A Resume of Cementing Practices and Materials

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ABSTRACT

The techniques involved in the completion of a well, with regard to cementing operations, vary with areas and operators. Certain procedures are, however, looked upon as being most suitable for particular applications and often certain cementing slurry components have been found to give better performance in one of the two major cementing operations: primary cementing and squeeze cementing.

A resume of proper cementing techniques is presented which will include flow characteristics of cementing slurries, effect of turbulent flow velocities on mud removal, effectiveness of chemical washes and the use of cementing plugs. The application of relatively new cementing practices using various low fluid loss slurries will be discussed from the standpoint of both primary and squeeze cementing and a resume given on results obtained while using these techniques.

Not only are proper application techniques important, but the selection of slurry composition to fit a particular circumstance also is fundamental to obtaining a successful primary cementing job. A brief discussion of the various materials that have appeared to be most advantageous in the West Texas area for primary cementing will also be presented along with the aspects of these materials when applied to squeeze cementing.

INTRODUCTION

Basically, oil well cementing is the process of displacing a cement slurry down the casing and up the annular space behind the pipe where it is allowed to set, thus bonding the pipe to the formation. Oil well cementing is one of the important factors in the completion of oil wells.

The first verified use of portland cement in an oil well, for shutting off water that could not be held with a casing shoe, was in 1903. Since that time, tremendous advances have been made in cementing materials, techniques, and equipment. In 1905 the first packer was used in cementing a well. Also, when pumps were made available for pumping the cement slurry instead of dumping it down the hole, it became necessary to add more water to thin the slurry.

A major improvement to cementing operations was put on the market in 1912; a cement retainer used to pack off between the tubing and casing when pumping cement through tubing. In 1911 the first cement plug to separate slurry and drilling fluid was used. Prior to this time a majority of the wells were cemented by use of a dump bailer.

Following the use of cementing plugs, cam the use of a measuring line to follow the downward movement of the plug and, by knowing its position, allow pumping to be stopped and the proper amount of cement left in the casing. The first measuring line was no more than a clothesline run through a rebuilt oil saver.

The first jet type mixer was used in 1920. Various types of mechanical mixers had been tried up until this time, but none had been very widely used. Cement was packaged in cloth bags until 1925 with a general transition to paper bags by 1927. The use of bulk cement equipment was made available to the industry in 1940.

In 1922 one of the major service companies advertised a "four-day" setting cement. In the early days the only criteria for a good cement was strength. Wells were initially closed in for 28 days in accordance with the accepted practice for construction work. In the years from 1926 to 1933 there were some general changes in the composition of portland cement as well as in the grind.

In the late 1920's oil wells were being drilled to depths of 6,000 feet and trouble was encountered with the cement. Generally faster cementing operations by better planning and better equipment allowed the use of portland cement; however, a means of testing the effect of temperature and pressure on the cement slurry was essential. From 1930 to 1940 three distinct apparatus were built for this purpose.

Standard Oil Company of California and Halliburton Oil Well Cementing Company built consistometers for testing the pumpability of cement slurries at elevated temperature and atmospheric pressure. Pan American Oil Comapny (then Stanolind Oil and Gas Company) constructed a cement tester that would test the thickening times of cement slurries under controlled temperature and pressure. With this Pan American tester the thickening time of cements could be ascertained under simulated well conditions.

In 1937 the American Petroleum Institute, Division of Production, established a committee on cements with the objective of establishing a standard or code to cover the testing of oil well cements. A progress report was submitted in 1939, but it was not until 1947 that the first tentative "API Code For Testing Cements Used in Oil Wells" was pproved.

Gun perforating was introduced in California in 1932 and into the Gulf Coast in 1934, as was electric logging. Also an important development to make an appearance in 1934 was the temperature survey. Many more improvements such as centralizers, scratchers, lost circulation additives for cement, improved drilling practices and drilling muds came into being between 1930 and 1940 to aid in successful cementing operations.

The technique of oil well cementing is known and practiced wherever oil wells are drilled. It is a skilled operation which requires special equipment and personnel trained not only in cementing techniques, but also in the use of the innumerable materials presently being used. The potential as well as the life of a producing well depends to a great extent on a good cementing job.

During the drilling of an oil well it is necessary to pass through many and varied types of formations. They may be permeable zones which produce oil, gas, or water or combinations of these materials. Also there may be highly permeable and porous formations such as gravel, glacial drift, and other coarse sediments; or the formation openings may be vugular, cavernous, fractures in formations such as limestone, or broken shale and rock. These formations must be segregated one from another to prevent the migration of fluids up or down the hole.

Basically, cementing procedures may be classified into two groups, primary and secondary. Primary cementing is performed immediately after the casing is run in the hole. The main objectives of primary cementing are to obtain an effective zonal separation and to protect the pipe itself. Cementing also serves the purpose of:

1. Bonding the pipe to the formation.
2. Protecting oil producing strata.
3. Minimizing the danger of blow-outs from high pressure zones.
4. Sealing off "lost circulating zones" or other troublesome formations as a prelude to deeper drilling.

Secondary cementing, more often called squeeze cementing; is a method whereby a cement slurry is forced under pressure to a specific point in the well. It is an important development in cementing techniques as it has added greatly to our recoverable reserves. Squeeze cementing may be performed during drilling and completion operations or at a later date during a workover program.

Squeeze cementing may serve one or more of the following purposes:

1. Repair a faulty primary cementing job.
2. Reduce the gas-oil, water-oil or water-gas ratio.
3. Repair defective casing or improperly placed perforations.
4. Minimizes the danger of lost circulation in openhole while drilling deeper.
5. Abandon permanently a nonproductive or depleted zone.
6. Isolate a zone prior to perforating for production or to fracturing.
7. Supplement primary cementing job on a casing string or liner where the desired full-up was not attained.

There are many problems to be solved before proceding with either a primary or squeeze cementing operation. A complete plan of operation should be written and every effort made to insure a successful job. The proper use of the essential subsurface equipment is of vital importance.

