Primary Cementing Fundamentals

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FOREWORD

Oil well cementing is a process which aids in the isolation and control of fluids encountered while drilling and producing oil and gas. Cementing also helps:

(1) Bond the pipe to the formation.
(2) Protect casing from corrosion.
(3) Protect casing from shock loads while drilling deeper.
(4) Seal off "lost circulation" zones.

Cementing procedures are usually classified as primary and secondary. Primary cementing is performed just after casing is placed in the hole; secondary cementing is usually performed to correct a specific problem.

The first drillers were, by heritage, salt-water well drillers. If they used cement to seal the casing shoe it was not important enough to mention, or too secret to reveal.

In 1903, Frank F. Hill was in charge of developing the Lompac Field in California for the Union Oil Co.[1] Water encroachment from above the oil sands threatened to ruin the project. Mr. Hill mixed construction cement in a large box and placed it in the bottom of the hole with a bailer. The casing was then run in place. After waiting 28 days, the cement was drilled and the well completed, water free. This is acknowledged as the first oil well cementing job.

Water has always been a problem when drilling and producing oil. Before cementing in some areas for many years, successively smaller strings of casing were run when water influx became too great. These casings were sealed with mud, seeds, or by just setting on a hard shoulder. Formations in California were particularly difficult to seal by this method. The practice of cementing spread quickly in this state and many early developments occurred there. The first job using the Perkins Double-Plug method was performed in 1910. The cement retainer was invented by R. C. Baker in 1912. High-pressure pumps were first used to place cement. Indeed the need for properly cementing casing gave rise to a new breed of men . . . the Petroleum Engineer.

In 1919, Erle P. Halliburton resigned from the Perkins Cementing Company and went to Burkburnett, Texas. In 1920, he cemented Skelly Oil Company's No. 1 Dillard successfully with casing off bottom and out of control. Having proved that casing could be cemented off bottom, calls for this service became frequent. The invention of the jet mixer in 1922 furnished the industry with a method of mixing large volumes of material in a rapid and consistent manner.

The pioneer petroleum engineers were first concerned with the proper placement of cement to help obtain water shut-off; however, they quickly became concerned with all problems associated with cementing procedures. They knew the cement could not be disturbed while it was setting. WOC was originally observed for 28 days. Therefore, early development was directed toward reducing this time. Accelerators (alkaline chlorides) and special quick-setting cement were soon available. Deeper wells soon presented other problems.

Quality tests for cement were first performed under procedures for ASTM testing. Engineers recognized these tests were not satisfactory. Thickening time tests were first run with an ice-cream freezer using heated water in the tub. Strength tests were conducted on cubes mixed with 20 to 24 per cent water without regard to temperature and pressure. Halliburton built a "consistometer" for testing fluidity or pumpability in 1937. R. F. Farris constructed a cement tester in 1939 for Stanolind Oil and Gas Company; this device tested the thickening time of cement under controlled temperature and pressure conditions. Modern equipment can be used to test simulated well conditions of 400°F temperature and 50,000 psi pressure.

The need for uniform procedures and specifications was recognized early but agreement was difficult. The American Petroleum Institute in 1937 established a committee to propose a code for testing oil-well cements. The first committee report was presented at the 1939 annual meeting of the Institute. However, it was 1947 before API Code 32 (API Code for Testing cements used in wells) was adopted. Under specified conditions, cements were graded as to various classes. These classes follow in general the ASTM-type nomenclature. In 1952, standardization of oil well cements was transferred to a permanent committee. API Standard 10A, Specification for Oil Well Cements, was published in 1953. API 10B, Recommended Practices for Testing Oil Well Cements, was issued to replace API Code 32. The latest edition of the Standard contains specifications for eight classes of portland cement and one tentative specification.[2]

CEMENTING MATERIALS

Modern portland cement began with discoveries by Joseph Aspdin in 1824. Correct proportions of calcarious and argillaceous materials were ground and heated to about the melting point. This clinker was then ground with a controlled amount of gypsum to form a hydratable product. Grinding aids and other additives are addeu at this time.

