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[54] **METHOD AND APPARATUS FOR COMPLETING A WELL IN VERTICALLY SPACED POROUS STRATA**
 18 Claims, 5 Drawing Figs.

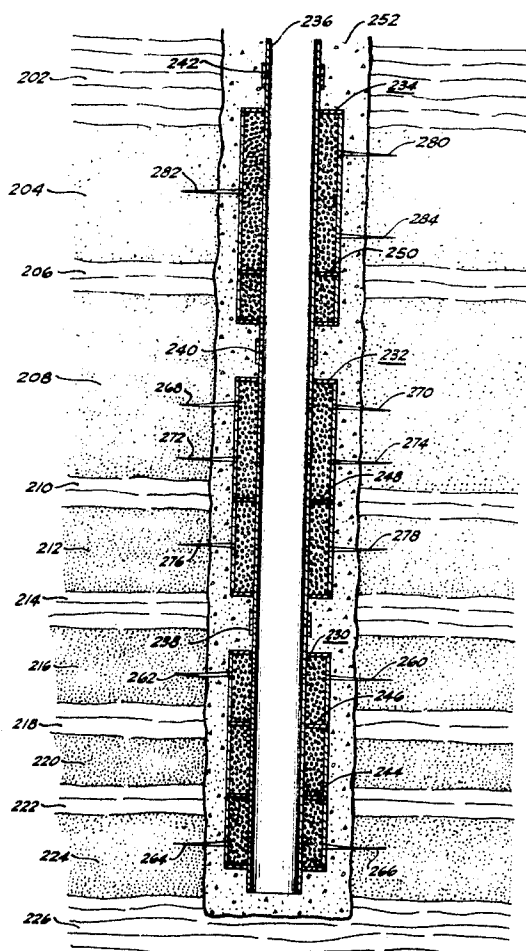
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 E21b 43/10, E21b 43/14
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ABSTRACT: A method for completing wells in incompetent formations wherein a prepacked gravel liner is cemented into place in the well adjacent to one or more productive zones, and thereafter the gravel pack and cement sheath is perforated to establish communication between the producing zones and the interior of the liner. The apparatus comprises an imperforate gravel pack assembly. The gravel pack can be divided into longitudinal sections by horizontal partitions located so as to coincide with impermeable strata separating the producing zones. Any selected producing zone can then be placed on production by perforating the section of gravel pack and outer cement sheath adjacent to that zone, and any zone can be shut off by plugging the adjacent section of gravel pack.



