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METHOD AND APPARATUS FOR STABILIZING PRODUCTIVE FORMATIONS

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2 Sheets-Sheet 1

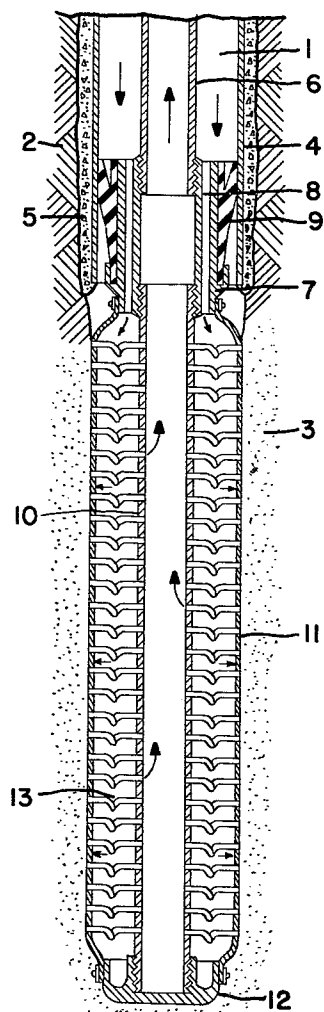


FIG.-1

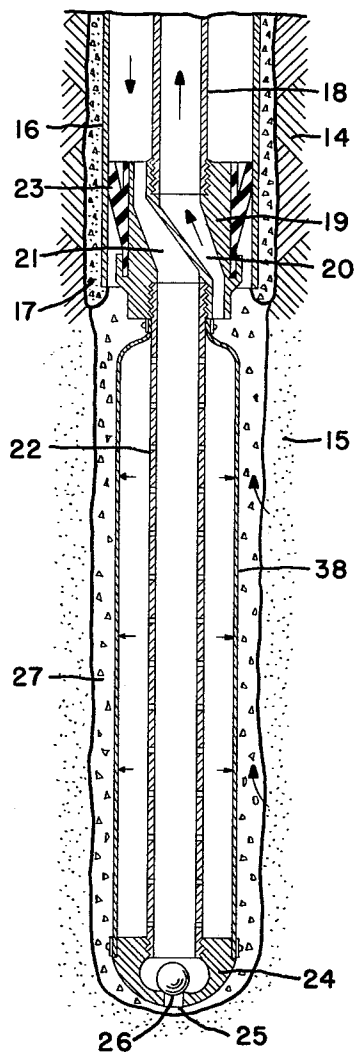


FIG.-2

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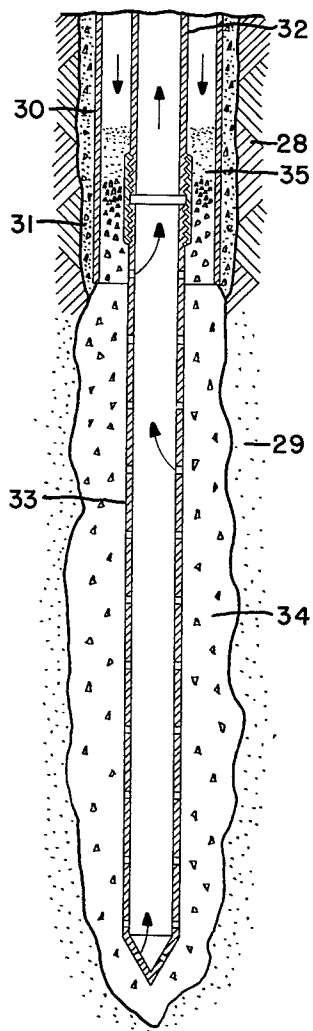


