Dec. 3, 1940. E. V. CROWELL 2,223,442

APPARATUS AND METHOD FOR CEMENTING WELLS

Filed Aug. 14, 1939

FIG. 1.

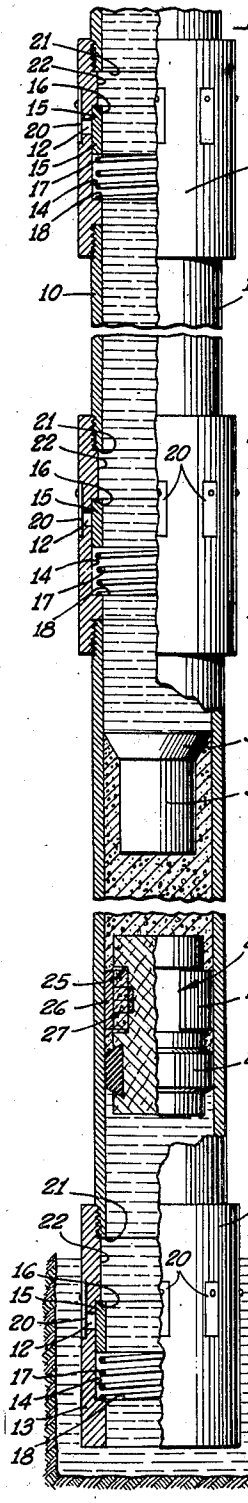


FIG. 2.

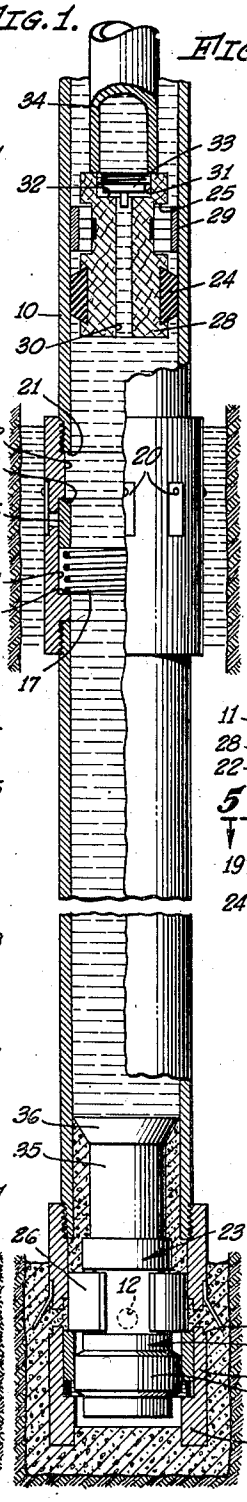


FIG. 3.

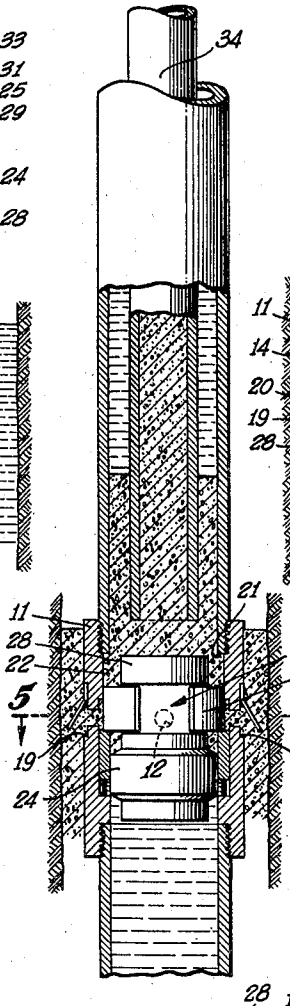


FIG. 4.

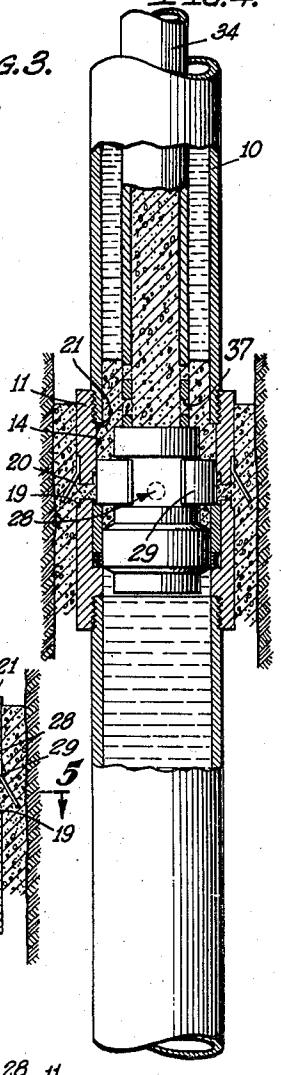
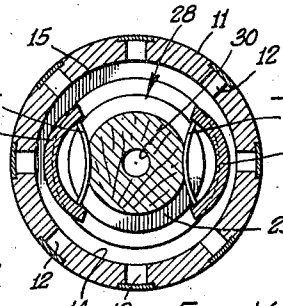


