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(54) Title: SYSTEM AND METHOD FOR USE OF PRESSURE ACTUATED COLLAPSING CAPSULES SUSPENDED IN A THERMALLY EXPANDING FLUID IN A SUBTERRANEAN CONTAINMENT SPACE

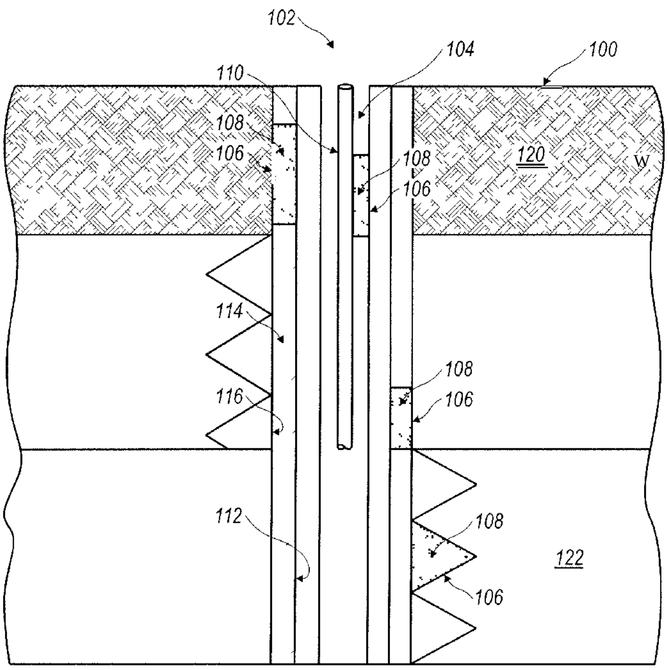

FIG. 1

(57) Abstract: Systems and methods for use of pressure actuated collapsing capsules suspended in a thermally expanding fluid in a subterranean containment space are herein disclosed. According to one embodiment, a system comprises a subterranean pressured fluid receiving containment space (106) located in a wellbore of a subterranean well (102) and a pressured operating fluid (108) filling at least a portion of the containment space. The pressured operating fluid comprises a mixture of substantially incompressible liquid and pressure actuated collapsing capsules. At least a portion of the pressure actuated collapsing capsules implode as pressure in the containment space exceeds a predetermined limit.

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SYSTEM AND METHOD FOR USE OF PRESSURE ACTUATED COLLAPSING CAPSULES SUSPENDED IN A THERMALLY EXPANDING FLUID IN A SUBTERRANEAN CONTAINMENT SPACE

FIELD OF TECHNOLOGY

[0001] The present application is directed to systems and methods for use of pressure actuated collapsing capsules suspended in a thermally expanding fluid.

BACKGROUND

[0002] Traditionally, geothermal wells are completed in porous geothermal formations having naturally high permeability and which contain heated brine and/or steam in relative close proximity to the surface of the earth. These hydrothermal formations are found in a number of locations around the world. However, the vast majority of geothermal resources exist in hot dry rock (HDR) formations that contain little to no geothermal fluid. Enhanced geothermal systems (EGS) are used to extract thermal energy from deep HDR formations exhibiting low permeability. Most HDR formations grow hotter with increasing depth, and in a related aspect, it is advantageous to isolate zones deep in the formation that generate the most heat. EGS wells completed in deep granite basement rock having in situ temperatures ranging from 150^{0}C to greater than 350^{0}C are capable of producing large quantities of thermal energy.

[0003] Drilling and completion of oil and gas wells and geothermal wells involves forming a subterranean wellbore by rotating an earth boring bit into an earth formation as weight is applied to the bit. The drilled wellbore is normally lined with a string of tubulars known as casing and the well is completed by pumping cement into the annulus between the casing and the wellbore wall. In oil and gas wells, the casing string is often cemented at the bottom. During cementing and completion of oil, gas and geothermal wells, fluid is often trapped in the annulus between the casing string and the wellbore wall or between two casing strings. Trapped annular fluid thermally expands when the wellbore is heated during drilling, production and other well operations. The thermal expansion of trapped annular fluid can cause annular pressure build-up (APB) and result in collapse of the casing string.

