LIGHT WEIGHT CEMENT SYSTEMS, WHAT THEY ARE - HOW THEY ARE USED

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ABSTRACT

Most light weight systems are produced by increasing the amount of water used with each sack of cement. To produce a uniform slurry with this additional water; pozzolans, clays or silicates may be added or fine grinding of the cement composition may be used. These systems, using water as the light weight ingredient have similar ultimate strengths and permeabilities for similar densities. Early strength development as well as ultimate strength and permeability depend on the temperature to which the cement is subjected.

Cements in which the density is reduced by using light weight particles instead of water have somewhat different properties. Those using light weight hollow bubbles produce high early strength and improved ultimate strength at an increased slurry cost. Care must be taken that hydrostatic pressure does not crush the bubbles.

INTRODUCTION

Light weight cements are becoming more important in the cementing of wells. Partly because we understand and are engineering them better, partly because of desired properties, partly because of shortage of cement, and partly because of economics. Since economics are always important, water is normally the extender added to cement and the materials we normally refer to as extenders are added to produce a stable slurry with the increased water. Those agents which increase water content may be classified as pozzolans, clays, silicates.[1] [2]

Well conditions and desired cement properties put a limit on how light a water extended cement can be. The usual limits placed are a lower limit on strength or an upper limit on permeability. Figure 1 lists the approximate ultimate strength and Figure 2 the permeability to be expected from a water extended portland type (calcium silicate) cement. The time required to reach these nearly stable conditions depends chiefly on temperature. Several weeks may be required at 80 to 100°F (even longer with pozzolan cements), while at 250°F and above most cements will reach these conditions in a few days. Strengths up to 30 percent greater than these can often be obtained if this is the most important property desired. Conversely if care is not taken to condition the well and prevent contamination considerably lower strengths may be obtained. Above about 230°F the portland systems must be stabilized with silica or weaker and more permeable cement compounds will be formed. Above 300°F, numerous adequate cement compounds can be formed especially in light weight compositions. Both slurry composition and well conditions have an influence on these transformations.

POZZOLANS

Pozzolans are those materials which react with the calcium hydroxide released by Portland cement as it sets. At temperatures above 140°F they produce slightly stronger cements than most extenders. Below 140°F the increased strength may be very slow to develop. Most pozzolans will not produce low density slurries because they do not require as much additional water as other additives. The pozzolans may be classified as natural and artificial. The artificial pozzolans are those which have been heated to produce pozzolanic activity.

Fly ash is an artificial pozzolan produced as a residue when pulverized coal is burned in modern power plants. It is composed chiefly of small spheres of silicate glass containing some aluminum, iron, and calcium. It is also the most used pozzolan because of economical price and availability. Fly ash is available locally throughout the United States. Certain Western (high calcium) fly ashes produce higher early strength than normal API fly ashes but are more difficult to retard at elevated temperatures.[3]

Calcium chloride is more effective than sodium chloride as an accelerator for low temperature early strength. At temperatures above 450°F, the fly ash - cement blends deteriorate sufficiently that they are slightly weaker and more permeable than other cements of similar density.

Another artificial pozzolan is heated clay or shale. The particles may be gravel size down to finely ground material. The cost is usually slightly higher than fly ash. It is used in parts of North Central Texas.

There are a number of natural pozzolans including volcanic ash, volcanic glass and diatomaceous earth. Each natural pozzolan is mined in a limited area and is usually as costly or more costly than fly ash. Since the pozzolan properties of most are similar to fly ash, each has a very limited area of use. The one exception is diatomaceous earth which is a light weight hydrous silica. It has a high surface area and requires more mix water per pound of material than other pozzolans. Diatomaceous earth is an especially valuable extender at temperatures above 400°F. Being high in silica, it can replace a portion of the silica sand normally used to stabilize Portland. Depending on the purity of the diatomaceous earth, it requires 1.2 pounds or more to replace one pound of silica sand or silica flour. This makes diatomaceous earth one of the more expensive extenders.

