Oct. 29, 1957 J. A. KLOTZ 2,811,206

METHOD FOR INTRODUCING CEMENTING MATERIAL INTO A WELL BORE

Filed March 30, 1954 2 Sheets-Sheet 1

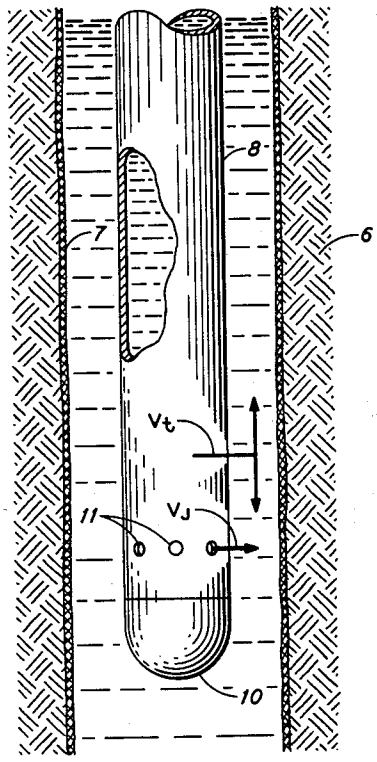

FIG. 1

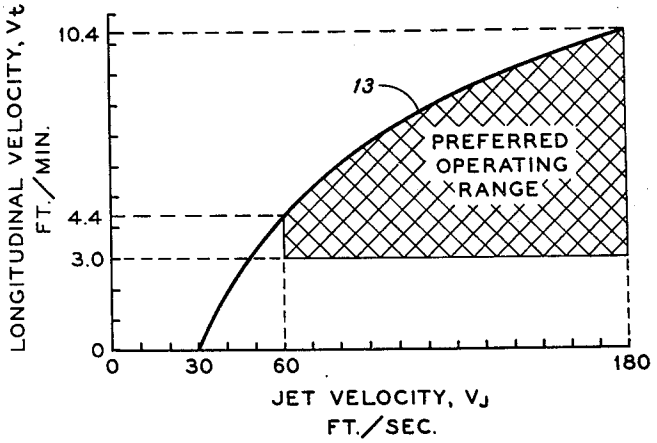

FIG. 2

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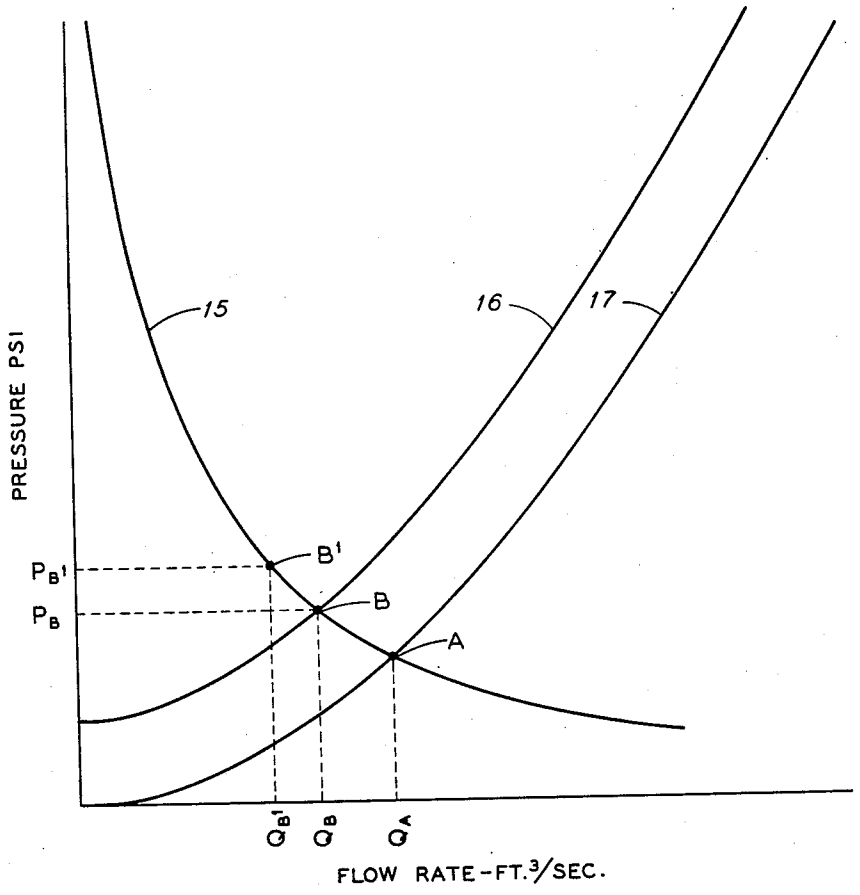