FIG.-3

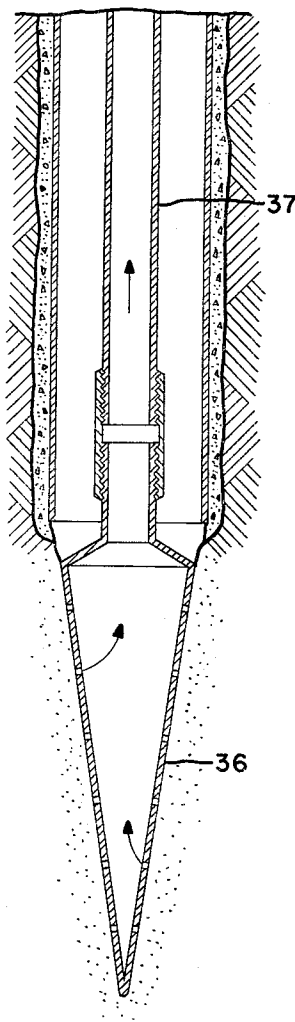


FIG.-4

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1

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**METHOD AND APPARATUS FOR STABILIZING
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The present invention relates to the completion of wells in unconsolidated sand formations and more particularly relates to an improved method and apparatus for the completion of wells whereby the sand particles in an unconsolidated producing formation are supported under pressure from within the well bore in order to prevent their entrainment in fluids flowing from the formation into the well.

The production of oil, gas or water from a well drilled into an unconsolidated sand formation is usually accompanied by numerous difficulties arising from the entry of particulate solids into the well bore. This "sand" not only tends to fill and clog the well but is also entrained in the fluids pumped to the surface, causing excessive wear on pumps, liners and other equipment, increased pumping costs, and added expense due to the necessity for separating the sand from the fluids. Sand production often leads to the undermining of large areas surrounding the borehole and the caving in of the overlying strata. When this occurs, the production tubing is usually badly bent or collapsed and it is necessary to stop production of the well and repair the damage. Frequently the well must be abandoned. Even if the production tubing is not damaged, caving of the overlying strata may permit the entry of foreign fluids into the producing reservoir or, in the case of gas wells, permit substantial quantities of gas to escape into higher reservoirs outside the producing area of the well.

Various methods designed to reduce sand production and thus alleviate these problems have been proposed from time to time and several such methods are currently in use. The most successful of these involves the placement of a bed of gravel or similar material around a perforated pipe or liner at the end of the production string in order to filter the sand particles from the producing fluids and prevent their entry into the well bore. A related practice is to use a fine screen as a filter in place of the gravel pack. Plastic consolidations which can be applied to the borehole walls and then perforated have also been used for this purpose.

None of these methods for controlling sand production has been found completely satisfactory. Filter media cannot be made fine enough to hold back all of the sand without being subject to excessive clogging. Gravel packs, screens and similar devices are therefore designed to admit the smaller particles into the borehole while filtering out the larger ones. Under these conditions the size of the openings in the filter medium becomes critical and the selection of the proper screen or gravel to minimize sand production is difficult. A change in the production rate of the well or other conditions may result in complete disruption of the filtering action, permitting the influx of large amounts of sand. Screens are generally short-lived unless they are made of expensive alloys because of corrosion and the eroding action of the entrained sand particles. Plastic consolidations partially seal the formation, decreasing the production rate, and are frequently ruptured by the pressure created by the producing fluids. For these and similar reasons the control of unconsolidated formations remains an acute problem and collapsed production strings are quite common even though gravel packs, screens, plastic consolidations and the like are used.

2

It has now been discovered, however, that unconsolidated sand formations can be effectively controlled by the application of force to the walls of the borehole within the formation, thus creating pressures which counteract the pressures tending to break down the formation and cause entrainment of sand particles in the producing fluids. These pressures should be substantially equal to but not in excess of the overburden pressure. It has been found that the frictional forces between individual sand particles under such pressures are sufficiently high to hold the particles in place over large unsupported areas and to prevent sand entrainment even though fluids flow from the formation into the borehole at high velocities. By positioning a porous producing medium in the borehole and expanding or otherwise forcing the medium against the formation so that the sand particles are retained in their original undisturbed position, sand production and the difficulties associated therewith can thus be virtually eliminated.

The porous producing medium utilized in accordance with the invention may comprise an expansible perforated sleeve or liner, a bed of gravel or similar granular material, a tapered production liner, or a bed of metallic burrs or the like which can be forced into the formation and interlocked. The size of the openings or free spaces in the medium is less critical and can be larger than in the case of conventional screens, gravel packs and the like. It has been found that under the conditions employed in accordance with the invention unconsolidated sands will bridge across unsupported areas 50 grain diameters or more in width, whereas in conventional well completion operations the openings must not exceed about $2\frac{1}{2}$ times the diameter of the smallest particle it is desired to exclude. The particles remain firmly in place even though fluids flow from the formation into the well at high velocities. The use of such a relatively coarse medium in conjunction with pressure against the borehole wall does not appreciably restrict the flow of fluids or reduce the production rate of the well.

