METHOD OF PLUGGING PERFORATIONS IN CASINGS

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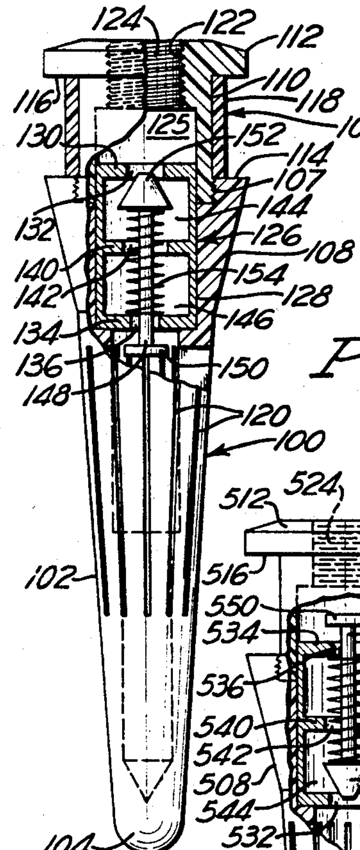

Fig. 1

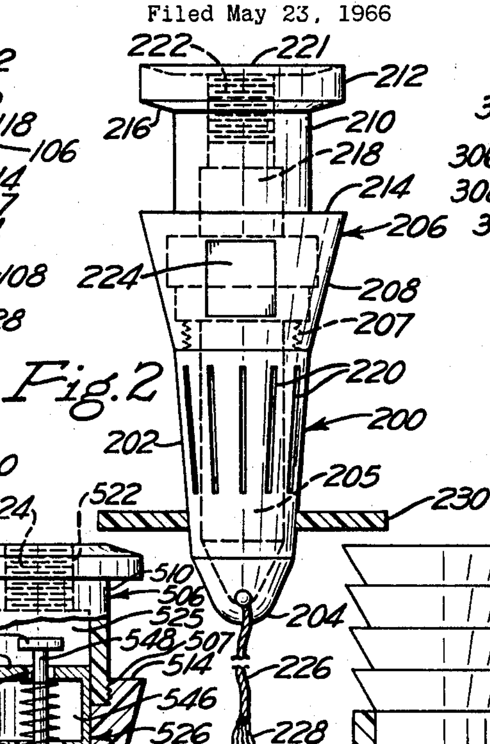

Fig. 2

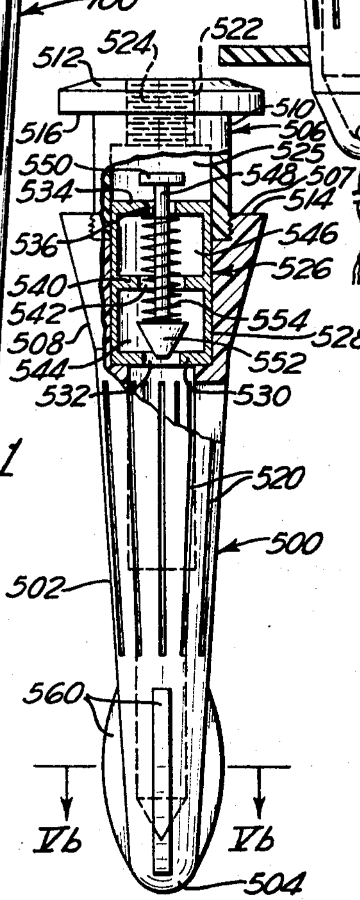

Fig. 5a

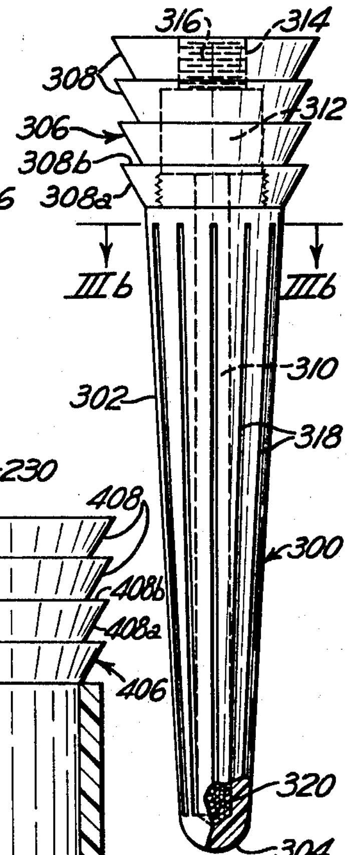

Fig. 3a

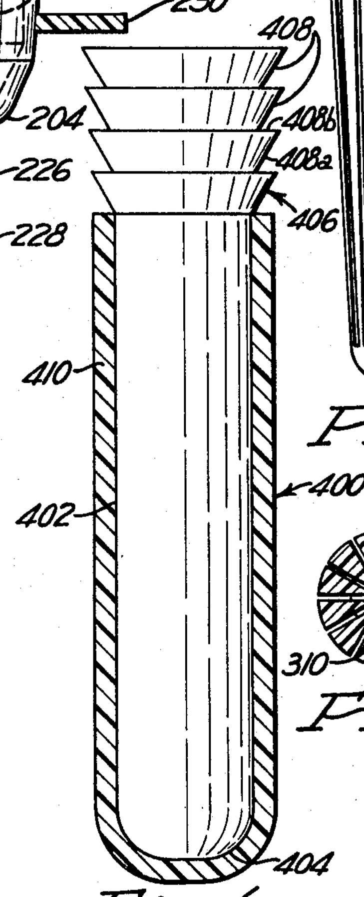

Fig. 4

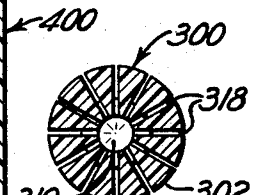

Fig. 3b

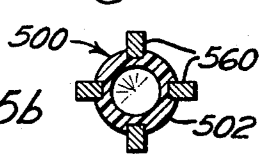

Fig. 5b

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ABSTRACT OF THE DISCLOSURE

The invention comprises casing plugs having an end cap having a largest diameter slightly larger than the diameter of the casing perforations and a tapering body. The plugs may be either permeable or impermeable to fluids. The method comprises introducing the plugs into a well one at a time in a carrier liquid and transporting them to the perforations where the liquid flowing into the perforations causes the plugs to turn and seat therein. Several system parameters are adjusted to assure that the hydrodynamic drag exerted upon the nose of the plug is sufficient to displace the plug laterally into the perforation.

This invention relates to a method for plugging perforations in a fluid carrying casing, and more particularly to perforations in the casing of a well bore penetrating a subsurface rock formation. The invention also relates to the specific construction of perforation plugs used in the process of the invention.

In drilling and completing a well bore penetrating a subsurface rock formation, it has become common practice to suspend in the well bore a string of casing, that is secured therein by a sheath of cement between the casing and the wall of the well bore. Thereafter, it is often desirable to establish fluid communication between the formation and the interior of the casing. A plurality of perforations are created in the casing and the cement sheath extending into the formation. During subsequent operation of the well it often becomes necessary or desirable to seal all or some of the casing perforations either permanently or temporarily, or to put sand screens in the perforation for various reasons well known to those skilled in this art.

It is an object of this invention to provide a method and apparatus for plugging or sealing casing perforations permanently without the use of special down-hole well bore tools.

Another object of this invention is to provide a method and apparatus which can be used in place of the so-called "squeeze cementing" method of sealing perforations.

A further object of this invention is to provide a means for inserting various different types of apparatus in casing perforations such as one-way valves, filtering plugs, apparatus adapted to indicate the occurrence in the well bore of a phenomenon of interest, apparatus adapted to enable automatic control of the well bore operation, and the like.