The principal compounds of cement formed in burning and their function are important to an understanding of oil well cements.[3] Figure 1 is a microphotograph of set cement. Tricalcium aluminate (C_3A) is the compound that promotes rapid hydration. It is usually the constituent which controls the initial set and thickening time. It is also responsible for the susceptibility of cement to sulfate attack. Tetra-calcium aluminoferrite (C_4AF) is the low-heat-of hydration compound in cement. It gives color to the cement. An excess of iron oxide will increase the amount of C_4AF and decrease the amount of C_3A in the cement. Tricalcium silicate (C_3S) is the major compound in most cement and is the principal strength producing material. It is responsible for early strength. Diacalcium silicate (C_2S) is the slow hydrating compound and accounts for the gradual gain in strength which occurs over an extended period.

FIGURE 1. — Microphotograph of Set Cement[4]

All cements are manufactured in essentially the same way from the same ingredients, but in different proportions. The water requirements of each type of cement vary with the fineness of grind or surface area.

Cement, in addition to its other functions, must help support and protect casing as well as reinforcing it for greater strength. Obviously, the first consideration must be the placing of the casing in the hole. After the casing is in place, cement is placed in the annulus to cover the desired section. The volume of cement to fill the desired annular section must be pumped. One of the first observations made by early investigators was the damage done to the set cement by moving it too long. C_3A forms a bonding material which joins the slower hydrating materials. If this material is broken in its formative stage, a permanent strength reduction occurs. This deformation is most likely to occur between the time of 100 poise thickness and the initial set.

The optimum viscosity of a pumpable slurry is usually 8-10 poise (maximum 30 poise).[5] The time required to thicken to 100 poise is the thickening time or the pumping time. API specifications are based on cements designed to meet certain standard well conditions. To alter thickening time and other properties of portland cement, many selected materials have been devised as cement additives. A more recent development is the use of a basic or universal type cement, Class G and H.[6] These cements are especially designed with consideration for use with additives.

As noted, early cements were designed to reduce setting times. This was done to reduce waiting on cement time. WOC time was reduced from 28 days to 72 hours from 1902-1930. Present standards run from 24 to 4 hours depending on conditions. Besides loss of working time, quicker sets reduce migration of formation fluids and loss of cement to porous formations. Cement thickening time may be increased by grinding fine or by additives. Additives which increase the setting of cement are salt, calcium chlorides, HA-5, sodium silicate, gypsum, and others. Dispersants which reduce water requirements may also be used with proper selection. Dry-blending is the more usual method of using additives. The use of special quick-setting cement has been largely discontinued.

The most widely-used accelerator is calcium chloride. For most purposes, the addition of 3-4 per cent by weight of cement will produce thickening times of 1-2 hours and adequate strengths in 8-18 hours (see Table 1). Sodium chloride or salt is moderately effective in concentrations of 5 to 8 per cent by weight of mixing water. Gypsum cement may be added for conditions where a rapid thickening is required. A 15-20 minute set may be obtained for special conditions.

TABLE I

CALCIUM CHLORIDE

API CASING DEPTHS — PORTLAND CEMENT CLASS H

Per Cent Calcium Chloride	Depth 2000	8 Hour Compressive Strengths 80	110
0	4:00	55	1025
2	3:14	495	1535
4	2:39	560	1875