[0004] Expandable or inflatable packers have also been used in the oil and gas and geothermal industries for well related operations such as zone isolation and formation treating. Expandable packers are used to block the flow of fluids through the annular spaces within the wellbore. Expandable packers are typically filled with a material such as cement, water, or drilling fluid to inflate an expandable packer element. The cement eventually hydrates to form a hard, solid material. In order to remove the packer, the cement and expandable packer must be drilled out. For some applications, it is desirable to both inflate and subsequently deflate a packer once a given operation within a well is completed. A filler material consisting of a liquid such as water, drilling fluid, oil, and other downhole fluids may be used for such an operation. However, when the packer is exposed to an increase in temperature the thermal expansion of the liquid water or other downhole fluids within the packer may cause a pressure increase within the packer. This pressure increase, if sufficiently large, could lead to either the rupture of the inflatable element of the packer and/or the crushing of elements inside the packer.

[0005] Conventional systems and methods for completing oil, gas and geothermal wells including casing strings and well packers are typically not capable of accommodating significant thermal expansion of downhole fluids.

SUMMARY

[0006] Systems and methods for use of pressure actuated collapsing capsules suspended in a thermally expanding fluid in a subterranean containment space are herein disclosed. According to one embodiment, a system comprises a subterranean pressured fluid receiving containment space located in a wellbore of a subterranean well and a pressured operating fluid filling at least a portion of the containment space. The pressured operating fluid comprises a mixture of substantially incompressible liquid and pressure actuated collapsing capsules. At least a portion of the pressure actuated collapsing capsules implode as pressure in the containment space exceeds a predetermined limit.

[0007] The foregoing and other objects, features and advantages of the present disclosure will become more readily apparent from the following detailed description of exemplary embodiments as disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Embodiments of the present application are described, by way of example only, with reference to the attached Figures, wherein:

[0009] FIG. 1 illustrates an exemplary system for protecting a subterranean containment space in a subterranean well or formation from over-pressure according to one embodiment;

[0010] FIG. 2A illustrates an exemplary pressured operating fluid according to one embodiment;

[0011] FIG. 2B illustrates exemplary pressure actuated collapsing capsules according to one embodiment;

[0012] FIG. 3 illustrates an exemplary system for protecting a subterranean containment space in an annulus of a subterranean well from over-pressure according to one embodiment;

[0013] FIGS. 4A through 4F illustrate an exemplary system for protecting a subterranean containment space in the annulus of a subterranean well from over-pressure according to another embodiment;

[0014] FIGS. 5A through 5E illustrate an exemplary system for protecting a downhole packer from over-pressure according to one embodiment; and

[0015] FIG. 6 illustrates an exemplary system for protecting a subterranean containment space in a geothermal well from over-pressure according to one embodiment.

DETAILED DESCRIPTION

[0016] It will be appreciated that for simplicity and clarity of illustration, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the example embodiments described herein. However, it will be understood by those of ordinary skill in the art that the example embodiments described herein may be practiced without these specific details. In other instances, methods, procedures and components have not been described in detail so as not to obscure the embodiments described herein. It will be understood by those of ordinary skill in the art that the systems and methods herein disclosed may be applied to subterranean wells including, but not limited to, geothermal wells, oil wells, gas wells, water wells, injection wells or any other well known in the art for producing or injecting fluids.

[0017] FIG. 1 illustrates an exemplary system for protecting a subterranean containment space 106 in a subterranean well 102 or formation 100 from over-pressure according to one embodiment. The subterranean well 102 may be a geothermal well, oil well, gas well, water well, injection well or any other well known in the art. During drilling, completion and production, subterranean pressured fluid receiving containment spaces 106 may form in the wellbore 104 or in the subterranean formation 100. For instance, a subterranean containment space 106, such as a downhole packer may be introduced into the subterranean well 102 in an annulus between the production conduit 110 and the casing string 112 or in an annulus 114 between the casing string 112 and the wellbore wall 116. In other instances, a subterranean containment space 106 may form in the annulus 114 during a primary well operation such as, cementing of the casing string 112.