Still another object of this invention is to provide means for plugging casing perforations which employ injection pressures and fluid flow rates that are substantially lower than those hitherto required.

One form of the plug embodying the invention comprises an elongated body tapering inwardly from rear to front, having a cap at its rear end, and formed with a nose integral with the front end of the body. The cap has a largest transverse dimension larger than the diameter of the casing perforations. The center of the gravity of the plug is preferably located between the nose and the mid-point of the longitudinal axis of the plug. Engaging means are provided at the rear end to prevent dislodgment of the plug from the perforation.

According to the method of this invention, the plugs are introduced into the well bore one at a time in a carrier liquid that is displaced down the well bore and through the perforations into the formation. The particular carrier liquid employed is preferably one that will not damage the casing and other well bore apparatus and does not substantially impair the permeability of the formation adjacent the perforations. It is also desirable that the carrier liquid be chemically inert with respect to the material of which the perforation plugs are constructed. Suitable carrier liquids include water or brine, and various hydrocarbon liquids such as lease oil and crude oil.

The material for construction of the plugs is preferably one that is not deleteriously affected by the carrier liquid, that will not absorb the carrier liquid, that will be slightly deformable to seat properly, and that has a density substantially equal to the density of the carrier liquid. If the density of the plug is substantially less than that of the carrier liquid, the plug tends to float. If the density of the plug is substantially greater than that of the carrier liquid, the dynamic inertia of a downwardly moving plug is too great and the plug tends to flow past the perforations without seating. Specific suitable materials include nylon, Teflon, polystyrene and other plastics, and other light weight materials such as aluminum, depending, of course, on the carrier liquid.

As used herein, the term "density difference" is defined as the difference obtained by subtracting the density of the plug from the density of the carrier liquid. Density differences that are preferred lie within the range of from about −0.027 gram per cc. to about +0.018 gram per cc. As is readily apparent, the density difference can be accurately controlled by changing the density of the plug or changing the density of the carrier fluid, as with various additives. A preferred manner of adjusting the density difference by adjusting the density of the plug is by the use of a hollow plug having an inner chamber with an opening through the rear end of the plug provided with a removable closure. If such a plug is used, the empty plug will have an extremely low density owing to the fact tht a substantial portion of its total volume is occupied by air enclosed in the chamber within the plug. The weight and density of such a plug can be varied by the addition of any suitable weighting means, such as steel shot in the inner chamber.

If necessary or desirable for any reason, the plug can be coated with a protective substance such as an inert or impervious resin, rubber base paint, varnish, or lacquer.

As a plug approaches a perforation, the flow of carrier liquid through the perforation exerts a hydrodynamic force on the nose of the plug, hereinafter referred to as "drag," which is of sufficient magnitude to change the motion of the plug from axial to transverse in the casing to seat the plug in the perforation. The density difference is one factor affecting drag. Another factor is the location of the center of gravity of the plug, and we have found that, to obtain good seating, the center of gravity should be located between the nose and the mid-point of the longitudinal axis of the plug. An additional factor affecting drag is the available surface area of the plug upon which the drag can act. Therefore, an increase in the surface area of the nose will increase the total drag force. It has also been found that a piece of frayed string or the like tied to the nose of the plug increases the drag force and helps to guide it into the perforation.

It has been found that the invention will operate at relatively low flow rates, on the order of about 0.055 barrel per minute to about 0.170 barrel per minute. By comparison, flow rates of about 30 barrels per minute, for the same size pipe are required with devices such as ball sealers.

If it is desired to maintain fluid flow through perforation, plug permeability can be obtained by providing a plurality of fluid passages, such as slots, in the body of the plug. If it is desired to seal the perforation temporarily, the plug can be coated with a readily removable seal, and after placement, a weak acid or the like can be displaced down the well bore to reopen the plugs. Another means of rendering an otherwise permeable plug temporarily impermeable comprises securing a removable fluid-tight seal in a central opening in the rear end of a hollow plug, and using an acid to dissolve the seal. In this embodiment, ball sealers of the usual construction can be later used to seal the rear ends of the plugs.

