



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
05.12.2001 Bulletin 2001/49

(51) Int Cl.7: **E21B 43/04**

(21) Application number: **01304633.9**

(22) Date of filing: **25.05.2001**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE TR
 Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **30.05.2000 US 583305**

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(54) **Method and apparatus for improved fracpacking or gravel packing operations**

(57) Methods and apparatus for completing an unconsolidated subterranean zone penetrated by a well bore (510) are provided. The methods basically comprise the steps of placing a pre-packed screen (521) having an outer screen and an inner screen in the zone whereby an annulus (522) formed between the inner and outer screen is packed with sand, placing a shroud (520) in the zone, isolating the screens (521), shroud (520), and well bore (510) in the zone, and injecting particulate material into the annuli between the outer screen and the shroud (520) and between the shroud (520) and the well bore (510) to thereby form packs of particulate material therein to prevent the migration of fines and sand with produced fluids.

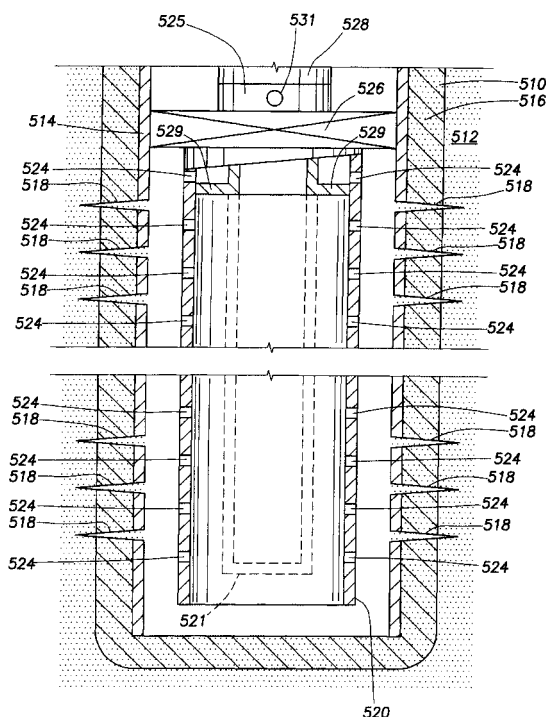


FIG.5

Description

[0001] The present invention relates to methods and apparatus for completing wells in unconsolidated subterranean zones, and more particularly, to improved methods and apparatus for completing such wells whereby the migration of fines and sand with the fluids produced therefrom is prevented.

[0002] Many reservoirs comprised of relatively young sediments are so poorly consolidated that sand will be produced along with the reservoir fluids unless the rate is restricted significantly. Sand production leads to numerous production problems, including erosion of downhole tubulars; erosion of valves, fittings, and surface flow lines; the well bore filling up with sand; collapsed casing because of the lack of formation support; and clogging of surface processing equipment. Even if sand production can be tolerated, disposal of the produced sand is a problem, particularly at offshore fields. Thus, a means to eliminate sand production without greatly limiting production rates is desirable. Sand production is controlled by using gravel pack completions, slotted liner completions, or sand consolidation treatments, with gravel pack completions being by far the most common approach.

[0003] In a gravel pack completion, sand or gravel that is larger than the average formation sand grain size is placed between the formation and a screen 110 or slotted liner. The gravel pack sand 106 (referred to as gravel, though it is actually sand in grain size), should retain most of the formation sand, but let very fine particles pass through it and be produced. The two most common types of gravel pack completions are an inside-casing gravel pack 102 and an openhole or underreamed-casing gravel pack 122. Examples of each are illustrated in Figures 1A-1B. The underreamed-casing gravel pack 122 provides better conductivity through the gravel 106, but is limited to single-zone completions. A successful gravel pack completion must retain the formation sand and offer the least possible resistance to flow through the gravel 106 itself.

[0004] For a successful gravel pack completion, gravel 106 must be adjacent to the formation without having mixed with formation sand, and the annular space between the screen and the casing or formation must be completely filled with gravel 106. Special equipment and procedures have been developed over the years to accomplish good gravel placement.

[0005] Water or other low-viscosity fluids were first used as transporting fluids in gravel pack operations. Because these fluids could not suspend the sand, low sand concentrations and high velocities were needed. Now, viscosified fluids, most commonly, solutions of hydroxyethylcellulose (HEC), are used so that high concentrations of sand can be transported without settling. Just as with the fluids used in hydraulic fracturing, it is desirable that these solutions degrade to low viscosity with little residue, requiring the addition of breakers to

the polymer solution.

[0006] In open-hole completions, the gravel-laden fluid can be pumped down 210 the tubing casing 226 annulus, after which the carrier fluid passes through the screen 204 and flows back up 220 the tubing. This is the reverse-circulation method 202 depicted in Figure 2A. A primary disadvantage of this method is the possibility of rust, pipe dope, or other debris being swept out of the annulus and mixed with the gravel, damaging the pack permeability. More commonly, a crossover method 250 is used, in which the gravel-laden fluid is pumped down 252 the tubing, crosses over 254 to the screen-open hole annulus 260, flows into a wash pipe 230 inside the screen 204, leaving the gravel in the annulus, and then flows up 270 the casing-tubing annulus to the surface as shown in Figure 2B. Notice that the open-hole section is usually underreamed 280 through the productive interval to increase well productivity.

[0007] For inside-casing gravel packing, washdown 300, reverse-circulation 302, and crossover methods 304 are used as shown in Figures 3A-3C. In the washdown method 300, the gravel 308 is placed opposite the productive interval before the screen 306 is placed, and then the screen 306 is washed down to its final position. The reverse-circulation 302 and crossover methods 304 are analogous to those used in open holes. A modern crossover method, is shown in Figure 3D-3F. Gravel 350 is first placed below the perforated 354 interval by circulation through a section of screen called the telltale screen 352. When this has been covered, the pressure increases, signaling the beginning of the squeeze stage. During squeezing, the carrier fluid leaks off to the formation, placing gravel in the perforation 354 tunnels. After squeezing, the washpipe 356 is raised, and the carrier fluid circulates through the production screen 358, filling the annulus formed between the casing 362 and the production screen 358 with gravel 350. Gravel 350 is also placed in a section of blank pipe above the screen 358 to provide a supply of gravel as the gravel 350 settles.

[0008] A problem that is often encountered in forming gravel packs, particularly gravel packs in long and/or deviated unconsolidated producing intervals, is the formation of sand bridges in the annulus. That is, non-uniform sand packing of the annulus between the screen and the well bore often occurs as a result of the loss of carrier liquid from the sand slurry into high permeability portions of the subterranean zone which in turn causes the formation of sand bridges in the annulus before all the sand has been placed. The sand bridges block further flow of the slurry through the annulus, which leaves voids in the annulus. An example of a sand bridge 402 and the resulting void 404 is illustrated in Figure 4A. When the well is placed on production, the flow of produced fluids is concentrated through the voids 404 in the gravel pack which soon causes the screen to be eroded and the migration of fines and sand with the produced fluids to result.

[0009] In attempts to prevent the formation of sand bridges in gravel pack completions, special screens having internal shunt tubes 406 have been developed and used. These shunt screens have flow tubes (shunts) 406 welded along the length of the gravel-pack screen 408 to bypass any bridges that may form in the annulus. If a bridge forms in the annulus, the slurry bypasses it by flowing through the shunts 406 and exiting through the nozzles as illustrated in Figure 4B. While such screens have achieved varying degrees of success in avoiding sand bridges, they, along with the gravel packing procedure are very costly and also reduce the diameter available for the production base pipe. Thus, there are needs for improved methods and apparatus for completing wells in unconsolidated subterranean zones whereby the migration of formation fines and sand with produced fluids can be economically and permanently prevented while allowing the efficient production of hydrocarbons from the unconsolidated producing zone.

[0010] The present invention provides improved methods and apparatus for completing wells, and optionally simultaneously fracture stimulating the wells, in unconsolidated subterranean zones that meet the needs described above and overcome the deficiencies of the prior art. The improved methods basically comprise the steps of placing a pre-packed screen having an outer screen and an inner screen in an unconsolidated subterranean zone whereby a first annulus is formed between the inner screen and the outer screen and the annulus is packed with sand, placing a shroud in the unconsolidated subterranean zone wherein a second annulus is formed between the shroud and the outer screen and a third annulus is formed between the shroud and the well bore whereby the second annulus provides an alternate path for the flow of particulate material and the third annulus provides a primary path for the flow of particulate material, isolating the annuli in the unconsolidated subterranean zone, and injecting particulate material into the third annulus between the shroud and the well bore whereby the second annulus between the shroud and the outer screen forms an alternate path for the flow of the particulate material such that the particulate material is uniformly packed in the second and third annuli and the migration of formation fines and sand with fluids produced into the well bore from the zone is prevented. The permeable pack of particulate material formed prevents the migration of formation fines and sand with fluids produced into the well bore from the unconsolidated subterranean zone.

[0011] As mentioned, the unconsolidated subterranean formation can be fractured prior to or during the injection of the particulate material into the unconsolidated producing zone, and the particulate material can be deposited in the fractures as well as in the annuli between the inner and outer screen, between the outer screen and the shroud, and between the shroud and the well bore.

[0012] The apparatus of this invention are basically comprised of a shroud having perforations there-through; a first screen cylindrically disposed within the shroud whereby a first annulus is formed between the shroud and the screen wherein the first annulus provides an alternate path for the flow of particulate material, and a second screen cylindrically disposed within the first screen whereby a second annulus is formed between the first screen and the second screen. For small diameter well bores, only a first screen is used.

[0013] According to another aspect of the invention there is provided a method of completing an unconsolidated subterranean zone penetrated by a well bore comprising the steps of:

(a) placing in said zone a pre-packed screen having an outer screen and an inner screen whereby a first annulus is formed between said inner screen and said outer screen said first annulus is pre-packed with sand;

(b) placing in said zone a shroud wherein a second annulus is formed between said shroud and said outer screen and a third annulus is formed between said shroud and said well bore whereby said second annulus provides an alternate path for the flow of particulate material and said third annulus provides a primary path for the flow of particulate material;

(c) isolating said annuli in said zone; and

(d) injecting particulate material into said third annulus between said shroud and said well bore whereby said second annulus between said shroud and said outer screen forms an alternate path for the flow of said particulate material such that said particulate material is uniformly packed in said second and third annuli and the migration of formation fines and sand with fluids produced into said well bore from said zone is prevented.

[0014] In an embodiment, the particulate material is sand; the subterranean zone may be open-hole. The well bore in said subterranean zone may have casing cemented therein with perforations formed through the casing and cement.

[0015] In an embodiment, the annuli are isolated in accordance with step (b) by setting a packer in said well bore.

[0016] In an embodiment, the method further comprises the step of creating at least one fracture in said subterranean zone prior to carrying out step (d).

