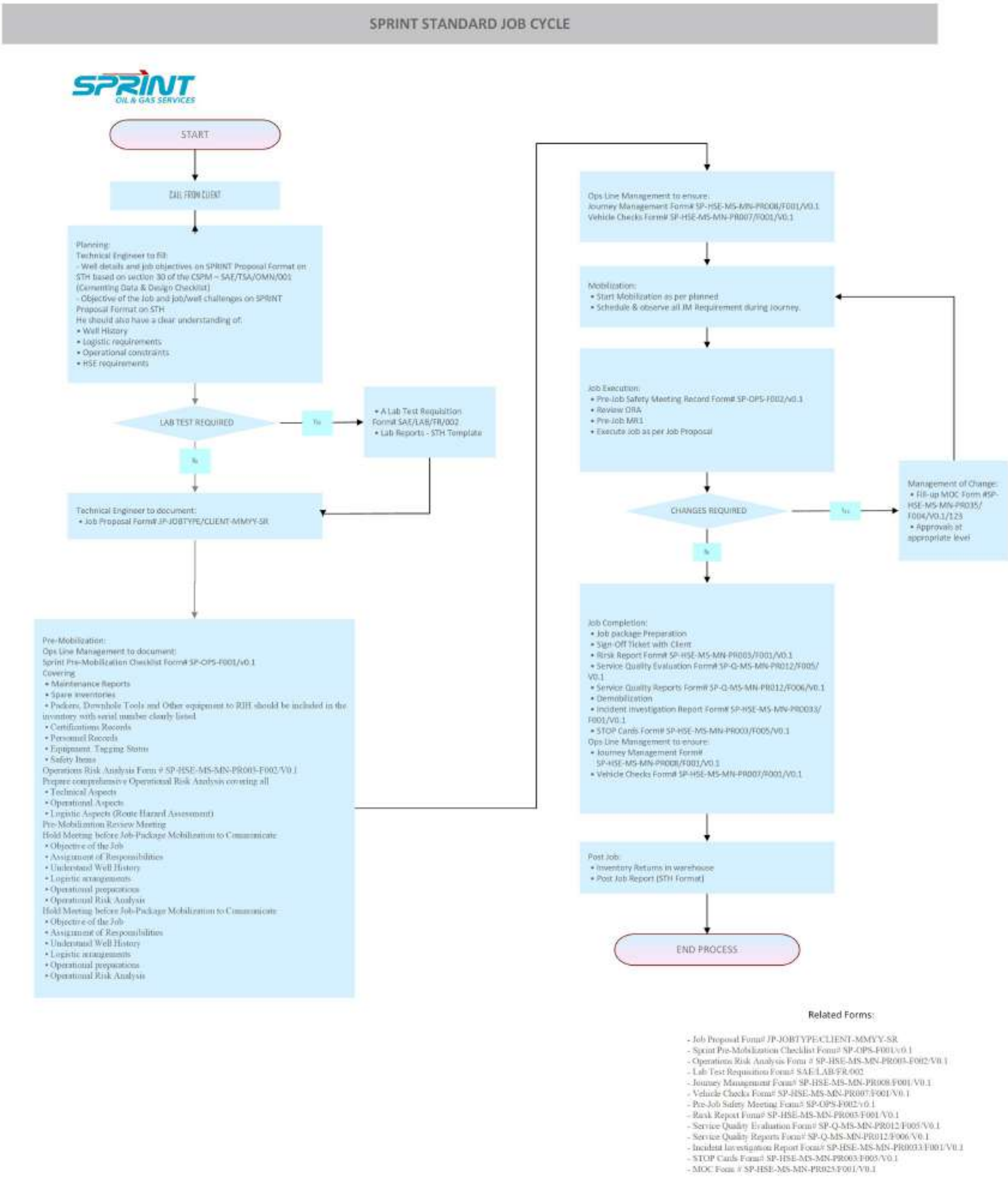
38.2.1.Definitions

STH: Sprint technical hub is developed to keep the record of all jobs of all categories for future reference. After execution of each job this record needs to be updated by technical engineers in to the system.

Routine Jobs: All jobs that are using existing fluid systems and has case histories available in Sprint STH.

All routine jobs require approval from line management.

All routine jobs have to follow the attached SPRINT STANDARD JOB CYCLE figure in the next page.



Critical Jobs: All jobs conforming to any of the following conditions is considered as Critical Job

- Any Existing Fluid system which will be pumped at new well conditions (Temp/Pressure/H_2S/CO_2/) - System never pumped before in similar conditions.
- Jobs with temperature above 300 deg F
- Cement jobs with moderate or severe gas flow potential (as computed by CemPRO+)
- Pumping jobs where well head pressure exceeds 7000 psi
- Nitrogen pump rate above 1500 scf/min

- Cement Jobs with high density slurries above 18 ppg.
- Cement Jobs with densities equal or less than 9 ppg.
- Jobs where safety margin on cement slurries thickening time is less than 1 hr.
- CT Cementing Jobs.
- Water Shut off treatments.

Note: For all critical Jobs, approval from the country technical/sales manager and regional specialists are mandatory.

Exception Job: Any Job consider as exception jobs if meeting the following conditions:

- Any deviation or exception from SPRINT OR API/ISO standards.
- Any new technology jobs performed under new well conditions.

Note: Approval of Regional Technical Manager is required for the execution of these jobs.

38.3.Financial Approval

All new technology jobs or product/services not covered in Sprint Middle East Price Book will require prior approval of the Regional Technical Manager before communicating to client.

38.4.Responsibility

Line Management, Country Technical/Sales Manager is responsible for compliance with this approval system, Line Management will ensure;

- All proposals prepared by technical engineers should comply to this approval process.
- All technical document should be written in STH porter with defined level of approval.
- All prices of new products or Services not covered in Price Book must be approved by Regional Technical Manager before quoting to Client.
- Record should be maintained for all Jobs in Data Base after Job execution, to be utilized for future reference.
- Country Technical/Sales Manager can delegate the above responsibility to Account Managers while retaining ownership of the process.