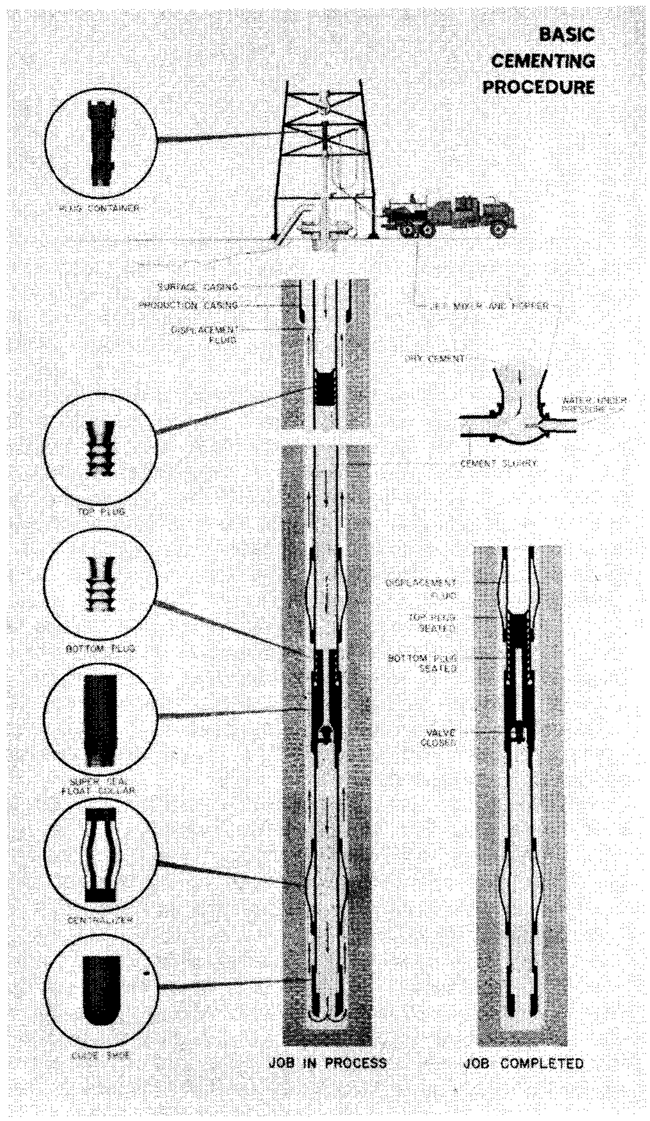
In primary cementing the use of guide shoes, float collars, casing centralizers, wall scratchers (rotating or reciprocating type) and cementing plugs as well as a proper tool, if one is used, greatly improves the chance for a good cementing job. For a squeeze cementing operation such things as type of fluid in the hole, type of squeeze tool - if one is to be used - maximum squeeze pressure, type and quantity of cement, and method of squeeze must be considered.

MECHANICS OF OIL WELL CEMENTING

There are many factors which may affect the success or failure of a primary cementing job. One that has been the cause of much discussion is the rate at which cements should be displaced. The displacement rate is the determining factor in the type of flow obtained.

Different pumping rates result in three specific types of flow, i.e., plug, laminar and turbulent. In plug flow, the fluid moves as a solid plug and travels at very low velocities. As the velocity increases, the flow becomes laminar, and is characterized by a central plug of cement slurry surrounded by telescoping concentric layers of the moving fluid. This central plug decreases in size with an increase in velocity until at a critical velocity it disappears and the cement slurry resembles a true fluid and enters the turbulent flow region. Turbulent flow is characterized by innumerable eddies throughout the moving slurry.

Tests conducted by Howard and Clark show that for annular velocities of less than 1 foot per second, the slurry would be in plug flow. The slurry would be in laminar flow with annular velocities ranging from 1



foot per second to 5.25 feet per second. The upper laminar flow region (transition zone) had a velocity range of 5.25 per second to 7.9 feet per second and above 7.9 feet per second the slurry would be in turbulent flow. Based on a 5-1/2 inch OD casing in a 7-7/8 inch hole the displacement rates for each type of flow would be as follows:

1. Plug flow - less than 1.85 BPM
2. Laminar flow - 2.0 to 11.0 BPM
3. Upper Laminar flow - 11.0 to 15.0 BPM
4. Turbulent flow - above 15.0 BPM

Experimental data indicates that when displacement rates for a cement slurry are in the region of plug flow approximately 60 per cent of the circulatable mud is displaced; in the laminar flow region approximately 90 per cent is displaced; and in the turbulent flow region over 95 per cent of the circulatable mud was displaced. The amount of circulatable mud displaced is also dependent upon the viscosity of the mud and the viscosity of the cement slurries. Laboratory tests made on API Class A Cement slurries using the API water ratio (46 per cent), showed that displacement rates varied from 11.6 BPM to 21.1 BPM with different brands of cement in order to obtain turbulence (Table I).

Data also indicate that additives such as bentonite, pozzolan and diatomaceous earth do not cause much variation from these rates when mixed with the proper amount of water and with a cement having a characteristic high viscosity. However, there is a tendency for the additives to stabilize the variations encountered with different brands of cement by increasing the displacement rate for turbulence of the normally less viscous brands.

TABLE 1

Pumping Rates for Turbulent Flow
7 Inch Casing - 9 Inch Hole

Cementing Composition	Water Ratio *Gal/Sack*	Displacement Ratio *Bbls/Minute*
API Class A Cement - Brand A*	5.2	21.1
API Class A Cement - Brand B*	5.2	11.6
API Class A Cement - Brand A	6.3	15.4
API Class A Cement - Brand B	6.3	8.5
20 per cent Diatomaceous Earth-Brand A Cement	13.1	20.0
20 per cent Diatomaceous Earth-Brand B Cement	13.1	17.7
Pozzolanic Cement - Brand A Cement	5.75	20.6
4 per cent Bentonite - Brand A Cement	7.7	21.7

* *These two brands of cement represent approximately the maximum and minimum viscosity* characteristics for API Class A Cement.

Pumping rates for turbulence with these additives varied from 20.0 to 21.7 BPM with the more viscous brand of cement. It was found that the less viscous cement, containing these additives, would go into turbulence at a pumping rate from 70 to 90 per cent that of the viscous cement, as compared to approximately 55 per cent for the next cement. Small quantities of chemical additives such as accelerators and retarders will alter the displacement rates for turbulence depending on whether they have a tendency to reduce or increase the slurry viscosity.