FIG. 3

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METHOD FOR INTRODUCING CEMENTING MATERIAL INTO A WELL BORE

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Application March 30, 1954, Serial No. 419,765

1 Claim. (Cl. 166—21)

This invention relates in general to oil well cementing, and relates more specifically to methods for introducing cementing materials for such cementing into a well bore in such a manner as to remove debris from the well bore wall and to deposit the cementing material so that it forms a more effective seal in a well bore.

In the production of petroleum from subterranean formations, oil well drillers customarily lower a length or string of casing into the well bore and cement the casing to the well bore to prevent intrusion of foreign fluids, such as gas and water, into the producing zone. In such cementing operations, a good seal is essential between the introduced cementing material and the well bore wall to prevent leakage of undesired fluids into the production formation. One obstacle to the attainment of such a seal between the cementing material and the well bore wall is a layer of drilling fluid or drilling mud filter cake deposited on the well bore wall during drilling of the well. Numerous methods and apparatus have been proposed for removing this mud cake to improve the seal between the cementing material and the well bore wall. Among the current methods is the use of scratchers which are attached to the casing and which comprise metal fingers for mechanically abrading the mud cake from the well bore wall. However, these scratchers have the disadvantage that they do not completely remove mud cake because of the gaps between the fingers.

Another method sometimes utilized is to flow a stream of wash fluid ahead of the cementing material. This wash fluid is intended to react with the mud cake so as to loosen or dissolve it, so that it may be carried away by the subsequent flow of cementing material. This method has the disadvantage, however, of requiring a considerable length of time for the washing fluid to react so as to dissolve or loosen any substantial amount of the mud cake. The time required for wash fluids to fully react with the mud cake is usually longer than the time available during cementing operations, and therefore, these solutions are not fully effective.

Another method for using wash fluids is to introduce them into the well bore in the form of high velocity jets. These jets remove mud cake mechanically, so that the operation is more rapid than the above chemical method. However, the use of a wash fluid, either in the form of a low velocity stream that reacts chemically or physically with the mud cake, or in the form of a high velocity jet that reacts mechanically with the mud cake, has the disadvantage that the wash fluid filters through the mud cake and into the producing formation. Thus the wash fluid may cause water blocking of an oil bearing formation, or may cause swelling of heaving shales adjacent to the well bore.

The present invention contemplates methods for introducing the cementing material into the well bore in a particular manner so that this cementing material, of itself, acts as the medium to remove mud cake from the wall of the well bore, thus resulting in a better cement job than can be produced by prior art methods or devices.

In the use of the methods described by this invention, the cementing material is introduced into the well bore and directed against the wall of the well bore in the form of a jet or multiple jets. The jet or multiple jets have predetermined characteristics to achieve the desired function of removing the mud cake and the jets may be moved relative to the well bore to clean an extended area of the well bore wall.

An object of this invention is, therefore, to provide improved methods for introducing cementing material into a well bore.

An additional object of the present invention is to provide methods for introducing a cementing material into a well bore having mud cake deposited on the walls thereof, in which apparatus the cementing material is introduced in the form of at least one jet directed at the wall and moved longitudinally of the wall to erode successive portions of the mud cake from the wall.

A further object of this invention is to provide methods for introducing a cementing material into a well bore having mud cake deposited on the walls thereof, in which the cementing material is introduced in the form of at least one jet directed at the wall and having a critical minimum velocity to erode the mud cake from the wall during movement of the jet longitudinally of the wall.

Objects and advantages other than those outlined above will be readily apparent from the following detailed description when read in conjunction with the accompanying drawing, in which:

Fig. 1 schematically illustrates the operation of the methods of this invention.

Figs. 2 and 3 are graphs illustrating relationships between certain variables involved in the operation of the apparatus of this invention.