[0017] In an embodiment, the method further comprises the step of creating at least one fracture in said subterranean zone while carrying out step (d).

[0018] In an embodiment, the method which further comprises the step of depositing particulate material in said fracture.

[0019] According to another aspect of the invention there is provided a method of completing an unconsolidated

idated subterranean zone penetrated by a well bore comprising the steps of:

- (a) placing in said zone a shroud and a screen disposed therein whereby a first annulus is formed between said screen and said shroud and a second annulus is formed between said shroud and said well bore;
- (b) isolating said annuli in said zone;
- (c) injecting particulate material into said second annulus between said shroud and said well bore whereby said first annulus provides an alternate path for the flow of particulate material whereby particulate material is uniformly packed in said first and second annuli and the migration of formation fines and sand with fluids produced into said well bore from said zone is prevented.

[0020] In an embodiment, the annuli are isolated in accordance with step (b) by setting a packer in said well bore.

[0021] In an embodiment, the method further comprises the step of creating at least one fracture in said subterranean zone prior to carrying out step (c).

[0022] In an embodiment, the method further comprises the step of creating at least one fracture in said subterranean zone while carrying out step (c).

[0023] In an embodiment, the method further comprises the step of depositing particulate material in said fracture.

[0024] According to another aspect of the invention there is provided an apparatus for completing an unconsolidated subterranean zone penetrated by a well bore comprising: a shroud having perforations therethrough; and a first screen cylindrically disposed within said shroud whereby a first annulus is formed between said shroud and said screen wherein said first annulus provides an alternate path for the flow of particulate material.

[0025] In an embodiment, the first screen comprises a sintered metal layer.

[0026] In an embodiment, the perforations are substantially 7/16 inches (11.1 mm) in diameter.

[0027] In an embodiment, the first screen comprise a wire wrap.

[0028] In an embodiment, the perforations are arranged in rows with individual perforations spaced two inches (50.8 mm) apart and with perforations on adjacent rows set off by one inch (25.4 mm).

[0029] In an embodiment, the apparatus further comprises a second screen cylindrically disposed within said first screen whereby a second annulus is formed between said first screen and said second screen.

[0030] In an embodiment, the second annulus is filled with particulate matter.

[0031] In an embodiment, the second screen comprises smaller openings than does said first screen.

[0032] In an embodiment, the second screen com-

prise a wire wrap.

[0033] In an embodiment, the first screen comprises a first wire wrap, the second screen comprises a second wire wrap, and the diameter of wire for said first wire wrap is larger than the diameter of wire for said second wire wrap.

[0034] The improved methods and apparatus of this invention avoid the formation of sand bridges in the annulus between the shroud and the well bore thereby producing a very effective sand screen for preventing the migration of fines and sand with produced fluids. Furthermore, the screen is more durable and less sensitive to washing out during the gravel placement during FracPack (fracturing and gravel packing a formation in one step) and gravel pack operations than are prior art screens. Additionally, the present invention maximizes the base pipe diameter by minimizing the space required for the sand screen.

[0035] It is, therefore, a general object of the present invention to provide improved methods of completing wells in unconsolidated subterranean zones having more durable screens that are relatively insensitive to washing out during gravel placement during FracPac and gravel pack operations.

[0036] Reference is now made to the accompanying drawings, in which:

Figures 1A-1B (Prior Art) illustrate examples of gravel pack completions for an inside-casing gravel pack and for an openhole or underreamed-casing gravel pack;

Figures 2A-2B (Prior Art) illustrate methods of pumping the carrier fluid through the tubing casing; Figures 3A-3C (Prior Art) illustrate washdown, reverse-circulation, and crossover methods for inside-casing gravel packing;

Figure 3D-3F (Prior Art) illustrates a modern crossover method for inside-casing gravel packing;

Figure 4A (Prior Art) illustrates a sand bridge inside a well bore;

Figure 4B (Prior Art) illustrates a sand screen having a shunt valve to provide an alternate path to pack sand in the annulus;

Figures 5-7 illustrates a vertical well bore having casing cemented therein extending into an unconsolidated subterranean zone with dual screen and shroud according to an embodiment of the present invention;

Figure 8 illustrates a perforation pattern for the shroud;

Figures 9 and 10 illustrate a horizontal open-hole well bore with dual screen and shroud according to an embodiment of the present invention;

Figures 11A and 11 B depict a quarter section cutout view showing more detail of a preferred screen and shroud assembly suitable for use as the screen and shroud assembly shown in Figures 5-7 and 9-10;

Figure 12 shows a sectional cutout view of a pre-

ferred pre-packed dual screen assembly 1200 suitable for use as dual screen 521 and 935 is illustrated;

Figure 13 shows a base pipe with perforations disposed within a single all metal premium screen disposed within a shroud;

Figure 14 shows an alternative embodiment of a single screen assembly wherein the single all metal premium screen is a pleated screen.

[0037] The present invention provides improved methods of completing, and optionally simultaneously fracture stimulating, an unconsolidated subterranean zone penetrated by a well bore. The methods can be performed in either vertical or horizontal well bores which are open-hole or have casing cemented therein. The term "vertical well bore" is used herein to mean the portion of a well bore in an unconsolidated subterranean producing zone to be completed which is substantially vertical or deviated from vertical in an amount up to about 80°. The term "horizontal well bore" is used herein to mean the portion of a well bore in an unconsolidated subterranean producing zone to be completed which is substantially horizontal or at an angle from vertical in the range of from about 80° to about 90°.

[0038] Referring now to the drawings and particularly to Figures 5-7, a vertical well bore 510 having casing 514 cemented therein is illustrated extending into an unconsolidated subterranean zone 512. Casing 514 is bonded within well bore 510 by a cement sheath 516. A plurality of spaced perforations 518 produced in well bore 510 utilizing conventional perforating gun apparatus extend through casing 514 and cement sheath 516 into unconsolidated producing zone 512.

[0039] In accordance with the methods of the present invention, a shroud 520 having a pre-packed dual-screen 521 installed therein whereby an annulus 522 is formed between dual screen 521 and shroud 520 is placed in well bore 510. Shroud 520 and dual screen 521 have lengths such that they substantially span the length of the producing interval in well bore 510. Shroud 520 is of a diameter such that when it is disposed within well bore 510, an annulus 523 is formed between it and casing 514. Holes 524 in shroud 520 can be circular as illustrated in the drawings, or they can be rectangular or other shapes.

[0040] For example, if well bore 510 has an outer diameter casing of seven inches, then, in one embodiment, hole 524 size is 7/16 inches (11.1 mm) in diameter. Eighteen rows of holes 524 are centered at 1.22 inches (31 mm) apart along the circumference of shroud 520. Each row has six holes for each foot (0.305 m) of length (two inch spacing [51 mm]). The rows are arranged down the side of shroud 520. Adjacent rows of holes 524 are off set by one inch (25.4 mm) so that for every two rows, there will be a hole 524 every inch (25.4 mm) along shroud 520 as illustrated by the pattern 800 in Figure 8. This corresponds to 108 holes 524 per foot

(0.305 m) of shroud 520, which comes out to an area of 16.24 square inches (106 cm²) of holes 524 per linear foot (0.305 m) of shroud 520. If the perforations are at 22 shots per linear foot (0.305 m) of casing (spf) with 0.9 inch (22.9 mm) perforations, the open area is 13.99 square inches (90 cm²). Therefore, the flow are through shroud 520 will exceed the flow area through perforations 518. Thus, the flow restrictions introduced with shroud 520 are minimized. These dimensions and layout are given merely as examples of a shroud. However, other dimensions and layouts will be obvious to one skilled in the art.

[0041] As shown in Figures 5-7, shroud 520 and pre-packed dual screen 521 are connected to a cross-over 525 which is in turn connected to a production string 528. A production packer 526 is attached to cross-over 525. Cross-over 525 and production packer 526 are conventional gravel pack forming tools and are well known to those skilled in the art. Cross-over 525 is a sub-assembly which allows fluids to follow a first flow pattern whereby particulate material suspended in a slurry can be packed in the annuli 522 and 523 between dual screen 521 and shroud 520 and between shroud 520 and well bore 510. That is, as shown by the arrows in Figure 6, the particulate material suspension flows from inside production string 528 to annuli 523 and 522 between dual screen 521 and shroud 520 by way of two or more ports 529 in cross-over 525. Simultaneously, fluid is allowed to flow from inside dual screen 521 upwardly through cross-over 525 to the other side of packer 526 outside of production string 528 by way of one or more ports 531 in cross-over 525. By pipe movement or other procedure, flow through cross-over 525 can be selectively changed to a second flow pattern (shown in Figure 7) whereby fluid from inside dual screen 521 flows directly into production string 528 and ports 531 are shut off. The production packer 526 is set by pipe movement or other procedure whereby annulus 523 is sealed.

[0042] After shroud 520 and dual screen 521 are placed in well bore 510, annulus 523 between shroud 520 and casing 514 is isolated by setting packer 526 in casing 514 as shown in Figure 5. Thereafter, as shown in Figure 6, a slurry of particulate material 527 is injected into annulus 522 between dual screen 521 and shroud 520 by way of ports 529 in cross-over 525 and into annulus 523 between casing 514 and shroud 520. The particulate material flows into perforations 518 and fills the interior of casing 514 below packer 526 except for the interior of dual screen 521. That is, as shown in Figure 6, a carrier liquid slurry of particulate material 527 is pumped from the surface through production string 528 and through cross-over 525 in to annulus 522 between dual screen 521 and shroud 520. From annulus 522, the slurry flows through holes 524 and through the open end of shroud 520 into annulus 523 and into perforations 518. The carrier liquid in the slurry leaks off through perforations 518 into unconsolidated zone 512 and through dual screen 521 from where it flows through cross-over

525 and into casing 514 above packer 526 by way of ports 531. This causes particulate material 527 to be uniformly packed in perforations 518, in annulus 523 between shroud 520 and casing 514 and within annulus 522 between dual screen 521 and the interior of shroud 520.

[0043] After the particulate material 527 has been packed into well bore 510 as described above, the well is returned to production as shown in Figure 7. The pack of particulate material 527 formed filters out and prevents the migration of formation fines and sand with fluids produced into well bore 510 from the unconsolidated subterranean zone 512.

[0044] Referring now to Figures 9 and 10, a horizontal open-hole well bore 930 is illustrated. Well bore 930 extends into an unconsolidated subterranean zone 932 from a cased and cemented well bore 933 which extends to the surface. As described above in connection with well bore 510, a shroud 934, having a dual screen 935 disposed therein whereby an annulus 941 is formed between shroud 934 and screen 935, is placed in well bore 930. Shroud 934 and dual screen 935 are connected to a cross-over 942 which is in turn connected to a production string 940. A production packer 936 is connected to cross-over 942 which is set within casing 937 in well bore 933.

