

Aug. 24, 1965

G. C. HOWARD

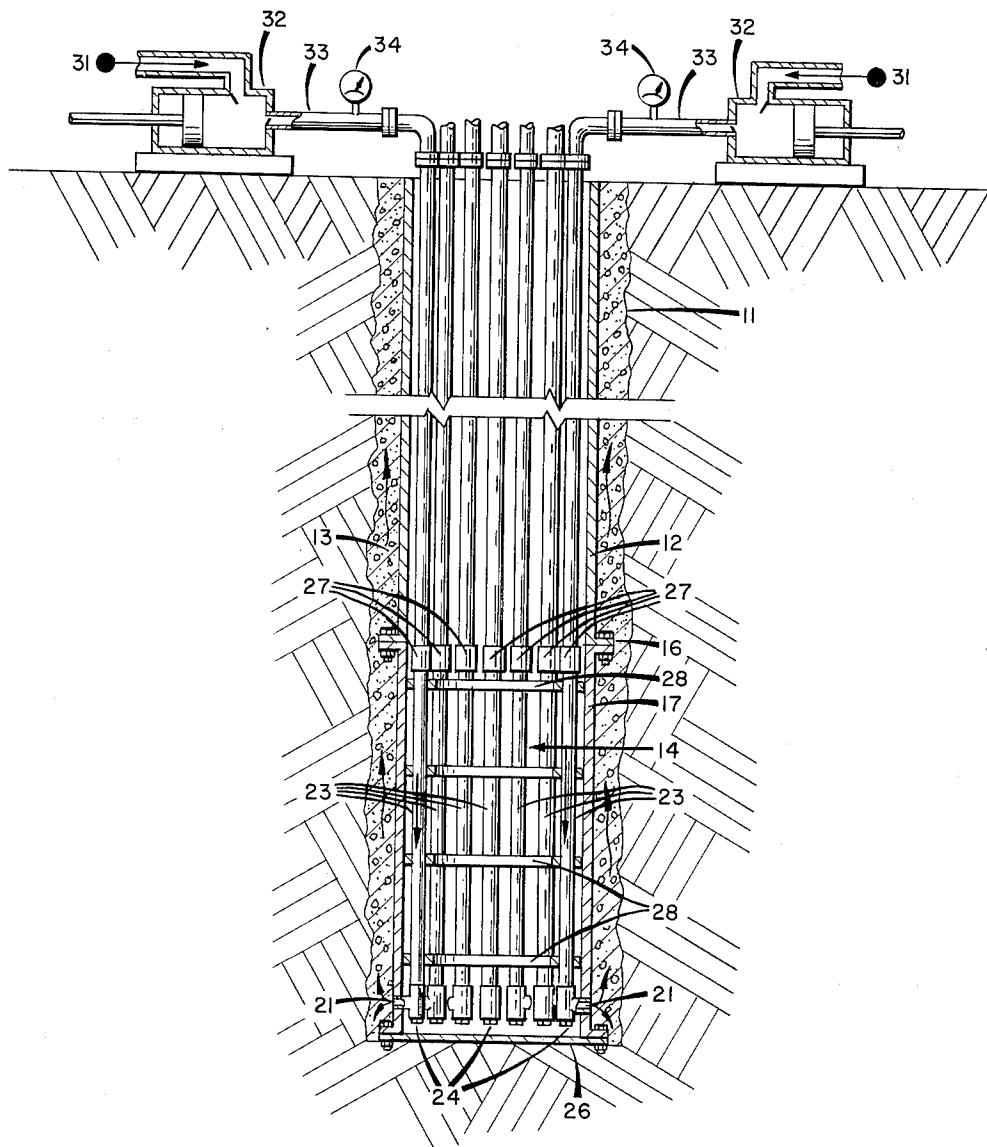
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METHOD AND APPARATUS FOR CEMENTING LARGE DIAMETER CASINGS

