Well Cementing

by Michael Campbell & Jay Lehr

(Excerpted from the book "Water Well Technology")

Water well industry cementing techniques are becoming highly specialized as water wells are drilled deeper. Cementing properly is an important phase of well construction, and many defects in construction can be traced to inadequate cementing practices, as shown in Figure 1.

The size of the grout space required when drilling the well usually depends upon the method of cementing. The area of the annular space around the casing frequently influences the success of the work because a complete sheath of cement around and along the casing is often necessary. Planning the diameter of the hole is important since tight areas and dead spots can occur when improperly centered casing contacts the wall of the hole causing the slurry to channel.

COMMON DEFECTS OF WELL CONSTRUCTION WITH REMEDIES

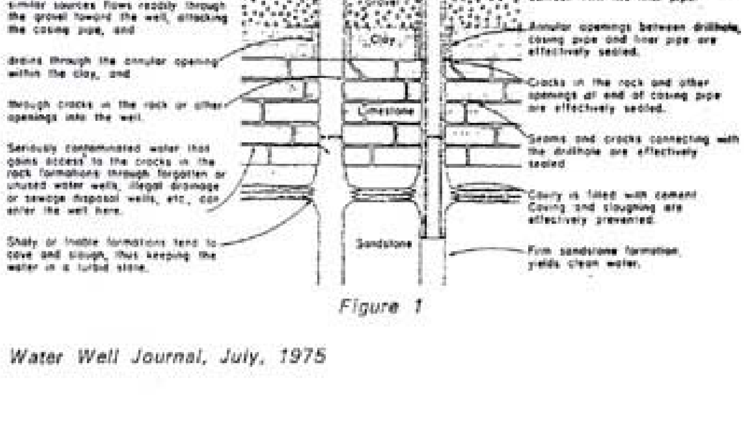

Figure 1

Isolation by grouting is desirable to protect the producing water-bearing formation from contamination by less desirable fluids or from the surface. The proper use of cementing materials will provide the most effective means of isolation, will form a seal to permit various techniques of well stimulation, and will help to protect the casing from corrosion.

Cementing Operations

The normal ratio of water to cement for a suitable grout is five to six gallons per 94-pound sack of cement. Laboratory tests indicate that 5.4 gallons of water will hydrate one U.S. sack of cement. Mixtures with more than six gallons of water per sack have been used as grouting foundation materials, but this is not acceptable for water well cementing. Shrinkage increases with water content. Water is removed from grouting mixtures by filtration through fine sand or other permeable formation materials. Cement can settle out of the slurry rather than remain in suspension if the water-cement ratio is greater than ten gallons per sack of cement.

One decided advantage of the proper water-cement ratio is that effective bridging of cement particles in the pores of permeable formations can be accomplished. Bridging prevents excessive penetration of the grout into the formation, although some penetration is desirable for adequate sealing.

Bentonite clay as well as other additives is commonly added in amounts from three to five pounds per sack of cement, in which case about 6.5 gallons of water per sack is required. Bentonite assists in the suspension of the cement particles which reduces shrinkage. The bentonite and water should be mixed before the cement is added to the clay-water suspension.

Additives are mixed with neat cement to increase yield per sack, to reduce cementing costs, and to alter slurry properties for special well conditions. Additives are utilized, generally, as the following:

(1) Extenders to provide a greater yield, or slurry volume, for each sack of cement.

(2) Weighting materials to increase slurry density and overcome high formation pressures.

(3) Accelerators, such as calcium chloride, to reduce waiting time in shallow well completions, particularly in cold climates.

(4) Retarders, commonly used in wells 8,000 feet and deeper, to increase thickening time.

(5) Low-water-loss additives important to the "squeeze" cementing technique where control of water loss is critical.

(6) Lost-circulation materials to reduce loss of cementing fluids to a very porous or permeable formation, fractured zones, or weak formations hydraulically fractured by the pressure of mud and cement in the annulus.