[0045] In carrying out the methods of the present invention for completing unconsolidated subterranean zone 932 penetrated by well bore 930, shroud 934 with dual screen 935 therein is placed in well bore 930 as shown in Figure 9. Annulus 939 between shroud 934 and well bore 930 is isolated by setting packer 936. Thereafter, a slurry of particulate material is injected into annulus 941 between dual screen 935 and shroud 934 and by way of holes 938 into the annulus 939 between shroud 934 and well bore 930. Because the particulate material slurry is free to flow through holes 938, the particulate material is uniformly packed into annulus 939 between well bore 930 and shroud 934 and into annulus 941 between dual screen 935 and shroud 934. The pack of particulate material 940 formed filters out and prevents the migration of formation fines and sand with fluids produced into well bore 930 from subterranean zone 932.

[0046] Turning now to Figures 11A and 11B, a quarter section cut-out view showing more detail of some aspects of a preferred screen and shroud assembly suitable for use as the screen and shroud assembly shown in Figures 5-7 and 9-10 is illustrated. (Note, not all features illustrated in Figures 5-7 and 9-10 are shown herein.) The well bore 1110 has a well casing 1112 that prevents the formations around the well bore 1110 from collapsing the well bore 1110. Well bore perforations 1114 allow fluid from the formations to flow into the well bore 1110. Inside the well bore 1110 is located a gravel pack packer 1116. Gravel pack packer 1116 is connected to a pre-packed screen 1122 by a swivel sub 1160. Swivel sub 1160 prevents torque from being transmitted

through screen 1122 to sump seals 1130 below. A three-way adapter 1120 connects an outer shroud 1124 to gravel pack packer 1116. A base pipe (not shown) is cylindrically disposed within screen 1122 that is cylindrically disposed within outer shroud 1124. Screen 1122 is attached directly to a sump packer 1126. Outer shroud 1124 simply hangs around screen 1122 from three-way adapter 1120. Optionally, shroud 1124 can be attached to sump seals 1130 to create a pressure tight fit if necessary for a particular application. Three-way adapter 1120 contains ports 1165 to provide the alternate flow path for gravel packing as high above screen 1122 as possible without the interference of shroud 1124. The size of ports 1165 is limited to encourage flow to the outside of shroud 1124 first.

[0047] Preferably, outer shroud 1124 is constructed from a very soft, easily milled, composite material. This allows for screen 1122 to be larger for a given casing size. If the need arose to fish screen assembly 1100, shroud 1124 can be milled out during the washing of screen 1122. In this embodiment, three-way adapter 1120 is constructed out of soft steel to assist in the milling.

[0048] Sump packer 1126 and sump seals 1130 isolate perforations 1114 in well bore 1110 for the unconsolidated subterranean zone of interest from the subterranean zones below and serve as a foundation to accumulate sand for the gravel pack. The pre-packed screen seals 1128 prevent fluid loss from the zone of interest into the subterranean zones below.

[0049] Pre-packed screen 1122 prevents sand and other unwanted particulate matter from being produced along with the desired fluids. Pre-packed screen 1122 essentially consists of an outer screen (not shown) and an inner screen (not shown) separated by an annulus (not shown) that is pre-packed with gravel (not shown). More detail about the pre-packed screen 1122 is provided below. Outer shroud 1124 and the outer screen define an annulus 1132. Outer shroud 1124 and well bore 1110 define an annulus 1150. Annulus 1132 provides an alternate path for the flow of gravel pack material during gravel packing. This alternate flow path prevents uneven packing of and the formation of sand bridges in the well bore 1110 by allowing the gravel pack material to bypass the pile-up. Thus gravel pack material is uniformly packed.

[0050] Turning now to Figure 12, a sectional cut-out view of a preferred pre-packed dual screen assembly 1200 suitable for use as dual screen 521 and 935 and pre-pack screen 1122 is illustrated. Pre-packed dual screen assembly 1200 has an inner base pipe 1201 having perforations 1202 therein for receiving the flow of produced hydrocarbons for production to the surface. An inner screen 1204 covers inner base pipe 1201. Inner screen 1204 consists of a wire wrap that wraps base pipe 1201 with wire wherein a gap is formed between inner screen 1204 and base pipe 1201 by the presence of raised bars 1205 that are fixed to the side of base

pipe 1201 between perforations 1202. An outer screen 1206 covers inner screen 1204 with a thin layer of gravel 1207 filling the annulus between inner screen 1204 and outer screen 1206, thus preventing voids. Inner screen 1204 allows produced hydrocarbons to flow through pre-pack gravel 1207, then move longitudinally unimpeded around base pipe 1201 to its nearest perforation 1202. Gravel used for pre-pack gravel 1207 may or may not be resin-coated and is very thin compared to gravel used with regular pre-pack screens. Preferably, inner screen 1204 is a microscreen with smaller diameter filter openings than outer screen 1206. Outer screen 1206 is preferably a regular outer screen jacket as conventionally used with prepacks, such screen jackets being well known to one of ordinary skill in the art.

[0051] In an alternative embodiment, dual screen 521 and 935 is replaced by a single screen. This embodiment is preferred in smaller diameter screen assemblies. Figure 13 shows a base pipe 1305 having perforations 1307 disposed within a single all metal premium screen 1310 disposed within a shroud 1315. Preferably, the screen 1310 diameter is approximately 1/2 inch larger than the outside diameter of base pipe 1305. Thus, allowing for a larger diameter base pipe 1305 than is allowed for with pre-packed screens.

[0052] An alternative example of a single all metal premium screen assembly is depicted in Figure 14. In this example, single screen 1310 is replaced with a pleated screen 1410. Pleated screen 1410 has more than twice the filtering surface area of traditional screens, thus, greatly increasing its contaminant capacity. This results in reduced plugging tendencies and greater flow throughput.

[0053] Preferably, single screen 1310 or pleated screen 1410 is a sintered metal, that is, it is constructed from multiple layers of woven, stainless steel wire mesh sintered together into a rugged, porous material. By sintering the layers, each wire is metallurgically bonded to the adjacent wires and layers of the screen, thus maximizing the strength and durability. This yields self-supporting filter media which do not deform, even under extreme pressures. The various wire mesh layers are selected to achieve accurate particle size control while maximizing flow rates. This may vary depending on the type of fines found in the unconsolidated zone. The appropriate size mesh layers to use for a particular application will be obvious to one of ordinary skill in the art.

[0054] The particulate material utilized in accordance with the present invention is preferably graded sand which is sized based on a knowledge of the size of the formation fines and sand in the unconsolidated subterranean zone to prevent the formation fines and sand from passing through the gravel pack, i.e., the formed permeable sand pack 527 and 940. The graded sand generally has a particle size in the range of from about 10 to about 70 mesh, U.S. Sieve Series. Preferred sand particle size distribution ranges are one or more of 10-20 mesh, 20-40 mesh, 40-60 mesh or 50-70 mesh, de-

pending on the particle size and distribution of the formation fines and sand to be screened out by the graded sand.

[0055] The particulate material carrier liquid utilized, which can also be used to fracture the unconsolidated subterranean zone if desired, can be any of the various viscous carrier liquids or fracturing fluids utilized heretofore including gelled water, oil base liquids, foams or emulsions. The foams utilized have generally been comprised of water based liquids containing one or more foaming agents foamed with a gas such as nitrogen. The emulsions have been formed with two or more immiscible liquids. A particularly useful emulsion is comprised of a water-based liquid and a liquified normally gaseous fluid such as carbon dioxide. Upon pressure release, the liquified gaseous fluid vaporizes and rapidly flows out of the formation.

[0056] The most common carrier liquid/fracturing fluid utilized heretofore which is also preferred for use in accordance with this invention is comprised of an aqueous liquid such as fresh water or salt water combined with a gelling agent for increasing the viscosity of the liquid. The increased viscosity reduces fluid loss and allows the carrier liquid to transport significant concentrations of particulate material into the subterranean zone to be completed.

[0057] A variety of gelling agents have been utilized including hydratable polymers which contain one or more functional groups such as hydroxyl, cis-hydroxyl, carboxyl, sulfate, sulfonate, amino or amide. Particularly useful such polymers are polysaccharides and derivatives thereof which contain one or more of the monosaccharides units galactose, mannose, glucoside, glucose, xylose, arabinose, fructose, glucuronic acid or pyranosyl sulfate. Various natural hydratable polymers contain the foregoing functional groups and units including guar gum and derivatives thereof, cellulose and derivatives thereof, and the like. Hydratable synthetic polymers and co-polymers which contain the above mentioned functional groups can also be utilized including polyacrylate, polymethylacrylate, polycrylamide, and the like.

[0058] Particularly preferred hydratable polymers, which yield high viscosities upon hydration at relatively low concentrations, are guar gum and guar derivatives such as hydroxypropylguar and carboxymethylguar and cellulose derivatives such as hydroxyethylcellulose, carboxymethylcellulose and the like.

[0059] The viscosities of aqueous polymer solutions of the types described above can be increased by combining cross-linking agents with the polymer solutions. Examples of cross-linking agents which can be utilized are multivalent metal salts or compounds which are capable of releasing such metal ions in an aqueous solution.

[0060] The above described gelled or gelled and cross-linked carrier liquids/fracturing fluids can also include gel breakers such as those of the enzyme type, the oxidizing type or the acid buffer type which are well

known to those skilled in the art. The gel breakers cause the viscous carrier liquids/fracturing fluids to revert to thin fluids that can be produced back to the surface after they have been utilized.

[0061] The creation of one or more fractures in the unconsolidated subterranean zone to be completed in order to stimulate the production of hydrocarbons therefrom is well known to those skilled in the art. The hydraulic fracturing process generally involves pumping a viscous liquid containing suspended particulate material into the formation or zone at a rate and pressure whereby fractures are created therein. The continued pumping of the fracturing fluid extends the fractures in the zone and carries the particulate material into the fractures. Upon the reduction of the flow of the fracturing fluid and the reduction of pressure exerted on the zone, the particulate material is deposited in the fractures and the fractures are prevented from closing by the presence of the particulate material therein.

[0062] As mentioned, the subterranean zone to be completed can be fractured prior to or during the injection of the particulate material into the zone, i.e., the pumping of the carrier liquid containing the particulate material through the slotted liner into the zone. Upon the creation of one or more fractures, the particulate material can be pumped into the fractures as well as into the perforations and into the annuli between the sand screen and shroud and between the shroud and the well bore.

[0063] The methods and apparatus of this invention are particularly suitable and beneficial in forming gravel packs in long-interval horizontal well bores without the formation of sand bridges. Because elaborate and expensive sand screens including shunts and the like are not required and the pack sand does not require consolidation by a hardenable resin composition, the methods of this invention are very economical as compared to prior art methods.

[0064] The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention and the practical applications to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated. It will be appreciated that modifications may be made.

