March 18, 1969 W. T. BELL 3,433,305

METHODS FOR DISCHARGING FLUENT SUBSTANCES INTO WELL BORES

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Fig. 1

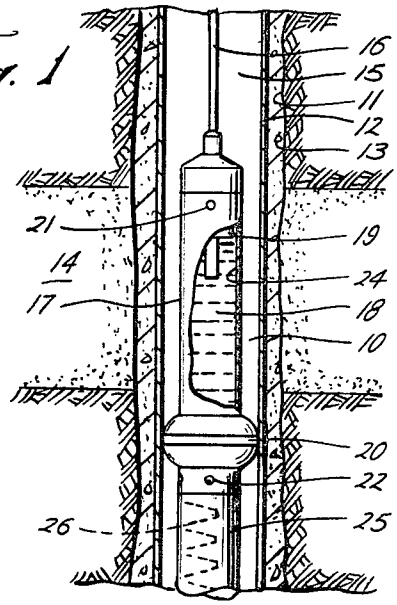


Fig. 2

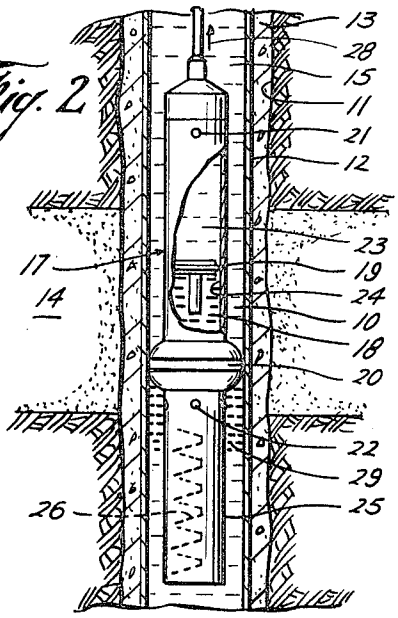


Fig. 3

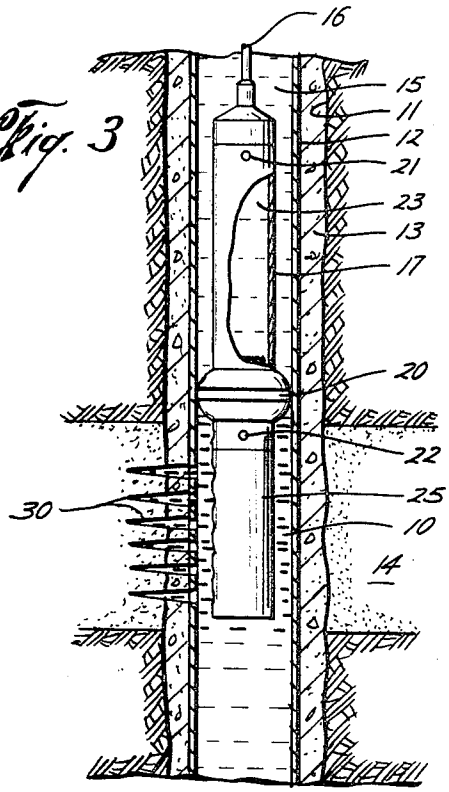
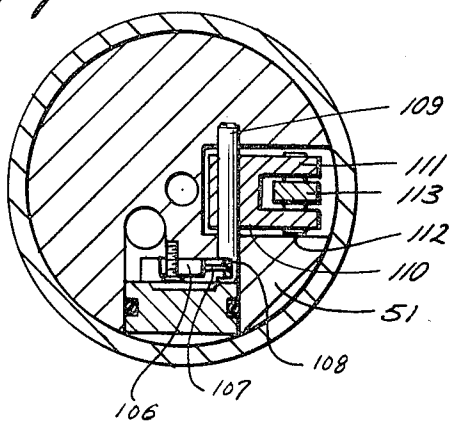


Fig. 5



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Fig. 4B

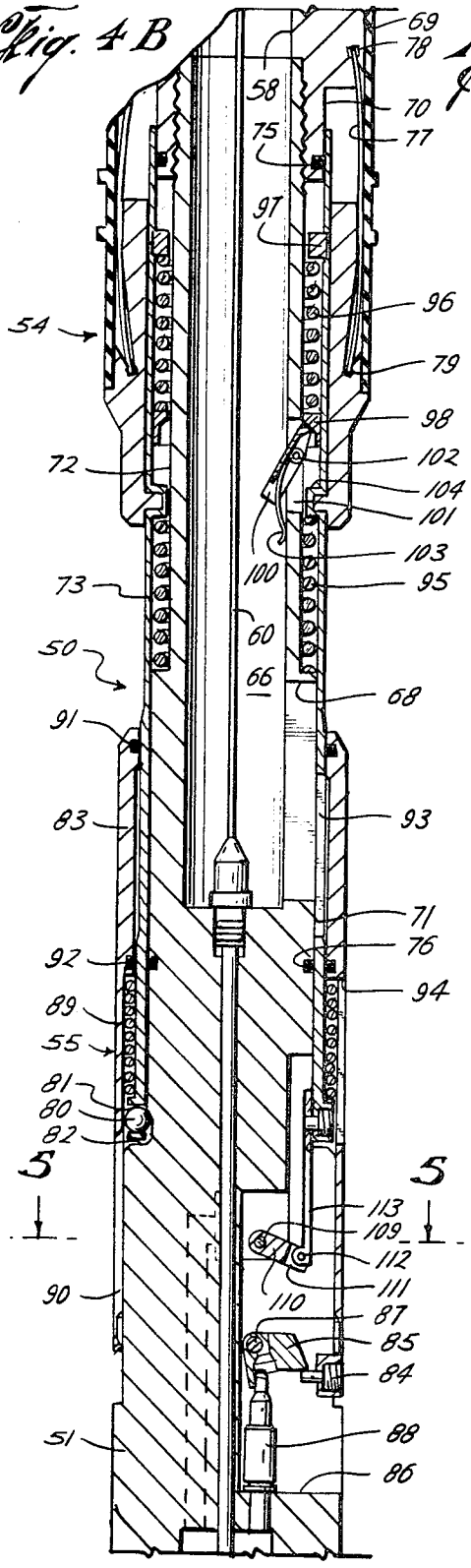
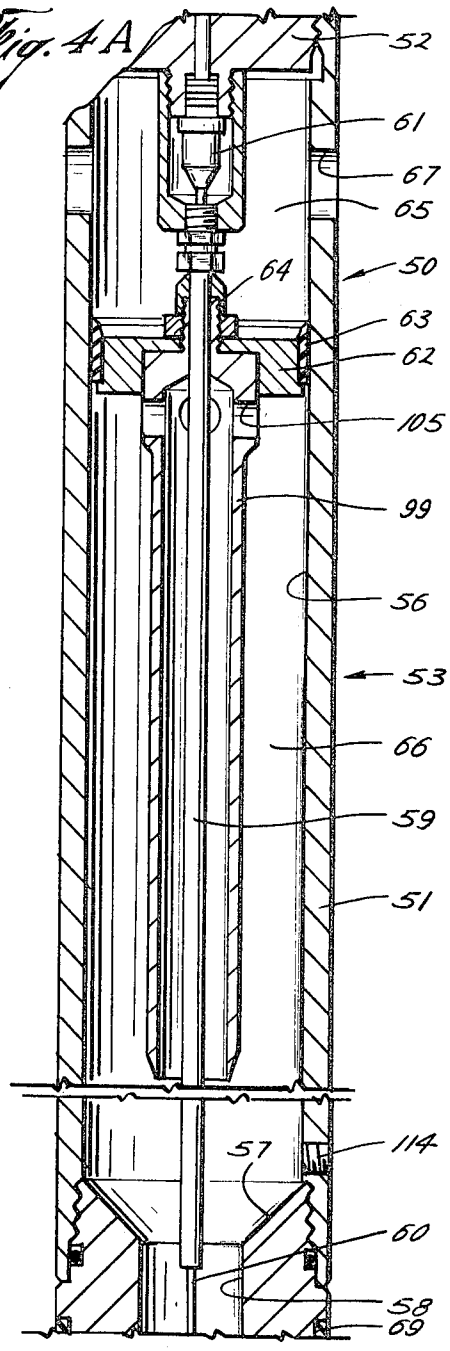