FIG. 5.



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APPARATUS AND METHOD FOR CEMENTING WELLS

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14 Claims. (Cl. 166—1)

This invention relates to apparatus and methods for cementing wells, and more specifically contemplates the placement of cementitious material in the annular area of the well shaft around a casing string by pumping the cement from the well surface downwardly through the casing and/or through a tubing string within the casing string for ejection through lateral ports located in the casing at one or more levels.

The present application is a continuation-in-part of my copending application, Serial No. 119,986, filed January 11, 1937, which matured as Patent No. 2,177,172, dated October 24, 1939, and application Serial No. 645,656, filed December 5, 1932, the latter application having matured as Patent No. 2,071,389, dated February 23, 1937. Other subject-matter hereof has been disclosed in my application Serial No. 436,434, filed March 17, 1930, which matured as Patent No. 1,896,482, on February 7, 1933.

It is a general object of the present invention to provide method and apparatus for locating a quantity of cement in the annular area surrounding a string of casing or pipe in a well hole which involves the successive ejection of separate volumes of cement from selectively opened ports in the casing or pipe.

Another object is to provide as an improvement over my above-noted Patent No. 1,896,482 a method and means for pumping fluent cementitious material downwardly through tubing disposed in a well casing having a plurality of cementing valves carried in longitudinal spaced relation by the casing.

A more specific object is to provide in a ported casing string, apparatus including a barrier actuated by fluid pressure to close the bore of the casing below a pair of longitudinally spaced ports at which cement is to be serially ejected, and a second barrier actuated by a tubing string for closing the bore of the casing intermediate the ports.

It is a further object to provide a string of casing disposed in a well shaft with a plurality of cementing sections carried in longitudinal spaced relation and means and methods of cementing the same at each of said cementing sections to provide a high column of cement about the casing while maintaining drilling fluid of a known specific gravity and a fixed temperature within the casing.

Another object is to provide a pair of casing barriers movable by fluid pressure and lowered by a tubing string, respectively, each adapted to close the bore of the casing to a separate volume of cement, following each plug, to be ejected into the well bore at a predetermined level.

Another object is to provide a tubular member for lowering barriers into a casing string adapted to retain a column of fluid in its bore, through which tubular member separate volumes of fluent cement may be successively pumped from the well surface for ejection into the casing at spaced points under pressure and thence through ports in the casing into the well bore at different levels.

It is a further object of the invention to provide a method whereby cement is discharged at one level by the pressure of a column of hydraulic fluid filling the entire length of the casing string above the cement, and thereafter closing the bore of the casing immediately below a selected higher level by means associated with a string of tubing while retaining said hydraulic fluid in the casing and, subsequently, pumping a second and separate charge of cement downwardly through the tubing to said selected level and from the casing into the same bore the first charge of cement is ejected into.

It is a further object to provide a combination of what is commonly known as the casing method and tubing method of cementing, whereby the lowermost cementing operation is accomplished by pumping the cement directly through the casing and the successive upward cementing operations are accomplished by pumping the cement through tubing.

Other objects and salient features hereof are enumerated in the parent cases of the present application above referred to and by such reference are incorporated herein.

In the drawing:

Fig. 1 is a longitudinal section of a casing string incorporating a plurality of cementing sections of my invention, and illustrating the first charge of cement in the casing nearing the ports from which it is to be discharged;

Fig. 2 is a longitudinal sectional view of a string of casing similar to Fig. 1, with the first charge of cement in position where it will be allowed to set, and with means for opening the second set of ports being lowered in the casing;

Fig. 3 is a sectional view of a portion of the casing in which one of the upper set of ports is located and illustrating the position of the apparatus during the ejection of a cement volume through the ports;

Fig. 4 is a sectional view of an upper ported level of the casing string depicting modified apparatus and method for controlling the ejection of cement laterally of the casing;

Fig. 5 is a sectional view taken on lines 5—5 of Fig. 3 of a cementing section and casing barrier mounted against longitudinal movement therein.