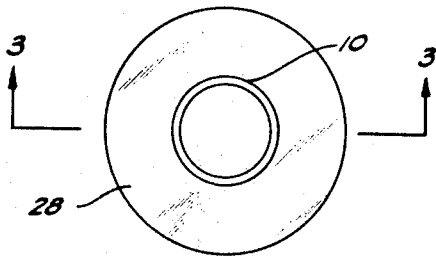


FIG-2

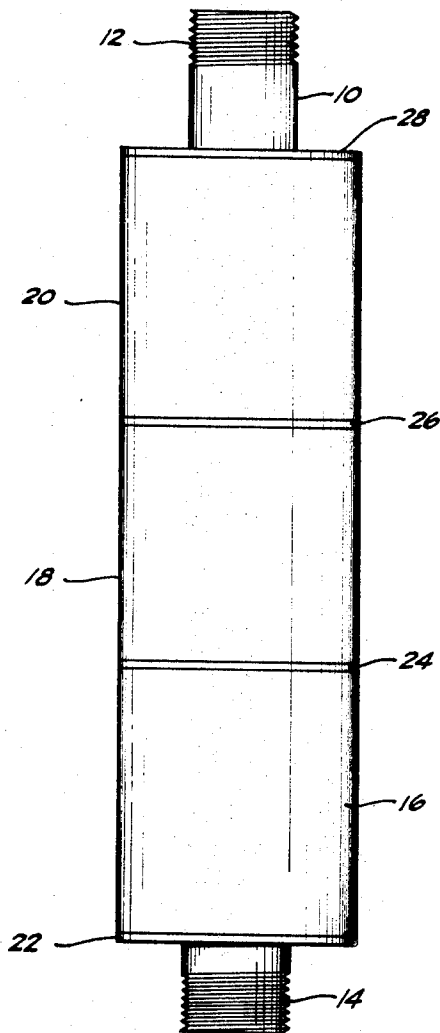


FIG-1

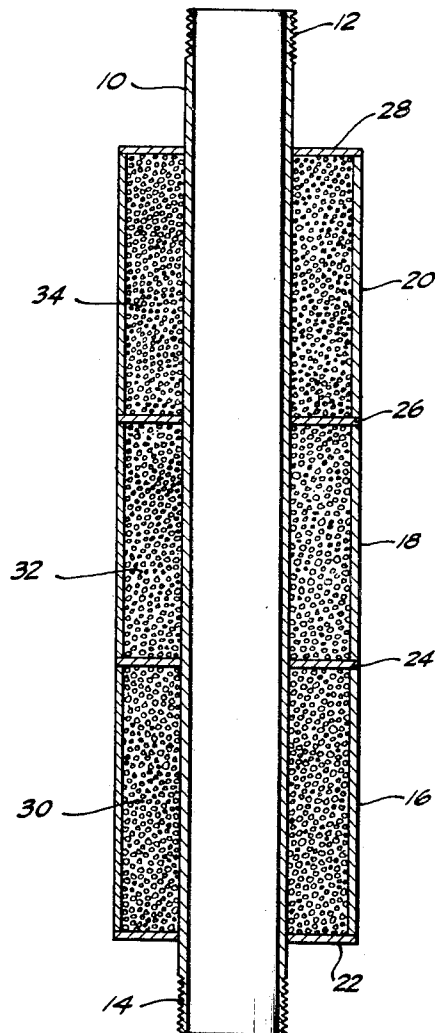


FIG-3

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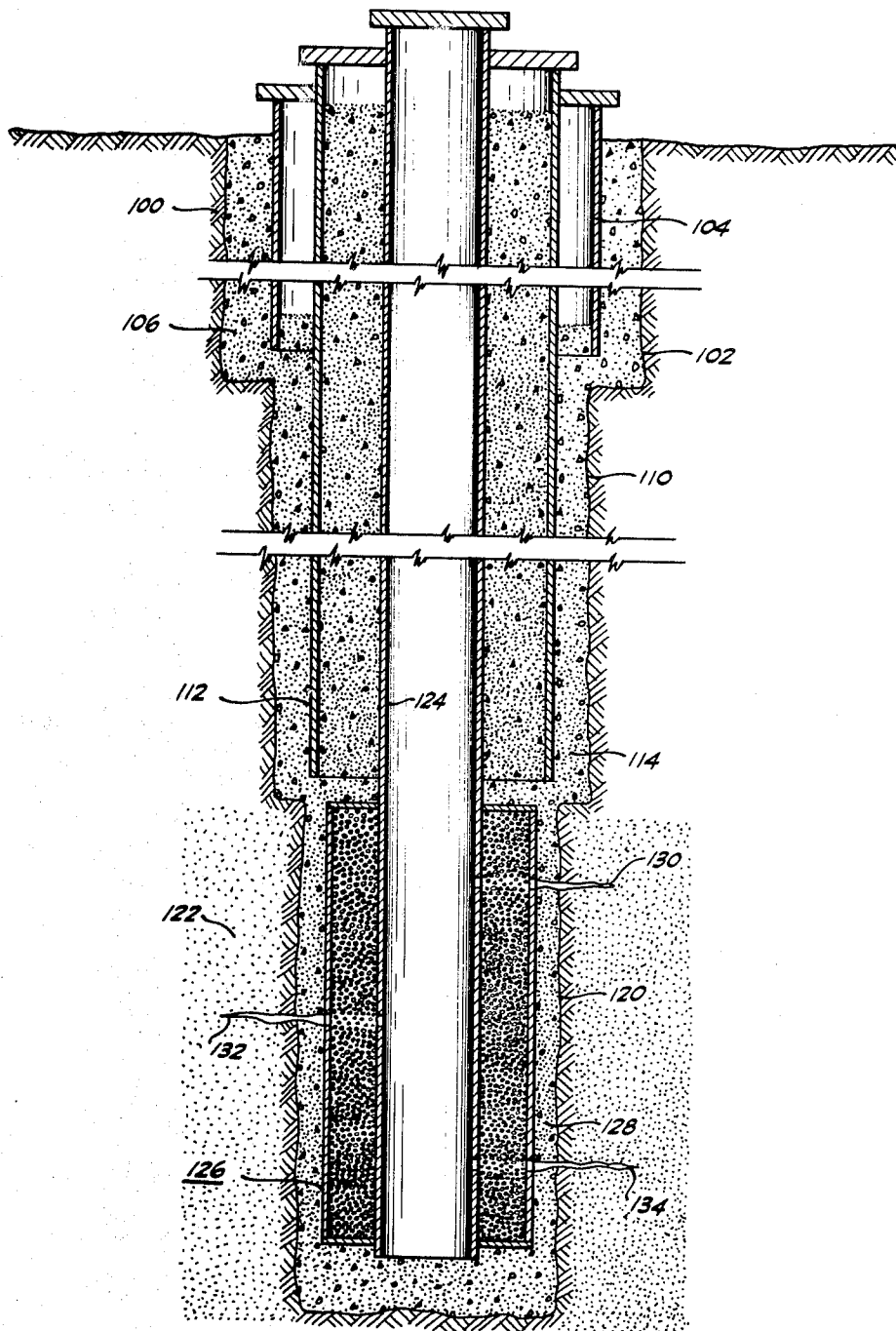