Fig. 4A



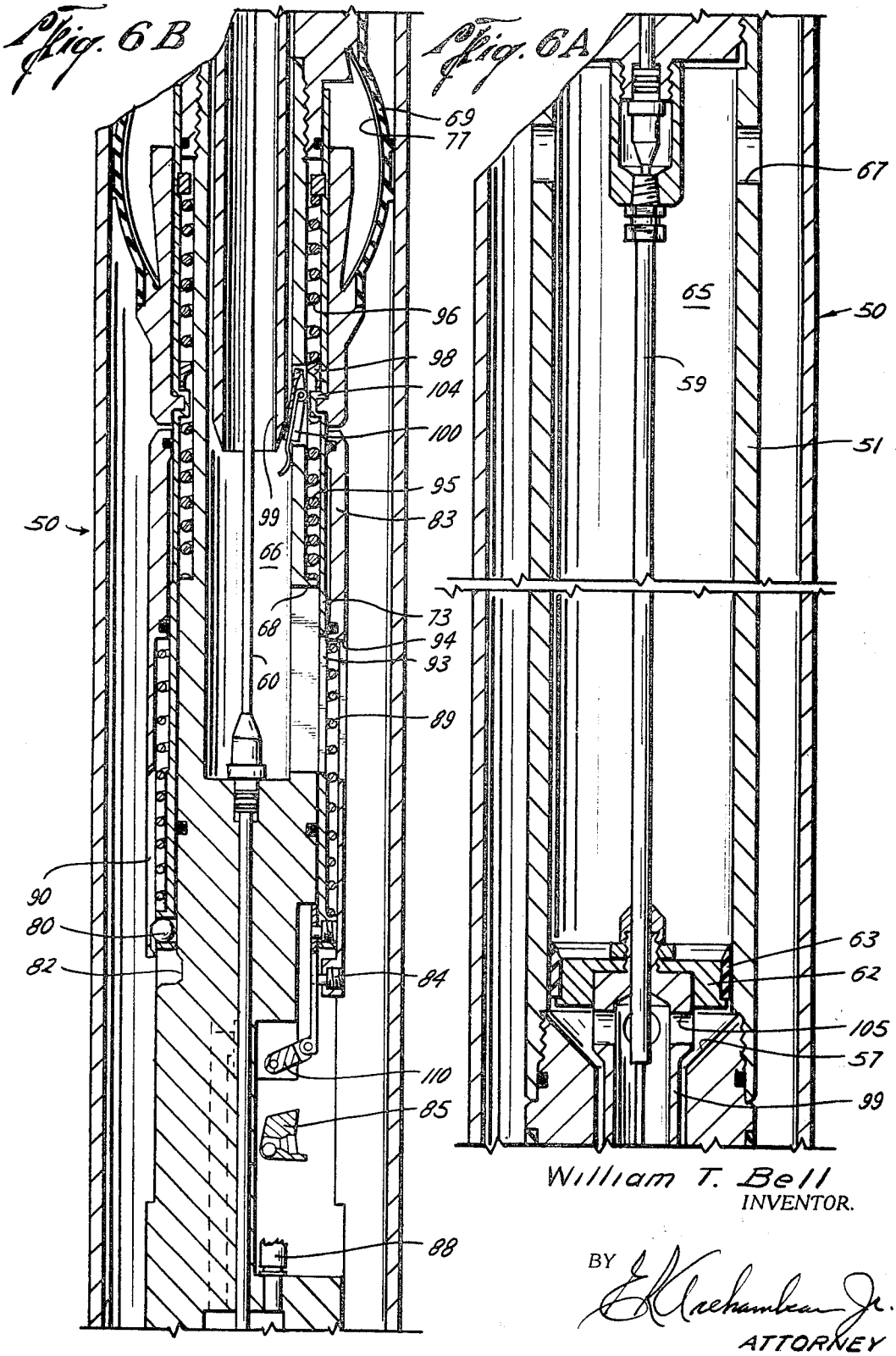
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METHODS FOR DISCHARGING FLUENT SUBSTANCES INTO WELL BORES

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Fig. 8

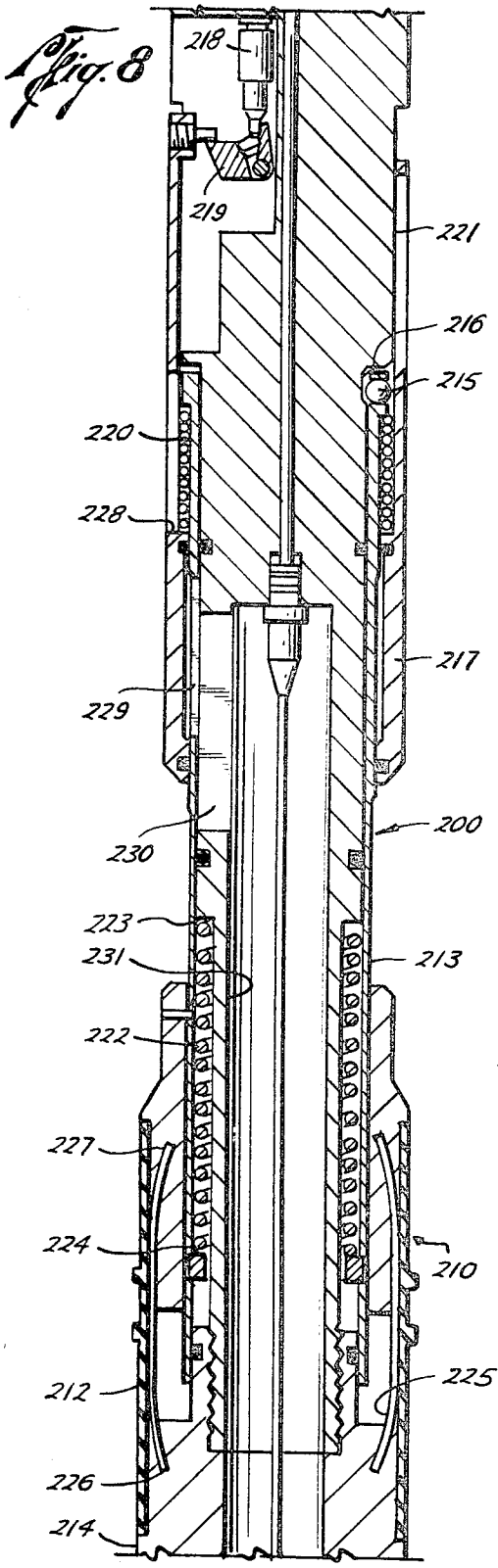
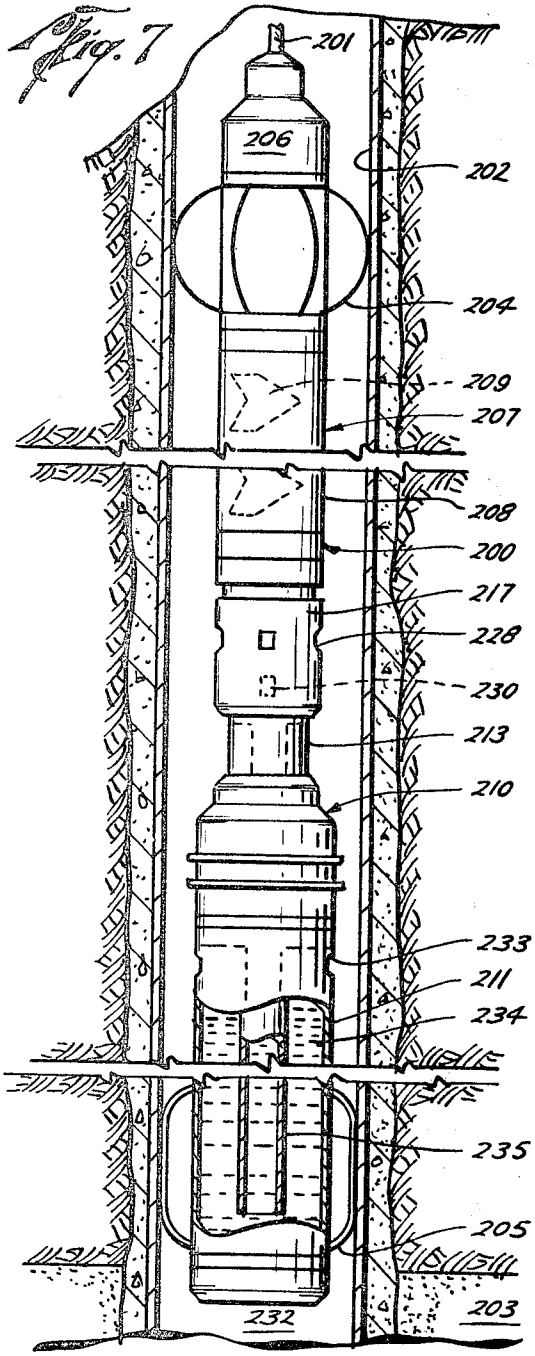