Cement slurries thicken faster when increased temperature and pressures are applied. Deeper wells, of course, encounter these conditions. Coarse ground materials, reduction of quantity of early strength components (C_3A), increase in pumping time and use of organic compounds will generally extend the thickening time. Special cements, Class D and E, possess these properties which meet the requirements for the conditions they are designed to meet. Lignins, CMC, acrylates, and certain organic acids have been used effectively as retarders. Compounds primarily used for other specific properties, i.e., fluid loss additives, may also be effective retarders. Calcium ligno-sulfonate has been the most widely-used retarder. This is added to specially manufactured cement as well as dry-blended mixtures. Lignin retarders become ineffective and must be supplemented with organic acids at temperatures above 260°F. Special cements sometimes become ineffective when additional additives are required to modify the properties. For this reason a basic cement (G or H) has considerable advantage. Cement thickening-time must be sufficient for cement placement. However, excessive time allows more chance for damage due to fluid movement in the cement-filled annulus. Strength development is also delayed if excessive retardation is used. With long cement columns at the higher temperatures, a consideration of the temperature at the top of the cement is required. Cement which will pump three hours at 350°F may remain fluid for a week at 200°F. This fact has limited the length of cement columns that can be placed using present materials in the deeper wells of West Texas.

Special cements or basic cement, using previously tested retarders, may be used for temperatures up to about 260°F. Above this temperature it may be advisable for the well operator, under certain conditions, to run a special test on components to be used for each batch. Thickening time tests are useful as quality control for complex blends. Water is important for control testing and should be supplied from the source to be used in the field.

Standard thickening time tests which are the basis of the API cement specifications are measured under temperature conditions generally true for Gulf Coast drilling. For conditions different from this, modifications of the standard test are commonly used. Temperature conditions are generally most difficult to determine. The heat exchange system of a drilling well is quite complex. For use in determining pumping time, the temperature while placing cement is required (bottom-hole circulating temperature). Temperature measurements in a drilling well may never reveal this temperature. Therefore, it is important that time since circulation be considered in reporting well temperatures. There is a reasonable agreement between temperature measurements in well-defined areas. However, a Gulf Coast gradient of 0.015 degrees per foot is not true for all areas. Gradients may prove to change in the older deeper formations. In areas of faulting or severe stressing, erratic changes have been found. Every effort should be made to establish a temperature which can be correlated to bottom-hole circulating temperature.

A third consideration for placing cement is the weight of the column. A simple hydraulic calculation will show how great a pressure will be exerted by the cement-mud system. Cement density is a function of the fineness. Class C (SR) weighs 14.1 lbs. per gallon when mixed with recommended water, Class A 15.6 lbs. per gallon and Class E 16.4 lbs. per gallon. For densities below these values, special lightweight additives have been devised. Generally, additives which help preclude water separation are used; however, in most cases the weight reduction is obtained only by serious strength losses. Bentonite is the most widely-used lightweight additive. The bentonite used should be a good grade sodium bentonite. It must be free of any peptizing agents. Normal usage has been to add up to 12 per cent bentonite by weight of cement. Examples of weight reduction are shown in Table 2.

TABLE II

BENTONITE

PORTLAND CEMENT CLASS H

Per Cent Bentonite	Water Gal/Sk	Slurry Weight lbs/gal	Slurry Volume Cu Ft/Sk
0	5.2	15.60	1.18
2	6.5	14.70	1.36
4	7.8	14.10	1.55
6	9.1	13.50	1.73
8	10.4	13.10	1.92
10	11.1	12.95	2.02
12	12.3	12.60	2.19

Diatomaceous earth will produce the lightest cement slurry.[7] This material is relatively inert and may be mixed 40 per cent by weight of cement with Class H cement. This gives a 11.0 lb. per gallon cement.

Expanded perlites trap water in the pores and produce satisfactory lightweight material. It also traps air which compresses under pressure. Perlite is best used at shallower depths. Gilsonite and other natural carbonaceous materials are effective lightweight additives. Lightweight additives are used extensively in cementing wells in West Texas.

Pozzolans also may be used as lightweight additives. These natural or artificial by-products of the fusion of silicates are by definition cementacious materials. Their principal function is to improve resistance of cement to corrosive environments. They also produce a more shock-resistant cement. Pozzolans usually will reduce cost.