39. Chemicals Glossary

SPRINT Product	Form	Appearance	SG	Bulk density (Lbs/ Cuft)	pH	Low end temp (DegF)	High end temp (DegF)
C010 Antifoam Agent	Liquid	Clear, pale yellow to amber	0.840		4.80	80	450
C011 Defoamer	Liquid	Milky white	1.010		7.25	80	450
C012 Antifoam Agent	Liquid	Colorless	0.930		4.50	80	450
C102 LT-MT Temp Retarder	Powder	Yellow or Brown Powder	1.320	41.88		80	210
C100 Retarder	Powder	Yellowish or brown	1.420	29.90		80	140
C103 MT Temp Retarder	Liquid	Brown	1.270		6.00	125	250
C104 HT Retarder	Powder	White	1.790	61.10		250	350
C104L HT Liquid Retarder	Liquid	Amber	1.250		1.30	250	350
C106 MT-HT Liquid Retarder	Liquid	Black brownish	1.300		6.40	194	302
C108 HT Liquid Retarder	Liquid	Clear light yellow	1.080		8.60	220	400
C111 MT-HT Retarder	Powder	Off-white	2.300	55.50		120	260
C200 Dispersant	Powder	yellow or brown	1.430	32.80		80	250
C304 LT FLAC	Powder	white to yellowish	1.390	44.30		80	200
C302 WR FLAC/ GasTIGHT	Powder	White	1.500	44.60		80	400
C302K WR FLAC/ GasTIGHT	Powder	white	1.590	34.70		80	356
C307 WR FLAC	Powder	White or faint yellow	1.590	40.00		80	302
C308 WR FLAC	Powder	White or faint yellow	1.600	40.00		80	356
C303 GasTIGHT Latex	Liquid	Milky white	1.020		7.09	80	250
C303N WR FLAC/ GasTIGHT	Liquid	Opaque amber liquid	1.130		5.01	80	400
C514 Antisettling Agent	Powder	Off white	2.370	50.44		80	300
C524 Anti Settling Agent	Powder	White or off white	2.470	67.17		80	302
SP100 CemBOND Spacer	Powder	Off white	2.360	61.55		80	275
C400 Sodium Silicate	Liquid	Clear to hazy	1.330		11.60	80	200
C201 Liquid Dispersant	Liquid	Brown	1.240		8.25	80	250
S412 Clay Stabilizer	Liquid	Colorless	1.090		6.08	68	350
C402 Cenospheres	Powder	Grey beige	0.850	30.20		80	450
C403 Hollow Glass Microspheres	Powder	White	0.470	17.30		70	1,149

SPRINT Product	Form	Appearance	SG	Bulk density (Lbs/Cuft)	pH	Low end temp (DegF)	High end temp (DegF)
C060 Microblock (TM)	Liquid	Gray	1.420		7.04	80	450
C601 Cement Foaming Agent	Liquid	Light Amber	1.050			80	450
C501 Bentonite Extender	Powder	Light brown	2.360			80	600
C511 Attapulgite	Powder	Light cream pulverized	2.650			80	500
C410 Fly Ash Pozzolan	Powder	Tan to Gray	2.400	74.00		80	450
C500 Hematite	Powder	Dark red to black	5.100	114.00		80	450
C305 WR FLAC	Powder	White or faint yellow	1.560	42.90		80	400
C030 Silica Flour	Powder	White	2.650	120.00		80	450
C031 Silica Sand	Powder	White	2.650	100.00		80	450
C351 HCS Agent	Liquid	Clear	1.100		10.00	80	450
C051 Microsilica	Powder	Gray powder	2.350			80	185
C090 CemFLEX Additive	Powder	Silver	7.200			80	450
C204 HT Dispersant	Powder	Tan	1.230	51.00		80	450
C605 Expansion Additive HT	Powder	Brown	3.190			200	400
C513 Calcium Carbonate	Powder	White	2.720			80	450
C053 Microfine Cement	Powder	Grey	2.940			80	450
WW100 WellWash	Liquid	Clear or Yellowish	0.965			80	450
SP200 WellSHIELD	Powder	Light brown	1.800			80	275
SP300-LC3K WellSHIELD LC3K	Powder	Particulate Brown	1.400	31.80		80	450
C080 Fibre additive	Powder	White fibers	0.910			80	450
WW200 WellWash	Liquid	Amber	0.950		3.10	80	450
C052 Liquid Microsilica	Liquid	Grey	1.400		5.00	80	185
C310 CemFLEX-R Additive	Powder	Black	1.500	24.97		80	230
C507 Weighting Agent Non-Magnetic	Powder	Red	4.900	59.30		80	450
M519 ACID SOLUBLE AGENT II	Powder	White	2.960			80	350
M520 ACID SOLUBLE AGENT III	Powder	White	3.580			80	200
C508 Retarder and HT retarder stabilizer	Powder	White or off white	1.730			80	390
M512 ACID SOLUBLE ACTIVATOR III	Powder	White	2.320			80	450
C517 Cement Class G	Powder	Gray	3.200	94.00		80	400
C509 Expandable Cement Agent	Liquid	Clear pale red	1.240		1.70	80	450