A preferred means for creating pressure against the unconsolidated sand formation in accordance with the invention involves the expansion of a tubular member in the bottom of the borehole by the hydrostatic pressure of a column of liquid maintained above a packer positioned on the production string. In lieu of using such an expansible member, a piston may be formed above a granular producing medium and the weight of the annulus fluid used to compress the medium and force it outward against the formation. In certain instances the weight of the production string may be utilized to exert pressure against the formation.

The exact nature of the invention can be more clearly understood by reference to the accompanying drawings, in which:

FIGURE 1 shows in sectional elevation one means for controlling sand production in accordance with the invention whereby a perforated sleeve is expanded against the formation;

FIGURE 2 depicts a further embodiment of the invention whereby a tubular member is expanded against a gravel pack in order to create the necessary pressure;

FIGURE 3 is a sectional elevation showing yet another embodiment of the invention which is adapted for use in well bores wherein considerable washout has occurred during the drilling operation; and,

FIGURE 4 shows an embodiment of the invention adapted for use in relatively thin unconsolidated sand formations.

Referring now to FIGURE 1, reference numeral 1 represents a well bore which has been drilled down through various subterranean formations 2 into an unconsolidated

3

producing formation 3 containing oil, gas or water, or a mixture of these fluids. Casing 4 has been set and cemented in place in the well, the cement being designated by reference numeral 5. A string of tubing 6 carrying a producing element as described below has been lowered in the well into the unconsolidated producing formation.

Connected to the lower end of tubing 6 is collar 7 having multiple passages 8 extending therethrough parallel to the bore of the collar. Packer 9 is affixed to the collar surface and may be of the cup or lip type as shown in the drawing or instead may be of the bottom-hole type which is expanded in place against the borehole wall or casing by the telescoping of internal sleeves in response to the weight of the production string. Packers set in place against the borehole wall by the rotation of the production string may also be used. Such packers are widely used in drilling operations and methods for their incorporation into the apparatus used in the present invention will be apparent to those skilled in the art. Production tube 10 is connected to the lower bore of collar 7 and expansible sleeve 11 is attached to the lower outside edge of the collar surrounding the production tube. The sleeve and production tube are joined at the bottom by shoe 12 to form an annular compartment into which fluids may be introduced through passages 8 in collar 7. Production tube 10 and sleeve 11 contain corresponding holes or perforations spaced evenly over the surfaces thereof and each hole or perforation in the production tube is connected to a corresponding hole or perforation in the sleeve by means of a flexible connecting tube 13. The connecting tubes are affixed in fluid-tight relationship to the walls of the production tube and sleeve and are coiled or looped to permit expansion of the sleeve away from the production tube. Sleeve 11 may be made of relatively thin copper, lead, aluminum, Teflon or similar material and may be corrugated in order to permit maximum expansion. In lieu of using coiled or looped connecting tubes, telescoping tubes having O-ring or similar seals may be employed. The producing element may be of any desired size but before expansion should have a diameter only slightly less than the diameter of the well casing and will preferably be of sufficient length to extend substantially through the producing formation.

After the producing element described above and shown in FIGURE 1 has been positioned at the bottom of the borehole, water, drilling mud or a similar liquid is introduced into the annulus of the borehole. It is preferred that water be used as the annulus fluid. The annulus liquid flows downward through passages 8 in collar 7 and fills the annular space between the production tube 10 and sleeve 11. As a column of liquid is built up in the annulus of the borehole, the hydrostatic head of this liquid causes sleeve 11 to expand outward against the unconsolidated sand formation, creating pressure against the formation. The introduction of the annulus liquid is continued until the pressure at the bottom of the column is substantially equal to the overburden pressure. Sleeve 11 bears against the sand and holds the particles firmly in place in substantially their original undisturbed position. Producing fluids flow from the formation into the openings in the sleeve, through the connecting tube, and into the production tube, from which they are withdrawn to the surface. The sands bridge across the openings in the sleeve and are not swept into the producing element.