Additives are needed to increase the weight of cement if well pressures are sufficient to need weight greater than 16.4 lbs. per gallon. Additives are available to make slurries up to 22 lbs. per gallon. The most suitable-weight materials are hematite ore, ilmenite ore, barite and sand. Sand has proven especially valuable for moderate, 2.50 lbs. per gallon, weight increases. It also has the added function of bridging and increasing the strength of the set cement.

Cement weight may also be increased chemically. Salt will increase the weight from ½ to 1 lb per gallon. Viscosity reducers may also be used. One to 1 and ½ lb per gallon increases can be realized by reducing the mixing water. The viscosity of friction reducers allow a pumpable slurry to be mixed at weights too great to be pumped without these aids.

Cement slurries are non-Newtonian fluids; thus viscosity is a function of shear rate. The Power Law concept more nearly describes the properties of cement, rather than the Bingham Plastic Concept used to describe muds. However, both of these concepts will allow a reasonable analysis of friction likely to be encountered while pumping. It is important in cement design that friction be maintained below a safe value to help prevent excessive bottom-hole pressure. To enable cement to be pumped at more desirable rates, certain viscosity reducers have been formulated. These materials are essentially dispersants or thinners. Their function is to reduce the rate at which turbulence can be achieved. However, for Reynolds numbers below 3100, considerable friction reduction has been achieved. This is especially important for small-diameter pipe and narrow annular spaces. Salt, fluid-loss agents, and dispersants may be used to achieve apparent viscosity reduction. However, newly-developed special "friction reducers" have given more spectacular results. These materials are also used to obtain increased weight as previously noted. When used for this purpose, strength increases approaching 100 per cent nominal values have resulted.

Fluid-loss additives are usually considered as additives for squeeze cementing. To place cement mention has been made of the various materials which will allow control of the hydraulics of these systems. However, unless the fluid remains within the limits of the designed system, difficulty can be expected. Fluid-loss control is not as generally recognized nor as well defined for primary cementing systems as it is for squeeze conditions. Radically short thickening time (flash set) is more often due to filter cake build-up than to short thickening times. Lost returns while cementing may be due to fracturing of a low strength formation. This can occur because of excessive pressure due to the greater fluid density of the slurry with reduced water. The annulus also may be squeezed off at a zone of high porosity, the weaker formation will then break down and "thief" the remaining cement. Excessive cement pumped into a formation may create extensive damage.

Definition of fluid-loss requirements for primary cementing is difficult. Normally, if noticeable filter cake build-up is measured on the electric log, fluid-loss agents should be considered. A place where high filtration occurs is in old productive sections. These formations generally have good permeability and reduced reservoir pressure. Fluid loss requirements depend upon formation characteristics.

API procedures for a fluid-loss test (API 10B) require filtration over a 325 mesh screen at 100 or 1000 psi. Unless otherwise specified, 1000 psi pressure should be used. It is believed filtration tests should be conducted at bottom circulation temperatures. However, a fluid-loss cell which will perform this type testing has not been designed. Standard tests are performed at no specified temperature. For deep well cementing in West Texas, a value of 190°F for wells with circulating temperatures equal to or greater than this is commonly used.

Fluid-loss control was first accomplished by applying high shear in mixing a cement mixture containing a dispersant plus a high per cent of bentonite (modified cement).[8] Later materials including CHMEC, acrylics, AMCY, and other high molecular weight organic compounds were developed. Fluid-loss additives have small to considerable retardation effects on cement slurries. This property must be considered in slurry design. Fluid-loss materials are normally used in the amounts of 0.6 to 1.5 per cent of the weight of cement.