SPRINT Product	Form	Appearance	SG	Bulk density (Lbs/Cuft)	pH	Low end temp (DegF)	High end temp (DegF)
C300 Fluid Loss Additive	Powder	White	1.400			80	200
C515 Gypsum (Calcium Sulfate Hemihydrate)	Powder	White to transparent	2.350			80	450
C013 Calcium Chloride	Powder	White	2.200			80	450
C505 NaCl Salt	Powder	White	2.160			80	450
C606 Anhydrous Sodium Sulfate	Powder	White	2.680			80	450
M607 MICA	Powder	Available in multiple colors	2.800			80	450
M610 NUTSHELLS	Powder	Brown	1.300			80	250
C504 Barite	Powder	off white to grey or brown	4.330			80	450
C502 Gilsonite Extender	Powder	Dark brown to black	1.060			80	300
C020 Latex Stabilizer	Liquid	Colorless to yellow pale	1.030		6.00	80	320
S282 Mutual Solvent	Liquid	Clear	0.890		7.50	80	250
SP201 HT WellSHIELD	Powder	Light brown	1.500	31.20	12.00	80	350
C404 HP LW Agent	Powder	White	0.900			80	300
C405 Hollow Glass Microspheres	Powder	White	0.400			70	1,149
C406 Hollow Glass Microspheres	Powder	White	0.600			70	1,149
C029 Microfine Silica	Powder	White	2.650			80	450
C4020 Medium Cenospheres	Powder	Grey beige	0.750			80	450
C530 Coarse Hematite	Powder	Dark red to black	5.100			80	450
C055 Micro Fly Ash	Powder	Pale grey ultra fine powder	2.200		11.00	80	450
SP300-LC1K WellSHIELD LC1K	Powder	Particulate brown	1.440	23.90		80	450
SP300-LC4K WellSHIELD LC4K	Powder	Fibrous and Particulate Brown	1.250			80	400
C433 Hollow Glass Microspheres	Powder	White	0.630			70	1,149
C516 Cement Class A	Powder	Gray	3.200	94.00	12.00	70	200
C518 Cement Class H	Powder	Gray	3.200	94.00	12.00	80	450
C603 LT-MT Expansion Additive	Powder	Tan	3.350			77	235
C607 Expansion Additive HT	Powder	Pale gray powder	3.410			190	316
S281 Surfactant Non Ionic	Liquid	Clear	0.985		10.00	80	280
F073 Inert Fluid Loss Additive	Powder	Test Appearance	1.000	1.00	1.00	1	1

40. Glossary Definitions

Term	Definition
Absolute Volume	Volume a solid occupied or displaced when added to water divided by its weight: the volume per unit mass; or 1 divided by absolute density. Units are gallons per pound.
Absorption	The taking up of one substance into the interior of another substance; see Adsorption.
Accelerator	A material which accelerates or speeds up the normal rate of reaction between cement and water, resulting in an increase in the development of early strength, and usually a decrease in the thickening time.
Acid Resistance	The ability of a hardened cement slurry to withstand the softening and corrosive effects of organic or mineral acids, or water solutions of these acids and their salts having a pH lower than 7.0.
Adhesion	Firm attachment between unlike materials: bonding.
Admix	To blend one material with another by mixing.
Adsorption	A surface phenomenon exhibited by solids that consists of the attachment on their surfaces of gases, liquids or dissolved substances with which they are in contact.
Ageing	Maturing of cement slurries producing changes that occur beyond the normal setting time over a period of months or even years.
Aggregate	An essentially inert mineral having a particle size predominately greater than 100 mesh, which forms a mortar or concrete when bound with a hardened cement slurry.
Air (or Aerated) Drilling	Drilling operations using air, mist, foam or aerated mud to remove the cuttings during drilling.
Alkalinity	The combining power of a base or alkali as measured by the number of equivalents of an acid with which it can react to form a salt.
Anion	A negatively charged atom or radical.
Annulus, Annular Space	That space in a wellbore outside one or more strings of pipe.
Antifoam Agent	An additive initially added to the mix water or incorporated in the cement blend to prevent foaming during mixing.
Antisettling Agent	An additive incorporated in the slurry to prevent sedimentation and/or free water.
API Cement Classes	A classification system for oil-well cements defined in API Standard 10A.

API Procedure	Laboratory test procedure defined by API.
API Water	Amount of mixing water stated in API Specification 10.
Apparent Viscosity	Viscosity of a non-Newtonian fluid at a specific shear rate.
Asphaltic Materials	A group of solid, liquid, or semi-solid materials, predominantly mixtures of hydrocarbons, obtained either from natural bituminous deposits, or from the residue of petroleum refining.
ASTM Type Cement	A cement meeting the requirements of ASTM Specification C150; see Construction Cements.
Atmospheric Pressure Curing	The aging of specimens for test purposes at normal atmospheric pressure (14.7 psi at sea level), for a designated period of time under certain given conditions of temperature and humidity (see API Specification 10).
Autoclave Expansion	A measurement or test made as provided in ASTM D 151; Method of Test for Autoclave Expansion of Portland cement; see Soundness.
Barite, Barytes or Heavy Spar	A native cr ystalline barium sulfate, which occurs in snow-white crystalline masses, or grayish, reddish, and greenish ores with a specific gravity of 4.0 to 4.6. It is used for increasing the density of oil-well cement slurries and drilling fluids (see API Specification 10A).
Baroid Cell	Laboratory apparatus used to determine the fluid loss of a cement slurry as defined in API Specification 10.
Base Exchange	A chemical reaction in which cations exchange places, as when the calcium and magnesium of the salts in hard water are exchanged for the sodium of a silicate over which the water passes.
Base Slurry	Conventional cement slurry used as the cementitious component of a foamed cement slurry.
Batch Mix	Total slurry volume is mixed either into a tank or into a tank where it is agitated to ensure consistency. The slurry density is adjusted, if required, by the addition of more water or cement prior to being pumped.
Bearden Units of Consis- tency (Bc)	The pumpability or consistency of a slurry is measured in Bearden units (Bc), a dimensionless quantity with no direct conversion factor to more common units of viscosity such as the poise.
Bentonite	A highly-plastic, highly-colloidal clay, which is largely made up of the mineral montmorillonite.
Bingham Plastic	A material which can be continuously and permanently deformed without rupture under a stress exceeding the yield value. A constant rate of shear results from each increase in stress after reaching the yield point, so that its behavior can be defined as a linear function.
Blaine Fineness	The particle size or fineness of a cement in cm2/g as determined from air permeability tests using a Blaine permeameter.
Blowout	A sudden or violent uncontrolled escape of gas, oil, or water from the well due to : the formation pressure being greater than the hydrostatic head of the fluid in the hole; and the failure or lack of mechanical means, such as blowout preventers, to control such an occurrence.