Fig. 7



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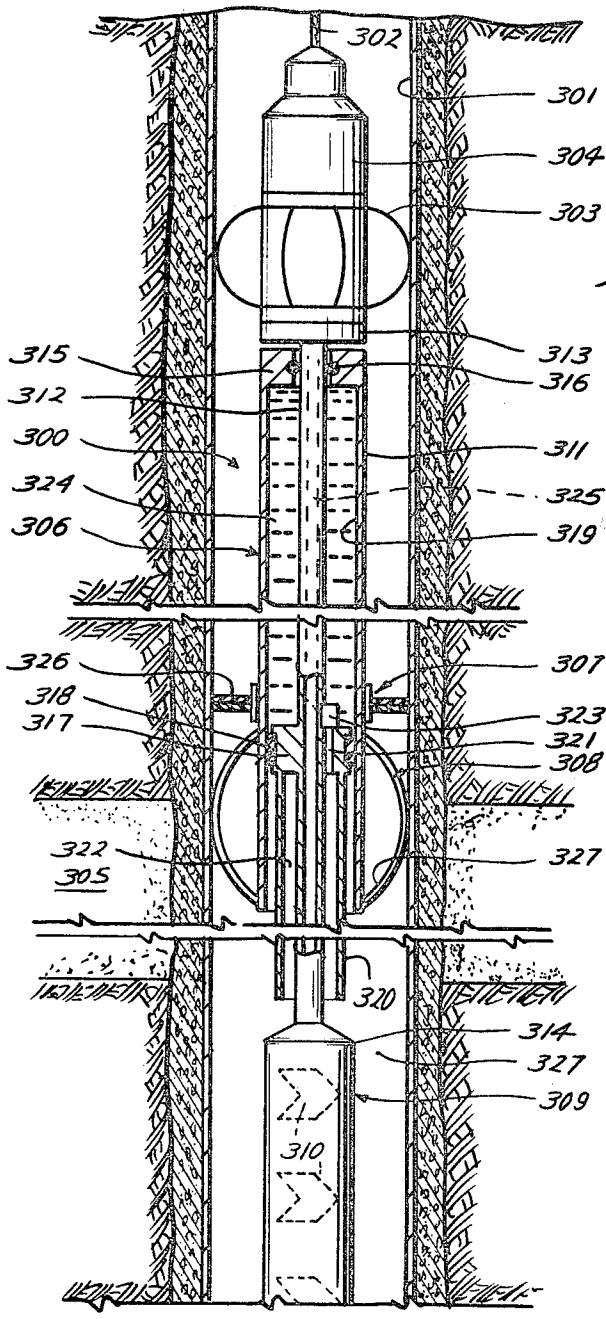


Fig. 9

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Patented Mar. 18, 1969

3,433,305

METHODS FOR DISCHARGING FLUENT SUBSTANCES INTO WELL BORES

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Filed Nov. 6, 1967, Ser. No. 680,648
U.S. Cl. 166—297 4 Claims
Int. Cl. E21b 43/11, 33/13

ABSTRACT OF THE DISCLOSURE

The particular methods described herein as illustrative of the invention are operative for replacing fluids in a selected interval of a well bore with suitable fluent substances. Various embodiments of apparatus for practicing the methods of the invention are described and generally include a reservoir adapted to contain a fluent substance. A flow diverter is also included with each of the disclosed tools so that movement of at least a portion of the tool in relation to a well bore will induct well bore fluids into the reservoir and discharge the fluent substance into the well bore.

It is widely recognized that the entrance of well control fluids or so-called "mud" into newly-formed perforations into an earth formation may, in time, plug the perforations so tightly that subsequent production of oil and/or gas from the formation will at least be impaired if not halted altogether. To counter this damage, suitable oil-soluble liquids and the like are commonly injected into the well bore at least in the vicinity of where perforations are to be made and a perforator is then actuated while these protective liquids are hopefully still in place. In this manner, it is believed that the soluble protective liquids will immediately rush into the perforations as they are made and block the subsequent entry of the well control fluids. Then, when connate fluids are produced through perforations protected in this manner, the produced fluids can easily flow into the well bore and wash away the soluble protective liquids.

Various proposals have been made heretofore for injecting such protective liquids around a perforator just before it is actuated to produce perforations at a desired location in a well bore. For one reason or another, however, these proposed techniques and devices have not been commercially accepted by the industry. For example, one tool proposed heretofore employs a self-contained pump that will supposedly pump a limited supply of protective liquids into the annulus around the perforator and completely displace the well control fluids in this space up above an inflated packer on the tool. A similar proposed tool is arranged to employ a source of high-pressure gas for discharging protective liquids around the perforator to displace the well control fluids upwardly away from the perforator.

It will be appreciated, however, that for the latter one of these tools to accomplish its intended function, the protective liquids must displace a significant volume of the well control fluids against the extreme hydrostatic pressure typically encountered in well bores. Moreover, with either of these techniques, there is no assurance that the protective liquids will not be discharged at such a rate that they will merely diffuse into the surrounding well control fluids rather than enveloping the perforator in a substantially homogeneous mass of the protective agent that will remain in position until the perforator is actuated. Similar problems are also encountered where it is desired to perforate a formation interval and then inject a treating agent, such as acid or the like, to clean the perforations.

Accordingly, it is an object of the present invention to provide new and improved methods for reliably discharging a homogeneous mass of selected fluent substances around a well perforator and then perforating an interval of a well bore traversing this mass of fluent substances so that the selected substances will enter the resulting perforations rather than being diluted by or being dispersed through other fluids in the well bore.

This and other objects of the present invention are accomplished by positioning a tool including a perforator adjacent to a formation interval to be completed. As the perforator is moved into alignment with the formation, fluids in the well bore are removed from the space to be occupied by the perforator and simultaneously replaced with a fluent treating substance. Thus, upon actuation of the perforator, the treating substance will enter the resulting perforations without interference from the displaced well bore fluids. Various embodiments are shown of tools which, in response to movement of the supporting member, will displace the well bore fluids and discharge a suitable treating agent into the resulting voided space at a rate corresponding to the movement of the suspension member.