Fig. 1 shows a well bore and the equipment directly necessary for the use of the methods of this invention. Numeral **6** designates a subterranean formation penetrated by a well bore, the walls of which are coated with a layer **7** of drilling fluid or drilling mud filter cake. The purpose of the cementing operation, which this invention improves, is to secure a length or string of casing **8** to the walls of the well bore.

In the present invention, suitable means are provided to produce at least one jet of cementing fluid directed at the mud cake **7**. Such means may be in the form of perforations **11** around the periphery of the lower end of the casing **8** to act as openings through which a cementing material may be jetted. Alternatively, the perforations **11** may be provided in a separate cementing shoe secured to the lower end of the casing **8**. The perforations **11** may be in a single row spaced about the periphery of the casing, but, preferably, the perforations form two rows, as shown in Fig. 1, with the perforations of one row offset longitudinally of the casing with respect to the perforations of the other row. Suitable auxiliary valving (not shown) may be provided in the casing **8** to control the flow of cementing material through the perforations **11**. The lower end of the casing **8** may be provided with a plug **10** of drillable material.

The cementing material is supplied under pressure through casing **8** and forced through the perforations **11** in the form of jets directed at the well bore walls so that these cement jets impinge on the mud cake **7**. The casing **8** is also moved longitudinally in the well bore to cause the jets of cementing material to impinge on successive portions of the mud cake **7**. The number of openings or perforations **11** to be provided around the periphery of the cementing device is dependent upon the diameter of the device; this number should be such that the jets effectively cover the total surface of the mud cake without undue rotation of the casing, and such that a minimum of overlapping occurs between the areas

cleaned by adjacent jets. For example, I have determined experimentally that jets which impinge on the well wall about one inch apart remove all mud cake under usual operating conditions. The diameter of the jet openings **11** will depend upon the characteristics of the particular equipment used in the cementing operation. The method of determining the proper area for the jet perforations **11** will be discussed more fully below.

I have found that to obtain most effective removal of the mud cake, a critical relationship exists between the velocity with which the jet cementing material flows from the perforations **11** and the velocity of the movement of jets longitudinally in the well bore, corresponding to the rate of movement of the casing **8** within the well bore. This critical relationship is a function of both of the above velocities and may be expressed in the form of a curve **13** as shown in Fig. 2. In this figure, the velocity, V_j in feet per second, of the jet of cementing material issuing from the perforations **11** is plotted on the axis of abscissa and the velocity, V_t, in feet per minute, with which the jet or the casing moves longitudinally in the well bore, is plotted on the axis of ordinates. This critical relationship may also be expressed by the empirically derived equation $V_t=25-70/V_j0.3$; curve **13** is a plot of this equation.

In curve **13**, the coordinates of any point lying on or under the curve represent a jet velocity, V_j, and a traversal velocity, V_t, for which complete removal of the mud cake will be obtained in one traversal of the mud cake by the jet. Similarly, coordinates of a point lying above curve **13** correspond to a jet velocity and a longitudinal traversal velocity at which the layer of mud cake may not be completely removed in one traversal of the jets of cementing material. The curve **13** represents a somewhat conservative specification of the required jet velocities and traversal velocities, however, so that under favorable conditions, substantially complete mud cake removal might be obtained for velocities represented by points lying slightly above curve **13**. Mud cake removal under these conditions is not, however, assured.

I have found that the relationship expressed by curve **13** is not changed by substantial variations in the thickness of the mud cake layer **7** and that the relationship expressed by curve **13** is also substantially independent of the density of the cementing fluid, the composition of the mud cake and, within the limits of casing and well bore diameter usually encountered in oil field practice, the distance between the perforations **11** and the mud cake layer **7**. For example, I have found that variations in the density of the cementing fluid from 100 pounds per cubic foot to 120 pounds per cubic foot have substantially no effect on the curve **13**. Similarly, variations in the shear strength of the mud filter cake from 0.1 p. s. i. to 10 p. s. i., representing variations in the composition of the mud or mud cake, have substantially no effect on curve **13**. This is because the energy of the jet of cementing material employed in accordance with this invention is so much greater than the mud cake shear strength that variations in the shear strength are negligible. Also, variations in the thickness of the mud cake from one fourth of an inch to three fourths of an inch, the range of mud cake thickness commonly found in field practice, have no substantial effect on curve **13**.