From the above data it becomes evident that with cement slurries turbulence is seldom attained. Also, the circulatable mud is affected by the slurry velocity, but the velocity does not generally affect the removal of the mud filter cake. To provide maximum assurance for a successful job it is often necessary to use other methods to remove the mud cake.

The use of water as a spacer between mud and cement slurry is a common practice in certain parts of the country. The use of water spacers has a two-fold purpose: 1. contamination of the cement slurry by drilling mud after it leaves the casing is reduced and 2. it is easier to get water into the range of turbulent flow and, therefore, a larger percentage of the circulatable mud may be removed at a lower displacement rate.

The addition of chemicals such as sodium tetra phosphate, calcium chloride, lime, sodium chloride or sodium bicarbonate is also a fairly common practice. Care must be exercised when adding many of the mud dispersing chemicals because of the detrimental effect they may have on the setting and strength of the cement. Chemicals such as quebracho (tannin) and salts of lignosulfonic acid have a retarding effect on cement slurries and, with a high enough concentration, may defer the set of the cement indefinitely.

There are many mud dispersing materials that have been designed and developed for the specific purpose of removing mud from the wall of the formation. This type of wash is usually composed of a dilute solution of hydrochloric acid and a small volume of a surfactant. Laboratory tests on various types of drilling mud have shown that some filter cakes are completely dispersed by a mud clean-out acid and when washed with a dilute acid without a surfactant, the filter cake was merely cracked by shrinkage of the bentonite and not removed. Precautions must be taken when using a mud removal wash when cementing through a zone of lost returns. A lost circulation zone previously sealed by the addition of lost circulation additives to the mud system may be cleaned up to such a degree that lost returns will again be encountered during the cementing operation.

Nearly every state, where drilling operations are in progress, has a governing body or commission that sets up rules concerning the setting of casing strings. It is of utmost importance that these rules be adhered to when setting casing whether it be surface casing, intermediate or production strings. There are also some fundamental practices to be followed in setting each string of casing. These basic practices are as follows:

Surface Casing

(a) Set casing in a hard formation.

(b) Be sure the viscosity of the cement is greater than the mud viscosity.

(c) Use the two plug method.

(d) Use a water spacer - preferably chemically treated.

(e) Use adequate number of centralizers.

(f) Displace at the highest possible rate.

(g) Set casing below the lowest fresh water sand.

(h) Use sufficient amount of cement to assure cement returns.

(i) Chain down casing to prevent its being pumped out of the hole at the high displacement rates.

Production Strings

(a) Through (f) above. Apply also to production strings as well as surface casing.

(g) Cover the uppermost pay by 300 feet to 500 feet.

(h) Set casing approximately 50 feet below the lowest producing interval for a set - through completion. Set approximately 2 to 3 feet or more off bottom to insure unrestricted flow of mud and cement.

(i) If reciprocating scratchers are used, design stroke for overlap of scratched interval. When rotating scratchers are used, they should be spaced at 120° intervals around the casing with an overlap of 2 to 3 inches.

(j) API recommendations are to run casing at no more than 1,200 to 2,000 feet per hour. If lost circulation zones are present this speed should be reduced by 50 per cent to avoid excessive pressure surges. Casing should be filled every 10 to 15 joints where automatic fill-up equipment is not used.

(k) Prior to cementing the casing circulate about two complete hole volumes of mud and treat mud to reduce the viscosity.

(l) Scratch until all filter cake has been circulated to the surface before mixing cement.

(m) Scratch until plug hits bottom. Reciprocate on 2 minute cycles. Break circulation and start rotation at the same time with rotating wall cleaners. Rotate at about 10 rpm before breaking circulation and at 20 rpm thereafter.

(n) Provide a wash-out line to eliminate cement above the top plug.

(o) If the float is operating properly there is no need for shutting in under pressure. Often advantageous to leave pressure off casing.

Plug Back Operations

(a) Use fluid spacers - chemical wash.

(b) Use scratchers.

(c) Where feasable use a faster setting cement.

(d) Pull out slowly to insure no flow back. Fluid should fall in the direction of pumping.

(e) Be sure of correct displacement. Usually under displace one barrel.

(f) Use chemical additive in cement to insure hard cement in the event that mud contamination occurs.

Even with these basic procedures having been carried out it is important that the proper cementing composition for the particular job at hand has been selected.

CEMENTING MATERIALS

The API specifications lists seven classes of cement manufactured for oil well usage along with the well conditions pertaining to depth, temperature and pressure for their use. There are certain problems encountered where these classes of cement, when mixed with the recommended amount of water, do not fill all qualifications. The viscosity of a cement slurry may be increased or decreased by merely increasing or decreasing the water-cement ratio. However, this will also alter other physical properties.

All cement slurries have a recommended maximum and minimum water ratio. Minimum water ratios are often used in setting surface casing, and if used in conjunction with a cement accelerator it is often possible to drill out in 4 to 6 hours. Cements when mixed with the maximum water ratio will have a set volume equal to the slurry volume. The use of water ratios higher than recommended maximum, for the purpose of lowering the viscosity of the slurry or to increase the slurry volume, is very detrimental. This procedure will allow the formation of water pockets throughout the cement column and considerably reduce the strength of the set cement.

The basic materials that go into the manufacture of portland cements are the same whether it is to be used for construction work or for oil well cementing. Portland cement is produced from a properly proportioned blend of limestone and clay or shale which is composed primarily of the following compounds: silica, lime, alumina and iron oxide. These raw materials are intimately ground, then passed through a rotary kiln where they are calcined to make cement clinker. The clinker is then ground into a fine powder to which is added a small quantity of gypsum to control the setting properties of cement.

The final product contains compounds of silicon dioxide, calcium oxide, iron oxide, aluminum oxide, magnesium oxide and sulfur trioxide. These basic compounds are:

Tricalcium Silicate (C_3S) - Contributes to the early strength of the cement. This stage of strength development is the most important with respect to oil well cementing.

Dicalcium Silicate (C_2S) - This phase hydrates very slowly and therefore is the constituent which produces the long term and ultimate strength in portland cement.

Tricalcium Aluminate (C_3A) - Dissolves readily in water with the evolution of much heat. Its primary contribution to the cementing action is to provide the initial set of the cement. It also affects the thickening time and produces that portion of the cement most readily attacked by sulfate waters.