The novel features of the present invention are set forth with particularity in the appended claims. The operation, together with further objects and advantages thereof, may best be understood by way of illustration and example of certain procedures when taken in conjunction with the accompanying drawings, in which:

FIGURES 1–3 depict the successive steps of one manner in practicing the methods of the present invention;

FIGURES 4A and 4B are cross-sectional views of a portion of a preferred embodiment of a completion tool adapted for performing the methods of the present invention;

FIGURE 5 is a cross-sectional view taken along the lines 5—5 in FIGURE 4B;

FIGURES 6A and 6B are views similar to FIGURES 4A and 4B but showing various elements thereof in their final position;

FIGURE 7 is a schematic representation of an alternative tool for practicing the present invention;

FIGURE 8 is an elevational cross-sectioned view of a portion of the completion tool shown in FIGURE 7; and

FIGURE 9 is a schematic view of still another completion tool for practicing the present invention.

Turning now to FIGURES 1–3, a well-completion tool **10** is shown as it might appear while performing the methods of the present invention in a typical well bore **11**. As is customary, the well bore **11** has a string of casing **12** secured therein by cement **13**, with the casing extending through an earth formation **14** from which oil or gas is to be produced. A conventional well control fluid or so-called "mud" **15** is disposed in the casing **12** in the usual manner.

The completion tool **10** is supported from a typical suspension cable **16** that includes one or more electrical conductors (not shown) and is spooled in the usual manner on a winch (not shown) at the surface. To practice the methods of the present invention, the tool **10** must include fluid-displacement means such as a reservoir **17** containing a supply of a selected fluent substance such as, for example, a temporary plugging agent **18** that is to be selectively discharged for isolating perforations in the producing formation **14** from the mud **15** in response to movement of the tool through the well bore **11** over a span of travel that at least includes the interval of the formation to be perforated.

To accomplish this expulsion of the treating agent **18** as the completion tool **10** is traversed through the well bore **11**, the fluid-displacement means further include means such as a piston **19** that is initially positioned in

the upper portion of the reservoir **17** and fluidly sealed for sliding movement in relation to the inner walls thereof and a flow diverter **20** that is mounted around the outside of the reservoir between longitudinally spaced ports **21** and **22** respectively in communication with the spaces **23** and **24** in the reservoir above and below the piston. A typical well perforator **25** supported below the reservoir **18** and having one or more perforating devices, such as shaped charges **26**, adapted for selective actuation from the surface completes the well tool **10**. It is preferred to also include means, such as a typical casing-collar locator **27** mounted on the tool **10**, for providing indications at the surface from which the position of the completion tool in relation to the formation **14** can be established with reasonable accuracy. A casing-collar locator such as that shown in Patent No. 3,114,876 will, of course, be capable of accomplishing this.

Accordingly, as shown in FIGURE 1, in one manner of practicing the present invention, with the aid of the collar locator **27**, the completion tool **10** is brought to a position below the formation **14**. It will be appreciated, of course, that provisions must be made to prevent premature discharge of the fluent treating agent **18** as the tool **10** is being moved through the well bore **11** to the position depicted in FIGURE 1. Thus, depending upon the particular arrangement of the completion tool **10**, the tool is selectively enabled from the surface so that subsequent travel of the tool will expel the fluent treating substance **18** at a controlled rate from reservoir **17**.

Once the tool **10** has been enabled, the suspension cable **16** is moved to raise the completion tool in the direction indicated by the arrow **28** in FIGURE 2. It will be recognized that since the diverter **20** blocks most, if not all, of the annular clearance space between the tool **10** and the casing **12**, upward movement of the tool will be effective to displace a volume of the control fluids **15** that is directly related to the distance the completion tool is moved. Accordingly, as the completion tool **10** is moved upwardly, the control fluids **15** entering the upper reservoir space **23** by way of the ports **21** are effective in moving the piston **19** downwardly in relation to the reservoir **17**. It will be appreciated, therefore, that as the piston **19** is moved downwardly, the treating agent **18** will be exhausted from the lower reservoir space **24** through the lower ports **22** and into the annulus between the tool **10** and the casing **12**. The volume of the treating agent **18** that is exhausted, as at **29**, will, of course, be equal to the volume of the control fluids **15** entering the upper reservoir space **23**. Thus, the volume of fluent treating agent **18** discharged will be directly related to the distance the tool **10** is moved and the treating agent will be expelled at a rate corresponding to the speed at which the tool is moved.

Of particular significance, it will be noted that since the fluent substance **18** is discharged into the annulus below the diverter **20** as the well control fluids **15** formerly occupying that same clearance space are entering the upper reservoir space **23**, the discharged treating agent **29** will fill this annular clearance space rather than being diffused into the control fluids as has been the case heretofore. This will, of course, result in a more complete envelopment of a homogeneous mass of the fluent substance in that interval of the well bore **11** that is to be perforated. Moreover, the diverter **20** will prevent the well control fluids **15** above the diverter from settling into the discharged treating agent **29**. Since the treating substance has been selected to have a lower density than that of the well control fluids **15**, there will be little or no tendency for the well control fluids **15** below the diverter **20** to dilute the discharged treating agent **29**. Thus, the present invention insures that the treating agent **29** will compleely fill the annulus below the diverter **20** in a more consistent manner than has been possible heretofore.

As seen in FIGURE 3, as the tool **10** is moved further upwardly, the perforator **25** is brought into the blanket of discharged treating substance **29** opposite the formation **14**. Then, once it is established that the perforator **25** is correctly positioned, it is actuated to detonate the shaped charges **26** and produce a corresponding number of perforations **30** through the casing **12** and the cement sheath **13** into the earth formation **14**. Thus, once the perforations **30** are produced, they will be immediately filled by the discharged treating agent **29**. This will, of course, prevent subsequent entry of the well control fluids **15** into the perforations **30** after the tool **10** is removed from the well bore **11**. Accordingly, it will be appreciated that the practice of the present invention will be effective to provide a homogeneous mass of the selected fluent substance **18** completely enveloping the perforator **25** thereby insuring that only the treating agent can enter the perforations **30** once they are produced.

It will be appreciated, of course, that various arrangements of apparatus can be provided to practice the present invention. The central portion of an exemplary tool **50** for practicing the present invention is shown in FIGURES 4A–4B. As seen there, the tool **50** is comprised of an elongated housing **51** having an adapter head **52** connected at its upper end and adapted for coupling the housing to other tools (not shown) thereabove such as a typical centralizer and a casing-collar locator. Similarly, the lower end of the housing **51** is suitably adapted for connection to another tool centralizer (not shown) and a perforator (not shown). This perforator (not shown) may, of course, be any one of the various types of perforators customarily employed in well-perforating operations. Although it is customary to fabricate well tools in a number of separable sections for ease of manufacture and assembly, various portions of the tool **50** are shown in the drawings as being integral with other portions so that minor constructional details of the tool will not affect an understanding of the invention.

In addition to the perforator (not shown), the tool **50** includes a reservoir **53** adapted to carry a supply of a suitable fluent substance, a selectively-operable flow diverter **54** adapted to displace the substance from the reservoir once the diverter is enabled and as the tool is moved through a well bore, and a control section **55** for selectively enabling the diverter and perforator upon command from the surface. The inter-relatoin of these various elements **53–55** and the perforator will subsequently become more apparent.

The reservoir **53** in the upper portion of the housing **51** is formed by an enlarged longitudinal bore **56** of uniform diameter extending an appropriate distince between the upper adapter head **52** and the upwardly-facing shoulder **57** formed by the junction of the enlarge bore and a smaller coincidental bore **58** extending downwardly from thereon through the housing to a termination somewhat above the lower end of the housing. A tubular conduit **59** is depending secured and fluently sealed to the adapter head **52** and extended downwardly along the central axis of the reservoir **53** to a position at least adjacent to the shoulder **57** for enclosing an electrical conductor **60**. The electrical conductor **60** is passed through a typical fluid seal **61** in the adapter head **52** and extended on upwardly through the tool **50** for connection to conductors enclosed in a suspension cable (not shown).