Certain formation conditions of large vugular or fractured porosity may cause mud or cement to be lost. These lost circulation conditions may be bridged or plugged. Fibrous materials added to the slurry are most effective in high-porosity sandstones or gravels. Granulated materials have proven the best additives for fractured or vugular conditions. In many instances a combination of the two types of material is more effective than a greater concentration of a single type. Innovators have had a field day with lost circulation additives. Any cheap material unreactive with cement and readily available may be suggested; everything from chicken feathers to ground automobile tires has been used. However, certain requirements are necessary for use with cements. The material should be inert to the cement hydration reaction. It should be reasonably small in size. For granular material, the particles should be sharp-edged and have a uniform particle size distribution. Cellophane flakes are the most widely used fibrous agent. Sand, perlites and gilsonite are examples of granular materials.

For primary cementing in the deep Delaware Basin, gilsonite has proven quite effective as a lost-circulation material. In the fractured porosity as is encountered in the Delaware Mountain Group, a combination of additives is recommended. Shredded cellophane plus gilsonite are generally used. Normally, 1/4 lb. of Flocele plus 5 lbs. gilsonite can be used in lieu of 12 lbs. gilsonite.

Properly-graded sand is a good lost circulation material. A material especially controlled for cementing is most effective. This is a material with several beneficial effects; it is also a weighting material and a strengthening aid in addition to controlling lost circulation. It has proven especially valuable as an aid in repairing casing and squeezing for recompletion.

Strength of cement has been left for the last consideration of the properties of cement to be placed behind the pipe. This was done because most modifications necessary for altering other properties will reduce strength. One of the major compromises with strength is cost. Cement is relatively inexpensive; the cost is universally just over 1.5 cents per pound. The only way to materially reduce cost is to add more water; this reduces strength proportional to the water added.

The normal function of lightweight additives is to include extra water. The extra-included water reduces the weight of the mass and increases the total mixed volume. Water being a universally inexpensive additive, the unit cost is generally reduced. However, extra water will reduce set strength. Caution must be exercised by the well operator in selecting cement on basis of cost. Because cost reduction generally means weight reduction, density may limit the dilution of the cement. In West Texas, cost of slurries for use in deeper wells may not necessarily be lower with lightweight slurries because of the additional high-priced additives required.

Satisfactory strength is a phantom which has evaded us since the first cement job. Probably the driller's "all I can get" will meet most approval. Experiments[9, 10] have shown 8 psi tensile strength would support casing; however, a higher value of 50 psi is widely used and is the basis of most regulatory rules. For all other conditions, the customer's engineer may arrive at some higher or lower value depending on well or hole condition.

Portland cement mixed with sufficient water will have an ultimate compressive strength of 6-7000 psi. With 12 per cent bentonite added, the ultimate strength will be 1000-2000 psi. Reduced water ratio (densified) cements have strengths around 15,000 psi. Certain additives such as sand will increase strength; other additives such as coal will reduce ultimate strength even though extra water has not been added.

Another consideration for the design strength of cement should be the effect of mud contamination. This, of course, is a variable and must be left to the judgment of the customer's engineer. The value of 500 psi has proven satisfactory before drilling after setting casing. Strength at the time the cement is perforated is recommended to be 500 psi for bullets and 2000 psi for jets. For plugs used to whipstock, 8000-10,000 psi should be used as they will resist high percentages of mud contamination. Before a high-pressure fracture, the rock strength may be a good figure. For a filler type cement 200 psi may be sufficient.

Cement in place must perform its function for the life of the well. One of the necessary functions is to help protect the casing from corrosion. Corrosive sulfate waters attack cement by reaction with the C_3A complex. Sulfate-resistant cement contains 0 to 3 per cent C_3A. This

C_3A content is reduced by using a pozzolanic material as is used in Pozmix cement. Acid waters (H_2S) may also leach out the free lime in the cement. Since pozzolans react with free lime to form a cementacious hydrate, this attack may also be minimized.

The reaction of the sulfate ion with C_3A causes an expansion of the cement. If this reaction takes place during the early set of the cement an expansion occurs without deterioration. The action of pozzolan also causes expansion. Salt cement will expand more than cement mixed with fresh water. Expanding cement is one the present day research studies. While the expansion of cement is small, up to 0.3 per cent linearly, it can be important for certain cement operations.