Fine silica sand is a pozzolan material which does not reduce slurry density. The chief use is to stabilize Portland cement for use above 230°F. For lightweight slurries, silica flour is usually preferred over fine silica sand. It produces less segregation in the slurries and better overall strength stability.[4]

CLAYS

Bentonite is the chief clay used as a cement slurry extender. Besides increasing the amount of mix water used it reduces fluid-loss from a slurry plus reduces the permeability of the set cement. It may, however, interfere with the use of other more efficient fluid-loss agents. Bentonite, prehydrated in water before adding Portland cement is more efficient than bentonite blended with Portland. Whenever six percent or more bentonite (based on cement weight) is added to a slurry a dispersant should also be added to aid mixing, prevent gellation, and improve early strength.[5] At low temperatures, 3 to 10 percent sodium chloride (or potassium chloride) salt is a very efficient dispersant and accelerates early strength development. Calcium chloride does not so function as is shown in Table I. At temperatures of 100°F or higher, other dispersants such as polynaphthalene sulfonates or lignosulfonates may be used. Lignosulfonates can retard the initial thickening but enhance early strength development.

Attapulgite, a clay used to prepare salt water drilling muds, may also be used to extend salt water cement slurries or occasionally fresh water slurries. The API has not set up standards for attapulgite used in cement as has been done for bentonite. Care must be taken in selecting a supplier. A good grade attapulgite blended with Portland cement is a somewhat more effective extender than bentonite blended with cement but less effective than prehydrated bentonite.

Other clay-like materials have seen very limited use. Sepiolite, a magnesium silicate, has been used as a mud ingredient in geothermal wells, and considered in geothermal cementing.

SILICATES

Soluble sodium silicates are efficent extenders for cement slurries. The silicate reacts with calcium liberated by Portland cement to produce a calcium silicate gel in water.

This gel has sufficient viscosity to disperse and support solids in the cement slurry until they can hydrate and set. The anhydrous solid metasilicate is usually the most efficient additive. It is dry blended with the cement and added to water. High salt content in the water reduces the efficiency somewhat. Being strongly basic it accelerates early strength development. Calcium chloride normally improves early strength slightly but added in excess of the amount of sodium silicate can reduce the strength, as shown in Table I.

Any of the water soluble sodium silicates can be used with sea water to produce a gel which will extend Portland cement. The one most often used is the concentrated liquid (water glass type) on offshore cement jobs. The slurry properties are not appreciably different from those mentioned in the previous paragraph.

There are several insoluble or semi-soluble solid silicates on the market which these have higher silica content than sodium silicate. These dissolve too slowly to produce a good, dependable gel in cement slurries.

FIND GRIND SYSTEMS

Another method of getting more water into a cement slurry without excess free water is to grind the cement finer. This is done with Class C cement. Cement can be ground finer than this for increased mix water. Normally the extremely fine grind cements are blended with a fine pozzolan to produce even more extension. The properties of these slurries and set cements are much like other pozzolan cements except that the slurry is lighter and more fluid.

LIGHTWEIGHT PARTICLES

Light weight particles do not always depend primarily on water to lighten the slurry density. For this reason, Figures 1 and 2 do not necessarily apply for such particles. Strength and permeabilities depend more on the strength of the particles and of the set cement and the bond between them when light weight particles are used. Coarser particles are usually added to seal lost circulation zones while fine particles are primarily for density reduction. The solids may be broadly classified as expanded silicates, carbonaceous materials, cellulose materials, and small ceramic or glass bubbles.

The expanded silicates, perlite and shale, are used in moderate amounts in many areas.[6] They are used as lost circulation materials in areas where wells penetrate porous zones. They are used to improve insulating properties of cements in geothermal and steam injection wells. These particles are somewhat weak and prone to crush under downhole pressures. The slurry is still lightened since extra water is used.