Filed June 26, 1963

2 Sheets-Sheet 1

FIG. 1



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FIG. 2

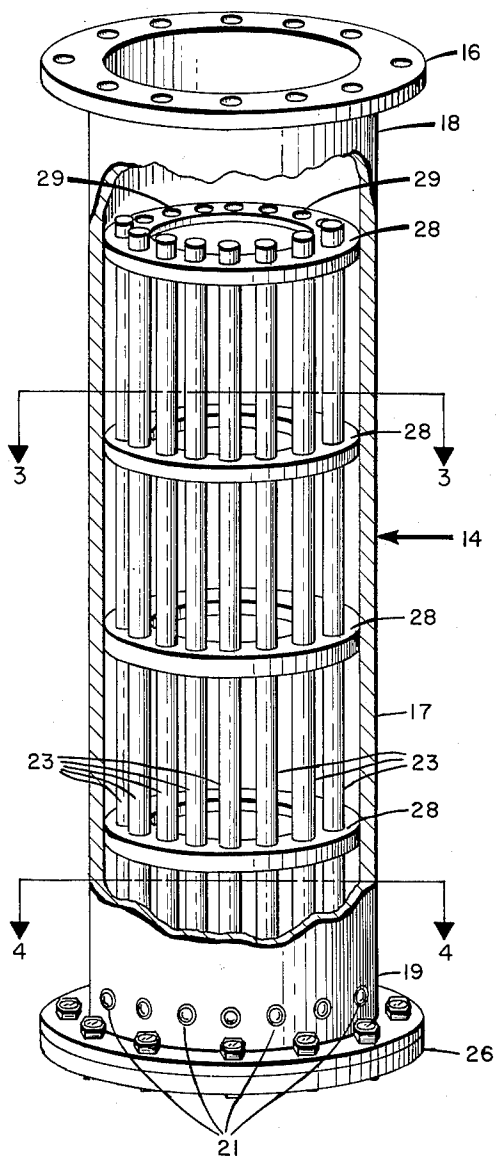


FIG. 3

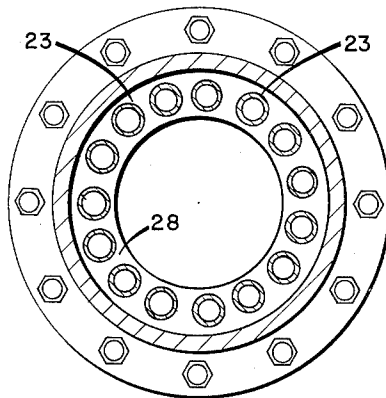
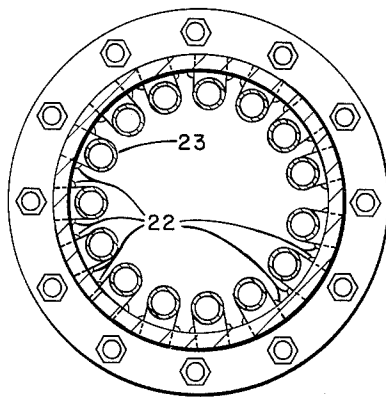


FIG. 4



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METHOD AND APPARATUS FOR CEMENTING LARGE DIAMETER CASINGS

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8 Claims. (Cl. 166—21)

This invention relates to the art of drilling and completing wells, or the like, drilled into the earth. More particularly, this invention relates to the cementing of casings in large diameter well bores.

It is well known in the art of oil production to seal off a well from undesired formations which may produce fluids, such as water, brine and the like, by placing in a freshly drilled well a tubular string of pipe, conventionally called casing, after which a slurry of cement, thin enough to be easily pumpable, is forced by pump pressure down through the casing to the bottom of the well bore and up through the annular space between the well wall and the casing string towards the surface. In carrying out this procedure, the cement slurry is passed upwardly through the annular space to the desired height in the well, the cement pump is then stopped and the flow of slurry ceases, after which the slurry proceeds to set. Upon setting, the cement forms a seal between the casing string and the well wall so as to prevent the flow of undesired fluids into the well. The cementing of well casing also may be employed to secure the casing in the hole, to protect the casing from corrosion or excessive fluid pressure, to prevent caving of the hole, and other like reasons.