Referring to the drawing in detail, the numerals of which indicate similar parts throughout the several views, 10 designates a casing string incorporating a plurality of cementing sections 11 arranged in spaced relation intermediate the ends of the casing string. Each cementing section 11 is provided with a series of lateral ports 12 for the ejection of a volume of cement. A casing shoe 13 is threaded to the lower end of the casing string in which also are located a series of lateral ports 12. The portion of the bore of the shoe 13 and of each cementing section 11 in which the ports 12 thereof are located is recessed as indicated by the numeral 14. A sleeve valve 15 is slidably disposed in the recess 14 of each cementing section and in the recess of the shoe so as not to restrict the bore of the casing string and thereby permit normal drilling operations to be carried on through the casing prior to cementing; i. e., the drill stem (not shown) may be lowered through a casing equipped with the cementing sections and sleeve valve assemblies of the present invention and may be actuated to deepen the well without interference by the sleeve valves 15 or injury to the latter. Each sleeve valve 15 is normally retained against an annular shoulder 16 forming the upper end of each recess 14, in a position closing the adjacent ports 12, by helical spring 17 which in turn is seated on an annular shoulder 18 forming the lower end of each recess. At each port in the string the exterior of the shoe 13 and the respective cementing sections 11 are recessed as at 19, for the normal disposition of a spring valve 20 secured to the shoe or casing section by a rivet or the like. Valves 20 may be opened by fluid pressure from within the casing after the sleeve valve 15 controlling them has been displaced, but will close to the pressure of fluid in the opposite direction.

The diameter of the bore of each casing section is slightly less than the diameter of the upper portion of the bores of the cementing sections and shoe to form a downwardly directed shoulder 21 in each casing section and in the shoe for a purpose about to be described. The diameter of the bore of each sleeve valve 15 is substantially the same as the casing sections whereby a recess 22 is provided in shoe 13 and in each cementing section 11 between the sleeve valve 15 and shoulder 21. The recesses 22 are of unequal length, the recess 22 in the bore of the shoe being greater than those in the cementing sections thereabove, and the length of each recess of the respective cementing sections from the lowermost thereof to the top of the casing being shorter in upward succession. In accordance with the method of my invention as is hereinafter more in detail described, the ports 12 of the shoe and of each cementing section in upward series may be opened to pressure within the casing by displacing the sleeve valve 15 therefrom. For purposes of displacing the sleeve valve 15 from the ports 12 of shoe 13, I provide a barrier plug 23 to be lowered through the casing and into the bore of the shoe, comprising a body of slightly smaller diameter than the casing bore but carrying a packer 24 adjacent its lower end forming a fluid tight fit with the casing. Above packer 24 the plug 23 is annularly recessed as at 25, in which recess is located a pair of arcuate slips 26 supported on the plug by bowed springs 27 which force the slips laterally against the wall of the casing as the plug is lowered therein. Slips 26 are of a length only slightly less than that of the recess 22 of the shoe but are longer than the recesses of the cementing sections thereabove, whereby slips 26 will remain in retracted position while the plug is lowered in the casing until they reach the shoe, whereupon they expand into recess 22 thereof and engage the upper edge of sleeve valve 15 controlling ports 12 in the shoe. Continued downward movement of the barrier plug 23 will displace the sleeve valve from the ports. The ports 12 of the cementing sections 11 thereabove may be opened in a similar manner by barrier plugs 28 carrying slips 29 adapted to cooperate with respective cementing sections. The barrier plugs 28 for opening the ports of the cementing sections are similar to barrier plugs 23 but are each provided with a bore 30 to by-pass fluid in the casing as they are lowered therein. The bore 30 of each plug 28 is enlarged adjacent its upper end as at 31 to form a valve seat 32 (Fig. 2) for a valve 33 adapted to open to pressure therebelow but to prevent the passage of fluid downwardly through the bore 30 of the plug. The length of the slips 26 and 29 of each barrier plug 23 and 28, respectively, is determined by the length of the recess 22 of the shoe or cementing section into which it is adapted to fit, the slips of each barrier plug being of greater length than sufficient to fit into the recesses of the cementing sections 11 above the shoe or the section with which it is intended to cooperate. A tubing string 34 is employed to move each barrier plug 28 downwardly through the casing to its respective cooperating cementing section 11. The bore of tubing string 34 is large enough to encircle the enlarged portion of the bore 31 of the plug whereby a portion of the fluid by-passed by the plug during the lowering operation will flow into tubing string 34.