The strengths and permeabilities given in Figures 1 and 2 do apply. There is also a tendency for the particles to float or clump in the slurry. Bentonite is often used to suspend the particles. People who are not accustomed to this thin conglomerate slurry, often have a poor opinion of it. Polymer foams have been tried for similar use but have never really caught on because of melting and crushing.

Carbonaceous materials such as coal, coke, gilsonite, and asphalts are normally used as lost circulation materials. Their density of 8.5 to 10 pounds per gallon allows considerable weight reduction without appreciably reducing the strength of the set cement. If the particles are sufficiently fine to require additional water, then strength reduction can result. Most slurry properties are not greatly changed by adding these inert particles.

Cellulosic materials such as cellophane flakes, cotton linters, cottonseed hulls and such are normally used in very small quantities as lost circulation materials and have minimal effect on slurry density. Sawdust and nut shells may be used in larger quantities. The chief limitation to the latter is that these contain lignin which can be extracted by the alkaline cement slurry. Lignin retards the set of the Portland cement slurry.

Small hollow bubbles, sometimes called microballoons, can be added to lighten a cement slurry. They are usually made of glass or other silicates (ceramic). These vary chiefly in crush strength and stability to heat and alkaline cement environment. The glass bubbles are the strongest and most inert and have been promoted for producing a strong lightweight slurry.[7] These bubbles are about one third the density of water so a slurry can be produced which is lighter than water. Since some additional water is added the strength is lower than a neat slurry. However, in the density range of 9.5 to 11 pounds per gallon the early strength is about double that of other light weight systems. The problems associated with these are that they cannot be used at great depths since they are crushed by pressure. Depending on the type bubbles used, a hydrostatic head of 500 to 2000 psi is the limit. They are more costly than other extenders so the improved properties must be weighed against the increased cost.

MISCELLANEOUS EXTENDERS

Various water soluble polymers and gums such as the substituted cellulose gums may be added to cement primarily as retarders or fluid-loss agents. These often increase slurry viscosity and thus require additional mix water to produce a reasonably fluid slurry. For this reason these materials may also be considered extenders for a cement slurry. Because of the expense and a natural tendency to retard and to thin at elevated temperatures, they are seldom used primarily to lighten a slurry.

Nitrogen may also be added to lighten the hydrostatic head on a well.[8] For this purpose it is usually added to the mud or spacer ahead of the cement but occasionally to part of the cement. If the nitrogen is to be brought back to surface, there should be some type of pressure control on the returns because of the compressibility of the gas under pressure and expansion as the pressure is reduced. For example,on a well having 1500 psi bottom hole static pressure, a 2% by volume gas in the fluid at the bottom of the well would be 67% gas and 33% liquid in the returns at the surface.

LIGHT WEIGHT PROPERTIES

Most people are willing to accept that the light weight slurries will be somewhat weaker and more permeable than neat slurries. The chief complaint is that they are slow to set and gain strength at low temperatures. The addition of calcium chloride will help early strength for those slurries containing pozzolans or lightweight particles or the fine grind systems. It often does not help bentonite or silicate extended systems. The bentonite systems respond to sodium chloride reasonably well while the silicates are themselves accelerators. There is no inexpensive magic ingredient to give adequate placement time and high early strength. If one is willing to pay the additional cost, slurries lightened with hollow spheres gain strength the most rapidly at low temperatures and pressures.

It is often stated that lightweight slurries do not respond to additives as well as normal density slurries. This is the result of basing the amount of additive on the amount of Portalnd cement used. If we double the yield from a sack of cement we should expect to nearly double the amount of fluid-loss agent or even retarder if the slurry is being taken to a high temperature. If this increased volume is taken into account, the response is about the same as with a more dense slurry.

The light weight slurries are usually more fluid than the heavier slurries and can be more easily pumped in turbulent flow for mud removal. This is just one reason that light weight slurries are often used as lead slurries in cementing.