I have also found that for coordinates of points lying on or under curve **13**, the number of times that the jet traverses the mud cake has a direct and substantially linear effect on the longitudinal traversal velocity, V_t, required to produce complete mud cake removal at a given jet velocity. For example, as shown in Fig. 2, at a jet velocity of 140 feet per second, the maximum longitudinal traversal velocity, V_t, at which complete mud cake removal may be obtained in one pass or traversal is 10 feet per minute, but I have found that if the layer of mud cake is traversed twice by the cementing fluid jets at this jet velocity, V_j, the longitudinal velocity, V_t, of the traversal may be increased to 20 feet per minute. A similar relationship holds for other longitudinal velocities and number of traversals for the area under curve **13**.

Although complete removal of mud cake may be obtained with any combination of velocities lying on or under curve **13**, in practice I have found that there is a preferred operating range within the area defined by curve **13**. This preferred range is defined, as shown by the shaded area under curve **13**, by the area between the jet velocities, V_j, of 60 feet per second and 180 feet per second and longitudinal velocities, V_t, between 4.6 feet per minute and 10.3 feet per minute. These values are the limits of the preferred operating range because they represent reasonably obtainable jet velocities, and because they represent a range of longitudinal velocities which provide a reasonable rate of movement of the casing **11** commensurate with quick removal of mud cake and with mechanical limitations of oil field equipment.

The jet velocities, within the critical limits set forth above, used on any particular cementing operation will depend on the capacity of the cementing equipment, pumps, and engines utilized; the diameter and length of the casing to be cemented; the diameter of the well bore; the quantity of cementing material used in the operation; and the total cross-sectional area of the perforations through which the cementing material is jetted. The successful design of apparatus for introducing cementing material into a well bore in accordance with this invention depends almost entirely upon selection of the proper total cross-sectional area of these perforations.

In order to select this area, the pressure-flow rate relationship of the following four parts of the system for circulating the cementing material must be considered: the cementing pumps and the engines that drive them; the surface piping, the casing, and the annulus between the casing and the wall of the well bore; the perforations through which the cementing material is jetted; and the column of cementing material in the annulus between casing and well wall at the end of the cementing operation.

The quantity of cementing material that the pumps and their driving engines can deliver against any discharge pressure is limited by the power of the engines. For pumps and engines commonly used on cementing operations, the product of the pump discharge rate, Q, in cubic feet per second, and the discharge pressure, P, in pounds per square inch, is very nearly constant. This relationship may be expressed graphically such as by curve **15** of Fig. 3.

The quantity of cementing material that flows through the surface piping, the casing, and the annular space between the casing and the well wall depends on the pump discharge pressure and on the resistance to the flow of cementing material and other fluids that usually precede and follow the cementing material during an oil well cementing operation. Commonly, the pressure and flow rate will be related according to an equation of the form

$$P=K_1+K_2Q+K_3Q^2$$

In this equation the symbols K_1, K_2 and K_3 represent the flow characteristics, respectively, of the particular piping, casing, and annular space for which the suitable total cross-sectional area of perforations is being calculated. These symbols K_1, K_2 and K_3 may be determined by methods commonly known to persons skilled in the art of hydro-dynamics. An example of application of the art of hydro-dynamics to flow of fluids in oil wells is given in a paper entitled, "The Flow Properties of Drilling Muds," by Beck, Nuss and Dunn, at page 9 of the 1947 issue of the A. P. I. Drilling and Production Practice papers. The methods described in this article may be used to estimate K_1, K_2, and K_3 for the purposes of my invention. In a typical cementing operation,

K_1 will be equal to 0.1 p. s. i. for each foot of well depth,
K_2 will be equal to 0.15 p. s. i per ft.^{3} per sec. for each foot of well depth,

K_3 will be equal to 0.007 p. s. i. per (ft.^{3} per sec.)^2 for each foot of well depth.

This relationship may also be expressed graphically, such as by curve **17** of Fig 3.