When cement is exposed to a sustained high temperature of 230°F or above, its strength may be reduced as much as 80 per cent. The loss in strength is accompanied by an increase is permeability, which can climb to values of 6 to 10 md from an original value of 0.01 md.

The addition of controlled fine silica will help prevent cement strength retrogression.[11] Competent cement has been formulated for deep wells with 400 to 500°F temperature. Portland cement appears to be limited to a temperature of near 700°F with present additives.

One of the most widely applicable additives at the present time is sodium chloride or salt. With this material we may accelerate or retard cement. It improves the bonding to marine sediments. An increase in slurry density is obtained. Expansion of the set cement is obtained. Although the effect is moderate in most cases, salt has quite wide application; it is also generally available. However, one drawback is its possible effect on some organic additives.

CEMENTING EQUIPMENT

The mechanical considerations of mixing and placing the slurry may be considered next.

Originally, portland cement was dumped from cloth bags into a large vat and mixed by hand with hoes. Bulk transportation of cement greatly improved the logistics of placing large volumes at the well. Probably equally important was the dry-blending of cement and additives. Dry-blending made possible the addition of several materials in a single mix with scientific accuracy. A simple listing of the available materials shows the numerous possible slurries available to the customer's engineer for the requirements of his individual well. Blending of additives in the mixing water also has been used. This method, however, has not proven as efficient or as economical as dry-blending. Exception to this has been special applications. Since the advent of dry-blending, the use of additives in the mixing water has largely been discontinued. Addition of materials directly into the cement slurry is normally inefficient.

Slurrying the dry cement with water has been the object of as much experimental effort as any other problem associated with oil well cementing. The jet mixer is by far the most widely-used device for this purpose. Research into this subject still continues. However, while modifications have increased the versatility of the mixer, the basic design has remained unchanged. The water-cement ratio of the slurry is maintained by monitoring the density. This is usually done with a mud scale or by a continous weighing device. The most effective slurry control is by the cementer. This technician, through experience, considers the flow properties of the slurry in the mixing tub to maintain the desired slurry weight. Viscosity measurements are normally not otherwise used except in laboratory testing.

Casing devices are used to aid cement placement. The most important item is a check valve or float, usually positioned one or several joints above bottom of the string in the float collar.

Floats were originally designed to reduce the load requirements of the hoisting equipment, and are still utilized in this respect. The float also limits plug travel, or guards against over-displacement of fluids used to pump cement into place behind pipe.

An improved casing-cement bond generally results if cement is allowed to set with greater pressure on the annulus than on the casing. The float makes this possible. The pressure can be released from the casing at the surface following the cementing operation since the check valve seals against a differential pressure into the bottom of the casing.

Dual float devices are generally used on longer casing strings. On some important strings in West Texas as many as four floats have been used.

Automatic fill units are sometimes used. These devices provide for a certain controlled rate of fill of mud into the casing as it is being lowered into the wellbore. These devices eliminate time required to fill the casing at the rig floor. They serve another important function by reducing pressure surges or hydraulic ram action against the formations as the casing is being run.

Other important casing devices are guide shoes, centralizers, and scratchers. The terms are self descriptive. Packer shoes have been popular in West Texas and are used to isolate annular cement fill above an open-hole completion zone.

Care in handling of casing and in control of lowering rates represents two important safeguards in primary cementing. No kind or amount of casing devices can compensate for damaged casing and lost circulation conditions.