In the embodiment of the invention shown in FIGURE 2, a gravel pack is used as the producing medium and a tubular sleeve is expanded against the gravel pack to create the necessary pressure. As shown in the figure, the borehole has been drilled down through overlying formations 14 into unconsolidated producing formation 15 and casing 16 has been set in place with cement 17. A string of tubing 18 has been lowered in the hole.

4

Attached to the lower end of tubing 18 is connecting member 19 having two fluid passages therethrough, a first passage 20 connecting tubing 18 with the annular section of the borehole below the connecting member and a second passage 21 connecting the annular section of the borehole above the connecting member with a perforated tube 22 connected to the underside of the connecting member. A packer 23 which is preferably of the lip or cup type, although other types may be used, is positioned on the outer surface of the connecting member 19. Perforated tube 22 is surrounded by an expansible sleeve 38 and is connected thereto at the bottom by a shoe 24 containing a port 25 fitted with a ball or similar type valve 26.

Following the placing of the expansible sleeve and associated equipment in the borehole, a gravel pack 27 is placed around the sleeve by entraining gravel or other suitable granular material in a drilling mud or other liquid introduced into tubing 18 at the surface. The liquid and entrained gravel flow downward through the tubing and passage 20 in the connecting member into the annular space surrounding the expansible sleeve. The gravel is deposited around the sleeve and the entraining liquid passes through port 25, pressure of the circulating liquid holding open the valve. The liquid then flows upward through perforated tube 22 and passage 21 in the connecting member into the annular section of the borehole above the connecting member and packer. During the deposition of the gravel pack the pressure differential inside and outside the sleeve is not sufficient to cause deflection of the sleeve. After the gravel pack has been placed, water is pumped downward through the production string in order to wash away the mud left behind.

To expand the sleeve and thus create the required pressure against the unconsolidated formation, water or other suitable liquid is passed downward through the annulus of the borehole, through passage 21 in the connecting member, and into the perforated tube and sleeve. Pressure of the liquid holds valve 26 over port 25 and a column of liquid is built up in the annulus above the packer and connecting member. The hydrostatic head of this column causes the sleeve to expand outward against the gravel pack, which in turn exerts pressure against the formation. The sand particles bridge across the free spaces in the gravel pack and are retained in place. Fluids flowing from the formation pass upward around the sleeve and flow through the connecting member and tubing to the surface.

FIGURE 3 depicts a further embodiment of the invention which is particularly adapted for use in boreholes wherein considerable washout has occurred during drilling and the diameter of the borehole within the unconsolidated formation is too large or irregular to permit use of the apparatus described heretofore. After the borehole has been drilled down through the overlying strata 28 into the unconsolidated reservoir 29 and casing 30 and cement 31 are in place, a string of tubing 32 having connected thereto a perforated production tube 33 is lowered into the well. The production tube is sealed at the bottom and may consist merely of a length of pipe or tubing with a plurality of holes, slots or other openings cut at regular or irregular intervals. A gravel pack 34 is placed around the production tube by circulating a gravel-laden drilling mud or other liquid downward through the annulus of the borehole and withdrawing the liquid, free of gravel, through the tubing to the surface. Water is then circulated through the borehole to wash any remaining drilling mud from the formation and the gravel pack.

After the gravel pack has been placed in the borehole and washed free of drilling mud, a piston is created above the gravel pack by introducing successively finer grades of gravel, sand, silt or other solid material until an impervious layer several feet thick has been built up. Binders such as bentonite and other clays, greases and similar

5

materials may be added to the finer grades of solid material used to form the piston in order to insure that it will be impervious to the passage of liquids. A column of water, drilling mud, or other liquid is then introduced into the annulus of the borehole. The weight of the liquid on the piston compresses the gravel pack and forces it outward against the formation, creating the necessary pressure. Producing fluids pass through the gravel pack and into the production tube, from which they are withdrawn to the surface.

In comparatively shallow formations the apparatus of FIGURE 4 may be employed to permit the control of unconsolidated sands in accordance with the invention. After the borehole has been drilled into the sand formation, a tapered reamer is used to extend the hole further into the producing sands. A tapered production liner 36 is then lowered into the hole at the end of a string of tubing 37. The weight of the tubing on the liner creates sufficient pressure against the formation to retain the sand particles in place as fluids flow from the formation into the liner and thence to the surface. In particularly soft unconsolidated formations it is frequently unnecessary to ream out the hole, the weight of the production string being adequate to force the liner into the formation to the desired depth.