In recent years the drilling of large diameter bore holes in the earth has become increasingly important. Such large diameter bore holes are employed in the mining and construction industries particularly, in providing mine shafts, foundation pier holes, tunnels and the like. Typically, these large diameter bore holes may range in size from about 4 feet to 10 feet in diameter, and even larger sizes have been proposed. Often it may be necessary to drill such large diameter holes to depths as great as 1,500 to 2,000 feet or more. Well casing of a slightly smaller diameter than the bore hole is generally required in connection with the preparation of these large diameter bore holes in order to prevent cave-ins and to exclude water from the hole. However, when employing relatively thin-walled large diameter casing, the casing is easily collapsed by hydrostatic or ground pressure applied externally to the casing set in the hole. This is a problem that is practically nonexistent with the smaller diameter tubular goods generally used for casing conventional oil and gas wells and the like. Procedures and equipment for preparing these large diameter holes are well known to those skilled in this art. For example, see the article, "Sinking Large Diameter Mine Shafts by Rotary Drilling," by Victor Zeni and T. N. Williamson, Mining Engineering, April 1957; "The Development of Large Diameter Rotary Drilling Machines and Equipment for the Mining and Construction Industries," 9th Annual Drilling Symposium at the Pennsylvania State University, October 8-10, 1959; "The Sinking of Two shafts for the New Beatrix Mine by the Drilling Method," Society of Mining Engineers of AIME, annual meeting, New York, February 14-18, 1960, preprint 60AU91.

In one instance where it was desired to employ a 72-inch inside diameter casing in a bore hole drilled to a depth of 3,500 feet, it was determined that, with normal pressure gradient, approximately a 5-inch wall thickness would be required to prevent collapse of the steel casing. However, rather than using such casing, the general practice is to employ a relatively thin-wall casing string, typi-

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cally rolled from one-quarter to one-inch-thick steel plate, allowing approximately a 4- to 5-inch radial clearance between the casing and the wall of the bore hole, and to cement the casing in the bore hole in order to strengthen and reinforce the casing.

In the cementing of casing in the above-mentioned large diameter holes, one practice has been to follow a procedure similar to that employed in the drilling of conventional oil wells and the like. The casing is placed in position in the well with an adaptor connected to the string near the bottom with a centrally located outlet in the bottom so that cement may be pumped through the outlet, around the bottom of the casing and upwardly through the annular space between the casing and the well wall. This method and other conventional cementing practices have been found incapable of distributing the cement throughout the annulus between the casing and the well bore to minimize the likelihood of water leakage or other damage to the casing.

Heretofore it has been determined, in connection with the cementing of casing in oil and gas wells, that in order to obtain the proper placement of cement between the casing and the well wall it is necessary to flow the cement slurry upwardly in the annular space at a flow rate sufficient to provide turbulent flow of the cement. Turbulent flow is designated as the velocity of flow above which the plastic cement slurry resembles a true fluid in that it is characterized by enumerable eddies throughout the body of the flow material, as distinguished from plug "flow" and laminar flow which occur at lower velocities. The desirability of establishing turbulent flow in casing cementing is discussed in detail in the paper "Factors to be Considered in Obtaining Proper Cementing of Casing" by George C. Howard and J. B. Clark, presented at the 28th annual meeting of the American Petroleum Institute in Chicago, Illinois, November 1948. As discussed therein, if a flow rate less than that which produces turbulent flow is employed in cementing casing, the cement slurry tends to channel in the annulus and incomplete distribution of the cement around the casing results. Hence, in order to obtain the most desirable placement of cement in the annulus, it is necessary that the cement flow upwardly in the annulus at a rate at least as great as that which produces turbulent flow. The physical characteristics of the cement slurry, taken with the diameters of the casing and the well bore, as well as the pumping rate, determine whether or not turbulent flow is established. The equation for computing the critical pumping rate providing turbulent flow is as follows:

$$Q_c = \frac{140(D_h + D_p)}{\rho} \left[n + \sqrt{n^2 + \frac{(D_h - D_p)^2 \rho}{2690}} \right]$$

Where

Q_c =critical pump rate, barrels per minute

D_h =diameter of hole, inches

D_p =outside diameter of casing, inches

ρ =slurry weight, pounds per gallon

n =rigidity, lbs./sec.-ft.

t =yield value, lbs./sq. ft.