Claims

1. A method of completing an unconsolidated subterranean zone penetrated by a well bore comprising the steps of:

(a) placing in said zone a pre-packed screen having an outer screen and an inner screen whereby a first annulus is formed between said inner screen and said outer screen said first annulus is pre-packed with sand;
(b) placing in said zone a shroud wherein a second annulus is formed between said shroud and said outer screen and a third annulus is formed between said shroud and said well bore whereby said second annulus provides an alternate path for the flow of particulate material and said third annulus provides a primary path for the flow of particulate material;
(c) isolating said annuli in said zone; and
(d) injecting particulate material into said third annulus between said shroud and said well bore whereby said second annulus between said shroud and said outer screen forms an alternate path for the flow of said particulate material such that said particulate material is uniformly packed in said second and third annuli and the migration of formation fines and sand with fluids produced into said well bore from said zone is prevented.

2. A method according to claim 1, which further comprises the step of creating at least one fracture in said subterranean zone prior to carrying out step (d).

3. A method of completing an unconsolidated subterranean zone penetrated by a well bore comprising the steps of:

(a) placing in said zone a shroud and a screen disposed therein whereby a first annulus is formed between said screen and said shroud and a second annulus is formed between said shroud and said well bore;
(b) isolating said annuli in said zone;
(c) injecting particulate material into said second annulus between said shroud and said well bore whereby said first annulus provides an alternate path for the flow of particulate material whereby particulate material is uniformly packed in said first and second annuli and the migration of formation fines and sand with fluids produced into said well bore from said zone is prevented.

4. A method according to claim 3, which further comprises the step of creating at least one fracture in said subterranean zone prior to carrying out step (c).

5. A method according to claim 1, 2, 3 or 4, wherein said particulate material is sand.

6. A method according to any preceding claim, wherein said well bore in said subterranean zone is open-hole.
7. A method according to any preceding claim, wherein said well bore in said subterranean zone has casing cemented therein with perforations formed through the casing and cement. 5
8. An apparatus for completing an unconsolidated subterranean zone penetrated by a well bore comprising: a shroud having perforations therethrough; and a first screen cylindrically disposed within said shroud whereby a first annulus is formed between said shroud and said screen wherein said first annulus provides an alternate path for the flow of particulate material. 10 15
9. Apparatus according to claim 8, wherein said first screen comprises a sintered metal layer. 20
10. Apparatus according to claim 8 or 9, further comprising a second screen cylindrically disposed within said first screen whereby a second annulus is formed between said first screen and said second screen. 25

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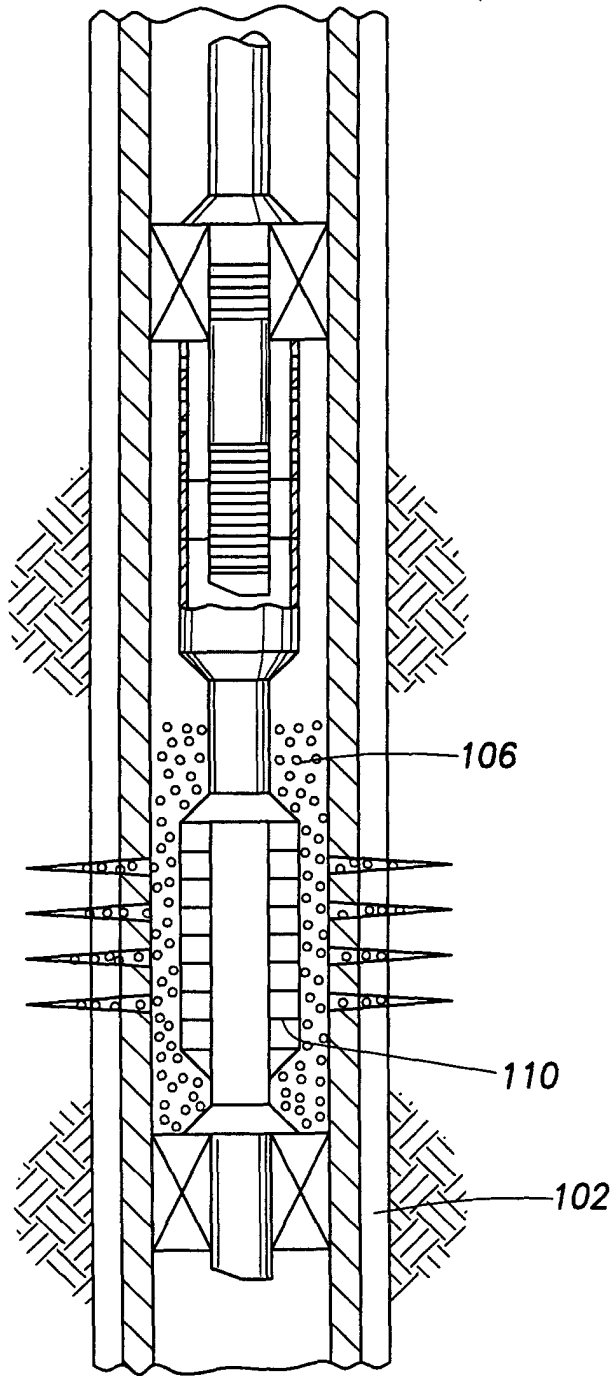


FIG. 1a
(PRIOR ART)

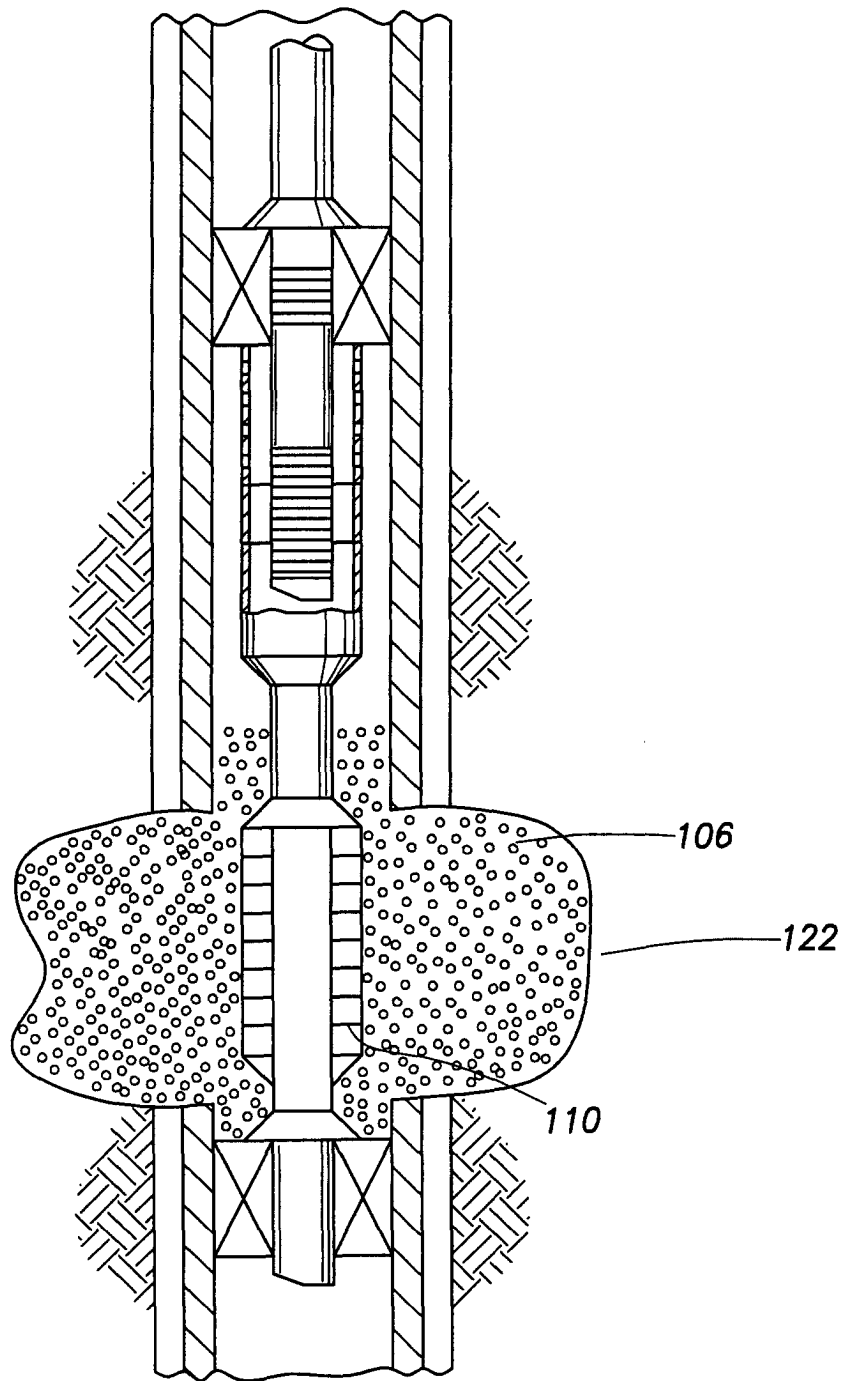


FIG. 1b
(PRIOR ART)

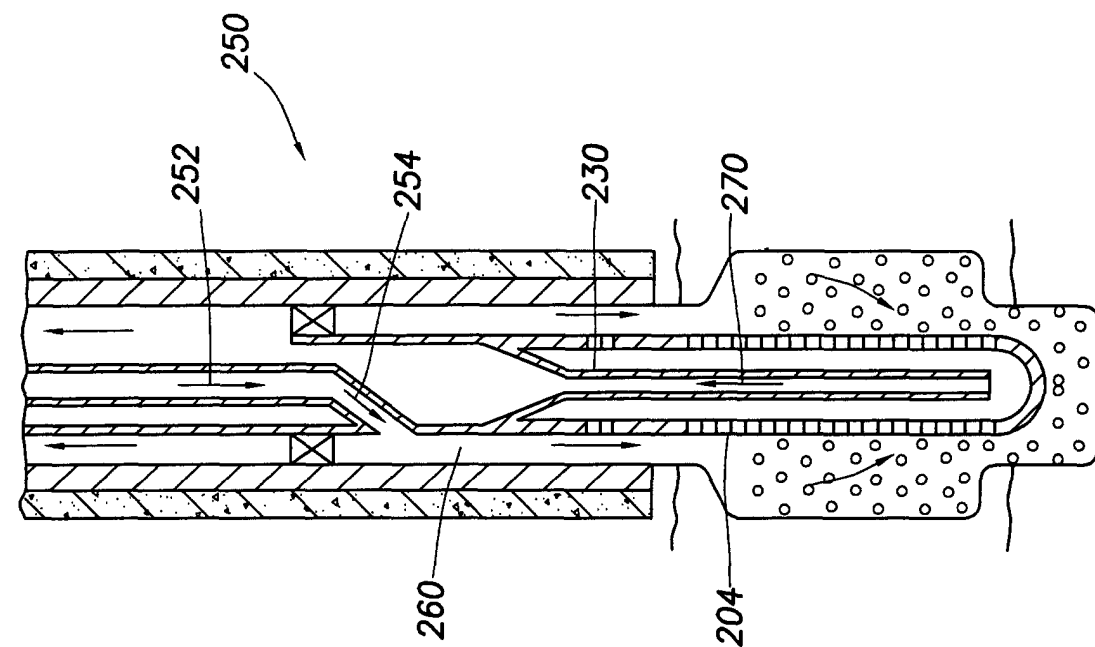


FIG. 2b
(PRIOR ART)