A multi-stage cementer is a special collar for cementing from a point any distance off bottom. Sleeves seal the ports while running casing and cementing the lower stage or stages. At the desired time, an opening sleeve is actuated by pumping a plug or dropping an opening device and applying pump pressure. The required cement is pumped through the ports. After proper displacement, the cementing ports are permanently closed by use of the closing plug. Two and three stages are not unusual with these collars. Stage cementing has been widely used in the West Texas area. Many of the more prominent formations are fractured and highly stressed. These formations rupture at comparatively low pressures. Rocks of the Permian Age are likely to fall in this category. To successfully cement casing through these sections, stage cementing techniques are used. The importance of this technique has been recognized in cementing intermediate casing in the deep Delaware Basin wells. Geometry of casing size requires a large casing to be cemented from the lower Wolfcamp to a shallower casing or to the surface. This may be between 9000 and 13,000 feet with the weak Delaware formations exposed. Even with stage tools, this is a difficult project. A special tool placement technique and low-water-loss cement is required to successfully design these cement jobs.[12]

An essential aid to cementing is the cementing plug. Because of the high viscosity of the cement slurry, cement is often left on the walls of the casing. The cement plug was devised to separate the cement from the displacing fluid. It was this invention that introduced the "pump and plug" method of cementing or oil well cementing as we know it. The top plug is usually a molded rubber plug with wiper vanes and an inner core of some solid material. The plug fits the casing tightly. A similar bottom plug is designed to by-pass fluid when it reaches bottom. Special plugs have been designed for specific functions. The merit of using a top plug is almost universally accepted. No such agreement for a bottom plug has been reached. After sixty years, argument can be expected against running a bottom plug in a specific situation. These cases must be considered in view of the well conditions. However, experts universally agree; better cementing jobs will result if a bottom plug is used by the well operator. Situations which would preclude the use of a bottom plug should be avoided or modified by the well operator as much as possible.

CEMENTING MECHANICS

Displacement rates have also been the subject of much study. For many years, displacement was limited by available pump capacity. It was generally agreed success was better with higher rates. Howard and Clark[13] in their classical paper described cement flow in terms of a Bingham Plastic. These terms are generally accepted when discussing cement flow properties. Their findings indicate turbulent flow removes 95 per cent of the displaceable mud. Further studies indicate complete removal may be achieved by pumping several hole volumes in turbulent flow. A value of seven volumes appears to be practical. The function of modern friction reducers is to lower the rate at which turbulence begins. These additives may reduce the turbulent rate by 70 to 90 per cent. Studies also have been made on the displacement efficiency of highly viscous slurries at low rates. The flotation effect also aids in cement fill.[14] Generally a cement slurry should be at least one pound per gallon heavier than the mud. For deep well cementing, the limiting rate is usually controlled by the hydraulic pressure on the exposed formations and the thickening time of the cement.

Pre-flushes have been used and are generally recommended. The usual pre-flush is a volume of water, often the same as that used for mixing. The value of chemicals in this water depends on the character of the mud. For the simple salt water muds of West Texas, chemical flushes have not proven highly effective. Muds having a large amount of treating chemicals require more consideration. When oil base or emulsion type muds are used, flushes are essential. These muds require a hydrocarbon pre-flush and should be followed by a water flush. Both the hydrocarbon and the water should contain chemical additives.

Casing movement is generally associated with scratchers. For this reason, the merit of casing movement is often overlooked. Nonetheless, every serious study indicates the merits of moving the casing while placing the cement. Rotation or reciprocation of the casing appear equally useful. Casing movement aids in completely filling the annulus and also dilutes the effect of unavoidable mud contamination. It is suggested that casing movement should be the first consideration of the well operator if a change in cement techniques is required.

A "liner" is casing used to case off a section of open-hole below existing casing. The liner is joined to the bottom of the existing casing. This technique is used for economy when drilling new wells. It is also used to improve the hydraulics of drilling. This is especially important when drilling deep wells. There are other important reasons for using a liner on a drilling well. Liners also have important usages for old wells.

All factors for full casing cementing should be considered for liner cementing. In addition, special consideration must be made for removing the drill pipe. Liners are usually run with less clearances than may be used otherwise. Cement thickening time for casing cement is not valid when cementing a liner. Thickening time tests have been set up for testing liner cements.