An annular piston member **62** is slidably disposed in the enlarged bore **56** and fluidly sealed therein by an external sealing member **63** engaging the housing **51** and an internal sealing member **64** engaging the conduit **59** to define upper and lower enclosed spaces **65** and **66** in the reservoir **53**. In its initial position shown in FIGURE 4A, the piston member **62** is located as near as possible to the adapter head **52** to enable the lower enclosed space **66** of the reservoir **53** to receive a maximum quantity of a treating agent (not shown). One or more lateral ports **67** (FIGURE 4A) are provided in the upper portion of the housing **51** to admit well control fluids into the upper enclosed space **65** of the

reservoir 53 as the tool 50 is used in practicing the methods of the present invention. Similarly, one or more normally-closed ports 68 (FIGURE 4B) are provided in the lower portion of the housing 52 and adapted, when open, for discharging a fluent substance from the lower enclosed space 66 of the reservoir 53. Accordingly, as will subsequently be explained, once the lower ports 68 are opened and the tool 50 is operated so as to admit a flow of well control fluids into the upper ports 67, the piston 62 will move downwardly in the reservoir 53 and displace a corresponding volume of the treating agent from the lower space 66 through the lower ports as the well control fluids enter the upper ports and fill the upper space 65.

To facilitate the movement of the tool 50 through a fluid-filled well bore to a starting position, the diverter 54 is initially retracted to provide sufficient clearance therearound between the housing 51 and the internal wall of the well casing (not shown). Similarly, although the piston 62 will normally tend to remain in its elevated position shown in FIGURE 4A so long as the diverter 54 is retracted, it is preferred to keep the ports 68 closed so that the fluent substance will not be lost from the lower space 66. It will be appreciated, therefore, that means must be provided to selectively extend the diverter 54 as well as open the ports 68 upon command from the surface.

Accordingly, as shown in FIGURE 4B, the diverter 54 is preferably comprised of a flexible sleeve 69 of an elastomeric material that is secured at its upper end around the central portion of the housing 51. The outer diameter of the housing 51 is reduced just below the upper end of the elastomeric sleeve 69 and appropriately formed to provide longitudinally-spaced external surfaces 70 and 71 of equal diameter that are separated from one another by an external surface 72 of a more-reduced diameter. An elongated sleeve member 73 having an enlarged-diameter upper portion 74 is slidably mounted around the reduced central portion of the housing 51 and fluidly sealed thereto by sealing members 75 and 76 respectively encircling the spaced external surfaces 70 and 71. The elastomeric sleeve 69 is disposed around a plurality of longitudinally-extending, outwardly-bowed flexible strips 77 that are circumferentially spaced around the housing 51 and have their upper and lower ends secured between opposed shoulders 78 and 79 on the housing and enlarged portion 74 of the slidable sleeve members 73 respectively. The lower end of the elastomeric sleeve 69 is carried below the lower end of the bowed spring strips 77 and secured around the enlarged sleeve portion 74. To insure that the spring strips 77 will remain in the outwardly-bowed position shown in FIGURE 4B, the enlarged portion 74 of the slidable sleeve member 73 is extended upwardly to about the middle of the spring strips and progressively enlarged so as to engage the rear surface of each strip and keep the central portion of the strips bowed outwardly.

It will be appreciated, therefore, that so long as the slidable sleeve member 73 remains in the position illustrated in FIGURE 4B, the elastomeric sleeve 69 will retain its generally relaxed position. By moving the slidable sleeve 73 upwardly in relation to the housing 51, however, the sleeve shoulder 79 is moved toward the housing shoulder 78 to shorten the distance between the opposite ends of the spring strips 77 and cause their central portions to bow radially outwardly. Thus, as the slidable sleeve member 73 is moved upwardly, the outward movement of the midportions of the spring strips 77 will radially expand the central portion of the elastomeric sleeve 69 a corresponding distance. Conversely, by returning the sleeve member 73 downwardly, the spring strips 77 will relax and restore the elastomeric sleeve 69 to its original position.

Accordingly, it will be recognized that by releasably securing the slidable sleeve 73 in the position shown in FIGURE 4B, the diverter sleeve 69 will be maintained in its fully-retracted position and the tool 50 can be readily moved in a well bore with the well fluids therein freely bypassing the tool through the annular clearance around the diverter 54. To releasably secure the sleeve 73, the control section 55 includes latch means such as are provided by one or more ball members 80 that are loosely confined in lateral openings 81 spaced around the lower portion of the slidable sleeve and adapted to be partially retained in a peripheral groove 82 around the housing 51 by a second sleeve member 83 that is telescoped over the slidable sleeve and releasably coupled to the housing 51.

An inwardly-projecting lug 84 on the retaining sleeve 83 is normally engaged with a dog 85 disposed in a housing recess 86 below the retaining sleeve and pivotally mounted therein on a shaft 87 journalled to the housing 51. To retain the pivoted dog 85 in engagement with the lug 84, the control section 55 further includes a selectively-operable release such as an electrically-responsive detonator or so-called "explosive squib" 88 that is adapted for abutting engagement with the dog to prevent it from rotating into a non-abutting position. Biasing means, such as a compression spring 89 arranged between opposed shoulders on the sleeves 73 and 83, are provided to urge the retaining sleeve upwardly in relation to the slidable sleeve member once the explosive squib 88 has freed the dog 85 for rotation.

Accordingly, once the retaining sleeve 83 is allowed to move upwardly in relation to the slidable sleeve 73, a diametrical enlargement within the retaining sleeve, such as provided by longitudinal grooves or slots 90 that are respectively longitudinally aligned with the balls 80, is moved into juxtaposition with the retaining balls. It will be appreciated, therefore, that by appropriately sizing the retaining balls 80 in relation to the annular clearances between the inner surface of the peripheral groove 82 and the inner surface of the sleeve 83 on the one hand and the inner surface of the slots 90 on the other hand, the balls cannot be freed from the peripheral groove until the retainer sleeve has moved upwardly to bring the slots into registration with the balls.

By extending the retainer sleeve 83 upwardly and fluidly sealing it around the slidable sleeve 73 by sealing members 91 and 92 spaced above and below one or more ports 93 in the slidable sleeve and approximately in registration with the lower housing ports 68, the retainer sleeve also serves as a valve that selectively blocks the flow of a treating agent from the lower space 66 until the squib 88 is detonated and the diverter 54 is extended. Once, however, the squib 88 is detonated and the retainer sleeve 83 is moved upwardly relative to the slidable sleeve 73 by the spring 89, lateral ports 94 in the retainer sleeve are brought into registration with the housing ports 68 and ports 93 in the slidable sleeve to allow the treating agent to be exhausted therethrough as the piston 62 moves downwardly.

From the description of the tool 50 to this point, it will be seen that once all of the various elements described so far are in their respective positions depicted in FIGURES 4A and 4B, the diverter 54 will be retained in its retracted position so long as the explosive squib 88 is not detonated. When the squib 88 in the control section 55 is detonated, the spring 89 will urge the retainer sleeve 83 upwardly in relation to the slidable sleeve 73 which, at this time, is still secured to the housing 51 by the retainer balls 80. Once, however, the retainer sleeve 83 moves a sufficient distance upwardly to bring the slots 90 into registration with the outer surfaces of the balls 80, the combined force of a compression spring 95 carried between opposed shoulders on the slidable sleeve 73 and the housing 51 and another compression spring 96 will cause the balls to be cammed out of the circumferential groove 82 and into the enlarged annular space between the outer surface of the housing 51 and the inner surfaces of the slots 90. The spring 96 is engaged between a fixed shoul-

der 97 on the sliding sleeve 73 and an abutment 98 releasably secured at this time to the housing 51. The function of this movable abutment 98 and the manner of securing it will be subsequently explained.