[0018] Subterranean containment spaces 106 may also be naturally occurring voids or cavities in the subterranean formation 100. Downhole fluids may become trapped in subterranean containment spaces 106 during drilling, completion, production and other well operations. If the subterranean well 102 including the wellbore wall 116 and/or fluids within the wellbore 104 are heated during well operations, trapped fluids will thermally expand and pressurize the subterranean containment spaces 106. Thermally expanding downhole fluids can damage the subterranean well 102 and/or elements within the well 102 including, but not limited to. well casing, well liners, well packers, production conduit, downhole tools and other downhole tubulars within the wellbore 104. Thermally expanding downhole fluids can also cause damage to the subterranean formation 100 by propagating undesired fractures within the formation 100.

[0019] In order to accommodate thermal expansion of downhole fluids and protect the subterranean well 102 and downhole elements within the well 102 from over-pressure, subterranean containment spaces 106 are at least partially filled with pressured operating fluid 108 having a mixture of substantially incompressible liquid and pressure actuated collapsing capsules. The pressure actuated collapsing capsules rupture, implode or collapse when pressure in the subterranean containment space 106 exceeds a predetermined limit, thus compensating for the thermal expansion of the liquid in the containment space 106 and preventing over-pressure from damaging the subterranean well 102.

[0020] The pressured operating fluid 108 may also be pumped or circulated into a plurality of laterally or vertically arranged subterranean zones 120, 122 in the formation 100 to protect the formation from undesired fracture propagation. Containment spaces 106 in the well 100 and the formation 100 may be partially or fully filled with pressured operating fluid 108 by pumping or circulating the pressured operating fluid 108 into wellbore 104 through the production conduit 110, the casing string 112, or the annulus 114 between the casing string 112 and the wellbore wall 116.

[0021] FIG. 2A illustrates an exemplary pressured operating fluid 30 comprising a mixture of substantially incompressible liquid 32 and pressure actuated collapsing capsules 32 according to one embodiment. The pressure actuated collapsing capsules 34 are suspended in the substantially incompressible liquid 32. A viscosifying agent may be added to the pressured operating fluid 30 to aid in the suspension of the pressure actuated collapsing capsules 34. The viscosifying agent may be an organic polymer such as hydro ethyl cellulose, hydropropyl guar, guar gum, and/or any other compatible organic polymer capable of aiding in the suspension of the pressure actuated collapsing capsules 34. The viscosifying agent may also be an inorganic material such as fumed silica, bentonite, or attapulgite. Weighting materials such as barite or hausmanite may also be added to the pressured operating fluid 30 to modify the density of the fluid. The pressured operating fluid 30 comprising a mixture of substantially incompressible liquid 32 and pressure actuated collapsing capsules 34 is designed to accommodate thermal expansion of liquid in a subterranean containment space, including but not limited to, an expandable bladder of a well packer, an annulus between the casing string and the wellbore wall, an annulus between the production conduit and the casing string, an annulus between two casing strings, a fracture in the subterranean formation or any other downhole tubular, downhole tool, or void in a subterranean well or formation capable of containing liquid.

[0022] The substantially incompressible liquid 32 component of the pressured operating fluid 30 may be selected based on the specific application of the pressured operating fluid 30 and/or the downhole fluids present in the well such as, drilling fluids and production fluids. For most applications, the substantially incompressible liquid 32 may comprise water. The substantially incompressible liquid 32 may also comprise one or more components that make up a drilling fluid present in the well to maintain compatibility between the pressured operating fluid 30 and the drilling fluid. For instance, if the well contains a synthetic oil-based drilling fluid, the substantially incompressible liquid 32 may comprise the drilling fluid or a competent thereof such as the base oil. The substantially incompressible liquid 32 may also comprise mineral oil and/or synthetic oil. In geothermal and other applications, the substantially incompressible liquid 32 may comprise various concentrations of potassium chloride brine, sodium chloride brine, production brine and/or other substantially incompressible liquid that is compatible with downhole fluids present in the subterranean well.