Various illustrative embodiments of apparatus suitable for use in practicing the invention are shown in the accompanying drawing wherein;

FIG. 1 is a vertical view partially in cross section of a plug according to a first embodiment;

FIG. 2 is a vertical view of a second embodiment of the plug;

FIG. 3*a* is a view similar to FIG. 1 of a third embodiment;

FIG. 3*b* is a cross-sectional view taken on line III*b*—III*b* of FIG. 3*a*;

FIG. 4 is a view similar to FIG. 1 of a fourth embodiment;

FIG. 5*a* is a view similar to FIG. 1 of a fifth embodiment; and

FIG. 5*b* is a cross-sectional view taken on line V*b*–V*b* of FIG. 5*a*.

Referring in detail to the drawing, the various embodiments are generally indicated by the reference numerals **100**, **200**, **300**, **400** and **500**, respectively. Each of the plugs comprises a body **102**, **202**, **302**, **402** and **502**, respectively, a nose **104**, **204**, **304**, **404** and **504**; respectively, and a cap **106**, **206**, **306**, **406** and **506**, respectively. The cap can lie integral with the plug, joined thereto by threads, or joined thereto by any other suitable means such as a tongue and groove "pop-in" connection.

The longitudinal dimension of the plugs are each many times greater than the largest lateral dimension of the plug. The tapering longitudinal cross section of the body assures a streamlined configuration which is generally desirable in maintaining the plug oriented vertically with its nose downward in the carrier liquid, and in seating the plug in the perforation. However, there are instances when the plug body can have a cylindrical cross section such as the body **402** of plug **400**.

Plug bodies **102**, and **502**, of FIGS. 1 and 5*a*, respectively, have a rear body portion **108** and **508** sloping outwardly and rearwardly from the longitudinal axis of the body at a slightly greater angle than that of the major portions of bodies **102** and **502**. Caps **106**, and **506** comprise intermediate portions **110** and **510** which are cylindrical and of smaller diameter than the largest diameter of portions **108**, and **508**. The rear ends **112** and **512** of the caps have a transverse dimension substantially equal to or larger than the largest transverse dimension of the portions **108** and **508**. The rear end of body portions **108** and **508** comprises an annular shoulder **114**, and **514**. The caps are joined to the bodies by means of threads **107**, and **507** respectively.

Portions **110**, and **510** are circular in cross-section and of a diameter substantially equal to or just slightly smaller than the diameter of the perforation to be plugged. The junctures of portions **110** and **510** with their respective rear portions **112** and **512** form annular shoulders **116**, and **516**. Portions **112**, and **512** are slightly larger than the diameter of the perforation to be plugged, and the length of portions **110** and **510** is equal to or just slightly larger than the wall thickness of the casing around the perforation. This structure assures that the plug engages the casing around the perforation in fluid-tight relation therewith.

If a fluid-tight seal is not necessary, the plug can be constructed of a rigid or substantially non-deformable material. However, in most instances it is desirable to effect a fluid-tight seal, and it is then desirable that the plug be constructed of a slightly deformable material capable of forming a seal with the casing material.

In FIG. 1 a layer of resilient sealing material **118** is provided around the intermediate portion **110** of the cap. Any suitable gasket or sealing material, such as rubber or Teflon or a hardenable resin, may be used as gasket material **118**, so long as such material is resistant to damage by the well bore fluids and the formation fluids.

Plug **200** in FIG. 2 has a cap **206** which is similar to caps **106** and **506** plus their rear body portions, cap **206** comprises an outwardly tapering front portion **208**, similar to plug body portions **105** and **508**, and a rear portion **212** connected by a recessed intermediate portion **210**, said structure providing a front shoulder **214** and a rear shoulder **216**. Shoulder **216** of plug **200** slopes back toward the rear to form a better seal with the inside wall of the casing, since this slope conforms more closely than a flat annular surface to the curvature of the casing, particularly when small diameter casings are being plugged.