Bond	Adhering, binding, or joining of two materials; e.g., cement to casing.
Bond Log	An acoustic log used to measure the attenuation rate of a sound wave propagating along the casing. Can be used to quantify the contact between pipe and cement.
Bonding	The state of bond between cement and casing and/or formation.
Borehole	The wellbore; the hole made by drilling or boring a well.
Bottomhole	Refers to the lowest or deepest part of a well.
Bottomhole Circulating Pres- sure (BHCP)	The pressure at the bottom of a well during circulation of any fluid. It is equal to the hydrostatic head, plus the friction loss required to pump the fluid to the surface, plus any back pressure held at the surface.
Bottomhole Circulating Tem- perature (BHCT)	The maximum temperature that occurs at the bottom of a well while fluid is being circulated.
Bottom hole Pressure (BHP), Bottom hole Static Pressure (BHSP)	The maximum shut-in pressure at the bottom of a well.
Bottom hole Static Tempera- ture (BHST), Bottom hole Temperature	The temperature attained at the bottom of a well after the well is shut in. See also Static Temperature.
Break Circulation	To resume the movement of fluid down the pipe and upward through the annulus.
Bridging Material	Fibrous, flaky or granular material added to a cement slurry or drilling fluid to aid in sealing formations in which lost circulation has occurred; see Lost Circulation Material.
Brine	Any solution consisting of a salt in water.
Bulk Volume	The volume of a dry material plus the actual volume of the entrapped air per unit mass.
BWOB	Abbreviation: By Weight Of Blend.
BWOC	Abbreviation: By Weight Of Cement.

BWOW	Abbreviation: By Weight Of Water.
Cable Tool Drilling	A method of drilling a well by allowing a weighted bit at the bottom of a cable to fall against the formation being penetrated.
Cake Thickness	The measured thickness of the filter cake deposited against a permeable medium by a fluid containing suspended solids.
Calcined Gypsum	Gypsum partially dehydrated by means of heat.
Calcium Chloride	Inorganic salt commonly used as cement accelerator to decrease thickening time and increase the early strength.
Casing Cementing	The practice of filling the annulus between casing and open hole with cement in order to prevent fluid migration between permeable zones and to support the casing.
Casing Cementing Tempera- ture	The temperature of a cement slurry while it is being placed in a well during a casing cementing operation.
Cation	A positively charged atom or radical.
Cement Blend	A mixture of cement and dry cement additives.
Cement Channeling	During a cementing operation, the action of the cement slurry rising between the casing and borehole wall which fails to completely displace all of the previous fluids.
Cement Setting	The chemical reaction between cement and water which changes it from a fluid phase into a solid phase that exhibits compressive strength and low permeability.
Cement Sheath	The set cement in the annulus.
Cement Slurry	Suspension of cement in water, oil or a mixture of both.
Cement System	A particular slurry containing cement, water and an additives.
”Cemented-up”	Expression used to describe any equipment containing prematurely-set cement.
Cement-to-Water Ratio	Weight ratio of cement to water in a cement slurry.
Cementing Time	The total elapsed time for a cementing operation from the beginning of mixing through the completion of displacement to final depth and complete circulation of any excess slurry to the surface when applicable.
Centipoise	Unit of viscosity, one hundredth of a poise.

Ceramic Bubbles (C400)	Hollow ceramic aluminosilicate spheres containing a gas mixture of carbon dioxide and nitrogen, and having a specific gravity less than water.
WellWash	Fluid containing a mixture of dispersants and surfactants, and having a density and viscosity close to that of water. It thins and disperses the drilling mud to assist in efficient mud displacement.
Circulating Pressure	The pressure at a specified depth required to circulate a fluid in a well at a given rate.
Circulating Temperature	The temperature inside casing or drillpipe of any fluid at any specified depth in a well while it is being circulated.
Circulation	The movement of fluid down pipe and up the annular space in the hole to the surface.
Loss of Circulation	The result of fluid (mud, cement slurry, etc.) escaping into the formation by way of fractures or porous media.
Clay	A plastic, soft, variously-colored ear th, commonly a hydrous silicate of alumina, formed by the decomposition of feldspar and other aluminum silicates
Coagulation	See Flocculation.
Cohesion	The attractive force between identical molecules; that is, the force that holds the molecules of a compound together.
Colloid	Most frequently, a special type of liquid mixture or suspension in which the particles of suspended liquid or solid are very finely divided, but not molecular in size.
Colloidal Suspension	A stable, homogeneous system of very fine par ticles of matter dispersed uniformly throughout a liquid medium, having proper ties which differ both from a true solution and from a suspension of larger par ticles. True colloidal suspensions have a particle size range of 5 nm to 200 nm.
Communication (Zonal)	Physical path in the cemented annulus between two or more zones through which fluids or gases can migrate.
Compressive Strength	The degree of resistance of a material to force acting along one of its axes in a manner tending to crush it. Usually expressed in pounds of force per square inch (psi) of surface affected (see API Specification 10).
Concentric Annuli	Annuli where the casing has been perfectly centered in the open hole.
Connate Water	Water that was laid down and entrapped within sedimentary deposits, as distinguished from migratory waters that have flowed into deposits after they were laid down.
Consistency	A rheological proper ty of matter which is related to the cohesion of the individual par ticles of a given material, its ability to deform and its resistance to flow. The consistency of cement slurries is determined by thickening time tests in accordance with API Specification 10A and is expressed in Bearden units of consistency (Bc).
Consistometer	Laboratory apparatus used to determine the thickening time of a cement slurry as described in API Specification 10.