In one instance, a standard cementing shoe was attached to the bottom of a 72-inch inside diameter casing. A 7-inch diameter casing was screwed into the center of the shoe through which the cement was passed. Due to the very large casing hole annulus, it has been extremely difficult, if not impossible, to assure complete and uniform placement of the cement along the outside of the casing. In other instances where the cement is merely pumped through a shoe having multiple openings into the annulus fed from a manifold arrangement, experience has indicated that the cement follows the path of least resistance;

and, if any blockage or restrictions are present in or around one of the openings, a significant portion of the annulus around the casing would not receive cement. Incomplete, nonuniform distribution of the cement can negate the beneficial effects of the cementing job and allow damage to the casing or hole.

I have now discovered a novel method and apparatus for use in cementing casing in large diameter well bores whereby substantially complete and uniform distribution of the cement slurry in the annular space between the outside of the casing and the well wall is achieved. Briefly, in accordance with the present invention, a fluid cement mixture is introduced at multiple injection points into an annular space exterior of a casing string positioned in a bore hole, the points being spaced around the periphery of the casing and near the end thereof away from the surface opening of the bore hole, and supplying multiple, independent streams of cement to each of said points under a pressure sufficient to cause the cement to flow to a preselected position along the well bore, the flow rate of all of said streams being substantially equal. Preferably, in practicing my invention, the cement is supplied to each of the injection points through multiple, relatively small diameter conduits extending along the large diameter casing, and the number of such conduits and the size thereof are correlated with the diameters of the casing and the bore hole to enable the desired turbulent flow of cement in the annular space to be achieved.

A general object of the present invention is an improved method and apparatus for cementing casing in a large diameter bore hole, which provides a practical means of obtaining more uniform distribution of the cement in the annular space around the casing in the bore hole. Other objects will become apparent from the following description of my invention.

My invention will be more fully understood by referring to the following description and accompanying drawings of a preferred embodiment of apparatus employed in the practice of my invention, wherein:

FIGURE 1 diagrammatically illustrates, in partial cross section, a typical hole bored vertically in the earth and apparatus employed in cementing casing placed in the bore hole; and

FIGURE 2 is an oblique view, partially cut away, of a preferred cementing shoe; and

FIGURE 3 is a cross-sectional view taken along line 3—3 of FIGURE 2; and

FIGURE 4 is a cross-sectional view taken along line 4—4 of FIGURE 2.

Referring to the drawings, in FIGURE 1 there is illustrated a large diameter vertical hole bored vertically into the earth 11. A cylindrical metal casing 12, typically fabricated from $\frac{1}{2}$ -inch-thick steel plate, is positioned in the bore hole 11, with the outside diameter of the casing being separated from the wall of the hole by an annular space 13. At the bottom of the casing, and attached thereto to form a portion thereof, is a cementing shoe 14 joined to the lower portion of the casing string by flanges 16 or by welding. As shown, the cementing shoe typically is of the same diametrical dimensions as the casing and forms a portion of the casing. The cementing shoe is comprised of a relatively large diameter tubular element 17 having an upper end 18 and a lower end 19, and a plurality of orifices 21 positioned near the lower end as shown. The orifices are spaced apart at equal intervals around the periphery of the tubular element and maintained in a fixed relationship to one another. As shown, the orifices are positioned in holes provided in the wall of the tubular element and secured in place by means of welds 22. Each of the orifices is connected to a conduit 23 at the lower, or outlet, end of the conduit and places the conduit in flow communication with the exterior of the tubular element. As illustrated, each orifice may be constituted of a pipe fitting, such as an L or a T, of substantially the same inside diameter as

the conduit. In this embodiment, T's are employed with the lateral extension forming the orifice into the annulus, while removable plugs 24 are placed in the bottoms of the T's extending downwardly to permit further use of the conduits placed in the bore hole for other purposes after the cementing operation is completed. A bottom head 26 is attached to the bottom end of the tubular element and the shoe is landed on the bottom of the bore hole as shown.