FIG-4

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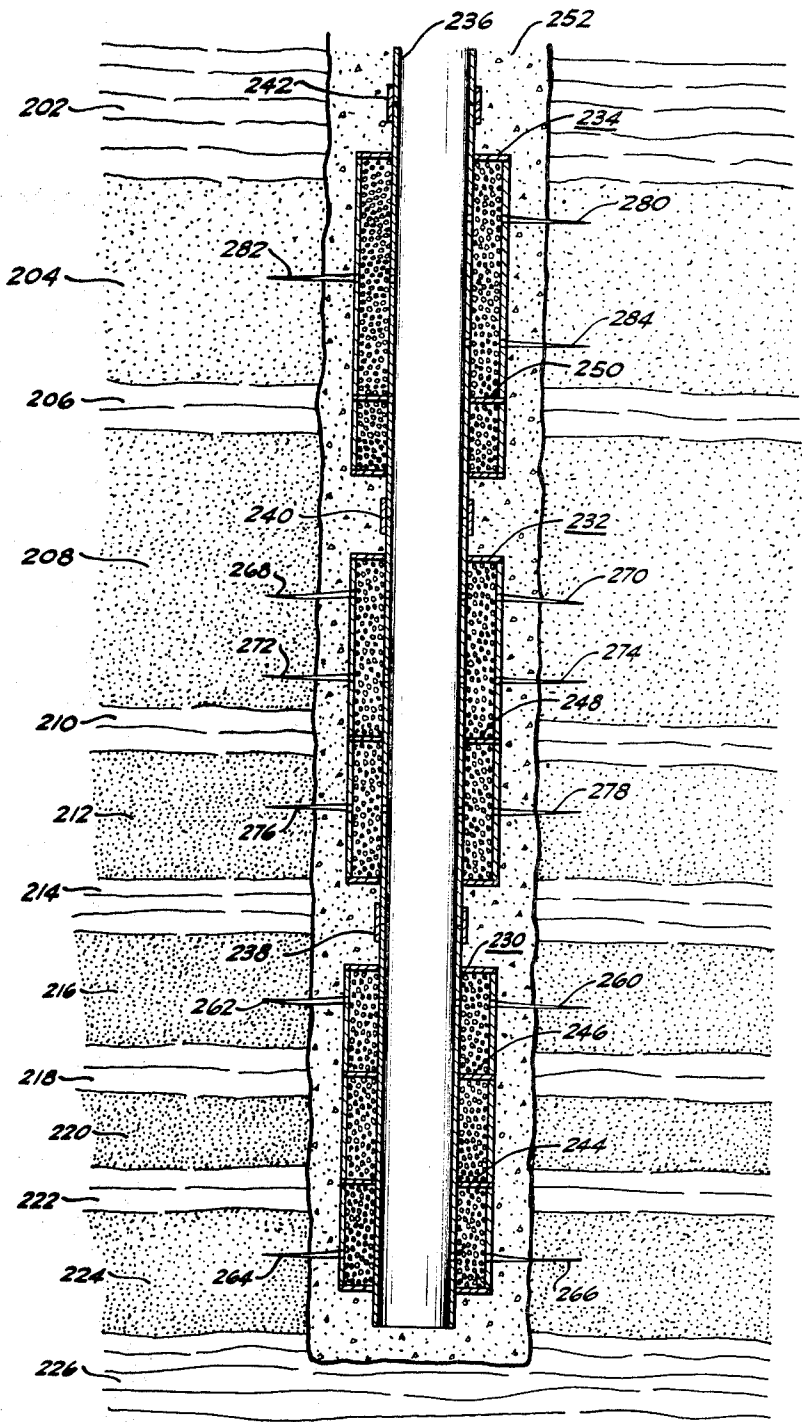