(7) Special additives to change cement-flow behavior.

Water for grout should be free of oil or other organic material, and the dissolved mineral content should be less than 2,000 ppm—a high sulphate content is particularly undesirable. Exceptional conditions may call for the addition of sand or other bulky material to permit the grout to bridge larger openings without excessive loss of fluid; a bentonite additive serves some of these requirements.

In cases where an open borehole has been drilled below the depth to which the casing is to be grouted, the lower part of the hole must be backfilled or a bridge set in the hole to retain the slurry at the desired depth. Backfilling the hole to the proper level with a fine-grained sand is a common procedure. If the sand is fine, cement will not penetrate the sandy backfill material more than two or three inches. Material ordinarily sold as plaster sand or mortar sand is generally used with grain sizes of 0.012 inch to 0.025 inch. Investigations indicate that no significant cement penetration occurs in sand with uniform grain sizes finer than 0.025 inch or in non-uniform sand with permeability less than 3,000 gallons per day per square foot.

To assure that grouting provides a satisfactory seal, the slurry must be placed by a continuous operation before initial setting of the cement. Regardless of the method employed, the grout should be introduced at the base of the grouting interval to minimize contamination or dilution of the slurry and bridging of the mixture with upper-formation material.

Suitable pumps, air pressure, or water pressure is used to force grout into the space to be filled, although placement by gravity is practical and satisfactory in some cases. Gravity placement in a shallow borehole, for example, is accomplished by introducing the slurry to the bottom of the hole and by then lowering the casing into the slurry. The casing is centered in the hole by centering guides, and the bottom of the casing contains a tight, drillable plug. As the casing is lowered, the grout is forced upward and around the casing, filling the annular space.

If the casing does not sink to the bottom, it is filled with water. More weight may be added in some instances. When a temporary casing is used to prevent caving of an oversized hole, this casing must be pulled before the grout has solidified so that the grout will make intimate contact with the wall of the hole. Figure 2 shows particulars of the procedure.

A pipe of two-inch to four-inch diameter shuold be used to conduct the proper quantity of slurry to the bottom of the oversized hole. If the hole is drilled by the rotary method and is filled with drilling fluid, the mud will rise up the hole since the cement mixture is the heavier slurry. The volume of grout placed must be adequate to fill the annular space around the permanent casing as it is sunk to the proper depth. Unless a caliper log has been run of the hole to estimate the volume of cement required, common practice is to estimate the required volume from the nominal-hole diameter and O.D. of the pipe. This volume is increased 20 to 25 percent to assure adequate quantities. Should there be an overrun, the extra grout is wasted at the ground surface as the pipe is lowered into the hole.

When the cement is set and has sufficiently hardened, the bottom plug is drilled out, and drilling is continued below the grouted section. A 72-hour setting period is normal for most Portland cement slurries. High early strength cement may be used to reduce the waiting period to about 48 hours.

Where the annular space is of sufficient size, grout is placed through a string of small pipe from outside the casing. The casing with centering guides attached is lowered into the hole. The lower end of the casing is closed with a drillable plug, or the casing may be driven into the clay bottom of the hole, if present, so that the grout cannot enter. To prevent the casing from floating in the slurry, the casing is filled with water or is held down by the weight of the drilling rig.

The ¾-inch or 1-inch grout pipe, generally used, must be large enough to allow the required volume of grout to be placed in the time available. The oversized hole should be four to six inches larger than the casing in order to provide sufficient space to accommodate the grout pipe.

Grout is placed by gravity flow only when it is certain that the operation can be completed quickly. Pumping facilitates the rapid introduction of the required volume of grout and is preferred. A pump pressure equal to the hydrostatic pressure of the grout, plus the fluid friction in the grout pipe and annular space, is usually required and should be anticipated.