API Classes A, B and C	API Classes A, B and C are similar to ASTM Types I, II and III, respectively. Airentraining cements are not suitable for oil-well work.
Construction Cements	Normally, ASTM Types I, II and III, Por tland cements (ASTM Specification C150), or air-entraining modifications (ASTM Specification C175).
Contact Time	The elapsed time required for a specific fluid to pass a designated depth in the annulus during pumping operations.
Contaminants	Materials, usually mud components, which become mixed with the cement slurr y during the displacement process, and which have an adverse effect on cement properties.
Continuous Mix	Cement slurry mixing and pumping which occurs simultaneously.
Core	A cylindrical sample taken from the formation for purposes of examination.
Critical rate	The minimum annular rate required to achieve turbulent flow; or the maximum annular rate allowed to maintain effective laminar-flow displacement.
Curing	The ageing of cement under specified conditions of temperature and pressure.
Darcy	A unit measure of permeability. A porous medium has a permeability of one Darcy when a pressure of one atmosphere on a sample (1 cm long and 1 cm2 of crosssection) forces a liquid of one centipoise viscosity through the sample at the distance of 1 mm per second.
Decontaminants	Materials added to cement or cement slurries for the specific purpose of counteracting the effects of contamination.
Deflocculation	A state of colloidal suspension wherein the individual par ticles are separated from one another by the assumption of like electrical charges by the particles, thus resulting in their mutual repulsion.
Defoamer	An additive added during slurry mixing to overcome foaming problems, or to prevent the formation of foam.
Dehydration	Loss of water from cement slurries or drilling fluid by the process of filtration.
Density	Mass per unit volume (lbm/gal, kg/L, etc.).
Absolute density	considers only the actual volume occupied by the material.
Bulk density	is mass per unit bulk volume which includes the actual volume of the entrapped air.
Deviated Well	Wells in which partorall of the wellbore is purposely inclined up to 90 deg with respect to vertical.
Diatomaceous Earth	The pulverized material from siliceous remains of unicellular algae. It is sometimes used as a cement extender

Difficult-To-Disperse (DTD)	Cement The dispersion of a DTD cement is not easily influenced by the addition of a dispersant.
Difficult-To-Disperse in Salt (DTDS)	Cement Rheology of a DTDS cement increases with increasing salt concentration.
Dispersant	A cement additive which reduces the effective viscosity of cement slurries.
Dispersion	A system of minute particles which are distinct and separate from one another and suspended in a liquid, gaseous, or solid medium.
Displacement	A predetermined volume of a non-cementitious fluid pumped following the completion of slurry mixing and pumping.
Displacement Rate	The volumetric flow rate at which cement slurry is pumped down the hole.
Disposal Well	A well through which water, chemical or radioactive waste is returned to subsurface formations.
Drilling Fluids	Any fluid circulated in a well during drilling operations. These usually are water or oilbase muds, which may or may not be air or gas cut.
Easy-To-Disperse (ETD)	Cement Cement which is highly sensitive to the addition of a dispersant, often leading to free-water problems.
Easy-To-Disperse in Salt (ETDS)	Cement Cement which is highly sensitive to the addition of a dispersant in saltwater slurries. Expect free water problems.
Eccentric Annuli	Annuli where the casing has not been perfectly centered.
Effective Laminar-Flow (ELF)	Technique A technique for effectively displacing drilling mud out the annulus in laminar flow.
Electrolyte	A chemical that, when dissolved in water, dissociates into positive and negative ions, increasing the water's electrical conductivity.
Emulsion	A liquid formed of a microscopically heterogeneous mixture of two liquids, one that is dispersed as globules within the other. Emulsion muds may be either oil-in-water or water-in-oil. An emulsifying agent or surfactant is necessary to form a stable emulsion.
Enhanced Oil Recovery	The additional recovery of oil from a petroleum reservoir over that which can be recovered by conventional primary and secondar y methods.
Equivalent Sack	The weight of any cementitious material or blend which has an absolute volume of 3.59 gallons.
Ettringite	Calcium trisulfoaluminate used to govern the early stages of cement hydration.

Expanded Perlite	A siliceous volcanic rock that is ground to small size and subjected to extreme temperature in an oven. This results in an expansion and release of combined water, leaving the rock par ticles considerably expanded and porous. In cementing, it is used as an extender.
Expanding Cement	Cement system exhibiting a volumetric increase when solid.
Expansion Factor	The volume ratio of salt water which contains a fixed salt percentage (by weight of water) to the original fresh water volume (without salt).
Extender	A material added to cement to increase the slurr y yield and/or to reduce the slurry density.
Extrapolated Thickening Time	The time required for a cement slurr y to reach a consistency of 100 Bc; obtained by extending the cur ve recorded during a thickening time test which may be stopped at 70 Bc under given conditions (see API Specification 10).
False Set	An abnormally early thickening of a cement slurry caused by the formation of a gel structure. The thickening may be reversible during the pumping history of the slurry (see Flash Set).
Fann Viscometer	The tradename of a rotational-type viscometer used to investigate the rheological proper ties of fluids.
Fibrous Material	Any tough, stringy material of thread-like structure employed to prevent loss of circulation or to restore circulation in porous or fractured formations. It is also used to provide tensile strength to set cement.
Fill Cement	Any cement system used to provide zonal isolation across non-productive zones located above the zones of interest.
Filler Material	A material added to a cement or cement slurry for the primary purpose of increasing the yield of the slurry.
Filter Cake	The solid material deposited on a porous medium from the filtration of the cement slurry or drilling fluid.
Filter Loss	The amount of fluid delivered through a permeable filter medium, after being subjected to a differential pressure for a specified time. See Fluid Loss
Filtrate	The liquid phase of a cement slurry that passes through a filter and deposited filter cake.
Fineness	The particle size to which a cement clinker is ground. This value is generally repor ted as surface area as determined with the Blaine air permeability apparatus or Wagner turbidimeter.
Fireflood Well	A well where in-situ combustion is initiated and then air is injected to propagate the combustion front to production wells, enhancing oil recovery.
Flash Point	The lowest temperature at which a liquid will give off flammable vapor at or near its surface.
Flash Set	An abnormally early thickening or setting of cement slurry wherein the cement slurry becomes unpumpable. This is often caused by cement dehydration downhole.
Flocculation	A gathering of the separate colloidal par ticles of a suspension into bunches or flocs with a resultant loss of colloidal properties.