The upper end of each conduit 23 is adapted to be connected into a string of additional conduits extending upwardly through the casing to the surface of the hole. Couplings 27 are employed for this purpose. As shown herein, the conduits 23 extend along the longitudinal axis of the large diameter casing and preferably are supported by a plurality of ring-like support members 28 which engage with the conduits to secure them in place adjacent the inside wall of the tubular element. Each of the ring supports is provided with a series of holes 29 provided therein through which the conduits are placed.

A fluid cement slurry is supplied for the cementing operation to each of the conduits 23 from a cement source 31. Cement pump 32, capable of providing the requisite volume of cement at the desired pressure is employed to pass cement individually and independently through each conduit down the casing, through the orifice at the lower end of the conduit, and up the annular space between the casing and the wall of the hole to the desired level. Various types of well-known cementing heads may be employed in connecting the pump to the conduit, and various methods of pumping the cement into the annulus are known in the art. Typically, one or more cement plugs may be employed in the manner known to those skilled in the art. The cement source is generally a cementing truck which mixes the slurry and pumps the cement down the hole.

As shown in FIGURE 1, multiple cement pumps 32 (only two are shown for clarity of illustration) are employed to pump the cement slurry through lines 33 to the conduits 23. Each of the pumps discharges an equal volume of cement. A flow meter 34 or other such metering device is connected to each of the lines 33 between the pump discharge and the conduit to which the pump is connected to indicate the flow rate. A variable power input is provided to each pump, so that in the event blockage occurs in or around an orifice (as indicated by increased back-pressure and reduced flow rate which is shown on the gauge) the pump discharge pressure may be increased to unblock the cement passageway and to maintain the equality of flow rate through the orifices.

In operation, an individual stream of the cement is supplied through the conduits to the shoe orifices at a flow rate substantially equal to the flow rates through the other orifices under a pressure sufficient to pump the cement through the orifice, laterally into the annulus and upwardly along the bore hole to the desired height, usually to the surface of the bore hole. The pressure at which the cement is supplied will be determined by the height of the cement, the physical characteristics of the slurry being pumped and the frictional losses occurring as a result of the orifices and the conduit dimensions. If a drilling fluid, such as drilling mud, is employed and must be displaced from the annulus by the cement, the characteristics of this drilling fluid also must be taken into consideration.

The volume of cement required will, of course, be determined by the volume of the annular space to be cemented. This will depend, to a large extent, upon the radial clearance between the outside diameter of the casing and the inside diameter of the bore hole together with the depth of the bore hole. Typically, the radial clearance for a 90-inch outside diameter casing may vary from about 2 to about 6 inches.

As previously mentioned, it is preferred to pump the cement through the annulus at a rate great enough to

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provide turbulent flow. The pumping rate required to produce the desired turbulent flow will vary according to the diameter of the well bore and the outside diameter of the casing. For example, when employing a 90-inch O.D. casing in a 94-inch diameter hole, a pumping rate of approximately 380 barrels per minute of a typical API class A cement is required to produce turbulent flow; while, with the same casing in a 100-inch diameter hole, a pumping rate of approximately 930 barrels per minute is required. The minimum number of conduits required to handle the quantity of cement necessary to provide turbulent flow will depend upon the pressure and the size of the conduit. For example, with a 1000 p.s.i. surface pressure, 53 strings of 2 $\frac{7}{8}$ -inch I.D. tubing are required for the 94-inch diameter hole while 9 strings of 5 $\frac{1}{2}$ -inch tubing are required for the same hole size. With the 100-inch diameter hole (at 1000 p.s.i. surface pressure) 21 strings of 5 $\frac{1}{2}$ -inch conduits are required, while only eight strings of 7-inch conduits are needed. With a greater surface pressure, such as 5000 p.s.i., 20 strings of 2 $\frac{7}{8}$ -inch conduits or three strings of 5 $\frac{1}{2}$ -inch conduits are required for a 94-inch diameter hole while eight strings of 5 $\frac{1}{2}$ -inch conduits or four strings of 7-inch conduits are required for the 100-inch diameter hole.