Plug **200** is hollow, and is formed with a chamber **205**. Body **202** may comprise plastic or metal, or any other suitable material. Body **202** is joined to its cap by threads **207**, at the front end of its cap portion **208**. Cap **206** has a central longitudinal opening **218** therein. Opening **218** extends throughout cap **206** and has the rear end **221** thereof adapted to receive a removable seal **222**. Alternatively, opening **218** can extend only partially from the front end of cap **206** toward the rear end thereof, thereby forming a blind inner chamber in the cap in communication and alignment with inner chamber **205** of body **202**. Body **202** of plug **200** is rendered permeable to fluids by a plurality of slots **220** or other openings extending through the wall thereof.

Secured in opening **218** is signal means **224**, represented diagrammatically in FIG. 2. The signal means can be constructed and arranged to be responsive to, and/or indicative of, the occurrence or presence in the well bore of a particular phenomenon of interest. Signal means **224** could be a miniature transmitter or other telemetering device. For example, signal means **224** can be thermally actuated to emit a warning signal responsive to an increase or decrease in well bore temperature. In other instances, signal means **224** can be responsive to changes in electrical conductivity of material within or surrounding the plug and thereby indicate the presence in the vicinity of the plug of such materials as saline interstitial water. Signal means **224** can be responsive to changes in the intensity of radioactivity and might thereby be indicative of the presence of tracer materials in the vicinity of the plug. Signal means **224** can be responsive to pressure variations, such as would be caused by the arrival of a transient pressure wave propagated through the formation around the well bore. Signal means **224** can be adapted to emit an output signal adapted to actuate automatic control means connected with the other well bore apparatus in a manner adapted to permit regulation or control of the well operations. Other applications of signal means **224** will be evident to those skilled in this art.

Each of the caps **306** and **406** is integral with its respective plug body **302** and **402** and has a plurality of outer circumferential ridges **308** and **408**. Each ridge **308** and **408** comprises an outwardly flaring side surface **308*a*** and **408*a*** and an annular surface **308*b*** and **408*b***. The rearmost ridge **308** and **408** has a largest diameter that is substantially equal to or slightly larger than the diameter of the perforation to be plugged. The outer diameters of the remaining ridges decrease in size from rear to front, to thereby create a barb-like structure to prevent movement of the plug within the perforation in either direction after seating in a perforation.

Plug **400** has a solid cylindrical body **402**, of metal or plastic or other suitable material that is unitary with a solid cylindrical cap **406**. Plug **400** is used to permanently seal a perforation. An optional structural element that can be employed with plug **400**, or with any of the other plugs, is outer coating **410**, which can be of a material that prevents attack or corrosion of the plug by well or carrier fluid or can serve as weighting material. Depending on its use, the coating can comprise a metal or plastic or other suitable material.

Plug **300**, shown in FIG. 3, is a hollow fluid-permeable plug having an inner chamber **310** in the plug body **302**. Chamber **310** is in communication with a central longitudinal opening **312** extending through cap **306**. The rear of opening **312** is threaded as at **314** or otherwise adapted to receive and secure a removable or destructible seal **316**. Body **302** is formed with a plurality of longitudinal slots **318** extending substantially along the entire length of the body. The slots also could be lateral extending partly around the circumference of the body, or could have any other orientation. Slots **318** should have a width which permits the flow of fluids therethrough and, in some instances, it is desirable to have a slot width which prevents the passage of formation particles through the plug while permitting the flow of fluids therethrough. Hollow plug **300** contains weighting material **320** such as glass beads, metallic pellets, or shot to increase the density of plug **302**. Any of the hollow plugs shown in the drawing can be used without any weighting material when it is desired to maintain a volume of air in the interior of the plug to create a relatively low plug density.