Fluid	A substance which is capable of flowing; either a gas, liquid, slurry or suspension.
Fluid Loss	The volume of fluid lost to a permeable material due to the process of filtration. The API fluid loss is the volume of fluid in a filtrate as determined according to the "Fluid-Loss Test" presented in API Specification 10.
Fluid-Loss Additive	An additive used to reduce the fluid loss of cement slurries.
Fly Ash	The residue from power plants which burn pulverized coal.
Foam Half-Life	The time required for 50 % volume of the liquid contained in a foam to separate out.
Foam Quality	Ratio between the volume occupied by a gas in a foam and the total foam volume.
Foam Stabilizer	An additive used to increase the foam half-life.
Foamed Cement Slurry	A homogeneous, ultra-lightweight cement system consisting of a base cement slurry, nitrogen and surfactants.
Foaming Agent (Foamer)	An additive used to create and sometimes to stabilize a foamed fluid or slurry.
Fracture	Cracks and crevices in the formation either inherent or induced.
Fracture gradient	The pressure per unit depth gradient of a formation at which a fracture will be initiated.
Free Water	The volume of supernatent fluid (expressed in mL) developed during the free fluid (free water) test as described in API Specification 10A.
Gas Cutting	The retention by drilling fluid of gas entrained during drilling. Unless a drilling fluid is able to release entrained gas before returning to the well, that fluid will become gas cut and the hydrostatic head of the fluid column will be reduced. A thick drilling fluid will gas cut more readily than a thin one.
Gas Migration (Annular)	Gas migration is a generic term which covers all possible routes for annular gas entry and propagation like casing/cement interface, mud channels, mudcake and cement matrix.
Gas Percolation	Form of gas migration in the cement matrix through propagation of microscopic gas bubbles.
Gel	Sodium bentonite clays belonging to the general class of montmorillonites (modified usage). The colloidal suspension in such a state that shear stresses below a certain finite value fail to produce permanent deformation.
Gel Cement	A cement or cement slurry that has been modified by the addition of bentonite.

Gel Strength	The measured ability of a colloid to develop and retain a gel form.
Gilsonite	The mineral uintaite, a naturally occurring solid hydrocarbon belonging to the asphalt group. A granular form of gilsonite is sometimes used as a cement additive.
Grind	The fineness to which the cement clinker is ground.
Grout (verb)	A mining and construction term designating the process of: • forcing sealing material into soil, sand or rock formations for the purposes of stabi-lization or to prevent water flow; or • filling the annulus between shaft walls and a shaft lining.
Grout (noun)	Sealing materials used in grouting; i.e., cement slurry, plastics, chemical sealants, etc.
Gunk Squeeze	A bentonite-diesel oil mixture that is pumped down the drillpipe to mix with drilling mud being pumped down the annulus. The two mix to form a stiff, putty-like material that can be squeezed into lost-circulation zones.
Gypsum	A naturally occurring crystalline form of calcium sulfate combined with two molecules of water (CaSO4\xb0 2H2O). Gypsum and cement clinker are ground to produce the finished cement during the manufacturing of Portland cement.
Hi-Early Cement	An ASTM Type III or API Class C cement; may or may not be sulfate resistant.
High Calcium-Hydrated Lime	A hydrated or slaked lime that contains not more than 5 % magnesium oxide.
Horizontal Well	A well in which part of the wellbore is inclined 90 dega with respect to vertical; lessthan-horizontal, high-angle wells often receive this designation.
Hydrated Lime	A dry powder obtained by treating quicklime with water enough to satisfy its chemical affinity for water; calcium hydroxide.
Hydraulic Cement	A substance which when mixed with water becomes hard like stone because of a chemical reaction between it and water. A hydraulic cement will set under water.
Hydromite	A Halliburton trade name for gypsum cement containing a water-soluble resin.
Hydrophilic	A substance that absorbs or adsorbs water.
Hydrophobic	A substance that tends to repel water.
Hydrostatic Head	The pressure exer ted by a column of fluid, the magnitude of which is dependent upon the density and ver tical height of a column of fluid.
Initial Set	Cement shall be considered to have acquired its initial set when it will bear, without appreciable indentation, the initial Vicat needle (ASTM Specification C191-82). This corresponds to a slurry consistency of slightly over 100 Bc as measured on the consistometer.

Injection Well	Wells used for secondary oil recovery: fluid is injected into the oil-bearing formation to enhance oil recovery by production wells.
In-situ Combustion Well	See Fireflood Well.
Interstitial Water	Water contained in the interstices of formations or par ticulate fluids. May be migratory water or connate water.
Inverted Emulsion	An emulsion of water in oil. Irreducible Water Saturation The connate water remaining in an oil-bearing structure that is tightly held. It cannot be displaced by oil.
Kembreak	The tradename of calcium lignosulfonate used primarily as a dispersant in drilling mud or cement slurries, and also as a retarder for cement. It is frequently used in high-gel cements. Trademark of Magcobar.
KOLITE	A granular, solid hydrocarbon of the coal family used by as a cement additive.
Latex	Colloidal suspension or emulsion of organic materials. Certain latexes are sometimes used as cement additives.
Lightweight Cement	A cement or cement system which permits stable slurries having densities of less than the optimum weight of the neat cement.
Lignosite	A dispersing agent for drilling mud and cement.
Lignox™	The tradename of a calcium lignosulfonate. Trademark of Baroid; see Kembreak.
Lime	A general term, which includes the various chemical and physical forms of calcium oxides, quicklime, hydrated lime, and hydraulic lime used for any purpose.
Lost Circulation	The total or partial loss of drilling fluids or cement slurries into highly permeable zones, cavernous formations, or natural or induced fractures during drilling or cementing operations.
Lost Circulation Material	A material added to cement slurries or drilling fluids which is designed to prevent the loss of cement or mud to the formation. See Bridging Material.
Marsh Funnel	A calibrated funnel commonly used in field tests to determine the viscosity of drilling mud.
Microannulus	Small annular space between casing and cement sheath resulting from downhole stresses (pressure or temperature).
Microblock™	Elkem trademark name for a specific liquid microsilica grade used as a multipurpose additive for cement slurries.
Microsilica	Spheres of amorphous silica, a manufacturing process by-product of silicon metals and ferrosilicon alloys, with an average par ticle size between 0.1 μm and 1.0 μm.
Millidarcy	One thousandth of a Darcy; see Darcy.