The pressure required to lift the column of cementing material, which is commonly more dense than the drilling mud or other fluid that follows the cementing material down the casing, does not depend on the flow rate, Q. Instead, this pressure depends on the difference between the density of the cementing material and the density of the fluid following it and on the height of the column of cementing material. The height of the column of cementing material is greatest at the end of the cementing operation, and this pressure acts more strongly to oppose the pump discharge and to reduce the flow rate at the end of the operation than at any other time. If all calculations to select the jet total area are made for conditions at the end of the operation, the jet velocity at other times during the cementing operation will be greater than it is at the end. In Fig. 3, the effect of this pressure increase at the end of the cementing operation will be to raise curve **17** to the position of curve **16**. When the cementing operation is performed by conventional means, rather than with jets of cementing material, the cementing material circulating system; that is, the pump and engine and the casing and well bore; will allow the cementing material to flow at rates and pressures on curve **15** between the points A and B. The material will flow at the rate Q_A at the start of the operation; then as the hydrostatic pressure at the bottom of the annular column of cemening material increases, the flow rate will decrease to the rate Q_B. If apparatus in accordance with this invention is used for introducing cementing material into a well bore in the form of jets, the pressure through the jet will cause the flow rate and pressure at the end of the cementing operation to correspond to point B'.

At the end of the operation, the difference between the pressure represented by point B' and the pressure represented by point B is the pressure that causes cement to flow through the jet perforations. This pressure can be related to the jet velocity V_j, according to the laws of fluid mechanics, by an equation such as

$$P_j = DV_j^2$$

I have found, for example, that for one form of jet perforation and one cementing material

$$D = 0.012 \text{ p. s. i. per (ft. per sec.)}^2$$

In utilizing the apparatus of this invention, the jetting velocity, V_j, at which it is desired to operate should be determined. As shown on Fig. 2, the preferred range of V_j is between the limits of 60 and 180 feet per second. The exact choice of V_j may depend upon a variety of considerations, such as the need to maximize the flow rate, Q. In such a case, a low jetting velocity, V_j, should be selected so that point B' will be at the lowest possible pressure and the highest possible flow rate consistent with the restrictions of curves **15** and **16** in Fig. 3.

In another instance, the operator may suspect that his estimate of the position of curve **16** is not accurate. Then a high velocity should be chosen so that it will fall within the preferred range even though the cementing material flow rate, Q, is considerably below the operator's estimate.

When V_j has been chosen, P_j may be estimated from commonly-known laws of fluid mechanics or from the equation

$$P_j = 0.012\, V_j^2$$

Then the point B' may be located and the flow rate at

the end of the test will be determined as Q_B'; and the total cross-sectional area of the perforations, A_j, will be found according to the equation

$$A_j = \frac{Q_{B'}}{V_j}$$

In order that V_j fall within the preferred operating range between 60 and 180 feet a second, the total area of all perforation should be between the following limits:

$$\frac{Q_{60}}{60} > V_j > \frac{Q_{180}}{180}$$

where Q_{60} and Q_{180} are the flow rates of cementing material, corresponding to Q_B' in Fig. 3, for jet velocities of 60 and 180 feet a second, respectively. The number of perforations should be such that each jet impinges on the well wall about one inch away from the impingement center of the adjacent jets.

By providing two or more rows of perforations **11**, with the perforations of one row offset longitudinally of the casing with respect to the perforations of the other rows, as shown in Fig. 1, a more complete removal of the mud cake is insured. The use of such offset rows prevents mud cake from remaining in the small area between the centers of impingment of adjacent jets in a given row, since this small area is directly in line with the jet issuing from the offset perforation in the adjacent row as the perforations and casing move longitudinally of the well bore wall.

Although but a few embodiments of the present invention have been described, it will be apparent that various changes and modifications may be made therein without departing from the spirit of the invention or the scope of the appended claim.

I claim:

A method of introducing a cementing material into a well bore having mud cake deposited on the wall thereof comprising the steps of forming a plurality of jets of said cementing material directed substantially perpendicularly at said wall, the number and size of said jets being such that said jets of cementing material effectively cover the circumference of said well bore wall, moving said jets longitudinally of said wall, regulating the velocity of said jets and the velocity of said longitudinal movement for a single longitudinal traversal of said wall in accordance with the expression

$$V_t = 25 - \frac{70}{V_j 0.3}$$

where V_t is the velocity of said longitudinal movement in feet per minute and V_j is the velocity of said jets in feet per second, while maintaining said jet velocity between the limits of 60 feet per second and 180 feet per second and maintaining said longitudinal velocity between the limits of 3 feet per minute and 11 feet per minute, to erode said mud cake from said wall and to deposit said cementing material in said well bore.

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