Accordingly, it will be appreciated that once the balls 80 are released from the circumferential groove 82, the sliding sleeve 73 will be shifted upwardly by the combined force of the springs 95 and 96 to begin bowing the spring strips 77 outwardly. The retainer sleeve 83 is, of course, carried further upwardly by the sliding sleeve 73. It will be recognized, therefore, that the spring 89 will move the retainer sleeve 83 upwardly in relation to the sliding sleeve 73 to a position where the ports 93 and 94 are in registration with one another. Thus, once the sliding sleeve 73 reaches its elevated position, the sleeve ports 93 and 94 will be in registration with the housing ports 68. At this point, the bowed spring strips 77 will have been expanded outwardly a sufficient distance to bring the elastomeric sleeve 69 either very near to or into engagement with the inner wall of the casing. This will, therefore, block the annular space between the tool 50 and the casing.

Once the diverter 54 is fully expanded and the ports 68 opened, it will be appreciated that upward movement of the tool 50 will force the well bore fluids through the ports 67 at the upper end of the housing 51 and into the upper enclosed space 65 therein. Thus, continued upward movement of the tool 50 will be effective to move the piston 62 downwardly in relation to the housing 51. As the piston 62 moves downwardly, the treating agent in the lower enclosed space 66 will, of course, be forced therefrom by way of the lower ports 68 and into the annulus between the tool 50 and well casing below the expanded diverter 54.

When the piston 62 nears the lower limit of travel, a depending tubular probe 99 thereon will engage the inwardly-projecting ends of a plurality of inclined dogs 100 that are each carried in a housing recess 101 on a pivot pin 102 journalled to the housing 51 and have their outwardly-extending upper ends abutted against the lower face of the abutment 98. Biasing means, such as reversely-bent springs 103, are provided to normally maintain the upper ends of the dogs 100 extended in the position shown in FIGURE 4B to support the abutment 98 against the force of the spring 96.

As seen in FIGURES 6A and 6B, once the lower end of the depending probe 99 from the piston 62 engages and passes the inwardly-projecting lower ends of the pivoted dogs 100, the dogs will be cammed to a generally erect position once the piston has reached the shoulder 57. Once the dogs 100 are pivoted into an upright position, the compressive force of the spring 96 will shift the sliding abutment 98 downwardly in relation to the sleeve member 73 until an inwardly-projecting shoulder 104 thereon halts further travel of the abutment. With the spring 96 confined between the shoulders 97 and 104 on the sleeve member 73, the spring 96 will, of course, no longer be effective to urge the sleeve member upwardly in relation to the housing 51 and only the force of the spring 95 will be maintaining the sleeve member in its elevated position. Although the elastomeric sleeve 69 is shown still extended in FIGURES 6A and 6B for purposes of illustrating that position, it will be recognized, of course, that once the abutment 98 is released, the spring strips 77 will begin expanding.

Accordingly, by selecting the spring 95 to have an effective spring force somewhat less than that required to bow the spring strips 77 outwardly against pressure forces acting downwardly on the diverter 54, once the spring 96 is immobilized between the shoulders 97 and 104, the forces tending to straighten the bowed spring strips will be effective to return the sleeve member back to its initial position. It will be realized, however, that although the spring 95 must be appropriately selected to have a spring force which, when combined with that of the spring 96, will be sufficient to bow the spring strips 77 outwardly in the previously described manner, the spring 95 by itself will not be sufficiently strong to prevent relaxation of the spring strips once the spring 96 is immobilized. Thus, it will be appreciated that the function of the releasably-secured abutment 98 is to selectively enable and disable the spring 95 by initially maintaining the spring 96 in a first position aiding the spring 95 and then, once the abutment is released, allowing the spring 96 to move to a second position in which the spring 95 is no longer effective to maintain the elastomeric sleeve 69 in its extended position.

Return of the slidable sleeve 73, will of course, carry the outer sleeve 83 back downwardly with little or no change in its position in relation to the slidable sleeve. It will also be noted from FIGURES 6A–6B that by providing ports 105 in the upper end of the tubular probe 99, once the probe enters the bore 58 the remaining treating agent in the lower enclosed space 66 of the reservoir 53 will continue flowing therefrom to allow the piston 62 to move to a final position abutting the shoulder 57.

Those skilled on the art will, of course, recognize that several arrangements can be employed in the control section 55 to selectively detonate the explosive squib 88 from the surface without risking a premature actuation of the perforator (not shown) therebelow. In the exemplary tool 50 it is preferred, however, to employ selectively-actuated switching means to further and more positively prevent actuation of the perforator before it is in position to correctly perforate the well bore.

Accordingly, as seen in FIGURES 4B and 5, a so-called "single-pole double-throw" switch 106 is mounted in the housing recess 86 and adapted for movement between a first switching position electrically connecting the explosive squib 88 to the conductor 60 and a second switching position electrically connecting the conductor 60 to the perforating devices (not shown) in the perforator. To accomplish this, the switch 106 is provided with an actuator 107 that is normally engaged with cam means, such as a flat 108, formed on a shaft 109 that is journalled at its opposite ends to the housing 51. A crank arm 110 secured to the shaft 109 and extending laterally therefrom is provided with a bifurcated end portion of clevis 111 that is movably coupled, as by a pin 112, to one end of an extension 113 dependingly secured from the lower end of the sleeve 73.

In this manner, so long as the slidable sleeve member 73 remains in the position shown in FIGURES 4A–4B, only the explosive squib 88 will be electrically connected to the conductor 60. Then, as seen in FIGURES 6A–6B, once the sleeve 73 is released, the switch 106 will be operated to electrically connect the conductor 60 to the perforator (not shown).

To employ the tool 50 in the practice of the methods of the present invention, a suitable non-plugging liquid or some selected fluent treating substance of a similar or different nature is introduced into the lower enclosed space 66 of the reservoir 53 as by a filling port that is then closed by a plug 114 (FIGURE 4A). Typical treating agents that may be used are acid, propping agents containing particulate solids of sand, metal, glass, plastic and the like as well as various cleaning agents, and suitable temporary plugging agents such as gelled kerosene, gelled carbon tetrachloride, or such commercially available protective formulations as "Black Magic" sold by Oil Base, Inc. of Houston, Tex., or "Plug Ban" as sold by Humble Oil and Refining Co. of Houston, Tex. Any suitable agent can be used, of course, so long as it does not react adversely with formation materials and fluids and can be removed from a perforation when it is produced. It should also be noted that as far as the tool 50 is concerned, improved results will be obtained where the treating substance has a lower density than that of the well control fluids so that once it is injected into the well bore, the fluent substance will not tend to settle downwardly away from the diverter 54.

Once the reservoir 53 is filled and the other elements of the tool 50 are in their respective positions shown in FIGURES 4A–4B, the tool is suspended from a suitable cable (not shown) and lowered into a well bore to a position somewhat below the formation interval that is to be completed. It will be understood, of course, that a perforator and a depth-determining device are included with the tool 50 and are preferably arranged somewhat in the manner as the tool 10 depicted in FIGURES 1–3. Once the tool 50 is in position, electrical current is applied from a power source at the surface to the conductor 60 to detonate the explosive squib 88 and the tool 50 is raised toward the formation interval to be perforated.

When the squib 88 is detonated, the retaining sleeve 83 is moved upwardly by the spring 89 to free the balls 80 from the circumferential groove 82 and release the slidable sleeve member 73. Once the sleeve 73 is released, the combined spring force of the springs 95 and 96 will move the slidable sleeve member upwardly to extend the diverter 54 against the downwardly-acting pressure forces thereon. The outer sleeve 83 will have moved upwardly relative to the slidable sleeve 73 to bring the ports 93 and 94 into registration so that, once the slidable sleeve member has moved upwardly a distance sufficient to extend the diverter, the ports 93 and 94 will be in alignment with the housing ports 68.