Minimum Water	The minimum water content of a cement slurry as determined by the procedure as defined in API Specification 10.
Modified Cement	A cement whose chemical or physical proper ties have been altered by additives. This term has been used to refer to specific formulations of gel cement containing cer tain concentrations of dispersing agent.
Mud	A colloquial term referring to drilling fluids.
Mud Conditioning	The treatment and control of drilling mud to ensure it has the proper gel strength, viscosity, density, etc.
Mudcake	The sheath of mud solids which forms on the wall of the well when the liquid from the mud filters into the formation; see Filter Cake.
Neat Cement	Cement without any additives other than water (antonym: Additive Cement).
Oil-Well Cement	Cement or any mixture of cement with other materials that is intended for use in oil, gas or water wells.
Optimum Water	The amount of water used in a cement slurr y which provides the slurry with the best properties for its par ticular application.
Peptization	The process of conver ting bentonites and other clay minerals by ion exchange (of calcium by sodium) to increase the yield of the clay to approach that of Wyoming bentonite (sodium bentonite).
Percent Additive	The parts of additive per 100 par ts of cement either by volume or by weight. Percent refers to percent by weight. If percent by volume is meant, it should be so stated.
Percent Water	The water content of a cement slurry expressed as par ts of water per 100 par ts of dry cement or cementitious materials by weight. (Percent refers to percent by weight.)
Perforations	A device is lowered into a cased well to the zone of interest. Steel projectiles are then fired from it through the casing and into the formation to put a communication production-interval end inside of the casing.
Perlite	A volcanic rock that can be expanded to many times its original volume by crushing and heating under pressure. The pressure causes the expansion when the water in the rock turns to steam; see Expanded Perlite.
Permeability	A measure of the resistance offered by a reservoir to the movement of fluids or gases through its pore spaces (see Expanded Perlite).
Plaster	Calcium sulfate hemihydrate (CaSO4\xb0 1/2H2O) used to provide cement systems with thixotropic, expanding or right-angle-set properties.
Plastic Viscosity	An absolute flow proper ty indicating the flow resistance of a Bingham Plastic; a measure of the shear stress in excess of the yield point, that will induce a unit rate of shear.
Plasticity	The ability of a substance to be deformed by pressure without rupture.

Plugging Material	A material used to block off zones while treating or working on other portions of the well. This blocking may be temporary or permanent.
Point of Departure	During a thickening time test, the point in time where the thickening time curve begins to show an increase in slurry viscosity.
Poise	Poise is the basic unit of viscosity measurement.
Porosity	The amount of intergranular space in any sample piece of formation, usually expressed as volumetric percent. Rock porosity may be filled with water, oil, gas, or a mixture of.
Portland Cement	A complex mixture of calcined clay and limestone which forms a hard mass when mixed with water and allowed to cure.
Portland Cement (from ASTM Specification C150-56)	The product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and untreated calcium sulfate, except that additions not to exceed 1.0 % of other materials may beinterground with the clinker at the option of the manufacturer, provided such materials in the amounts indicated have been shown to be not harmful by tests carried out or reviewed by ASTM Committee C-1 on cement. Expanding cement is an exception.
Portland Cement Clinker	Hard granular nodules composed essentially of hydraulic calcium silicates, with smaller quantities of calcium aluminates and ferrites. It’s produced by the heat treatment of cement raw materials in a kiln. Clinker is pulverized with the proper quantity of gypsum in the manufacture of Portland cements.
Portlandite	Term used in the cementing industr y to designate hydrated calcium oxide.
Pozzolan (see ASTM C340-58T)	A siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value; but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.
Pozzolan Cement Mixture	A mixture containing both cement and a pozzolan (natural or ar tificial).
Pozzolanic Reaction	The reaction between pozzolan and any other material to form a cementation product; usually refers to Pozzolan-Lime reaction.
Pozzolan-Lime Reaction	The reaction between pozzolan and lime in the presence of water to form a cementitious material primarily composed of hydrated calcium silicates.
Preflush	A fluid pumped ahead of the cement slurr y which is compatible with both the cement slurry and drilling fluid. It is designed to clean the drilling mud from the annulus and leave the annular surfaces receptive to bonding with the cement.
Pressure	Force per unit area.
Pressure Curing	The curing of cement specimens for compressive or tensile strength tests in water above atmospheric pressures (see API Specification 10).
Primary Cementing	Primary casing cementing is the original cementing operation performed immediately after casing has been run into the hole; see Casing Cementing.

Pseudoplastic Fluid	A liquid whose apparent viscosity decreases as it is sheared faster.
Puddling	In cement laboratory work, the term applies to the agitation of cement slurry in molds with a rod to remove trapped air bubbles. In field practice, the term has been used to denote the reciprocation or rotation of the casing during or after a primary cementing operation.
Pumpability	This refers to a physical characteristic of a cement slurr y; the ability of the slurry to be pumped.
Pumping Time	It is synonymous to cementing time except in those instances where a volume of cement slurry is premixed prior to displacement in a well. In this instance, the pumping time will be total cementing time minus mixing time. Pumping time can also be the time to reach 70 Bc during a thickening time test.
Quicklime	Unslaked lime (calcium oxide).
Red-Lime Mud	A clay-water-base mud containing caustic soda and tannates to which lime has been added.
Reduced-Water Slurry	A cement slurry having a water content less than the API recommended amount.
Resistivity	The electrical resistance offered to the passage of a current.
Retarded Cement	A cement in which the thickening time is extended by adding a chemical retarder.
Retarder	A chemical which is added to cements to increase their thickening times.
Reverse Circulation	The movement of fluid down the annular space and up the drillpipe.
Rotary - Rotary Drilling	The method of drilling wells that depends for its effectiveness on the rotation of an auger, drag or roller-type bit and a constant circulation of fluid or periodic circulation of gas or foam to remove the cuttings and to plaster and consolidate the walls of the hole.
Rheology	A science dealing with the deformation and flow of matter.
Right-Angle Set	The setting characteristic of a cement slurry where its consistency changes from 30 to 100 Bc in only a few minutes.
Sack	The term ”sack of cement” has carried over from the early days of cementing. It has become a unit of weight or bulk volume measurement. In the United States a sack of cement weighs 94 lbm and occupies 1.0 ft3. This is still the basis for slurry design.
Salt	The compound which is formed (along with water) by the reaction of an acid with a base.
Salt-Brine Cement	A cementing slurr y whose liquid phase contains sodium chloride.