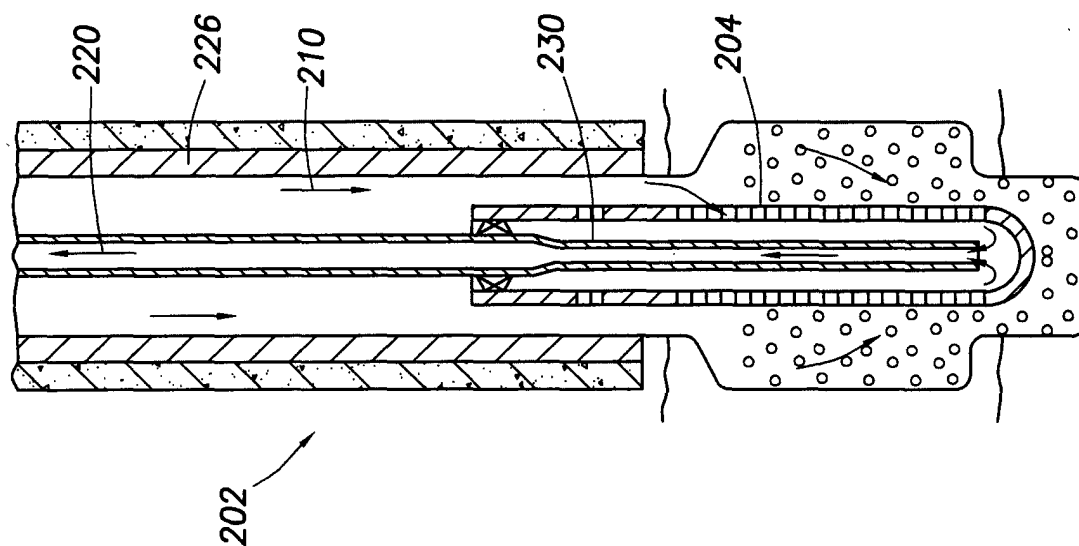


FIG. 2a
(PRIOR ART)

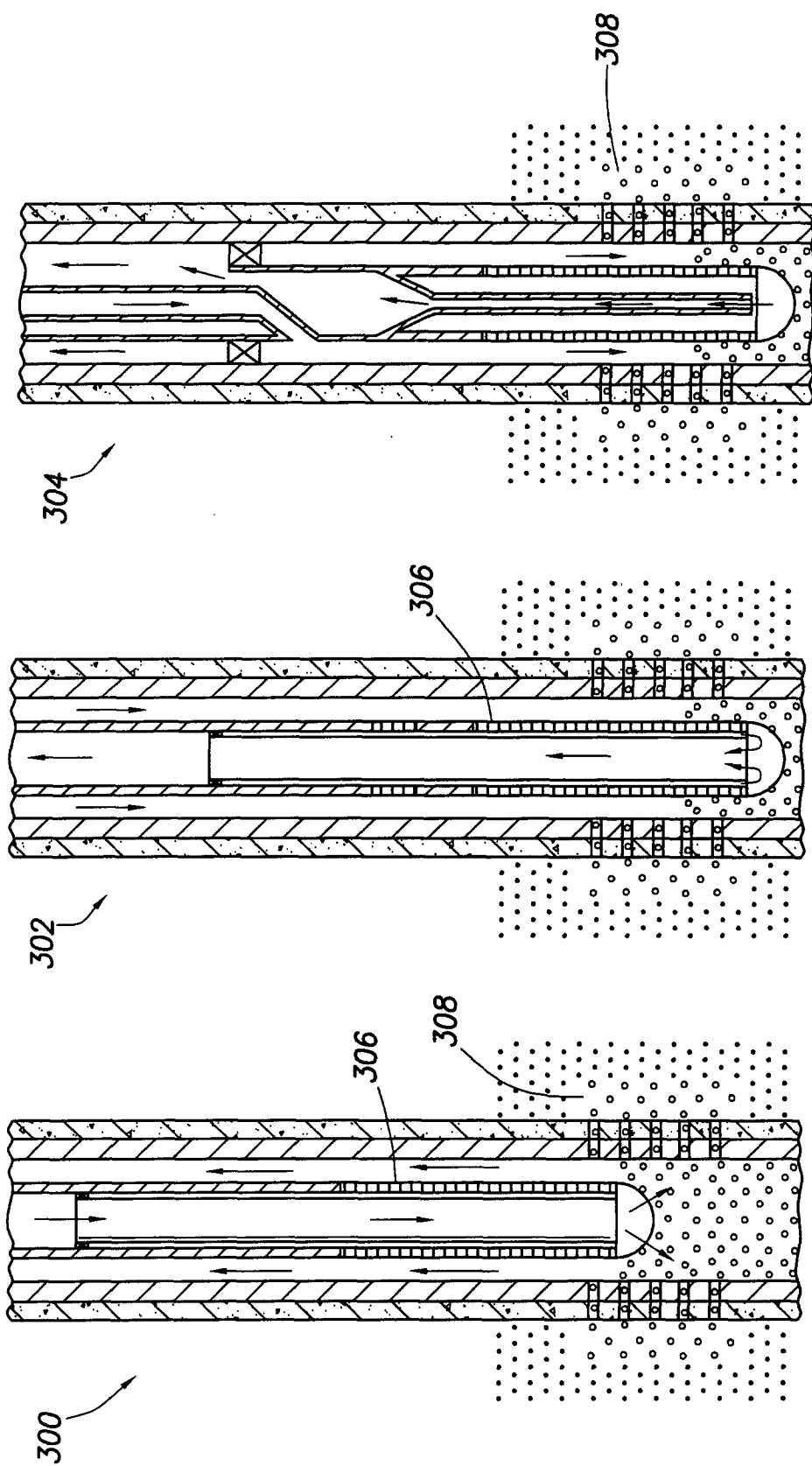


FIG. 3a
(PRIOR ART)

FIG. 3b
(PRIOR ART)

FIG. 3c
(PRIOR ART)

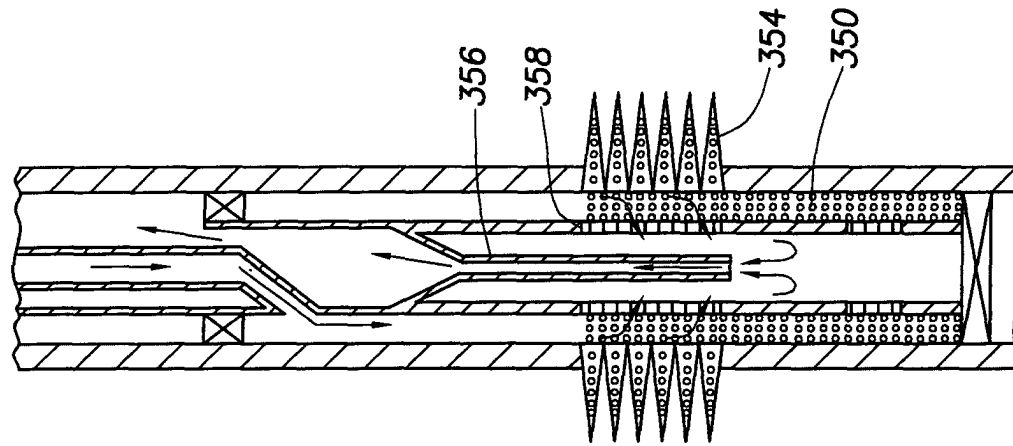


FIG. 3f
(PRIOR ART)

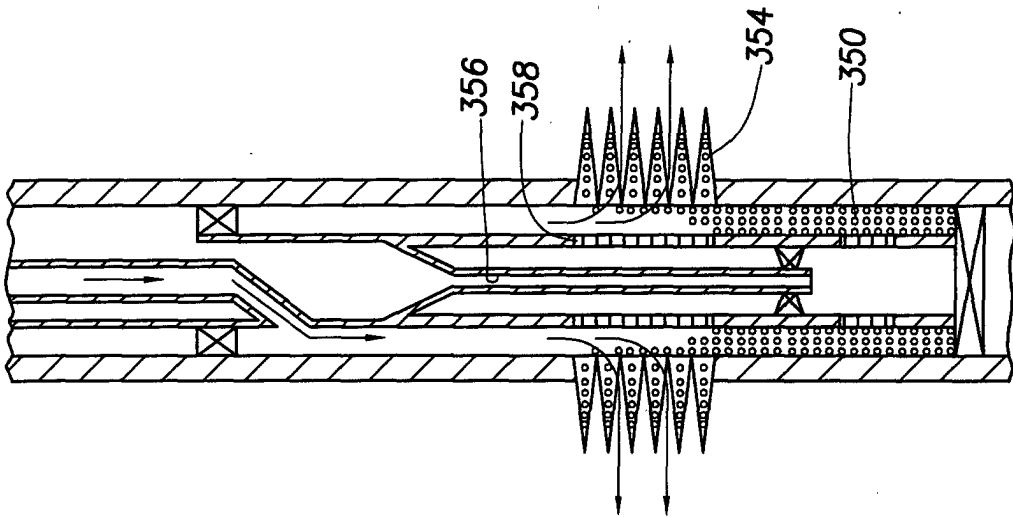


FIG. 3e
(PRIOR ART)

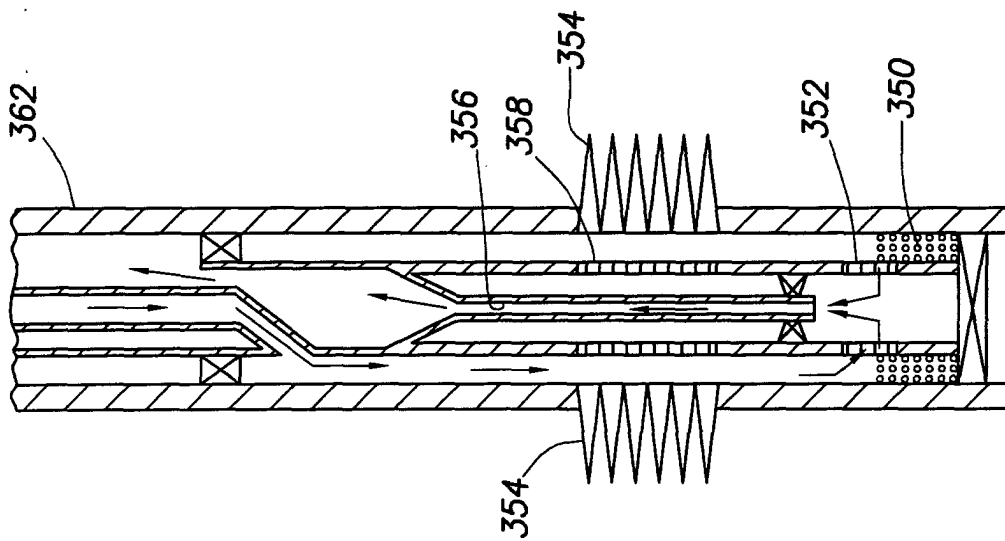


FIG. 3d
(PRIOR ART)