The wellbore environment has an effect on the properties of a light weight cement. As shown in Figures 1 and 2, the temperature has a definite effect on strength and permeability. Exposure to steam, fresh water, or light static brine does not effect these values greatly.[9,10] However, it has been shown that exposure to ciruclating acidic brine (containing carbon dioxide) has a more detrmiental effect on light weight than on regular density cement at 300°F. The light weight cements readily form calcite and scawtite in the exposed areas and may loose half their strength in a few months. Data given in Table 2.

Exposure to temperatures above 250°F requires that the Portland blends be stabilized with silica to prevent loss of strength with time. The ratio should never be more than one part calcium oxide to one part silicon dioxide and preferably less than this. In the presence of saturated salt or heavy brines, this stabilizer should be very fine silica (silica flour). Silica has a reduced solubility rate in heavy brine so increased surface area is needed.[4]

SUMMARY

1. Water is the light weight ingredient in most light weight slurries and the extenders are there to produce a uniform and stable slurry with this additional water by preventing free water separation.

2. These water extended slurries are slow to set and gain strength at low temperatures. The ultimate strength and permeability depends more on the slurry density (amount of mix water) than on the extending agent used.

3. The light weight hollow spheres produce the best early and overall cement strength. The larger light weight particles are used as lost circulation materials.

4. High temperatures produce a slight reduction in strength and a great increase in permeability of light weight systems. However, only in contact with circulating acidic brines does serious deterioration occur.

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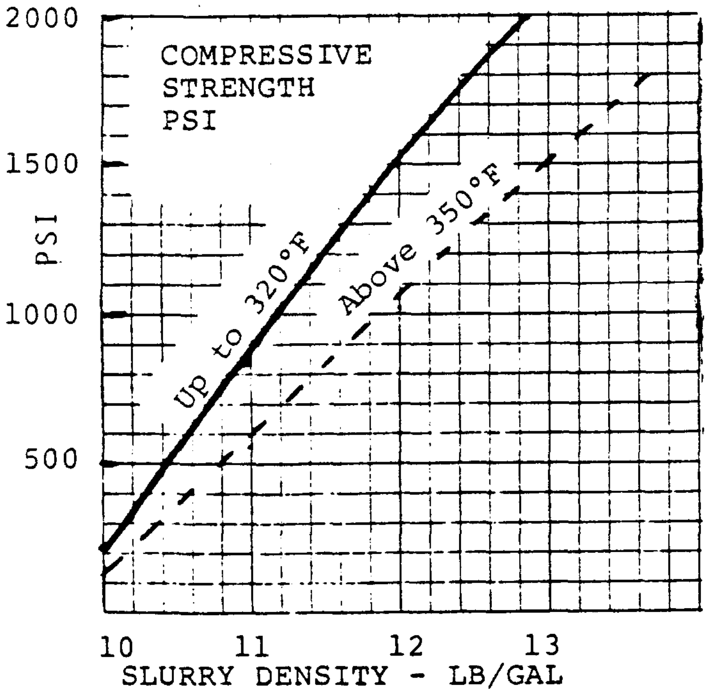