Tetracalcium Aluminoferrite (C_4AF) - A low heat of hydration compound in cement which has very little effect upon its properties.

There are two major methods of cement classification: The first was developed by the American Society for Testing Materials (ASTM) and covered five types of portland cement, primarily for construction usage. The second is the American Petroleum Institute (API) Specifications for Oil Well Cements. API classification is as follows.

Class A - intended for use from surface to 6,000 foot depth when special properties are not required.** Available in regular type only (similar to ASTM C 150, Type I).

Class B - intended for use from surface to 6,000 foot depth.** Available in regular type (Similar to ASTM C 150, Type II) for conditions requiring moderate sulfate resistance, and in high sulfate-resistant type.

Class C - intended for use from surface to 6,000 foot depth, for conditions requiring high early strenght.** Available in regular type (similar to ASTM C 150, Type III), and in the high sulfate-resistant type.

Class D - intended for use from 6,000 to 12,000 foot depth, for conditions of moderately high temperature and moderately high pressure.** Available in regular type (having moderate sulfate resistance) and in the high sulfate-resistance type.

Class E - intended for use from 6,000 to 14,000 foot depth, for conditions of high temperature and high pressure.** Available in the regular type (having moderate sulfate resistance) and in the high sulfate-resistant type.

CLASS F - intended for use from 10,000 to 16,000 foot depth, for conditions of extremely high temperatures and extremely high pressure.

The method for testing oil-well cements is outlined in API RP 10B, "Recommended Practice For Testing Oil-Well Cements."

Cement that is used in oil wells today is subjected to a wide range of conditions. These conditions range from temperatures less than 32° F. to over 400° F. in deep wells. Also, bottom-hole pressures in excess of 20,000 psi are encountered. The use of a single type cementing material for use under these extremes of temperature and pressure was impossible; therefore, it was of necessity that different types of cements be manufactured and suitable admixtures be developed to meet these variable conditions.

The cements used in oil wells are usually referred to as high early strength, portland and retarded. However, with the large number of admixes available, the cementing of an oil well has developed into what may be regarded as a chemical service. Cementing compositions are now being "tailor-made" for specific well conditions.

The first property of a cement to be considered in cementing an oil well is that which is referred to as pumpability or thickening time. A cement slurry must remain fluid for a sufficient length of time to allow it to be pumped down the casing and up the annular space behind the pipe in a casing-cementing job or, in squeeze-cementing, sufficient thickening time to allow attainment of squeeze pressure and reverse circulation of the excess cement. Also, the thickening time should include an adequate safety factor in case of unavoidable shut down during the job.

Secondly, the cement, after having been properly placed in the well, must set in a reasonable period of time and develop sufficient strength to allow well completion or continuation of normal drilling operations. The strength required of a cement before operations are resumed will vary with the operator, but a figure of 500 psi compressive strength is generally accepted by the industry as being adequate. According to published literature the minimum strenth required to support pipe in a hole on a primary casing cementing job is 8 psi tensile strength or approximately 100 psi compressive strength.

Admixtures To Cement

It is often necessary to alter or modify a cementing composition to meet certain well conditions. The different types of additives used in cement may be classified as follows:

Cement Accelerators

1. Calcium Chloride
2. HA-5
3. Sodium Chloride
4. Sodium Silicate

Cement Retarders or Dispersants

1. Calcium lignosulfonate
2. Carboxymethyl Hydroxyethyl Cellulose

Heavy Weight Additives

1. Barium Sulfate
2. Ilmenite
3. Ferrophosphorus
4. Iron Arsenate
5. Sand

Light Weight Additives

1. Bentonite
2. Gilsonite
3. Pozzolans
4. Expanded Perlites
5. Diatomaceous Earth
6. Hydrocarbon emulsions

Lost Circulation Additives

1. Shredded Fibrous materials
2. Cellphane Flakes
3. Gilsonite
4. Expanded Perlites
5. Granulated nut shells
6. Mica Flakes

Contamination Preventing Additives

1. Mud-Kil
2. Activated Charcoal

Low Fluid Loss Materials

1. Carboxymethyl Hydroxyethyl Cellulose
2. AMCY
3. Latex Cement
4. Modified Cement (PWC)

Special Cements

1. Resin Cement
2. Latex Cement
3. Diesel Oil Cement
4. Gypsum Cement

The use of additives in cements has become increasingly popular in the last decade. They are being used more and more to alter the physical properties of cement slurries to make them more suitable for the problems encountered in cementing operations. Additives have now become an essential part in the designing of oil well cementing compositions.

By the proper use of additives it is possible to alter the physical properties of cement slurries as follows:

(a) Decrease the slurry density.
(b) Decrease compressive strength.
(c) Increase the slurry density.
(d) Increase compressive strength.
(e) Accelerate the thickening time.
(f) Retard the thickening time.
(g) Decrease the water loss.
(h) Reduce slurry viscosity.
(i) Bridge over for lost circulation.
(j) Increase resistance to brine and sulfate waters.
(k) Reduce retrogression of strength at high temperatures.
(1) Reduce cost.

It may also be necessary to use more than one additive to secure the desired results. If that be necessary, it is advisable to have data available on the compatability of the materials or to have tests made on the composition to insure a trouble-free job.

Light Weight Cementing Compositions

The most frequently used additives are those designed to lower the slurry density. The most common additive of this type is bentonite.

TABLE 2

Comparative Properties of Light Weight Slurries

API Class A Cement — Slurry Weight: Approx. 12.5 pounds/gallon

Additive	Quantity Per Sack	Water Ratio Gallon/Sack	Slurry Volume Cubic Feet/Sack	Strength-psi 24 Hours - 100 F.
Bentonite	12 per cent	12.4	2.22	395
Diatomaceous earth	20 per cent	13.1	2.37	380
Expanded perlite with 4 Bentonite	1.5 cubic feet	13.5	2.45	650
Gilsonite	50 pounds	7.0	2.17	960
Gilsonite with 4 per cent Bentonite	28 pounds	9.50	2.15	690
Pozzolan cement with Gilsonite	25 pounds	7.00	1.80	450

Bentonite (gel) is a colloidal clay which will absorb large quantities of water and is used in cements to produce the following properties:

(a) Decreased slurry density.
(b) Decreased compressive strength which will give better perforating qualities.
(c) Decreased thickening time especially with high percentages.
(d) Decreased water loss.
(e) Increased slurry volume.
(f) Decreased cost.