Plugs **100** and **500**, FIGS. 1 and 5, respectively, are also hollow, and the bodies **102** and **502** of each contain pluralities of slots **120** and **520**, to permit the flow of fluids through the plugs. Caps **106** and **506** have central openings **122** and **522** to receive a removable or destructible seal **124** and **524** in the rear of the cap. Also enclosed partially within caps **106** and **506**, and partially within the rear of the body, are fluid flow control means designated generally by reference numerals **126** and **526**. Means **126** and **526** are one-way valves, each comprising a valve housing **128** and **528** slidably secured in the composite openings **125** in the caps and rear body portions. Each housing **128** and **528** comprises an inlet closure **130** and **530** formed with a central inlet opening **132** and **532**, and an outlet closure **134** and **534** extending inwardly from the side wall of valve housing **128** and **528**, and formed with a central outlet opening **136** and **536**. An inner closure **140** and **540** extends inwardly from the wall of valve housing **128** and **528** and has a central opening **142** and **542** therein. Inner closure **140** and **540** separates the interior of each housing **128** and **528** into two separate chambers; namely, inlet chamber **144** and **544** and outlet chamber **146** and **546**.

A valve stem **148** and **548** extends through the outlet closure and outlet chamber of each of the valve means into the inlet chamber thereof. The outer end of valve stem **148** and **548** is integral with stop means **150** and **550** to limit the longitudinal motion of the valve stems through the valve housing. Valve sealer **152** and **552** is secured to the inner end of valve stem **148** and **548**, and are constructed and arranged to seat in inlet openings **132** and **532**. Helical spring **154** and **554** surround valve stem **148** and **548** and is encased within outlet chamber **146** and **546** of the one-way valves. Helical spring **154** and **554** is constructed and arranged to urge valve sealer **152** and **552** into forcible fluid-tight engagement with inlet closure **130** and **530** around inlet opening **132** and **532** until the closing force of the helical spring is overcome by fluid pressure exerted upon the one-way valve by fluid in the well bore and the cap of the plug (in the

case of plug **100**), or by fluid in the formation and the plug (in the case of plug **500**).

In FIGS. 1 to 5, the nose of the plug is integral with the body thereof. The nose could be a separate member and connected to the body in any suitable manner. Two structural elements affecting the magnitude and direction of the hydrodynamic force or drag exerted upon the liquid-borne plug are the configuration and surface area of the nose. The noses **104**, **304**, and **404** of plugs **102**, **302** and **402**, respectively, have substantially the same configuration but have different surface areas available to be acted upon by the drag during transport of the plug because of different radii of curvature.

With reference to FIG. 2 it is seen that plug **200** has a nose **204** having a configuration different from that described above. The rear of nose **204** is formed by increasing the slope frontwardly from the front end of plug body **202** and providing a curved tip on the nose. The configuration and surface area of nose **204** was found to be particularly suitable for use with relatively short plugs.

Various types of drag means have been incorporated into the front end of the plug to assure the exertion of sufficient drag to seat the plug in the perforation. FIG. 2 shows a flexible elongated leader **226** secured in nose **204** of plug **200**. Leader **226** preferably comprises string, twine or hemp, and has a frayed, free end **228**. As the plug approaches a perforation, leader **226** tends to follow the streamlines of carrier liquid flowing into the perforation and guides the nose of the plug in a course substantially coincident with those streamlines.

Another type of drag means, also in FIG. 2, comprises a perforated disc or washer-like member **230** which extends laterally from the front portion of plug body **202** substantially at the juncture of body **202** and nose **204**. Disc **230** should be oriented with its largest dimension substantially perpendicular to the longitudinal axis of the plug, and preferably between the center of gravity and the front end of the plug. Disc **230** can be of any shape but is preferably circular to provide for equal distribution of the forces applied to the plug. However, in certain instances, it is desirable to use a disc of asymmetrical shape to impart a desired amount of instability to the plug and thereby induce the plug to oscillate and follow the streamlines of carrier liquid flowing toward the perforation. Member **230**, being flexible, folds over and creates no substantial resistance to entrance of the plug body into the perforation.