FIG-5

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METHOD AND APPARATUS FOR COMPLETING A WELL IN VERTICALLY SPACED POROUS STRATA

This invention is directed to the completion of a well in an earth formation, and more particularly to the completion of a well in an incompetent earth formation composed of unconsolidated or loosely consolidated earth particles.

Recoverable fluids such as petroleum oil, gas and water are frequently found in subterranean formations comprised of unconsolidated or loosely consolidated sand and sandstone. Also, some otherwise consolidated formations become incompetent when certain fluids are produced from or injected into the formation. When such incompetent formations are pierced by a well and the connate fluids therein removed, the loose or weakly bound sand particles become dislodged and are entrained in the fluid. The dislodged sand is moved into flow channels causing plugging and a reduction in permeability of the formation. Further, sand can accumulate in the well causing plugging, and can be carried to the surface with the withdrawn fluid. These entrained particles cause severe erosion of underground strainers and liners, the producing string, pressure control valves, pumps and flow lines. Oil produced from incompetent formations often requires special treatment to remove entrained sand, and substantial quantities of the entrained sand can be deposited in production tanks causing cleaning and disposal problems. In extreme cases, sufficient sand can be removed from the producing formation to cause it to collapse under overburden pressure resulting in loss of the well. Similar problems are encountered in the injection of water, gas and other fluids into unconsolidated or loosely consolidated formations, or into formations which become incompetent upon the injection of the fluid.

Various types of strainers, screens and gravel packs have been proposed to prevent entry of incompetent sands into the well. These devices are placed in the well adjacent to the producing zones. The produced fluids pass through one or more strainers or screens, or through a body of gravel or other particulate matter of a size selected to prevent passage of the dislodged earth particles into the well. One conventional method of bottom hole completion is to install a screen or slotted liner in the producing zone and then to place gravel or other particulate matter of selected size around the exterior of the liner to form a body of filter material in the annulus between the liner and the well wall.

While these techniques have sometimes been effective in limiting the entrainment of sand into the well, other problems result from their use. First, the particulate matter used as the filtering medium generally comprises a mixture of particles of different sizes carefully selected to prevent passage of the entrained earth particles into the well. The range and distribution of particle sizes used in the filter body depends upon the size of earth particles expected to be entrained from the formation in which the well is completed. However, uniform distribution of the filter particles cannot be assured when the particulate matter is pumped into the annulus. Hence, some portions of the filter body unduly restrict the flow of fluids into the well, while other portions are not effective in preventing the entrainment of earth particles into the well. Secondly, the gravel pack deposited in the well has vertical as well as horizontal permeability and fluids can flow vertically through the annulus preventing the production of only selected zones of the producing formation. Lastly, because of the high cost of rig time, it is desirable to minimize the time required for completion of the well and to reduce work over and repair operations.

Accordingly, one object of the present invention is to provide a method and apparatus for completing a well in an unconsolidated earth formation. Another object is to provide an efficient completion method requiring a minimum of rig time and reducing expensive work over and repair operations. Still another object is to provide a method and apparatus for installing a filter body in a well so as to provide uniform distribution of the filter particles within the body. A further object is to provide a method and apparatus for completing a well in an unconsolidated formation so as to restrict the flow of fluids

between vertically spaced producing zones. A still further object of the invention is to provide a well completion method and apparatus permitting any selected producing zone to be placed on production, and the production from any selected zone to be shut off without adversely affecting the production from other zones. Other objects and advantages of the invention will be apparent from the following detailed description.