An embodiment of a method of my invention utilizing the particular apparatus hereinabove referred to is briefly described as follows: The casing string 10 incorporating the ported shoe 13 and cementing sections 11 in spaced relation is lowered into the well shaft while mud fluid is circulated downwardly through the casing and shoe and thence upwardly through the annular area of the hole to the well surface. With the casing suspended from the bottom of the well hole, circulation is continued until it is determined that all debris tending to clog the annular area around the casing is removed. If the operator desires to cement through the ports in the shoe, barrier plug 23 is then inserted into the casing. A quantity of cement in an amount sufficient to fill the annular area of the casing from the shoe to the next higher series of ports is introduced into the casing on top of barrier plug 23. An indicator plug 35 carrying a packer 36 adapted for slidable engagement with the wall of the casing is released into the casing on top of the cement volume for a purpose later referred to. Mud fluid is then pumped into the casing under pressure to force the barrier plug and indicator plug with the cement volume therebetween downwardly toward the shoe. The slips of the barrier plug will remain retracted during the movement through the various cementing sections, there being no recess in the casing string above the shoe of a length sufficient to receive the slips 26 of the plug. Upon reaching the shoe 13, slips 26 will expand into recess 22 above sleeve 15 and continued pressure on the mud fluid will displace the sleeve from the ports

12 of the shoe. The cement under pressure of the fluid thereabove will force the valves 20 from the ports in the shoe, permitting the ejection of the cement into the hole around the casing to fill the well shaft to the next higher series of ports. Upon the discharge of substantially all cement from the casing, indicator plug 35 will seat on top of barrier plug 23 with the packer 36 thereof closing the bore of the casing above ports 12 in the shoe to prevent the continued introduction of mud fluid into the casing at the well surface, and thereby indicate to the operator that the first volume of cement has been discharged into the well bore. As soon as the further downward flow of fluid through the casing is stopped by indicator plug 35, the valves 20 controlling individual ports in the shoe will close to prevent return flow of the cement. The casing may be lowered to the bottom of the well hole at any time after the circulation of mud therethrough is completed, to prevent the subsequent displacement of the ejected cement, should a differential in pressure within and around the casing develop.

If the operator desires to cement the entire bore of the well around casing 10, each of the cementing sections 11 may be used in upward succession in the following manner. A barrier plug 28, carrying slips 29 of a size adapted to be received in the recess 22 of the first cementing section above shoe 13, is released into the casing and lowered by tubing string 34 (Fig. 2). All ports in the shoe and in the cementing sections thereabove being closed to pressure within the casing, there will have been retained in the casing the column of fluid utilized to force the first charge of cement from the shoe. As the plug moves downwardly through the casing in response to the weight of the tubing 34, valve 33 of the plug opens to permit the plug to bypass the fluid retained in the casing. The fluid passing through the plug enters the bore of the tubing and the bore of the casing around the tubing above the plug. Upon reaching the lower cementing section 11, the slips 29 of the plug 28 will expand into the recess 22 of said section so as to engage the sleeve valve 15 therein and displace said valve from the ports. The tubing string 34 is then preferably raised slightly from the plug 28 (see Fig. 3). At this stage both the casing and tubing will be substantially full of the same mud fluid which was in the casing when the plug was introduced. A predetermined quantity of cementitious material is then introduced into the tubing string on top of mud fluid therein. The cement is pumped downwardly through tubing 34 under pressure of mud fluid which follows the cement into the tubing. A tight head is maintained on the casing string around tubing 34 to prevent upward displacement of the annular column of fluid in the casing around the tubing while the mud fluid in the tubing below the cement, and the cement charge itself are successively pumped out of the tubing into the casing and immediately from the casing through the ports in the adjacent cementing section 11 into the well bore. The cement thus ejected from tubing string 34 will pass upwardly in the well shaft to fill the annular area of the well hole around the casing to the next higher series of ports 12. Tubing string 34 may then be withdrawn from the casing. The relief of pressure on the fluid in the casing incident to this withdrawal of the tubing will permit the sleeve valves 15 of the shoe and of the cementing section 11 from which the second charge of cement is ejected to move upwardly over the ports 12, which said valves control in response to the expansive force of the springs 17 by which they are supported, respectively, thus closing said ports and assisting valves 20 in preventing the return flow of cement into the casing.