"Puddling" or "long-life" liner cementing is the application of modern materials to an old technique.[15] Cement retarded for a long period, 18 to 24 hours, is placed in the hole before running the liner. For the cement to remain fluid the water loss is controlled to an extreme degree, 50 to 100 cc. Friction reducers are also used to help prevent high gelation of the static cement. After the liner is on bottom, it is reciprocated for a time before setting the liner. The liner may then be hung or it can be set on bottom. WOC time is generally 48 to 72 hours. For wells with small annular clearance, the success of this technique has been very good. It has also been helpful in getting a good job in low pressure wells. Over a hundred such wells in the Permian Basin have had successful liners set in preparation for waterflood operations using this technique.

"Long-life" cement has been used to cement multiple parallel casing strings in wells designed for tubingless completions. For this type of well, one string is usually run to bottom and the slurry is run in the usual manner. The other casing strings are then run to the required depth. This cementing technique has greatly reduced communication between strings in this type completion.

SECONDARY CEMENTING

Secondary or remedial cementing includes liner cementing and squeeze cementing. Liner cementing has been discussed above.

Squeeze cementing is defined as an operation in a well by which a cement slurry is forced under pressure to a specific point in the well. The economic importance of squeeze cementing is probably equally as great as any other phase of cementing. The time allotted for this presentation does not permit more than a brief observation of this phase of oil well cementing. Our definition of squeeze cementing states that cement slurry is applied to a specific point in the well. Stated otherwise, it is used to help correct a specific problem or well condition. The method to be chosen by the well operator is the one which a study of well conditions indicates most applicable. It should not be expected that any one method will be best for all conditions.

Some of the squeeze techniques used are:

1. High-pressure squeezing
2. Low-pressure squeezing
3. In-place squeezing

A high-pressure squeeze is applied under a packer. The packer may be a retainer or a retrievable cementer. A retainer is made of drillable materials and must be left in the well until the cement sets. The retrievable cementer is removed before drilling but may present more difficulties in use. Pressure is used to dehydrate the cement slurry against a permeable formation; this pressure is applied until the filter cake buildup is sufficient to minimize the chances of leakoff or fluid flow from the formation. Thousands of successful squeeze jobs of this classification have been performed in West Texas.

Low-pressure squeezing[16] would more properly be called a fluid-loss control squeeze. A fluid loss control additive is used to reduce the rate of filter cake deposition. This allows a more uniform deposition across the formation. The pressure used to form the filter cake is usually kept below the fracturing pressure of the formation. For naturally-fractured formations, it is sometimes necessary to add a bridging agent to the slurry. Packers are generally used to spot the cement.

In-place squeezing has been developed recently in the West Texas area. A packer with a pressure-balanced valve should be used for this application. The cement slurry may contain a bridging agent to aid in distribution of the cement. Sand is often used because of the added strength it gives the cement. Pressure development is not required. After cement is pumped below the packer the valve is closed. The cement is allowed to set in place.

Squeeze cementing techniques must be selected by the well operator after studying the formations being squeezed. Squeezing has been used to help:

1. Shut off undesirable water or gas.
2. Shut off depleted formations.
3. Repair damaged casing.
4. Repair unsatisfactory primary cement jobs.
5. Control lost circulation.

SUMMARY

Cement slurries are placed in the annulus of an oil well for many reasons. Among the benefits hoped for are to:

1. Isolate and contain formation fluids.
2. Strengthen casing.
3. Protect casing.
4. Consolidate formations to prevent heaving and extrusion.

For each well the list of required functions of the cement will be different. An evaluation of formation character by the well operator will determine the importance of each function for each well. A cement slurry should be determined to best fill these requirements. The cement can then be placed by the most efficient method. This is the first duty of the Petroleum Engineer. A proper consideration of the process will increase the success of our major objective . . . producing oil and gas.

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