The decrease in slurry density is expecially significant when cementing through weak formations as it is a means of lowering the hydrostatic head to prevent lost returns. The lower fluid-loss property is advantageous when cementing a production string since it decreases the chance of formation damage being caused by the filtrate.

This is especially important where the swelling type clays are found in the producing formation and contact between the water and the clay could drastically reduce the permeability. Also when using a low fluid loss cement there is less chance of dehydrating the cement into a permeable zone before displacement is complete.

Bentonite is commonly used in all classes of cements. When high percentages of bentonite are used in portland cement it becomes necessary to add a dispersant to lower the viscosity of the slurry. Calcium lignosulfonate is considered the most satisfactory chemical for this purpose. It also acts as a retarder and provides lower fluid loss properties as well as allowing use of the slurry under higher temperature conditions.

Another use of high bentonite cements (12 and 25 per cent) is squeeze cementing in permanent type well completions. Permanent type completions involve the placing of the lower end of the tubing string (setting the packer if one is used) above the uppermost producing formation and performing all future operations through the tubing.

A requisite in this application is the addition of calcium lignosulfonate which acts as a dispersant and a retarder. Due to the small volumes normally required for this type of operation a batch mixing process is preferred. By mixing these slurries at a high rate of shear it is possible to obtain a slurry with relatively good low fluid-loss properties (50 to 100 cc.) To prepare such a cementing composition it is essential that API Class A Cement, a good grade of bentonite (preferably unpeptized) and fresh water be used. Deviations from this recommendation could cause the slurry to flash set.

Most retarded cements have previously been blended with some type of retarder to increase the thickening time. When bentonite is blended with this type of cement two major changes take place. The bentonite has a tendency to absorb certain organic retarders and the addition of sufficient water to hydrate the bentonite causes a dilution of the retarder, both of which cause a reduction in the thickening time of the slurry.

Probably the biggest disadvantage to the use of bentonite cement slurries is the effect at high temperatures on their properties. Laboratory tests indicate a substantial decrease in compressive strength at temperatures above 230° F. Other disadvantages are the degradation caused by sulfate waters and the increase in permeability of bentonite cements.

Diatomaceous Earth Cement

The use of diatomaceous earth as a light-weight additive has greatly increased in the last few years. Diatomaceous earth is composed of silicious skeletons of diatoms deposited from either fresh or sea water. In the natural condition many diatomaceous earths have very little value as pozzolans; although they combine very actively with lime, the compounds resulting from this reaction have very low cementitious value because of the large quantity of water required to produce a pumpable slurry.

Diatomaceous earth is blended with cements in percentages ranging from 10 to 40 per cent. It is possible to produce slurry weights as low as 11.0 pounds per gallon which is effective for cementing over some relatively weak formations. However, the resulting compressive strength is quite low at low temperatures and the strength of the set cement retrogresses under high temperatures.

Gilsonite

Gilsonite for use in cementing slurries is a relatively new light-weight additive having been in use slightly over one year. It was developed primarily as an additive to cementing compositions to provide a slurry having low density and superior lost circulation control properties. Gilsonite is a solid hydrocarbon mined from the Uintah Mountains of Utah and Colorado; and although it resembles asphalt in color, its properties are unlike any other known product.

TABLE 3

Gilsonite

Physical Properties of Typical Sample

Specific Gravity - 1.07
Bulk Density - 50 pounds per cubic foot
Water Requirement - 2 gallons per cubic foot
Absolute Volume - 0.75 cubic feet per 50 pounds
Melting Point - Over 300°F.

A light weight slurry is obtained because the density reduction is a function of the low specific gravity (1.07) of the Gilsonite rather than the addition of large volumes of water. Gilsonite is inert and noncellular and as such, will have no effect on the thickening time of the cement slurry nor will it absorb water from the slurry when subjected to pressure. It resists attack by sulfate waters, brines, acids or alkalies.

The grade of Gilsonite selected for use with cementing slurries (Table 3) was that which had the proper particle size distribution to provide maximum control of lost circulation yet minimize the possibility of bridging the ports in cementing tools or similar down hole restrictions.

Gilsonite may be used with all API classes of cements as well as pozzolan cements and possolan-lime mixtures when used as recommended. Slurry weights in the order of 10 pounds per gallon — 74.9 pounds per cubic foot — 520 psi per 1000 foot of depth are possible with this material (Table 4).

TABLE 4

Slurry Properties
API Class A Cement (94 Pounds)
0 Percent Bentonite

Gilsonite Pounds/Sack*	Water Gallons/Sack*	Slurry Weight Pounds/Gal.	Slurry Volume Cubic Feet/Sack
Zero	5.20	15.6	1.18
25	6.00	13.6	1.66
50	7.00	12.5	2.17
100	9.00	11.5	3.18
200	13.00	10.3	5.22

* Figures per sack of cement.

Gilsonite cementing compositions have been used extensively in the field with over 200 jobs recorded to date. Types of jobs where Gilsonite cement has been used are as follows:

1. Surface casing.
2. Intermediate string.
3. Production string.
4. Setting liners.
5. Squeeze cementing.
6. Plug Back.
7. Recement.

Gilsonite cement has shown extraordinary success in primary cementing through weak formations as well as sealing off zones of lost returns present at the time of cementing or occuring during cementing operations. Also it has been used with success in setting a plug to seal off a lost circulation zone encountered during drilling operations. Drilling operations then continued with no loss of returns until a deeper zone of loss was encountered and a similar job on this zone again restored mud circulation and allowed continued drilling.

In one section of the United States where the problem of lost circulation is not severe, Gilsonite cement is used on primary cementing jobs because of the scouring action it exhibits in removing mud and the consequent minimization of squeeze jobs. In other areas, the per cent of excess cement used has been decreased from 200 per cent or more to 25 - 35 per cent. Greater fill-up is being encountered wherever Gilsonite is being used.

The recommended amount of Gilsonite to be used in combating lost returns was originally 100 pounds per sack of cement. Field experience has greatly reduced this concentration and areas where 100 pounds was first used, the results are equally successful with concentrations of 25 to 50 pounds per sack and in some cases as low as 12-1/2 pounds per sack.