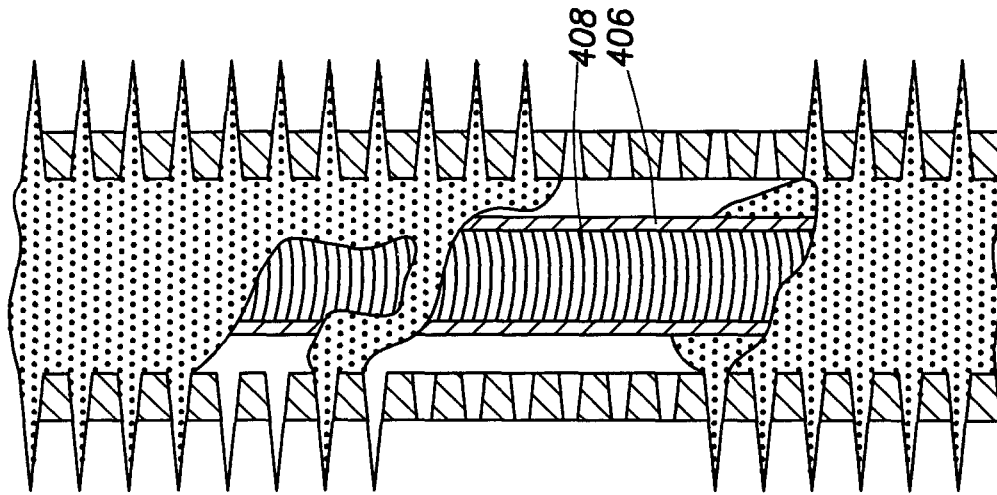


FIG. 4b

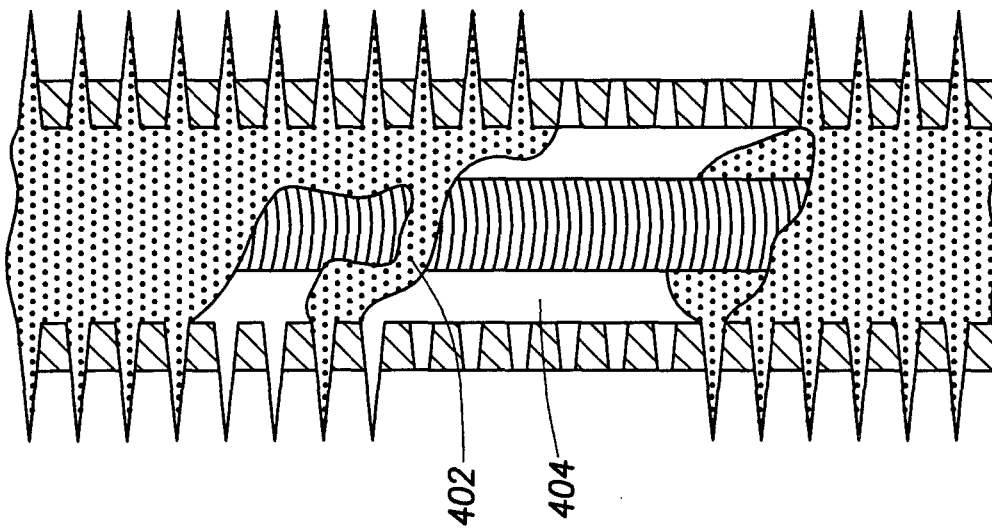


FIG. 4a

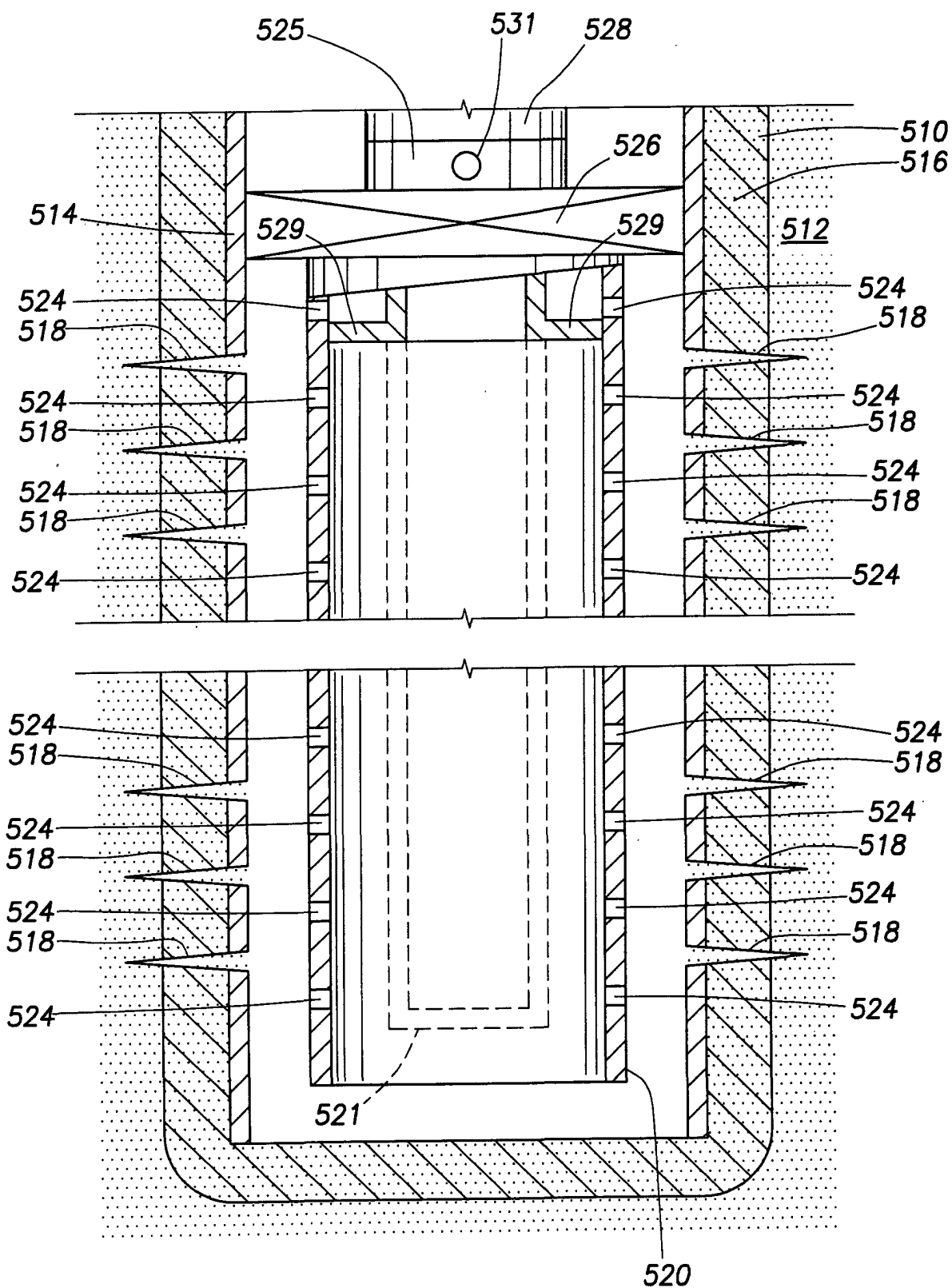


FIG.5

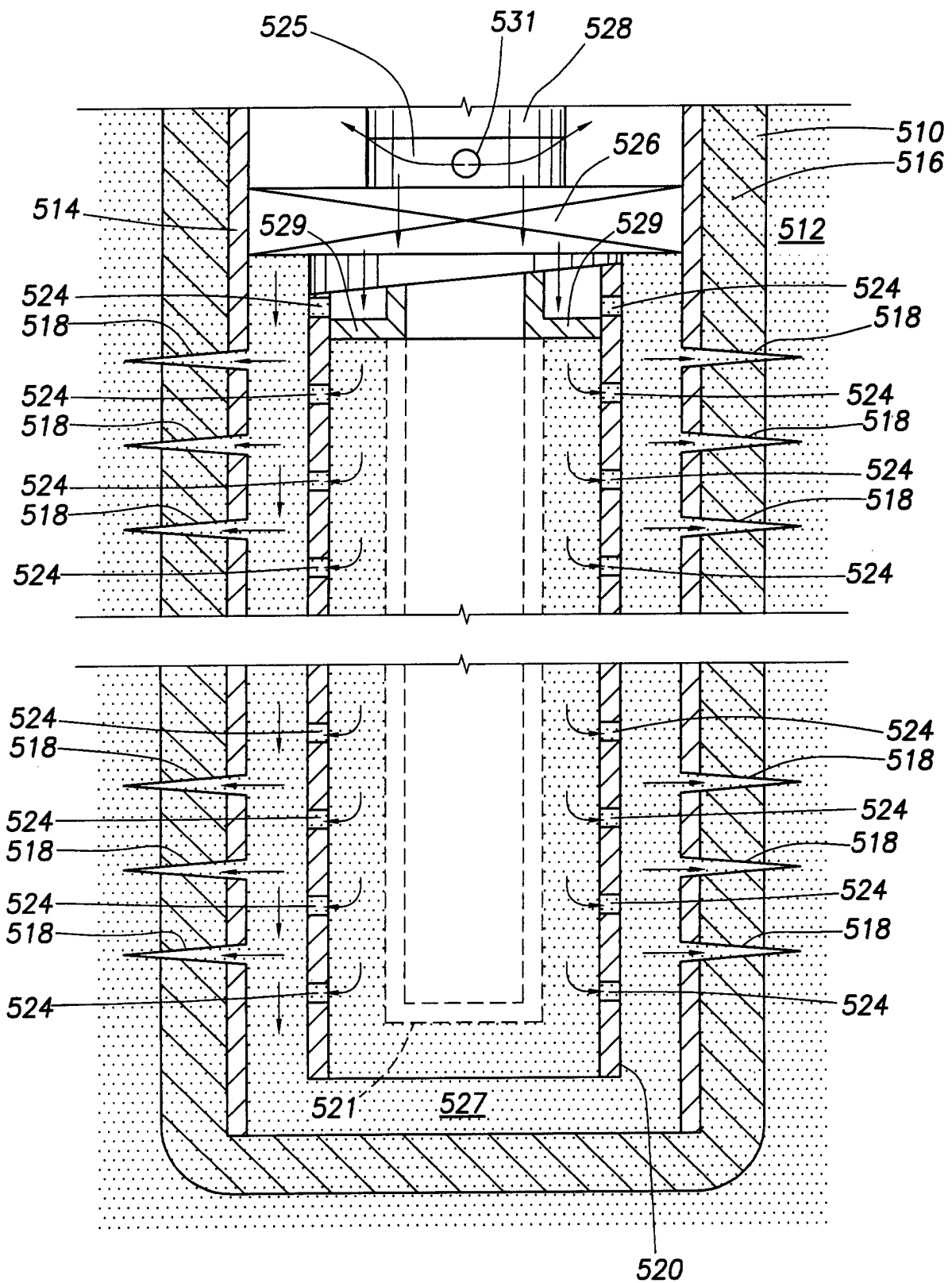