After withdrawal of the tubing string 34, a third series of ports 12 from the bottom of the casing string may be opened by lowering through the casing by means of the tubing, a barrier plug 28 carrying slips 29 of a size adapted to cooperate with recess 22 in the cementing section 11 in which the ports to be opened are located, for the displacement of the sleeve valve 15 controlling said ports. The barrier by-passes the fluid in the casing so that when placed by the tubing in the selected cementing section both tubing and the annular area of the casing bore around the tubing are filled with mud fluid. The cement volume to be ejected is then introduced into the tubing. The mud fluid in the tubing and cement are successively ejected from the tubing and through the open ports by a following volume of mud fluid in the manner above described. Other cementing sections may be operated in upward series in like manner to fill the entire bore of the well around the casing with cement. When the annular area of the well hole around the casing to the surface of the well is filled with cement, plugs 23, 35 and 28 and any cement remaining in the casing may be drilled out to prepare the casing for further development of the well.

In a modification of my invention illustrated in Fig. 4, the lower end of tubing string 34 is provided with a series of ports 37 through which mud fluid received by the tubing string as it is lowered into the casing and fluent cement pumped from the well surface through the tubing may more easily flow into the casing without raising the tubing string from the barrier plug.

It will be understood that while I have shown and described the introduction of cement volumes directly on top of the respective barrier plugs 23 and 28, mud fluid may follow any or all of the barrier plugs into the casing, and circulation of mud fluid may be established through each or any set of ports in the casing before the introduction into the casing of the cement volumes to be ejected therefrom, respectively.

The invention thus provides for cementing a well at a plurality of predetermined levels as an integral operation, or as a series of unitary cementing operations with the cement ejected at each selected level by a column of fluid extending to the earth's surface either through the casing or through the tubing string. The apparatus and methods also contemplate an unobstructed casing bore for circulation of a fluid medium, drilling or underreaming prior to cementing or for removing debris prior to any integral cementing operation.

While I have described but two embodiments of my invention by which the entire well bore around the casing may be filled with cementitious material, it will be understood that cement need not be ejected from all cementing sections in order to fill the bore, i. e., if pressure required for cementing is not prohibitive, a volume of cement may be discharged from one level of the casing sufficient to fill the area of the well hole around the casing extending higher than the next above cementing section or sections; and that portions of the well bore may be cemented, leaving an intermediate area uncemented for purposes obvi-

ous to those engaged in the art; and further, that numerous changes in size, shape, number and proportion of the various parts may be made without departing from the spirit of my invention as defined by the appended claims.

What I claim and desire to secure by Letters Patent is:

1. The method of cementing casing in a well that includes lowering into the well a string of casing having a normally closed cement discharge port intermediate its upper and lower ends, introducing and pumping a first volume of cement and a following fluid column directly into and downwardly within the casing past said port, discharging said cement from the casing into the well bore at a substantial distance below said port by the pressure of the fluid column above it, then opening the port and closing the bore of the casing below said port while retaining the fluid column in the casing, and pumping a second and separate volume of cement downwardly through a string of tubing to said port and outwardly therethrough from the casing into the same bore that said first volume of cement is discharged into, and preventing its return to the bore of the casing.

2. The method of cementing casing in a well bore which includes ejecting cement from the casing into said bore by the pressure of a column of hydraulic fluid in the casing in back of the cement extending above a predetermined higher level at which additional cement is to be subsequently ejected, closing the bore of the casing immediately below said higher level while retaining hydraulic fluid in the casing, and pumping a second and separate volume of cement downwardly through a string of tubing to said level and from the casing into the same bore said first volume of cement is discharged into.

3. The method of cementing casing in a well bore, which includes discharging cement at the lower end of the casing by a column of hydraulic fluid in the casing in back of the cement extending above a predetermined higher level at which additional cement is to be subsequently ejected, closing the bore of the casing immediately below said higher level by means associated with a string of tubing while retaining hydraulic fluid in the casing, and then pumping a second and separate volume of cement downwardly through the tubing to said level and from the casing into the same bore said first volume of cement is discharged into, and preventing its return to the bore of the casing.