Another drag means is shown in FIG. 5 and comprises a plurality of fins **560** equally spaced around the outer surface of plug **500**. The material used in the construction of the fins can be the same as, or different from the material employed in the construction of the body of the plug, depending upon the requirements of the drag means, such as, whether or not it is desirable to use a fin material that is capable of gradually absorbing carrier liquid so that the effect of the fins upon the flow behavior of the plug is increased with depth as the plug is transported down the well bore.

Practical application of this invention in field operations is explained in conjunction with the following example, wherein a well bore having therein a string of casing having a nominal inside diameter of 6.15 inch penetrates a rock formation at a subsurface depth of about 5000 feet. A plurality of perforations are formed in the casing over an interval of from about 4925 to about 4950 feet. Perforation plugs similar to that shown in FIG. 5*a* are injected in the well head, one at a time, into a stream of carrier liquid consisting of water. The density of the plug is adjusted to provide a density difference of +0.011 gram per cc. The carrier liquid and the entrained plugs are displaced down the well bore at a carrier liquid flow rate of 0.17 barrel per minute, and the plugs are introduced into the carrier liquid individually, for example, so as to provide intervals of about 10 feet between plugs in the flow stream. Under such conditions, the plugs first reaching the perforations through which the greater volume of fluid is flowing and, as those perforations are plugged, subsequent plugs will seat in other perforations until all of the perforations are plugged.

The use of this invention provides a means for plugging casing perforations simply and rapidly without extensive interruption of the operation of the well. This invention can be used to plug or seal casing perforations permanently or temporarily and can be employed to facilitate and supplement many well bore operations such as formation treatment, fluid displacement, formation consolidation, and so forth.

The slots **120**, **220**, **318**, and **520** permit the use of the respective plugs, if desired, as particle filters or screens. That is, filtering of fluid passing through the plug to remove sand or other particles from the fluid to prevent their entering into the well. A width of slot can be chosen based on particle size distribution for each particular formation so that the larger particles will bridge the slot and, thereafter a pack of particles will form around the plug and cause the formation to be retained in place.

While the invention has been described in some detail above, it is to be understood that the protection granted is to be limited only within the spirit of the invention and the scope of the following claims.

We claim:

1. A method of plugging perforations in the casing of a well bore comprising the steps of injecting a carrier fluid into the casing and through the perforations, introducing at least one elongated streamlined plug into the flow of carrier fluid going into the casing, adjusting the densities of the carrier fluid and the plugs, and adjusting the carrier fluid flow rate, whereby the plugs will be carried through the casing to the vicinity of a perforation with their axes substantially parallel to the direction of carrier fluid flow, and whereby the carrier fluid will thereafter exert a force on the plug to cause the plug to move substantially radially of the casing and partially through and into seating engagement within the perforation.

2. The method of claim **1**, and introducing said plugs into the flow of carrier fluid one at a time.

3. The method of claim **1**, wherein the density difference found by subtracting the density of the plug from the density of the carrier fluid is adjusted to a value within the range of about −0.027 to about +0.018.

4. The method of claim **1**, wherein the flow rate of the carrier fluid is adjusted to a rate within the range of about 0.055 barrel per minute to about 0.170 barrel per minute.

5. In combination with the method of claim **1**, rendering hollow plugs sealed against fluid flow, using the method of claim **1**, treating said well, and unsealing said sealed plugs seated in the casing perforations.

6. The method of claim **1**, introducing a plurality of said plugs to plug a plurality of perforations in said casing wherein said plugs comprise means to filter particles out of the fluid passing therethrough into said casing.

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