There are definite precautions that must be taken when using large volumes of granular type lost circulation additives which apply also to the Gilsonite cement slurries. These precautions are as follows:

1. Recommended water ratios must be closely controlled and may be checked by slurry weight.
2. Precede the Gilsonite cement slurry with an adequate volume of neat cement slurry or bentonite slurry to alleviate slurry dilution from water in the pumps and lines.
3. The use of a bottom plug is not recommended.

Expanded Perlites in Cement

Expanded perlites have been used extensively in cementing compositions to provide a light weight slurry and to control lost circulation. Perlite is of volcanic origin. The perlite ore is calcined, at low temperatures, to form a cellular product of low density. It may be used with all API classes of cement in recommended amounts not to exceed 1-1/2 cubic foot per sack of cement. The perlite cement slurry usually contains a small amount of bentonite (recommended amount - 4 per cent) to prevent flotation or settling of the perlite particles and to act as a lubricant while pumping the slurry.

The outer shell of the perlite particle is relatively weak. When pressure is applied to the perlite slurry the walls break down and the particle absorbs water from the slurry. It is extremely important that recommended water ratios be used to keep the perlite particle from dehydrating the cement to the extent of no longer being pumpable. This process of absorbing water from the slurry, under pressure, will make a variation in slurry viscosity. It will cause the set cement to have a greater density and lower slurry volume than identical slurries set at atmospheric pressure.

In the use of expanded perlite cements precaution must be exercised in using the recommended water-cement ratios due to dehydration to the cell spaces. Also, the use of bottom plug is not recommended.

Pozzolanic Cements

Pozzolans have been used as a cementing material dating back to the time of the early Romans and Greeks. However, their use in oil well cementing compositions did not come into prominence until 1949. Pozzolans may be defined as materials which, though not cementitious in themselves, contain constituents which will combine with hydrated lime at ordinary temperatures in the presence of water to form stable compounds possessing cementing properties.

Pozzolans are divided into two groups; natural pozzolans and artificial pozzolans. The natural pozzolans are for the most part materials of volcanic origin, but include also certain diatomaceous earths. The artificial pozzolans are mainly products obtained by the heat treatment of certain siliceous rocks and as a by-product collected from the exhaust stacks of power plants where powdered coal is used as a fuel.

Pozzolans such as fly ash and finely ground natural pozzolans do not have the water absorbing capacity of materials such as bentonite and diatomaceous earth; therefore, they do not yield as light a slurry. The lower density slurry is more a function of the reduced specific gravity of the pozzolan since the water requirements closely resemble those for portland cement.

Generally, pozzolans are mixed in equal proportions (by volume) with portland cement for use in oil well cementing. Pozzolanic cements can be accelerated in much the same manner as portland cement to reduce the W.O.C. time or they may be retarded for use in deeper wells by use of various chemical retarders. The early strength of these materials is less than that of portland cement under identical curing conditions, but the strength development will continue over a longer period of time, until the ultimate strength of the pozzolanic cement approaches, or exceeds, that of portland cement.

Advantages of pozzolan cements, aside from being a moderate weight slurry, are as follows:

1. Lower permeability than portland cements (due to the reaction between free lime in the cement and the pozzolan).
2. Greater resistance to brine waters and sulfate attack (for the same reason).
3. Better perforating qualities (deeper penetration with less shattering).
4. Low heat of hydration.
5. More economical.

Also, field experience has shown that considerably less pump pressure is needed to displace a pozzolan cement slurry and that less flocculation from mud contamination takes place at the cement-mud interface than with portland cement.

More recent development in cementing materials have introduced to the oil industry a light weight cementing composition made from pozzolan and hydrated lime. This material is recommended for use in wells having a bottom-hole temperature of 140° F. or higher. It may be increased in density with the commonly used weighting materials to produce a high density slurry to overcome excessive gas pressures encountered in deep wells; and it can be retarded with chemical retarders to provide adequate thickening time (Table 5) under the most severe conditions of temperature and pressure currently existing. Laboratory tests indicate no strength retrogression of the set material under these extreme conditions.

TABLE 5

Pozzolan Lime Compositions

Percent Retarder	Well Depth	Temperature-° F. Static	Thickening Time Hours:Minutes
0.30	16,000	320	2:02
0.50	"	"	2:31
0.75	"	"	2:58
1.00	"	"	3:40
1.50	"	"	4:59
2.00	"	"	3.47*
2.00	"	"	3:21**
1.50	18,000	350	2:36
2.00	18,000	350	3:56

* Slurry weighted to 17.5 pounds/gallon with Barium Sulfate.

** Slurry weighted to 19.0 pounds/gallon with Barium Sulfate.

Hydrocarbons in Cement

Hydrocarbon emulsions have been used to a limited degree to reduce the density of a cementing composition below the normal range of bentonite or perlite cements. Their limited use is due to the disadvantages of having very low compressive strength, requiring extra equipment with which to prepare the emulsion and the increased cost of the slurry due to the kerosene or diesel oil used in the emulsion.

The emulsion is prepared by mixing the hydrocarbon, mixing water and an emulsifying agent prior to adding the cement. A slurry of this type will have a slurry weight of approximately 11.0 pounds per gallon (570 psi/1000 feet) and exhibit low fluid-loss properties. This slurry also has a much higher angle of repose than do bentonite cements and has been used occasionally to combat lost circulation where the heavier conventional slurries were unsatisfactory.

Latex Cements

Latex type cementing compositions have recently been introduced to the oil industry. Though the slurry density (14.0 to 14.5 pounds per gallon - - 710 to 750 psi/1000 feet) is not comparable to those obtained with bentonite and diatomaceous earth, it has been successfully used in many of the cementing methods. Latex cementing slurries have been used in:

1. Primary cementing.
2. Tailing - out on primary cementing.
3. Squeeze cementing.
4. Cementing liners.
5. Plug back operations.

The primary advantage of a Latex cement slurry is its low fluid-loss properties which makes it an excellent cementing composition for placing around the shoe and through the producing formation, thus minimizing the formation damage that could possibly occur from the cement filtrate. These cements also exhibit good bonding properties, excellent perforating qualities to both bullet and jet guns and greater essiliency.