The grout pipe is similar to a tremie pipe normally used by the construction industry for placing masses of concrete under water. Initially the pipe is extended to the bottom of the annular space and is submerged in the slurry during the entire grouting operation. The pipe must be removed soon after grouting emplacement has been completed. If the flow of grout is interrupted, the pipe must be raised above the grout level until all air and water have been displaced. The grout pipe must, however, be pulled prior to hardening, to allow the grout to fill the hole made by this pipe. Otherwise the hole left by the grout pipe will allow contamination from the surface or other sources.

When the use of a small pipe outside the casing is impractical, grouting is accomplished by means of a grout conductor pipe installed within the casing referred to as the *tubing method* of cementing in the oil industry. A suitable packer connection—a cementing or float shoe—is used at the bottom of the casing to regulate the flow of fluid from the grout pipe and to prevent reverse flow of the grout into the casing during and after the grouting procedure. A common type of packer connection, with a ball-type check valve, prevents reverse flow of the grout. The internal materials are drilled-out of the casing upon completion of the cementing after an adequate setting period.

Cementing can be accomplished without using the cementing plug or float shoe on the casing. The *inside casing method* requires a fluid-tight stuffing box which accommodates the grout pipe and a heavy cap to close off the top of the casing. The grout pipe is positioned three or four feet above the lower end of the casing which, in turn, is suspended from the bottom of the hole. The air inside the casing is released by a bleeder valve as the casing is filled with water or drilling fluid. The details of this method can be found in the literature.

The *casing method* of grouting, by which the slurry is forced down the casing and into the annular space, is widely practiced in the oil well industry. Either one or two spacer plugs are used in this method, which was developed and patented a number of years ago by the Halliburton Oil Well Cementing Company of Duncan, Oklahoma. One plug separates the cement slurry from the fluid in the casing, the other separates the slurry from water pumped in above the plug.

After pumping water or mud through the casing to circulate fluid in the annular space and clear any obstructions from the hole, the first plug is inserted and the casing capped. A measured volume of grout is pumped in, the casing is opened, and a second plug is inserted. A measured volume of water is then pumped into the casing until the second plug is pushed to the bottom of the casing expelling the cement slurry from the casing and into the annular space. The water in the casing is held under pressure to prevent backflow until the slurry has set.

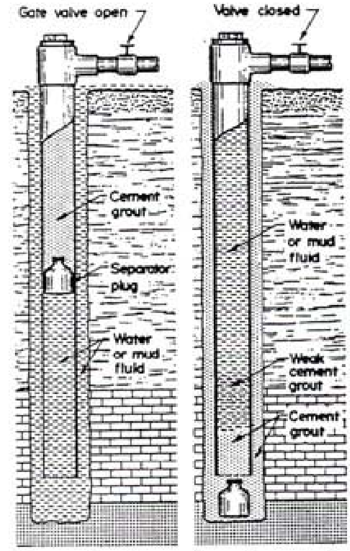

Figure 2. Cementing by casing method using single plug between grout column and drilling fluid. Plug and grout are forced out of bottom of pipe; grout then moves upward in annular space.

A modification of this procedure is to use only the lower plug; then, after pumping a predetermined quantity of slurry, a volume of water sufficient to force most of the grout out of the casing is added. The usual practice is to leave 10 to 15 feet of grout in the pipe (See Figure 2).

Another modification is to use only the upper plug, the reasoning being that the part of the slurry which may be diluted by the fluid in the well will be expelled to waste at the surface. This assures sound, uncontaminated grout at the lower critical end of the casing.

Spacer plugs are necessarily made of materials which can be drilled-out. Wood and rubber-fiber plugs can be difficult to drill since these materials tend to elude the bit teeth. A plaster-type plug or equivalent is suitable.