As will be apparent to those skilled in the art, a variety of methods may be employed in order to create pressure against an unconsolidated sand formation and thus prevent the entrainment of sand particles in fluids produced from the formation in accordance with the invention. Regardless of the particular method employed, it is preferred that the pressure created be substantially equal to the overburden pressure, although in some formations less pressures will be required than in others because of differences in the size and shape of the particles making up the formation.

It will be understood that the apparatus disclosed herein is merely representative and that numerous modifications in the exact procedures described may be made without departing from the scope of the invention.

The nature of the invention having thus been disclosed and illustrated, what is claimed is:

1. A well completion method for controlling sand production in a well bore drilled into an unconsolidated producing formation which comprises placing a porous medium in the well bore adjacent to the producing formation, continuously forcing said medium against said formation during production of said well with a force sufficient to create a pressure against said formation substantially equal to but not in excess of the overburden pressure, and conducting fluids from said formation through said medium into a production string extending to the earth's surface.

2. A well completion method for preventing the influx of sand particles into a well bore from an unconsolidated formation while conducting fluids from said formation through a production string to the earth's surface which comprises placing a particulate porous medium in the well bore adjacent to the producing formation, maintaining a column of liquid in the annulus of the well bore above said producing formation whereby said medium is forced against the formation with a pressure substantially equal to the overburden pressure, and conducting fluids from the formation through said medium into the production string with said column of liquid being maintained while said fluids are being conducted from said formation.

3. An apparatus for controlling sand production in a well bore having its lower portion tapered and drilled into an unconsolidated producing formation which comprises: a production string adapted to be positioned in a well bore; and a tapered, perforated production liner attachable to said string, said tapered production liner substantially matching said tapered borehole, the weight of said drill string forcing said liner downwardly against said tapered borehole to retain the sand particles in place.

6

4. A well completion method for preventing the influx of sand particles into a well bore from an unconsolidated formation while producing fluids from said formation through a production string having a tapered, perforated liner attached to the lower end thereof to the earth's surface which comprises: forming a tapered cone shaped hole in said formation to substantially match said tapered liner; and forcing said liner downwardly during production of said well with a force sufficient to force said tapered liner against said producing formation with a force normal to the borehole wall substantially equal to the overburden pressure.

5. An apparatus for controlling sand production in a well bore drilled into an unconsolidated formation in which casing has been set to at least the upper portion of said formation and a tubular production string has been suspended within said casing which comprises in combination: a production tube having perforations in its wall and of a character to connect to the lower end of said production string in a fluid tight relationship; an expandable sleeve member surrounding said production tube and having spaced perforations in its wall; tube means fluidly and sealingly connecting each perforation in the production tube to a corresponding perforation in the sleeve; packing means sealing the lower annular space of said well bore between said production string and said casing; and means establishing fluid communication between the annular space above said packing means and the space between said production tube and said sleeve not occupied by said connecting tube means.

6. A well completion method for preventing the influx of sand particles into a well bore from an unconsolidated formation while conducting fluids from said formation through a production string to the earth's surface which comprises: placing a particulate porous medium in the well bore adjacent to the producing formation; depositing an impervious layer of finely divided solids above said porous medium between said production string and said casing; maintaining a column of liquid in the annulus of the well bore above said impervious layer while producing fluids from the formation through said medium into the production string whereby said porous medium is forced against the formation with a pressure substantially equal to the overburden pressure.

7. An apparatus for controlling sand production in a well bore drilled into an unconsolidated formation in which casing has been set to at least about the upper portion of said formation and a tubular production string has been suspended within said casing which comprises in combination: a packer means sealing the annular space between the lower end of said production string and said casing; a perforated tube supported from and sealingly attached peripherally at its upper end to said packer means; an expansible sleeve surrounding said perforated tube and the upper end of said sleeve peripherally attached in sealing relationship to said perforated tube; means to close the lower end of said perforated tube and said expansible sleeve; a first passage in said packer means establishing fluid communication between the interior of said tubular production string and the exterior of said expansible sleeve below said packer means; and a second passage in said packer means establishing fluid communication between the annular space above said packer means between said production string and said casing and the interior of said perforated tube.

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