Briefly, this invention is directed to a method for completing a well in an unconsolidated earth formation in which a prepacked gravel liner is cemented into place in a well adjacent to one or more productive zones and the gravel pack and cement sheath perforated to establish communication with the producing zones, and to an imperforate gravel pack useful in the practice of the method. The gravel pack is contained in the annular space between a pair of imperforate, coaxially mounted tubular members and can be divided into longitudinal sections by transverse partitions separating the annular space. The transverse partitions can be arranged so that when the gravel pack is placed in the well, the longitudinal sections are adjacent to selected sections of a producing zone. Any selected producing zone is placed on production or opened for fluid injection by perforating the tubular members of the gravel pack and the outer cement sheath at a point adjacent to the selected zone, and any zone can be shut off by plugging the gravel pack adjacent thereto.

The construction of the preassembled gravel pack and the method of placing it in the well can best be illustrated by the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is an elevation view of a preassembled gravel pack liner which may be used in carrying out the method of this invention;

FIG. 2 is a top view of the preassembled gravel pack liner;

FIG. 3 is a cross-sectional view taken generally along line 3-3 of FIG. 2;

FIG. 4 is a cross-sectional view of a portion of an unconsolidated formation showing a well completed by the method of this invention; and

FIG. 5 is a cross-sectional view of a well completed by the method of this invention in an earth formation comprised of a plurality of producing zones separated by impervious strata.

Referring now to FIGS. 1 through 3, inclusive, there is shown a preassembled, gravel packed liner comprised of an inner imperforate tubular member 10 which can be formed from a length of standard well casing of appropriate diameter and wall thickness. Tubular member 10 is provided with threads 12 and 14 at either end to permit attachment of additional sections of preassembled liner, or well casing, by conventional threaded couplings. Alternatively, one end of tubular member 10 can be provided with male threads and the other end with female threads adapted to engage similarly threaded tubular members. Also, the threads can be omitted and tubular member 10 attached to the adjacent tubular sections by welding, or other means, if desired. The outer shell of the preassembled, gravel packed liner is made up of one or more imperforate tubular sections of larger diameter than tubular member 10. In the illustrated embodiment, the outer shell is comprised of three tubular sections 16, 18 and 20 having the same diameter larger than that of inner tubular member 10 and maintained in fixed, spaced relationship concentric with tubular member 10 by means of plates 22, 24, 26 and 28 so as to form the annular chambers 30, 32, and 34 on the exterior of tubular member 10. Alternatively, the end plates 22 and 28 can be replaced by welding caps cut out to receive member 10, or by other means of providing a rounded end construction. Chambers 30, 32, and 34 are filled with particles which form filter bodies capable of passing fluids, but which prevent the passage of sand from the formation into the interior of tubular member 10 on its subsequent perforation. Although tubular member 10 can be constructed with any desired length, it is convenient to construct member 10 from standard sections of casing having a length of about 30 feet. The lengths of the individual tubular members comprising the

outer shell of the preassembled, gravel packed liner and the spacings between the transverse plates can be adjusted to provide annular chambers having different lengths, as hereinafter more fully described.

The aforementioned preassembled, gravel packed liner can be conveniently constructed by attaching the bottom plate to the inner tubular member by welding, or other convenient means, and then attaching the outer tubular member. The annular chamber is then filled with particulate material of selected size, and the next plate and outer tubular member installed. A preassembled gravel packed liner having any desired number of sections can be constructed by this technique. In the embodiment specifically illustrated in FIGS. 1 through 3, inclusive, plate 22 is welded to tubular member 10 at a point near threaded end 14. Outer tubular member 16 is then welded to plate 22 and the annular chamber formed by the concentric tubular members filled with particulate material of selected size. Next plate 24 is welded to tubular members 10 and 16 to close the chamber 30. Tubular member 18 is then welded to plate 24 to form the chamber 32, which is also filled with particulate material. This chamber is closed by welding plate 26 to tubular members 10 and 18, and the next tubular member 20 is welded to plate 26. Chamber 34 is filled with particulate material and end plate 28 welded in place.