Salt-Saturated Cement System	Cement system containing 37.2 % sodium chloride by weight of mixing water.
Sand	A loose granular material resulting from the disintegration of rocks and which consists mostly of quar tz (silicon dioxide).
Settling	Separation of particles because of different sizes and specific gravities.
Shear	An action or stress, resulting from applied forces, which causes or tends to cause two adjoining par ts of a body to slide relative to each other in a direction parallel to their plane of contact.
Shear Strength	See Gel Strength.
Shelf Life	The storage life of a product, after which its performance may not be as per specifications/ expectancy.
Sieve Analysis	The determination of the percentage of particles that will pass through screens with various size openings.
Silica Flour	Silica (Si02) ground to a fineness equal to that of Por tland cement. The fineness of Portland cement is specified in API Specification 10A.
Slaked Lime	See Hydrated Lime.
Slow Set Cement	A manufactured cement in which the thickening time is extended by: coarser grind, eliminating the rapid hydrating components in its composition, and by adding a chemical retarder.
Slurry	Suspension of cement in water, oil or a mixture of both.
Slurry Density	The weight per unit volume of a cement slurr y.
Slurry Porosity	The volume of liquid in a slurry divided by the total slurry volume, expressed in percent.
Slurry Viscosity	Rheological characteristic of a slurry.
Slurry Volume	The sum of the absolute volumes of solids and liquids that constitute a slurry.
Slurry Weight	A commonly used term, but by definition incorrect for slurry density.
Slurry Yield	Volume of slurry obtained when one sack of cement (94 lbm) is mixed with desired amount of water containing any other additive such as accelerators, fluid-loss additives, etc.
Sodium Chloride	Common salt, NaCl. Sometimes used in cement systems as an accelerator or a retarder, depending upon concentration.

Soundness	A measure of the quality of a cement as determined by the autoclave expansion test defined in ASTM C-151. The soundness test detects the presence of undesirable materials which cause a cement to disintegrate internally by an uncontrolled expansive action.
Spacer	A preflush with carefully designed density and rheological proper ties. A spacer must be compatible with both mud and cement slurr y. It assists in mud removal and well control.
Specific Gravity	Ratio of the weight of a body to the weight of an equal volume of water at 4 degC.
Squeeze Cementing	The forcing by pressure of cement slurry into specified zones or channels for the purpose of shutting off the flow of fluids or gases.
Squeeze-Cementing Tem- perature	In a squeeze-cementing operation, the temperature of a cement slurry while it is being displaced at the maximum cementing depth.
Static Pressure	See Bottomhole Static Pressure (BHSP).
Static Temperature	The temperature attained at a specified depth in a well after the well is shut in long enough to reflect the ambient formation temperature.
Steam-Recovery	Well Wells used for steamflooding or cyclic steam stimulation. Steamflooding consists of injecting steam into an injection well and on through the formation to a production well. Cyclic steam stimulation of production wells involves the injection of steam into the production well for a short period of time, and returning the well to production.
Stratification	The natural layering or lamination usually characteristic of sediments and sedimentary rocks. Stratification is the result of the settling of par ticles of different sizes and specific gravities.
Strength Retrogression	The decline of cement strength at elevated temperatures with age. This decline of cement strength is pronounced at temperatures above 110 degC (230 degF), unless 30 % to 40 % silica is added to the cement.
Sulfate Resistance	The ability of a cement to resist deterioration in the presence of sulfate ions.
Sulfate-Resistant Cements	Cements which contain less than 3 % tricalcium aluminate as specified by the API Specification 10A.
Surface Pressure	The pressure measured at the wellhead.
Surfactant	Any compound that affects (usually reduces) surface tension when dissolved in water or water solutions, or which similarly affects interfacial tension between two phases.
Tail Cement	The last cement system pumped during primary cementing.
Temperature	The amount of heat, usually expressed as degrees Celsius or degrees Fahrenheit.
Tensile Strength	The force per unit cross-sectional area required to pull apar t a substance.

Thermal-Recovery Well	Generic name for a well where heat is used to stimulate oil production. See SteamRecovery Well and In-situ Combustion Well.
Thickening Time	The length of time a slurry is pumpable. Time to 100 Bc as measured on the consistometer.
Thixotropy	The property exhibited by cer tain systems which gel in a static state, and then liquefy when subjected to agitation.
Turbulent Flow	The flow of a fluid in non-linear motion as a result of high velocities.
Ultrasonic Cement Analyzer	An instrument for determining the strength development of a cement sample by nondestructive ultrasonic measurement.
Viscometer - Viscosimeter	An instrument for determining viscosity.
Viscosity	A property of the internal friction of a fluid. The attraction between the molecules of a liquid that causes resistance to flow.
Water Loss	See Fluid Loss.
Water-to-Cement Ratio (or Water Ratio)	In a slurry, the ratio of water to cement expressed as percent; the pounds of water used to mix 100 pounds of cement.
Weighting Material	A material with a specific gravity greater than cement which is used to increase the density of drilling fluids or cement slurries.
Wellbore	The hole made by the drill bit.
W.O.C. Time	Abbreviation: Waiting On Cement Time, or the time required before drilling operations are resumed.
Yield Point	The resistance to flow in a drilling fluid caused by forces between the particles in the suspension. Yield point is measured in pounds per 100ft2. This value is designated as Ty in cementing calculations.