While the diverter 54 is being extended, the tool 50 is still being moved upwardly so that once the ports 68, 93 and 94 are in alignment and the diverter is extended, the continued upward movement of the tool will divert the well bore fluids above the expanded elastomeric sleeve 69 through the upper housing ports 67 and into the upper reservoir space 65. As the well bore fluids are diverted into the upper reservoir space 65, the piston 62 will be moved downwardly in relation to the housing 51 to discharge whatever fluent substance there is in the lower reservoir space 66 through the lower housing ports 68 and into the well bore below the elastomeric sleeve 69.

It will be recognized that the treating agent being expelled into the well bore is moving into the annulus from which the well bore fluid entering the upper enclosed space 65 has just been displaced by the "swabbing" action of the diverter 54 resulting from the upward movement of the tool 50. Thus, there will be little or no chance that the treating agent will be dispersed into the well bore fluids. In this manner, the continued upward travel of the tool 50 will insure that a substantially homogeneous mass of the fluent substance will simultaneously envelop the lower portion of the tool 50 below the diverter 54. Accordingly, by the time that the perforator on the tool 50 has been moved into a position adjacent the formation interval to be perforated, the perforator will be completely enveloped by a homogeneous mass of the selected treating agent.

Once it is determined that the perforator is correctly positioned, electrical current is applied from a power source at the surface to the suspension cable to actuate the perforator. It will be recalled that the release of the retaining sleeve 83 will have actuated the switch 106 to connect the perforator to the conductor 60. Although the tool 50 can be halted before the perforator is actuated, it is preferred to continue moving the tool 50 upwardly as the perforator is actuated to insure that the last portion of the treating agent is expelled from the reservoir 53 a short time after the well bore is perforated. It will be appreciated, of course, that the position of the perforator in relation to the formation interval being completed will be known at all times by virtue of typical depth indicators at the surface whose accuracy is confirmed by depth-correlation devices on the tool 50 such as the aforementioned casing-collar locator.

The effective volume of the reservoir 53 must, of course, be determined to insure that when the perforator is actuated, it is completely surrounded by the fluent substance. Moreover, where an enclosed retrievable carrier perforator is employed, the effective volume of the reservoir 53 should be sufficient to accommodate the volume of the fluent substance that will fill the carrier once it is perforated. In a typical arrangement of the tool 50 where an enclosed retrievable carrier perforator is used, the effective length of the lower enclosed space 66 will accordingly be in the order of about 1.5 to 2.0 times the length of the carrier. With relative proportions of this order, a continuing discharge of the fluent substance will be obtained as the tool 50 is moved further upwardly after the perforator is actuated.

Once the piston 62 reaches the lower limit of its travel as determined by the shoulder 57, the tubular probe 99 thereon will have actuated the pivoted latch fingers 100 to release the movable abutment 98 and disable the spring 95. Once the spring 95 is disabled, the elastomeric sleeve 69 will be restored to its retracted position and well bore fluids can again freely bypass the tool 50 as the tool is returned to the surface.

Turning now to FIGURE 7, a somewhat schematic view is shown of a second completion tool 200 which is also capable of practicing the methods of the present invention. As seen there, the tool 200 is suspended from a cable 201 in a cased well bore 202 just above an earth formation 203 which is to be completed in accordance with the principles of the present invention. The completion tool 200 preferably includes one or more typical centralizers 204 and 205 longitudinally spaced along the tool to maintain it centered in the well bore 202 as well as some means, such as a casing-collar locator 206, for determining the depth of the tool. A typical well perforator 207, such as an enclosed carrier 208 with one or more perforating devices or shaped charges 209 therein, is coupled below the collar locator 206 and electrically connected to the suspension cable 201 in such a manner that the perforator can be selectively actuated upon command from the surface. The lower portion of the tool 200 is comprised of a selectively-actuated fluid diverter 210 and a reservoir 211 adapted to contain a fluent substance for carrying out the particular completion operation.

As best seen in FIGURE 8, the fluid diverter 210 is preferably arranged in a similar fashion to the tool 50 previously described. Accordingly, as will be seen from a comparison of FIGURES 4A–4B with FIGURE 8, the fluid diverter 210 includes an elastomeric sleeve 212 that is releasably secured in a relaxed position by a sleeve 213 slidably mounted around the tool body 214. The slidable sleeve 213 is held in an elevated position on the body 214 by one or more retaining balls 215 that are loosely disposed in lateral openings in the sleeve and are normally retained in a circumferential groove 216 by an outer sleeve 217 slidably mounted around the upper portion of the inner sleeve 213. An electrically-responsive release, such as an explosive squib 218 engaging a pivoted latch 219, is employed to prevent a spring 220 mounted between opposed shoulders on the sleeves 213 and 217 from moving the outer sleeve downwardly in relation to the inner sleeve until the squib is detonated upon command from the surface.

Once the outer sleeve 217 is released and has moved downwardly a sufficient distance to allow the balls 215 to move outwardly into longitudinal slots 221 in the outer sleeve, the inner sleeve 213 will be urged downwardly by a compression spring 222 retained between opposed shoulders 223 and 224 on the body 214 and inner sleeve respectively. Once the inner sleeve 213 begins moving downwardly in relation to the body 214, the spring force of the spring 222 will be sufficient to bow a plurality of circumferentially spaced, longitudinal spring strips 225 that are confined within the elastomeric sleeve 212 and have their opposite ends engaged with opposed shoulders 226 and 227 on the tool body 214 and inner sleeve 213 respectively. Thus, downward movement of the inner sleeve 213 will cause the elastomeric

sleeve 212 to be expanded outwardly a sufficient distance to at least approach the inner surface of the well casing.

It will also be appreciated that the initial downward movement of the outer sleeve 217 by the spring 220 will bring one or more ports 228 in the sleeve into alignment with a corresponding number of ports 229 in the inner sleeve 213. Then, as the inner sleeve 213 is subsequently moved downwardly by the spring 222 and carries the outer sleeve 217 along with it, the ports 228 and 229 will be brought into registration with a plurality of ports 230 in the upper portion of the tool body 214. Once the ports 230 are uncovered, the upper end of a longitudinal bore 231 in the tool body 214 forming the upper end of the reservoir 211 is opened. Thus, once the elastomeric sleeve 212 is expanded and the ports 230 uncovered, downward movement of the tool 200 through the well bore 202 will force the well bore fluids 232 into a plurality of ports 233 in the upper end of the reservoir 211 to displace the treating agent 234 upwardly from the reservoir 211 and expel the agent through the ports 230 into the well bore 202 above the diverter 210. To insure that the treating agent 234 is displaced from the reservoir 211, a tubular member 235 is connected to the tool body 212 at the lower end of the bore 231 and extended downwardly therefrom to about the bottom of the reservoir.

Accordingly, to employ the tool 200 in practicing the methods of the present invention, a selected treating substance is disposed in the reservoir 211. Although this substance may be one of those previously described, it is preferred that this substance have a density somewhat greater than the density of the well bore fluids 232 to insure that the treating agent will remain as a homogeneous mass in the well bore 202 just above the expanded diverter 210.

Once the tool 200 has been brought into position just above the selected formation 203, the explosive squib 218 is detonated to expand the elastomeric sleeve 212 and open the ports 230. Thus, as the tool 200 is lowered further into the well bore 202, the well bore fluids 232 will be forced into the ports 233 to expel the treating agent 234 out of the ports 230 and envelop the annular clearance around the tool. Then, once the tool 200 has been lowered a sufficient distance to bring the perforator 207 into position opposite the formation 203, the perforator will be completely surrounded by the treating substance 234 and, upon detonation of the shaped charges 209, only the treating substance can enter the resulting perforations into the formation.

The tool 200 is simply raised to retrieve it to the surface following the actuation of the perforator 207. It will be recognized, of course, that the expanded diverter 210 will not materially hamper retrieval of the tool 200 since the well bore fluids 232 will pass freely through the tool by way of the ports 230 and 233 since they are interconnected by the tubular extension 235 and the bore 231. Accordingly, the tool 200 is also capable of practicing the methods of the present invention.