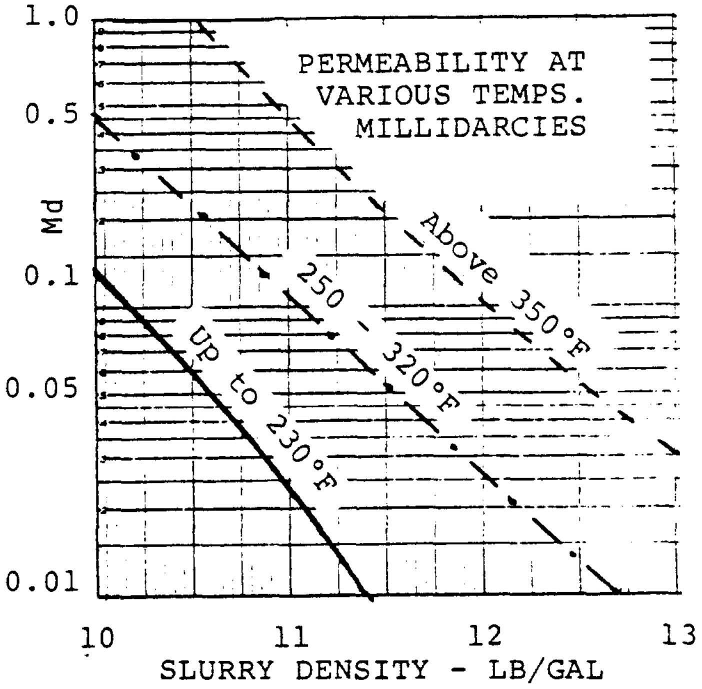

Approximate ultimate strength and permeability obtained with water extended lightweight slurries

FIGURE 1

FIGURE 2

TABLE 1—EARLY STRENGTH DEVELOPMENT OF LIGHT WEIGHT CEMENTS USING VARIOUS ACCELERATORS. EARLY STRENGTH DEVELOPMENT VARIES CONSIDERABLY DEPENDING ON SOURCE OF CEMENT USED.

Type Cement	Type Extender	Other Additive	Density Lb/gal	24 Hr. Compressive Strength, PSI 80°F	120°F
50% G	50% fly ash	0	15.1	130	1325
50% G	50% fly ash	1% $CaCl_2$	15.1	215	1450
50% G	50% fly ash	2% $CaCl_2$	15.1	265	1425
H	10% bentonite	0	12.9	180	455
H	10% bentonite	2% $CaCl_2$	12.9	170	460
H	10% bentonite	5% NaCl	13.0	250	560
H	10% bentonite	0.2% lig. sulf.	12.9	150	475
H	2% SS*	0	12.5	310	585
H	2% SS	2% $CaCl_2$	12.5	375	570
H	2% SS	5% $CaCl_2$	12.6	275	---
H	2% SS	0.2% lig. sulf.	12.5	265	530
Fine grind	0	0	12.5	115	550
Fine grind	0	2% $CaCl_2$	12.5	185	630
Fine grind	0	5% NaCl	12.6	145	615
H	Glass Bubbles	0	11.5	625	1350
H	Glass Bubbles	0	10.0	400	1065

* Sodium Silicate

TABLE 2—EFFECT OF ELEVATED TEMPERATURES ON LIGHT WEIGHT CEMENTS. ALL PORTLAND CEMENTS STABILIZED WITH AT LEAST 35% VERY FINE SILICA. ALL EXPOSURES STATIC EXCEPT FOR CIRCULATING 3% BRINE

Type Cement	Type Extender	Density lb/gal	Exposure Condition Temp. °F	Fluid**	Comp. Strength* 30 Day	90 Day
G	Silica Flour	15.9	450 to 600	Steam	6500	6400
G	Silica Flour	15.9	600	25% brine	5875	5750
G	Perlite	13.5	600	Steam	2250	2175
	Perlite		600	3% brine	2225	2050
	Perlite		300	Circ. 3% brine	1600*	900*
	Perlite		600	Dry heat	3025	---
G	Bentonite	12.3	600	Steam	1775	1275
	Bentonite		600	3% brine	1900	1125
	Bentonite		300	Circ. 3% brine	1500*	775*
	Bentonite		600	Dry heat	1675	---
G	Diat. Earth	12.3	600	Steam	1950	1750
	Diat. Earth		600	3% brine	2100	1700
	Diat. Earth		300	Circ. 3% brine	2600*	1475*
	Diat. Earth		600	Dry heat	1725	---

* Geothermal data from DOE report COO/4190-6, Phase II: Progress report No. 5, Jan-March, 1979

** Circ. 3% brine similar to sea water but containing 10 psig CO_2 gas over reservoir pH app. 5.6