4. The method of cementing casing in a well that includes lowering into a well a string of casing having a plurality of cementing sections carried in longitudinal spaced relation by said casing, each of said cementing sections including an outer ported member and an inner sleeve valve closing the ports, introducing and pumping a first volume of cement and a following fluid column directly into and downwardly within the casing past said cementing sections, discharging said cement from the casing into the well bore at a substantial distance below said cementing sections by the pressure of the fluid column above it, then as successive integral operations at each of said cementing sections, opening the ports and closing the bore of the casing below the ports by means associated with a tubing string, and pumping a volume of cement downwardly through said tubing string to said opened ports and outwardly therethrough from the casing into the same bore that said first volume is discharged into.

5. The method of cementing casing in a well bore comprising the steps of: progressively opening in upward series a pair of longitudinally spaced normally closed ports in the casing, pumping a volume of fluent cement through the lower port by a column of fluid in the casing extending to the well surface, pumping a second volume of cement from the well surface and through said upper port while maintaining a portion of said fluid column above the upper port in the casing.

6. The method of cementing casing in a well bore comprising the steps of: lowering a barrier through a column of fluid standing in a ported casing, mounting said barrier in a zone in the casing directly below a lateral port in the casing through which cement is to be ejected, and conducting a volume of cement through the casing to said port while retaining a portion of said fluid column in the casing above said port.

7. The method of cementing casing in a well bore comprising the steps of: pumping a volume of fluent cement from the casing by a fluid column extending to the well surface, moving a casing barrier through the casing to a position above the point of ejection of the first volume of cement and below a level at which a second volume of cement is to be ejected, and discharging the second volume of cement into the casing intermediate the ends of said fluid column and from the casing.

8. The method of cementing casing in a well bore comprising the steps of: pumping a quantity of fluent cement into a string of casing and ejecting said cement from the casing by a column of fluid in the casing extending to the well surface, closing the bore of the casing intermediate the ends thereof and below a series of ports therein, discharging a second volume of cement into the casing at said ports and intermediate the ends of said fluid column and ejecting said cement from the casing through said ports by means including the weight of a portion of said fluid column.

9. In apparatus for cementing a well casing, a casing string having a pair of ports arranged in longitudinal spaced relation, means comprising fluid under pressure to open one of said ports, a tubing string having a casing barrier associated therewith to close the bore of the casing above the open port, and means comprising fluid under pressure to move a charge of cement through the tubing and into the casing above said barrier.

10. In apparatus for cementing a well casing, a casing string provided with a pair of spaced ported cementing sections, a pair of casing barriers and a tubing string to successively position said barriers in the casing immediately below respective cementing sections, and means comprising fluid under pressure to eject a separate charge of cement from the tubing string into the casing at each of said sections and above said barriers, respectively.

11. In appartus for cementing a well casing, a casing incorporating a pair of ported cementing sections spaced apart longitudinally of the casing, means in each of said sections to normally maintain the ports in said sections closed, a pair of casing barriers, means comprising a tubing string to successively lower said barriers and open the ports in said sections, and means comprising fluid under pressure to eject separate quantities of cement from said tubing into said cementing sections adjacent said ports, respectively.

12. In apparatus for cementing a well casing, a casing string provided with a pair of ported ce-

menting sections carried in longitudinal spaced relation by said casing, said sections each having normally closed ports therein, means comprising a casing barrier and fluid under pressure to open ports in one of said cementing sections and direct a quantity of cement through the opened ports, means to close said casing above said open ports while retaining a column of fluid in the casing extending to the well surface, a second casing barrier, and means to lower said last-named barrier through said column of fluid to close the bore of the casing immediately below the uppermost of said pair of ports and conduct a volume of cement to a point adjacent said last-named port.

13. The method of cementing casing in a well shaft which includes lowering into the well a string of casing having a plurality of cementing sections carried in longitudinal spaced relation by said casing, each of said cementing sections including an outer ported member and an inner sleeve valve controlling the ports, then, as successive integral operations at each of said cementing sections, closing the bore of the cementing sections by means associated with a tubing string, and pumping a volume of cement downwardly through said tubing string to the point at which the bore is closed and outwardly through said ports in the last-named sections and from the casing into said well shaft.

14. In combination, a string of casing disposed in a well shaft provided with a cementing section intermediate the ends of the casing, said cementing section including an outer ported member and an inner sleeve valve controlling the port adapting the casing to retain a column of hydraulic fluid in its bore, means for closing the bore of said cementing section above and below the port to fluid pressure therein at the port, and a tubing string for conducting cementitious material downwardly to said port and intermediate said column of hydraulic fluid retained in the casing.

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