LOW WATER-LOSS ADDITIVES

The need for a low fluid-loss cement was pointed out by Farris in 1952. Mr. Farris defined such a cement as one in which a slurry tested by the procedure of API Code 29, Second Edition, July, 1942 (Tentative) would have a filter loss of not over 100 ml. It has been estimated that the fluid-loss of neat portland cement slurries is in the range of 600 to 2400 ml. As mentioned previously, a low fluid-loss cementing composition will minimize the damage to a formation by the filtrate, which may cause the formation of a water block, an emulsion or, by coming in contact with clay in the formation, causing it to swell and greatly reduce the permeability. It is also an assurance that the slurry will not dehydrate into a permeable formation farther up the hole and stop the operation before all the slurry has been displaced.

Many patents have been issued pertaining to low fluid-loss cements but their use has been curtailed due to their effect on the cement slurry. Many of the chemicals used to reduce the water loss do so by increasing the viscosity of the water. Also, a limiting factor on the general use of low water loss chemicals is the retarding effect they have on the cement.

Carboxymethyl Hydroxyethyl Cellulose (CMHEC)

The most widely used low fluid-loss additive for oil well cements is Carboxymethyl Hydroxyethyl Cellulose (CMHEC). The addition of 0.50 per cent CMHEC to a cement slurry will produce a fluid-loss of 10 to 20 ml in a standard mud filter press. The addition of larger percentages of CMHEC produces a marked increase in slurry viscosity which necessitates an increase in the water cement ratio to obtain a pumpable slurry.

An example of the need for a low fluid-loss cement took place in a well in north Louisiana. Using a regular cement slurry containing no low fluid-loss additive, a squeeze job was planned on 40 feet of perforations. A good pressure buildup was obtained and the excess cement reversed out. When drilling resumed, 20 feet of hard cement was encountered before the bit went to bottom, indicating the dehydration of the cement slurry and the formation of a plug before the slurry ever reached the bottom of the perforations.

An improved high pressure squeeze cementing technique using CMHEC is now being used in areas along the Gulf Coast. The mechanics of the job are basically the same as those used on conventional squeeze jobs, except that the initial pumping rates are reduced to between 3/4 and 1 barrel per minute. Hesitation pumping may be necessary to obtain desired squeeze pressures since cement dehydration is not obtained.

If the desired pressure is not obtained, cement is often left opposite the peforations rather than being overdisplaced or reversed out. Because the low fluid-loss slurry does not dehydrate, it will generally penetrate into the various fractures and voids which necessitated the squeeze job and, after setting, will adequately seal these flow channels.

Another modification of the conventional technique, if formation pressure is not high enough to cause the slurry to flow back into the hole, is to reverse out the cement opposite the perforations after the desired squeeze pressure is obtained. This type squeeze has been done successfully, thereby eliminating the drilling of set cement from the casing. With this modification it is possible to perform certain operations in the well, such as dry or pressure testing, perforating, drill stem testing and re-squeezing, if necessary, without pulling the packer.

Laboratory tests indicate 0.50 per cent CMHEC will exhibit excellent low fluid-loss characteristics on both API casing and squeeze cementing schedules to depths of 12,000 feet. At temperatures below this depth, the material begins to lose its low water loss properties necessitating an increase in percentage of additive.

CMHEC is also used in conjunction with diatomaceous earth cementing slurries where a low density-low fluid-loss cementing composition is essential. When used in this manner, the per cent CMHEC will range from 1.0 to 1.5 to offset the dilution factor caused by the high water requirements.

When using CMHEC in shallow wells it is necessary to add an accelerator to combat the retarding effect of the CMHEC. A special brand of sodium silicate is available for this purpose. Calcium chloride must not be used in conjunction with CMHEC as it will cause a degradation of the CMHEC molecule with subsequent damage to the low fluid-loss properties.

AMCY

A product designated as AMCY and manufactured by American Cyanimid has been used to a limited degree as a low fluid-loss additive. This material does not have the retarding effect on a cement slurry exhibited by CMHEC. Laboratory tests indicate AMCY will manifest low fluid-loss properties, under both casing and squeeze cementing conditions, to depths of 6,000 feet where maximum static temperatures do not exceed 160 to 170° F. Above these temperatures the AMCY breaks down and the low fluid-loss properties are destroyed.

One major oil company has set up a program for the combination of CMHEC and AMCY for low water-loss squeeze cementing. The following table shows recommended blends (Table 6).

TABLE 6

Low Water-Loss Additives

API Class A Cement

Temperature-°F. Static	Per cent AMCY	Per cent AMCY
Surface - 155	0.50	0.00
155 - 215	0.50	0.10
215 - 290	0.00	0.50

The manufacture of AMCY is still in the pilot plant stage, which greatly increases the cost of the material. Until the demand for this material increases it is doubtful that it will ever be made a production item.

CEMENT ACCELERATORS

An accelerator is often used to reduce the W.O.C. time of cementing compositions. This is particularly true when cementing surface pipe, for it becomes economically desirable to resume drilling as soon as possible after cementing. It has been a common practice in the past to use calcium chloride for this purpose as it was the most effective accelerator that could be added to cement slurries; it is readily available as well as economical. New accelerators have also been made available to the oil industry and are sold under various trade names. Sodium chloride in low concentrations may also be used as a cement accelerator, but the increase in strength is not as great as with the other two compounds (Table 7).

TABLE 7

Accelerators For Portland or Pozzolan Cements

Accelerator	Optimum Amount	Strength-Portland 6 Hours - 80 F.
Calcium Chloride	2.0 per cent	585
HA-5	2.0 to 3.0 per cent	755
Sodium Chloride	2.0 to 8.0 per cent	105

Calcium Chloride

2 per cent calcium chloride based on the weight of the cement or pozzolan cement will 1. decrease the thickening time, 2. accelerate the set time, 3. increase the early strength and 4. reduce the waiting on cement time. With most portland cement, the addition of 2 per cent calcium chloride will approximately double the compressive strength in 24 hours at temperatures less than 120° F. The addition of more than 2 per cent seldom achieves any beneficial results, unless it be for high water ratio cements where the dilution of the calcium chloride renders it less effective.

A special accelerator has been developed for use in cementing surface casing and shallow wells. This chemical exhibits greater accelerating properties with most cementing compositions than does calcium chloride, resulting in higher compressive strengths during the early age of the cement (Table 7). The W.O.C. time of portland cement can normally be reduced to 4 hours on surface pipe at temperatures of 80° F. In some instances drilling has resumed in 3 hours and 20 minutes where this material was used.