The particulate material packed into the annular chambers must be of a size that will bridge earth particles entering through the perforations ultimately formed in the outer tubular member to prevent their passage into inner tubular member 10, and which will bridge the perforations in member 10 to prevent entrainment of the gravel from the annular chamber. Preferably, the size range and size distribution of the particulate material is selected based on the size of the earth particles expected to be entrained from the formation. Various techniques are available for determining the optimum gravel size for any particular size of formation sand particles. Satisfactory bridging can be obtained when the size of gravel particles is 10 to 13 times the 10 percentile sand grain size. The proper size of gravel particles can be readily determined by making a Tyler screen analysis of the formation particles, plotting the results on a cumulative weight percentage graph, determining the size of formation particle at the 10 percentile on the graph, and selecting a gravel having a size 10 to 13 times this size.

In the practice of this invention, a well is drilled into a formation in conventional manner. To complete the well, a prepacked gravel liner such as illustrated in FIGS. 1 through 3 is placed in the well adjacent to a productive zone. A cement slurry is then pumped down through the inner tubular member and up around the exterior of the liner. The cement fills the void between the exterior of the prepacked liner and the well wall, and upon hardening, forms a seal preventing fluids from flowing around the exterior of the liner. After the liner is cemented in the well, a gun perforator is lowered into the interior of the inner tubular member and the liner walls and cement sheath perforated with shaped charges or projectiles fired outwardly through the liner walls and cement sheath into the surrounding formation. The spacing and orientation of the perforations can be varied to provide the desired producing or fluid injection channels communicating the interior of the liner with the formation.

The method of this invention is further illustrated in FIG. 4 wherein a schematic view of a typical well completed by the method of this invention is shown. The well is comprised of a rather large diameter bore hole 102 drilled into earth strata 100. A first string of surface casing 104 is set to the bottom of bore hole 102. The surface casing is then cemented in the bore hole by pumping cement down the interior of the casing and upwardly around the exterior so as to fill the annular space between the exterior of the casing and the face of the bore hole. The cement is conventionally displaced through the casing by drilling mud, and drilling mud is displaced from the annulus by the cement. On hardening, the cement forms a sheath 106 on the exterior of casing 104 that provides an effective, impermeable seal between the formation and the casing.

After surface casing 104 is set and cemented, a smaller diameter bore hole 110 is drilled through the casing. Drilling is continued until the subsurface conditions require the setting of an intermediate casing string, such as casing 112. Intermediate casing 112 is set and cemented in place by pumping cement down the interior of the casing and upwardly around the exterior so as to fill the annular space between the exterior of the casing and the formation face. Cement sheath 114 affords a fluid-tight seal between the casing and the formation face. If desired, sufficient cement can be pumped into the annulus to wholly or partly fill the annulus between intermediate casing 112 and surface casing 104.

The well is completed in the production zone by drilling a smaller diameter bore hole 120 into oil or gas-bearing strata 122. Production casing 124 having a prepacked gravel liner 126, such as hereinbefore described, attached to its lower end is set in the casing and cemented in place. As before, cement is pumped down casing 124, through the interior tubular member of liner 126, and upwardly around the exterior of liner 126. It is essential that the liner walls are impermeable to avoid entrance of cement into the gravel pack during the cementing operation. As illustrated, production liner 124 can be cemented to the surface, thus providing an impermeable sheath 128 to seal between the exterior of liner 126 and the formation face and in the annular space between production casing 124 and intermediate casing 112. Alternatively, only that portion of the annulus surrounding liner 126 need be cemented to facilitate completion of the well by the method of this invention.

After the cementing operation has been completed, the liner is perforated by positioning a carrier containing one or more perforation guns loaded with shaped charges or projectiles in the interior of the liner and detonating the charges in conventional manner. The spacing and orientation of the perforations are controlled by the position of the gun in the carrier, and by the position of the carrier in the liner. The projectile or shaped charge must be of sufficient strength to perforate the inner tubular member of the liner, pass through the body of gravel between the tubular members, perforate the outer tubular member and the surrounding cement sheath, and preferably penetrate into the formation adjacent to the well. The perforations in the tubular members should be sufficiently small to prevent entrainment of the particulate filter material from the annular chamber. Preferably, the diameter of the perforations is no larger than 3 times the diameter of the gravel particles. In the well completion illustrated in FIG. 4, the liner, the surrounding cement sheath, and the formation are perforated at 130, 132 and 134.