Turning now to FIGURE 9, another completion tool 300 is shown in a cased well bore 301 and in position for practicing the methods of the present invention. The tool 300 is suspended from a cable 302 and maintained in the center of the well bore 301 by a typical centralizer 303 mounted on the upper portion of the tool. A casing-collar locator 304 is also preferably included with the tool 300 for providing indications at the surface of the position of the tool in relation to an earth formation, as at 305, to be completed.

The completion tool 300 is comprised of a reservoir section 306 having a fluid diverter 307 and an anchor 308 mounted thereon. A typical perforator 309 dependently secured below the reservoir section 306 is provided with one or more perforating devices, such as shaped charges 310, that may be selectively actuated upon command from the surface. If desired, another centralizer (not shown) similar to the centralizer 303 may be arranged on the perforator 309 to assure that the perforator is centrally located in the well bore 301.

The reservoir section 306 is comprised of an outer tubular housing 311 that is slidably telescoped around an elongated axial tubular member 312 dependently coupled, as by an adapter 313, to the upper portion of the tool 300 and connected, as by another adapter 314, to the upper end of the perforator 309. The upper portion of the tubular housing 311 is reduced in diameter, as at 315, and provided with a fluid seal, such as an O-ring 316, to slidably seal the upper end of the housing in relation to the depending tubular supporting member 312. The central portion of the tubular support 312 is enlarged in diameter, as at 317, and provided with a fluid seal 318 that is slidably engaged with the inner wall of the tubular housing 311 so as to define an enclosed space 319 within the housing between the reduced upper end 315 thereof and the enlarged portion of the depending support member.

A somewhat larger tubular member 320 is dependently secured to the enlarged central portion 317 of the elongated tubular support 312 and coaxially extended downwardly around the lower portion of the support to about the upper end of the perforator 309. A passage 321 through the enlarged-diameter portion 317 is adapted to provide fluid communication from the enclosed space 319 to the annular space 322 between the depending support 312 and the tubular member 320. Selectively-operable valve means, such as an explosively-actuated valve 323, are provided to normally close the passage 321 and retain a treating agent 324 in the enclosed space 319 until the valve is actuated upon command from the surface. It will be appreciated that the axial passage 325 will permit suitable electrical conductors (not shown) to be passed from the upper portion of the tool 300 to the valve 323 and perforator 309.

The diverter 307 is comprised of one or more annular discs 326 of a thin, flexible material, such as may be cut from an elastomeric sheet, that are secured around the lower portion of the housing 311 and suitably sized to engage the inner walls of the cased well bore 301. It will be appreciated, however, that passage of the tool 300 through the well bore 301 will not be unduly hampered inasmuch as the well bore fluids 327 can readily pass around the flexible discs 326.

For reasons that will subsequently become apparent, the anchor 308 is adapted to frictionally engage the inner walls of the cased well bore 301 with a force greater than the restraining force provided by the centralizer 303 and any centralizer (not shown) mounted on the perforator 309. The restraining force provided by the anchor 308 is not so great, however, that the combined weight of the tool 300 will not carry the tool on downwardly into the well bore 301 as the cable 302 is unspooled from the surface. The anchor 308 is typically comprised of a number of so-called "drag blocks" or bowed spring strips 327 arranged in the usual fashion.

Accordingly, once the enclosed space 319 is filled with the treating agent 324, it will be recognized that as the suspension cable 302 is unspooled at the surface, the tool 300 will descend into the well bore 301. As the tool 300 descends, the flexible elastomeric diverter 307 will retract as necessary to allow the well bore fluids 327 to pass around the tool. It will be appreciated that so long as the valve 323 remains closed, the fluent substance 324 in the reservoir space 319 will retain the housing 311 and support member 312 in the positions illustrated and prevent their relative movement. Once the collar locator 304 indicates that the tool 300 is so located with respect to the formation 305 that the lower end of the reservoir 306 is about even with the upper limit of the formation interval and the upper end of the perforator 309 is about even with the lower limit, the tool is halted.

Then, to practice the present invention, the tool 300 is selectively enabled by opening the explosively-actuated valve 323. Once the valve 323 is opened, upward move-

ment of the suspension cable **302** will be effective to displace the treating agent **324** from the reservoir space **319** as the central support **312** and its enlarged portion **315** are moved upwardly in relation to the housing **311** which is now held stationary by the anchor **308**. As the treating agent **324** is discharged through the passage **321** and annular clearance **322**, the well fluids **327** will, of course, fill the void below the enlarged portion **317** as it is moved upwardly into the now-stationary housing **311**. Thus, the well fluids **327** in that portion of the well bore **301** below the elastomeric diverter **307** will be drawn upwardly into the reservoir housing **311** as these fluids are replaced by the treating agent **324**. By extending the tubular member **320** to near the upper end of the perforator **309**, the perforator will be progressively enveloped in a homogeneous mass of the fluent substance **324** as the perforator is brought upwardly into position. It will be recognized that by selecting the fluent substances **324** to have a lower density that that of the well fluids **327**, the diverter **307** will keep the substances from moving on up the well bore.

As a result, once the perforator **309** is at the upper limit of its travel (as determined by the collar locator and other typical depth-measuring devices at the surface), the movement of the cable **302** is halted. The perforator **309** is at this time completely surrounded by the fluent substance **324** so that when the perforator is actuated, only the fluent substance can enter the resulting perforations (not shown). The tool **300** is then simply withdrawn.

As described above, the tool **300** is arranged so that when the perforator **309** is at its upper limit of travel and is in position for actuation, the upper end of the perforator is somewhat below the lower end of the reservoir housing **311**. It will be appreciated, however, that the tool **300** could also be so arranged that the perforator **309** would enter the lower open end of the reservoir housing **311** and be at least partially received by the reservoir **306** when the shaped charges **310** are detonated. This would, of course, require that the housing **311** either be expendable or have appropriately located replaceable wall portions through which the perforating jets would pass. The advantage of this alternative arrangement would be that the overall length of this alternate tool would be reduced by a significant amount in relation to the length of the tool **300**.

Accordingly, it will be appreciated that the present invention has provided new and improved methods by which a well bore can be perforated to allow only selected fluent substances to enter the perforations. As described above, these methods can be conducted by any one of the several new and improved tools disclosed. It is quite apparent, therefore, that the present invention will enable a homogeneous mass of a selected substance to envelop a perforator before it is actuated so that only the substance will contact the formations when they are perforated. It should be realized, of course, that these fluid-displacement tools are also suitable for use either alone or with other well tools aside from a perforator.

While particular procedures of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A method for completing an earth formation traversed by a well bore containing fluids and comprising the steps of: suspending a tool including a perforator and a reservoir containing a fluent substance in a well bore proximate to an interval of said well bore that includes an earth formation to be completed; moving said tool into said well bore interval for simultaneously withdrawing fluids from said well bore interval into said reservoir and discharging said fluent substance into said well bore interval to envelop said perforator with said fluent substance as it enters said well bore interval; and once said perforator is adjacent to said earth formation, actuating said perforator for perforating said earth formation to place said fluent substances in communication with such earth formations.

2. A method for completing an earth formation traversed by a well bore containing fluids and comprising the steps of: replacing well bore fluids occupying an interval of a well bore which traverses an earth formation with a fluent substance while simultaneously moving a perforator into said well bore interval for enveloping said perforator with said fluent substance; and, actuating said perforator while it is enveloped in said fluent substance for producing perforations into said earth formation and placing said earth formation into communication with said fluent substance.

3. The method of claim **2** wherein said fluent substance is an oil-soluble plugging agent adapted to isolate said perforations from entry of well bore fluids.

4. The method of claim **2** wherein said fluent substance is composed of acidic constituents adapted to clean said perforations.

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