One problem which may arise during the cementing operation is that of mud contamination. An excellent procedure for minimizing mud contamination is the "two-plug" system. This operation consists of a fixed container for the movable valve plugs as an integral part of the casing (See Figure 5). Drilling or circulating fluids may be pumped through this container until the slurry is introduced. The bottom plug valve is closed, and the plug is pumped ahead of the slurry, fulfilling two functions: (1) providing a barrier between the slurry and drilling fluid and (2) cleaning the casing wall of drilling mud. When this plug reaches the float collar, the differential pressure opens the valve of the plug and allows the cement slurry to flow through the plug and floating equipment, around the casing, and up the annular space.

Upon completion of the grouting operation, the top plug is released from the container. This plug should seat effectively on the bottom plug resulting in a pressure build-up which prohibits grout backflow. The two-plug system requires knowledge of formation permeability characteristics because, if the annular space is not filled to the top, the slurry is partially wasted, proper cementing is not achieved, and more slurry cannot be added.

There are instances when circulation of slurry is a necessity, but informatino is lacking as to washout factor. In order to minimize contamination, the continuous method is more effective. The *continuous method* involves running tubing or drill pipe to the proximity of the float shoe or collar with a sealing element between the tubing and the casing. Grouting materials can be pumped until returns are noted on the surface.

The *plunger-type receptacle method* is an improved technique of the continuous method involving a special type of floating equipment designed with the receptacle to seat an adapter attached to the tubing or drill pipe (see Figure 3). This system minimizes contamination and provides the advantage of continuous mixing. The continuous method is a very practical approach for cementing of casing sizes 16 inches and above, since a two-plug system in many instances would require special plugs, plug containers or swedges (see Figure 3).

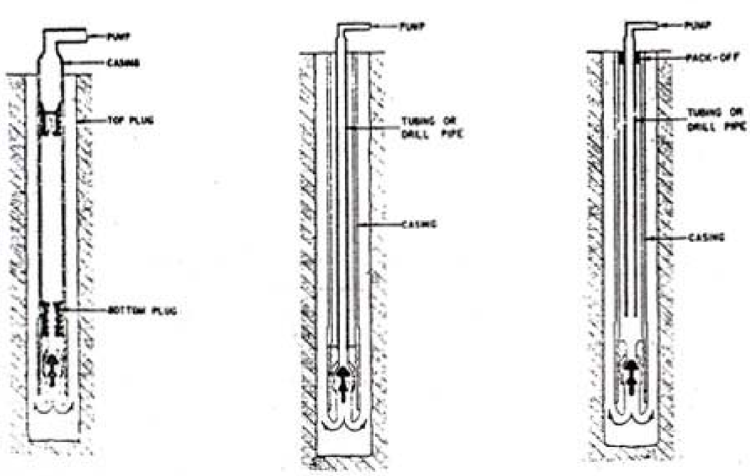

Figure 3. Techniques of cementing wells: Left, two plug system; center, plunger type receptacle; and right, continuous method.

A new grouting tool, developed for the petroleum industry, incorporates economic as well as operational features for water well completions. In the operation of this tool, a special plug is dropped from the surface, and by pressure of the pump, the sealing element is set, and circulating ports are opened. Grout material is mixed and pumped into the casing through circulating ports to above the sealing element. The top cementing plug seats on a special sleeve, and through application of pressure that shears the pins, plugs and sleeve are pumped out of the tool eliminating the drilling-out operation.

A problem encountered in cementing large diameter surface casing is that of flotation. To counteract the flotation factor, the density of the displacing fluids must occasionally be weighted-up or increased. This operation is expensive; however, with knowledge of the properties of various grouting materials, the cost can be minimized. The required volume of grout cannot always be accurately determined. Irregularities in the size of the borehole and losses in fractured or highly permeable rock occur in many holes.

Ordinary concrete mixers are used for grout that requires 15 to 50 sacks of cement. For larger volumes, a jet-type mixer, similar to the type that prepares drilling fluid, is generally used. As volume requirements of grout increase, the facilities for mixing and placing a uniform slurry must be more dependable. Halliburton has published a book of tables on various aspects of the cementing operation and should be consulted for detailed information. The literature on cementing practices is limited; however, the information available should be closely examined.

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