FIG. 6

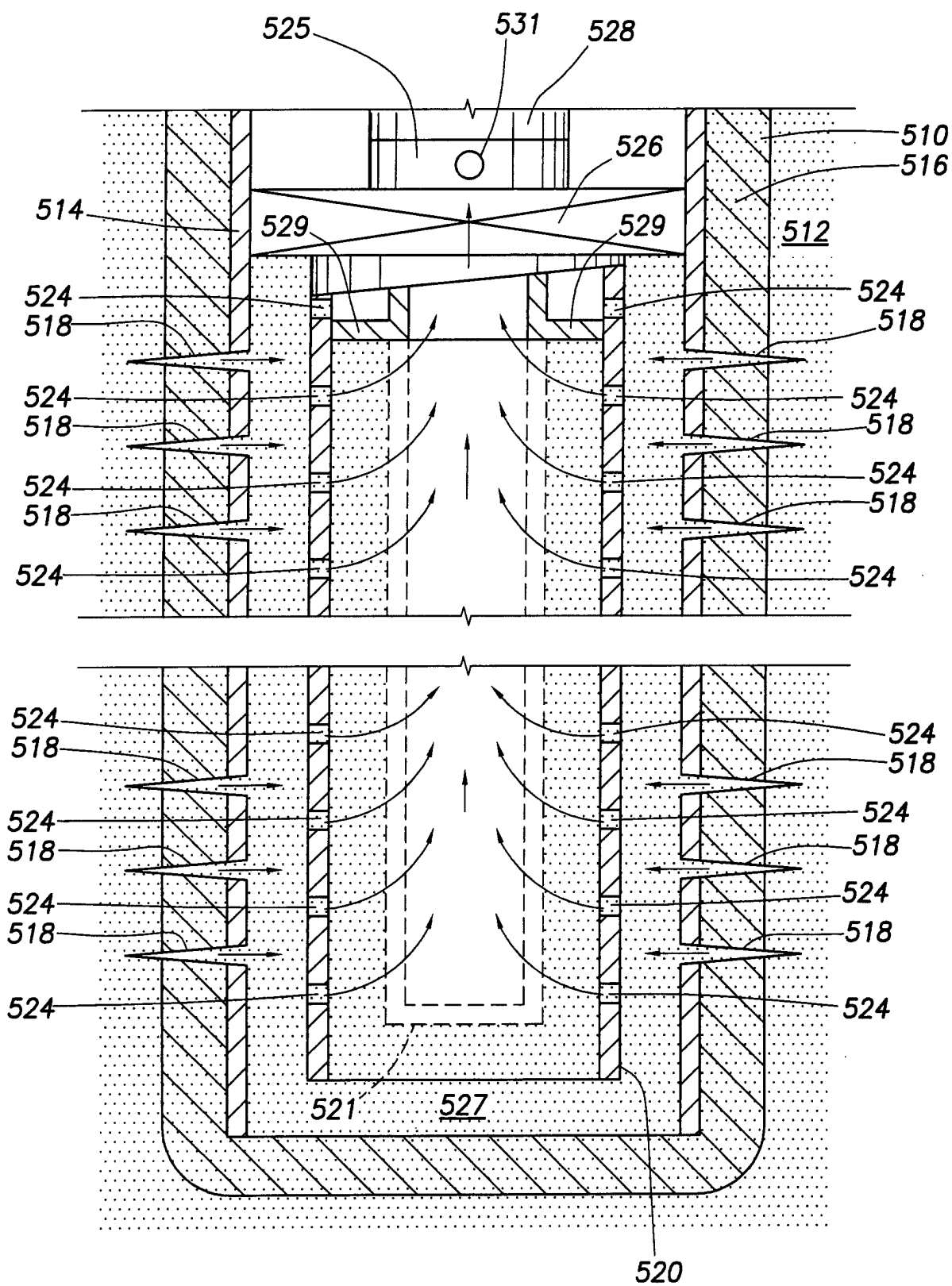


FIG. 7

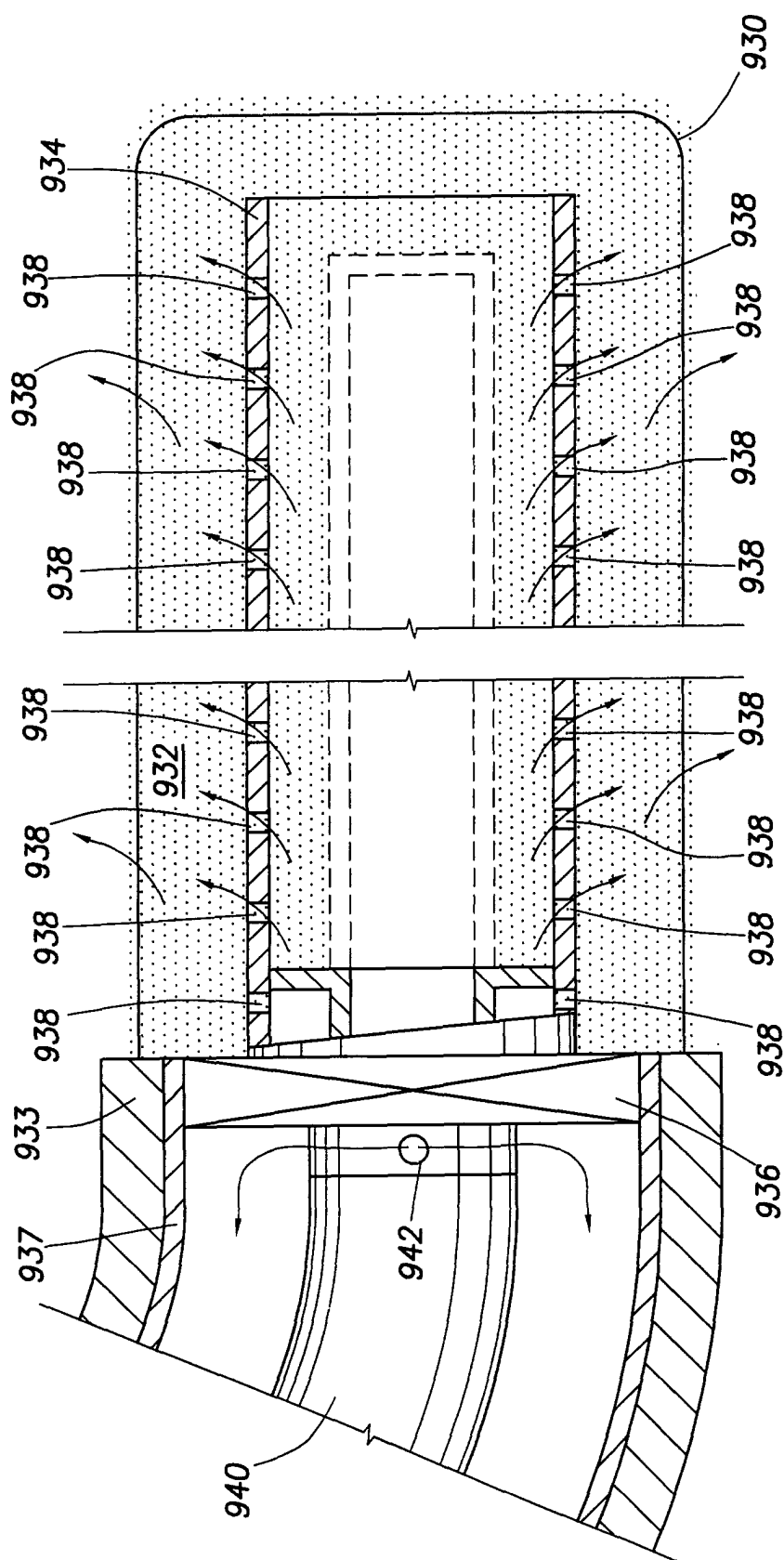


FIG. 9

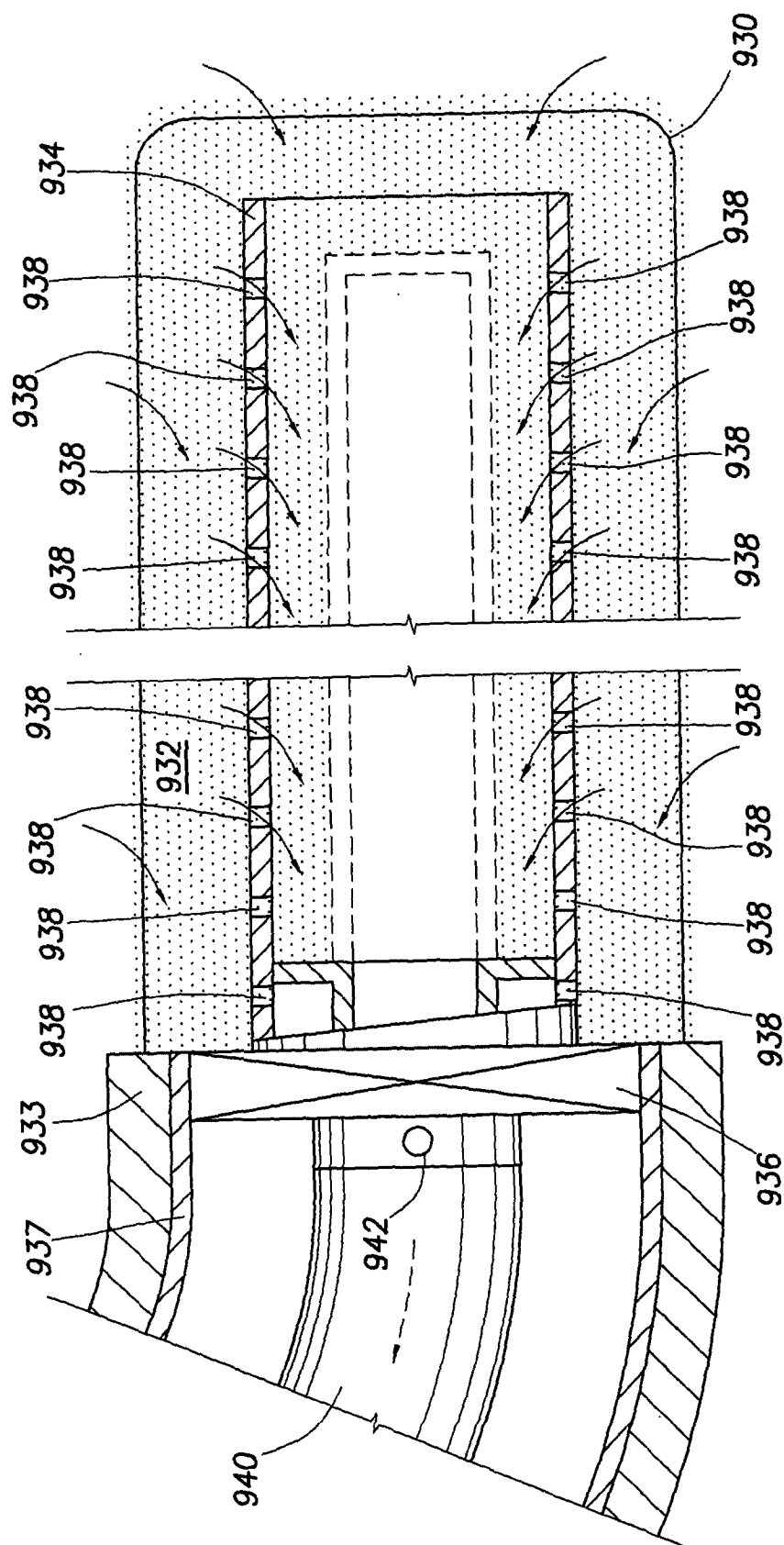


FIG. 10