The use of the method of this invention in completing a well in a multistructured formation is illustrated in FIG. 5. In the illustrated embodiment, bore hole 200 is drilled through relatively impermeable shale strata 202, 206, 210, 214, 218, 222, and intermediate porous oil-bearing strata 204, 208, 212, 216, 220 and 224, and is terminated in underlying impervious strata 226. Prepacked gravel liners 230, 232 and 234 are assembled on production casing 236 by means of threaded couplings 238, 240 and 242. Liner 230 is constructed with two transverse horizontal baffles 244 and 246 located so that they are adjacent impervious strata 222 and 218, respectively, when the liner assembly is positioned in the bore hole. Liners 232 and 234 are constructed with transverse horizontal baffles 248 and 250 located so that they are adjacent to impervious shale strata 210 and 206, respectively, when the assembly is positioned in the bore hole.

The liner assembly is run into the bore hole and positioned so that the baffles are aligned with the proper impervious strata. Cement is pumped downwardly through the casing 236 and through the liner assembly. The cement is displaced from the interior conduit upwardly around the exterior of the liners and around casing 236. The casing can be cemented to the surface, if desired. On hardening, the cement forms an impermeable sheath 252 filling the annular space between the exterior of the liners and the formation face providing lateral support for the liners and sealing against the flow of fluids.

After the cement has hardened sufficiently, the liners and surrounding cement sheath are perforated to establish communication between the production casing and the producing strata. Liner 230 is perforated at 260, 262, 264 and 266 so as to open permeable strata 216 and 224 to production. As previously stated, the number and pattern of the perforations can be varied as desired. In the illustrated embodiment, the center section of liner 230 is not perforated. Thus, stratum 220 is not opened to production. However, this can be opened for production or fluid injection at any future time by perforating the liner and cement sheath as hereinabove described. Liner 232 is perforated at 268, 270, 272, 274, 276 and 278 so as to open strata 208 and 212 for production. Similarly, liner 234 is perforated at 280, 282 and 284 to open stratum 204. The perforations are made by firing shaped charges or projectiles through the inner tubular member of the liner, the gravel pack, the outer tubular member, the cement sheath, and into the adjacent formation.

Thus, it is apparent that production from various zones of a multistructures formation can be controlled by perforating only those sections of well liner adjacent to the selected zone, and by controlling the number and location of perforations in any particular section of liner. Further, production or fluid injection into any selected zone can be discontinued without adversely affecting other zones by injecting cement, resin, or other plugging material into the section of liner adjacent to the selected zone, thereby rendering that section of filter body impermeable to fluid flow.

The well completion method and apparatus of this invention can be employed in completing production wells, such as those normally used in recovering oil, gas, or water from earth formations, and in completing injection wells, such as those used for injecting water and other fluids into an earth formation in secondary and tertiary oil recovery operations.

While particular embodiments of the invention have been described, it will be understood, of course, that the invention is not limited thereto since many modifications can be made and it is intended to include within the invention any such modifications as fall within the scope of the claims.

I claim:

1. A prepacked liner for completing a well in an earth formation, which comprises:
 - a first elongated imperforate tubular member;
 - an outer imperforate cylindrical shell comprised of a plurality of second tubular members having the same diameter larger than that of said first tubular member, said second tubular members being mounted end to end coaxially with said first tubular member;
 - transverse members attached to said first tubular member and to said second tubular members intermediate adjacent of said second tubular members;
 - means at the outer ends of said second tubular members to close the annular opening between said first and second tubular members; and
 - a body of particulate filter material contained within the annulus between said first and said second tubular members.
2. A method for completing a well in an earth formation comprised of a plurality of vertically spaced porous strata, which comprises:
 - placing an imperforate tubular prepacked liner having a plurality of longitudinally disposed, closed annular filter beds in a bore hole penetrating said earth formation so that said filter beds are positioned adjacent said porous strata;
 - cementing said liner in said bore hole to provide a substantially fluid-tight sheath of cement in the annulus between said liner and the formation wall; and
 - perforating said liner and said cement sheath adjacent selected of said strata to establish communication between the interior of said liner and said selected strata through the filter beds adjacent said selected strata, at least one of the filter beds in said liner remaining closed.