Sodium Chloride

Sodium chloride, in quantities of 2 to 8 per cent, by weight of mixing water, may be used as a substitute for calcium chloride or HA-5; however, the strengths produced are not as high. Salt water will have an accelerating effect where the sodium chloride concentration is from 40,000 to 60,000 parts per million. The normal concentration of sodium chloride in water from the Gulf of Mexico is 15,000 to 30,000 parts per million.

The recommended procedure for using these materials is to dry blend them with the cement as an excessive amount of foaming is often encountered by premixing the accelerator in the water. If bulk blending is not available and premixing is inevitable, the amount of foaming may be reduced by the addition of anti-foaming agent.

CEMENT RETARDERS

With the increase in drilling of deeper oil wells and the discovery of oil fields where abnormal temperatures were encountered, it became evident that the existing retarded types of cement would not meet these extreme conditions in respect to thickening time.

Many different compounds or mixtures of compounds have been used as cement retarders. One such material contained borox, boric acid and gum arabic.

Research on cement retarders has brought to the oil industry new materials capable of retarding cements so that the extreme conditions of temperature and pressure may be surmounted. A class of compounds, called Lignins, are being used extensively as cement retarders. The calcium salt of Ligno-sulfonic acid is being used in drilling muds as well as for a dispersant and retarder for cementing compositions.

Calcium Lignosulfonate

One type of calcium lignosulfonate has been found more effective in retarding cement where well conditions are beyond the range normally recommended for a specific class of cement. It has little value as a dispersant for use in modified cement.

The amount of retarder required, depending on the bottom-hole temperature of the well, may be dry mixed with the cement or premixed with the mixing water. The addition of 0.50 per cent of this material to API Class A Cement will give a thickening time of approximately 2 hours and 30 minutes following schedule 8 (14,000 foot casing-cementing), API RP 10B.

Another type of calcium lignosulfonate is generally used for its dispersing action in portland cements containing from 5 to 25 per cent bentonite. The dispersant lowers the viscosity of the bentonite-cement slurry to provide a pumpable slurry and also has a retarding effect, though not to the extent of the compound listed above. This material is discussed in more detail under Light Weight Compositions - Bentonite Cement.

Carboxymethyl Hydroxyethyl Cellulose (CMHEC)

CMHEC was originally developed as a low water-loss additive as well as a retarder for cementing compositions. The performance of the CMHEC depends to a large extent on the viscosity grade used. The first use of CMHEC employed a high viscosity grade material. This material produced longer thickening times and better fluid-loss properties, but had the adverse property of causing extremely high slurry viscosities.

The CMHEC presently being used as an additive to cements is a low viscosity grade. Contrary to the action of some retarders that tend to accelerate when excess amounts are used, there seems to be no limit to the amount of CMHEC that can be added to a cementing composition, aside from high initial slurry viscosity. This undersirable aspect is usually overcome by the use of additional water.

Field experience has shown that CMHEC may be used with retarded as well as portland cements. It may be used in neat cement slurries or in conjunction with light or heavy-weight additives.

The problem of strength retrogression in this type of cementing composition may be partially eliminated by the addition of silica flour to the cementing material.

SATURATED SALT WATER

There are many areas in which, when drilling oil wells, salt formations are encountered. Fresh water slurries will not bond properly to salt formations due to the water in the slurry leaching or dissolving away the salt at the cement-salt interface with the ultimate result of an inferior bond between these two materials.

Laboratory tests indicated a tight bond between a salt core and a cement when the amount of salt present was sufficient to saturate the mixing water. In an area where collapsed pipe was causing considerable trouble it was noted that in each instance the trouble was encountered in the salt section. Salt brine cement is now being used in this field for cementing through salt formations with no further trouble from collapsed pipe.

Further tests made on salt brine cements showed that the slurry was greatly retarded by the presence of the salt. Also the compressive strengths were greatly reduced and the slurry weights and slurry volumes were increased. A Pan American thickening time test on an API Class A Cement, under simulated 8,000 foot casing-cementing conditions, showed an increase in thickening time from 2 hours and 13 minutes with fresh water to 3 hours and 25 minutes with saturated saltbrine cement.

The technique of blending dry granulated salt to cement at the bulk plant greatly simplifies the use of salt brine cement. It reduces time and labor on the job location, eliminates waste and eliminates the problem of foaming which is common when mixing cement and salt water.

Laboratory tests and field experience have determined the amount of salt necessary to do the best job. The recommended amount is 3.1 pounds of salt per gallon of mixing water. In certain areas excess salt is always used to insure saturation at higher temperatures. Excess salt will have no detrimental effect on the set product.

CEMENT DECONTAMINATING ADDITIVES

A major problem in cementing operations has been that of setting a plug, eigher for shutting off bottom-hole water or for setting a whipstock. It has not been unusual to find soft cement after 5 or 6 attempts. It has been thought that the cause for these failures is contamination by highly treated drilling muds. Severe loss of strength and erratic thickening times are produced by small additions of mud treating chemicals such as quebracho (tannins), starch, caustic, sodium carboxymethyl cellulose and lignite.

Included herein are two methods for overcoming this problem.

One decontaminant is a blend containing three parts para-formaldehyde and two parts sodium chromate tetrahydrate. The recommended amount for use is 1 pound of the blend per sack of cement. The reaction of these two compounds with the organic mud-treating chemicals causes the removal of the retarding properties of such materials.

This material should not be used with commercial retarded cements as it may neutralize some of the retarders used therin. It may, however, be used with Portland cement retarded with calcium lignosulfonate since it has not appreciable effect on this divalent salt of lignosulfonic acid. This material has been proved very successful in all types of plug back as well as in primary and squeeze cementing operations.

Activated charcoal may be added to Portland and unretarded slow set cements to combat the effects of highly treated drilling muds by absorbing the treating chemicals. It will counteract the effect of quebracho (tannins) starch, sodium carboxymethyl cellulose and the salts of lignosulfonic acids. Before using activated charcoal in a retarded type cement, laboratory tests should be conducted to check the effect of the charcoal on the thickening time of the cement. Recommended amounts for use is from 3 to 5 per cent, based on the weight of the cement.

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