Thus, the size and number of the conduits and shoe orifices to be used for carrying out a cementing job in a given situation can be readily determined to provide optimum results. With the above-described apparatus, uniform distribution of cement along the casing can be attained.

The foregoing description of a preferred embodiment of the present invention has been given for the purpose of exemplification, and is not intended to limit the scope of the appended claims. From the foregoing description, various alterations and modifications in the details of operation and construction will become apparent to those skilled in the art and it is understood that, as such, these fall within the spirit and scope of the claimed invention.

What I claim is:

1. In the cementing of large diameter casing in a bore hole, the method comprising introducing a cement slurry at multiple points into an annular space exterior of a casing string positioned in a bore hole, said points being spaced around the periphery of said casing and near that end thereof away from the surface opening of said bore hole, and separately pumping a plurality of individual streams of said cement, each of said streams being pumped to a corresponding one of said spaced points under pressure to fill at least a portion of said annular space along the length of said casing, while maintaining the flow rates of all of said streams substantially equal, whereby uniform distribution of said cement in said annular space is achieved.

2. The method of claim 1 wherein said casing is positioned in a vertical bore hole and each of said streams of cement is separately pumped downwardly to its corresponding introduction point from a cement source above said bore hole to said annular space under such pressure as to cause said cement to flow upwardly in said annular space at a velocity causing turbulent flow of cement in said annular space.

3. Apparatus for cementing casing in a bore hole, which apparatus comprises a relatively large diameter elongated tubular element having a first end and a second end and having means for installing said tubular element in a casing string to form a portion thereof; a plurality

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of orifices positioned near said second end and spaced around the periphery of said tubular element in a fixed relationship to one another; each of said orifices communicating with the exterior of said tubular element; a plurality of individual supply conduits, each connected to a corresponding one of said orifices; and a plurality of connector means, each positioned on one of said supply conduits near said first end for separately connecting each of said supply conduits to an individual source of cement slurry.

4. The apparatus of claim 3 wherein each of said supply conduits extends along said tubular element; and further including a variable pressure, constant volume cement pump connected to each of said conduits; and a flow-measuring device connected to each of said conduits for measuring the cement flow in each of said conduits.

5. The apparatus of claim 3 further including a plurality of cement pumps, each separately connected to a corresponding one of said connector means for supplying a cement slurry to each of said orifices at substantially equal flow rates.

6. The apparatus of claim 3 wherein said supply conduits are positioned along said tubular element adjacent the wall thereof and a plurality of support members are positioned at intervals along the length of said element, each of said members having means for engaging with, and securing, said conduits adjacent said element wall.

7. The apparatus of claim 6 wherein said tubular element is connected into a string of casing placed in a bore hole and each of said supply conduits is connected to an individual source of cement capable of passing a cement slurry through each of said orifices at substantially the same flow rate, the flow rate and number of said conduits being such, in relation to the cross-sectional area of the annular space between said casing and the wall of said bore hole, to provide turbulent flow of the cement slurry between said casing and said bore hole wall.

8. A cementing shoe adapted to be installed in a string of large diameter well casing which comprises an elongated cylindrical tubular element having an upper end and a lower end; means for connecting said element to said casing string; a plurality of orifices near said lower end in the wall of said tubular element communicating with the exterior thereof; a plurality of small diameter conduits arranged inside said tubular element along the length thereof, each of said conduits having a lower end connected to one only of said orifices and an upper end having means for connecting the conduit to a string of tubing; and a plurality of ring-like support members in engagement with said conduits, each of said members having means for supporting said conduits adjacent the wall of said tubular element; said orifices and conduits being spaced around the periphery of said tubular element at substantially equal intervals.

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