3. The method defined in claim 2 wherein the cement is pumped into the annulus in the form of a slurry and permitted to harden prior to perforation.

4. The method defined in claim 2 wherein said liner is perforated by firing a projectile from the interior of said liner through said liner and said cement sheath.

5. The method defined in claim 2 wherein said liner is perforated by passing a high energy jet through said liner and said cement sheath.

6. The method defined in claim 2 wherein communication between at least one of said porous strata and the interior of said liner is interrupted by placing a plugging material in the annular filter bed adjacent to said selected strata.

7. The method defined in claim 6 wherein said liner and said cement sheath adjacent at least one of the previously closed filter beds are subsequently perforated to establish communication between the porous strata and the interior of said liner.

8. The method defined in claim 2 wherein formation fluid is produced through the filter beds adjacent the selected strata, and wherein said liner and said cement sheath adjacent at least one of the previously closed filter beds are subsequently perforated to establish communication between the porous strata and the interior of said liner.

9. The method defined in claim 2 wherein a plurality of axially connected imperforate prepacked liners are inserted into said bore hole.

10. The method defined in claim 2 wherein each of said filter beds comprise a body of particulate filter material.

11. The method defined in claim 10 wherein said filter material is gravel of a selected size range.

12. A method for completing a well in an earth formation comprised of a plurality of vertically spaced porous strata penetrated by a bore hole, which comprises:

- 35 determining the strata spacing by measuring the depth and vertical thickness of said porous strata;
- assembling an imperforate tubular prepacked liner having a plurality of longitudinally disposed, closed annular filter beds axially positioned on said liner so that the spacing of said filter beds corresponds to said strata spacing;
- 40 placing said prepacked liner in said bore hole so that said filter beds are positioned adjacent said porous strata;
- cementing said liner in said bore hole to provide a substantially fluid-tight sheath of cement in the annulus between said liner and the formation wall; and
- perforating said liner and said cement sheath adjacent selected of said strata to establish communication between the interior of said liner and said selected strata through the filter bed adjacent said selected strata.

13. A method for completing a well in a formation comprised of a plurality of vertically spaced porous strata, which comprises:

- 55 placing an imperforate tubular prepacked liner having a plurality of longitudinally disposed, closed annular filter beds in a bore hole penetrating said earth formation so that said filter beds are positioned adjacent said porous strata;
- cementing said liner in said bore hole to provide a substantially fluid-tight sheath of cement in the annulus between the exterior of said liner and the formation wall;
- perforating said liner and said cement sheath adjacent selected of said strata to establish communication between the interior of said liner and said selected strata through the filter beds adjacent said selected strata; and
- treating at least one of the filter beds adjacent the selected strata with a plugging material so as to render the treated filter beds substantially impermeable to fluid flow.

14. A prepacked liner for completing a well in an earth formation, which comprises:

- 75 an elongated imperforate tubular member;
- an outer imperforate cylindrical shell having a diameter greater than that of said tubular member, said cylindrical shell being mounted coaxially with said tubular member;

transverse members radially attached to said tubular member and to said cylindrical shell at the top and bottom of said cylindrical shell and at spaced intervals therebetween so as to define a series of longitudinally disposed closed annular chambers; and

a body of particulate filter material contained within each of said closed chambers.

15. A prepacked liner for completing a well in an earth formation, which comprises:

a first elongated, imperforate tubular member;

a plurality of imperforate second tubular members having a common diameter greater than that of said first tubular member and mounted coaxially on said first tubular member;

transverse members at the ends of said second tubular members radially attached to said first tubular member and to said second tubular members; and

a body of particulate filter material contained within each of the annuli between said first and said second tubular members.

16. The apparatus defined in claim 15 wherein said filter material is comprised of gravel of a selected size range.

17. The apparatus defined in claim 15 including means for attaching said liner to a tubular casing string.

18. The apparatus defined in claim 15 wherein said second tubular members are mounted abutting each other on said first tubular member.

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