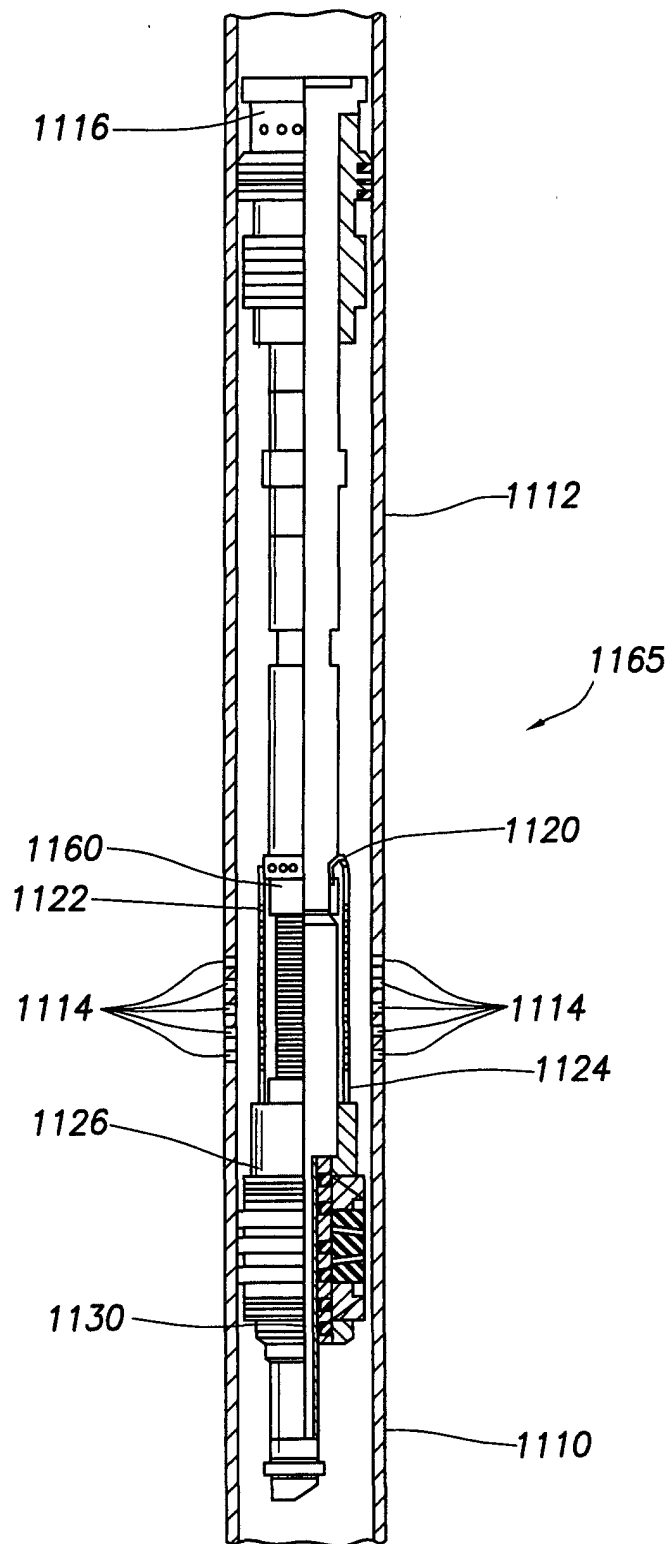


FIG. 11a

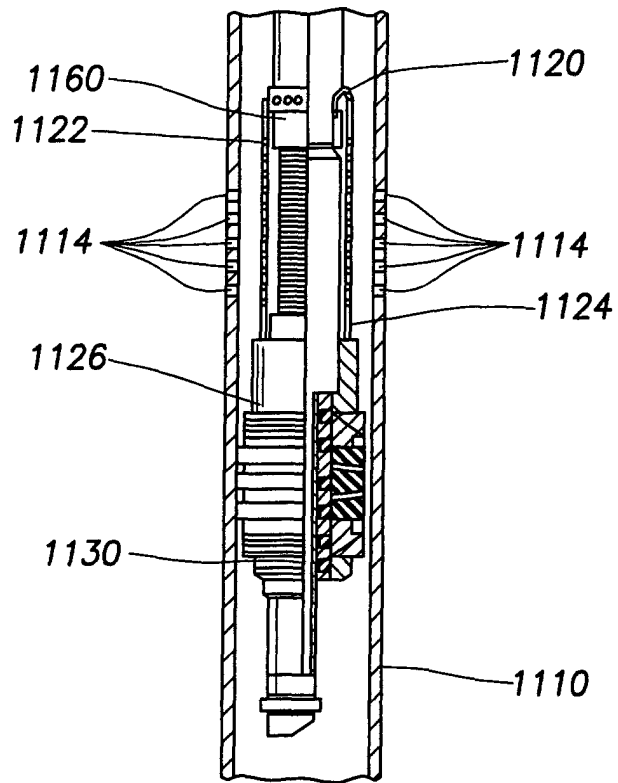


FIG.11b

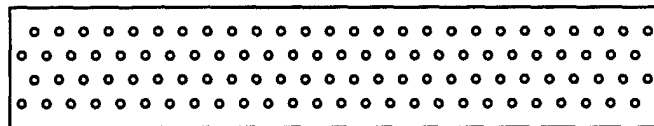


FIG.8

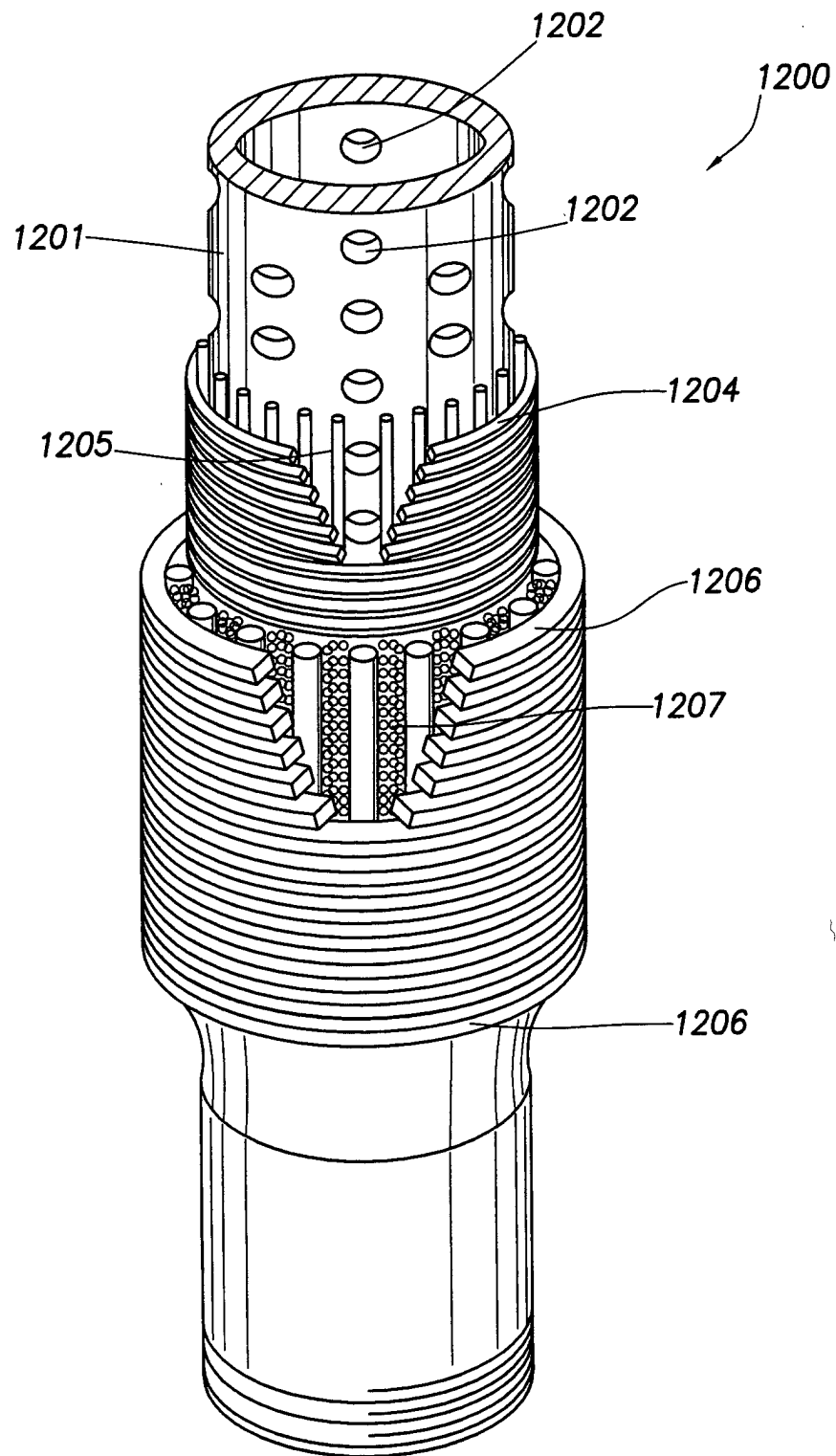


FIG. 12