[0023] Referring to FIGS. 2A through 2B, pressure actuated collapsing capsules 34 are designed to rupture, implode or collapse at a predetermined pressure during theπnal expansion of the substantially incompressible liquid 32. The pressure actuated collapsing capsules 34 may be of substantially fixed volume or they may have variable volumes within the substantially incompressible liquid 32. The pressure actuated collapsing capsules 34 may also be partially or fully filled with gas 38. The gas 38 may be air or an inert gas such as, nitrogen or argon to prevent chemical reaction with downhole fluids after collapse of the pressure actuated collapsing capsules 34. The gas 38 may also be one or more gases present in the subterranean well such as nitrogen, methane or other hydrocarbon gases. In other embodiments, the pressure actuated collapsing capsules 34 may be substantially void of gas.

[0024] The pressure actuated collapsing capsules 34 may be manufactured to have a predetermined collapse pressure. The pressure actuated collapsing capsules 34 may also be a waste byproduct which have non-uniform or graduated collapse pressures. In accordance with the example embodiment shown in FIG. 2B, the pressure actuated collapsing capsules 34 may be hollow and encased in a frangible material 36. The pressure actuated collapsing capsules 34 may be spherical, cratered or ellipsoidal. Hollow microspheres, because of their spherical form, can have a high isotropic compressive strength and are therefore well suited for applications that require high collapse pressures.

[0025] The pressure actuated collapsing capsules 34 may be designed to have a substantially uniform collapse pressure, such that the majority of pressure actuated collapsing capsules 34 fail or collapse at the same pressure. The pressure actuated collapsing capsules 34 may also be designed to have non-uniform or variable collapse pressures. The frangible material 36 may comprise glass, ceramic, polymer, metal or combinations thereof. The composition of the frangible material 36 may be selected to have a particular collapse strength which will determine the pressure at which the pressure actuated collapsing capsules 34 rupture, implode or collapse. The wall thickness of the frangible material 36 and the density of the pressure actuated collapsing capsules 34 may also be varied to increase or decrease the pressure at which the pressure actuated collapsing capsules 34 rupture, implode or collapse. The frangible material 36 may be coated with a strengthening material 40 to increase the pressure at which the pressure actuated collapsing capsules 34 rupture, implode or collapse. The strengthening material 40 may comprise glass, ceramic, polymer, metal or combinations thereof. The wall thickness of the strengthening material 40 may also be varied to increase or decrease the pressure at which the pressure actuated collapsing capsules 34 rupture, implode or collapse.

[0026] The pressured operating fluid 30 can be optimized to mitigate a large range of over-pressure conditions within a subterranean containment space in a subterranean well. During well operations that substantially and rapidly heat the subterranean well, it is desirable to establish an upper pressure limit within a subterranean containment space by filling at least a portion of the subterranean containment space with pressured operating fluid 30 having a composition of pressure actuated collapsing capsules 34 that have uniform collapse pressures. All or a majority of the pressure actuated collapsing capsules 34 may be designed to rupture, collapse or implode as pressure in a subterranean containment space approaches the upper-pressure limit.

[0027] During well operations that gradually heat the subterranean well over a large range of temperatures, it is desirable to use pressure actuated collapsing capsules 34 that have non¬uniform or graduated collapse pressures to accommodate varying over-pressure conditions. A percentage of pressure actuated collapsing capsules 34 may be designed to rupture collapse or implode at two or more operating pressures within a subterranean containment space. In one embodiment, the pressure actuated collapsing capsules 34 may have a collapse pressure less than or equal to 1000 psi of one another. In another embodiment, the pressure actuated collapsing capsules 34 may have a collapse pressure of greater than 1000 psi of one another.

[0028] In one example embodiment, the pressure actuated collapsing capsules may be glass, ceramic, polymer or metal encased microspheres 34, such as those manufactured by 3M Company. The microspheres 34 may be designed to rupture, implode or collapse when pressure exceeds a predetermined limit. The microspheres 34 may be designed to have a substantially uniform collapse pressure, such that the majority of microspheres 34 fail or collapse at the same pressure. By designing the microspheres 34 to collapse at a uniform pressure, the pressured operating fluid 30 may be tailored to provide overpressure protection above a predetermined pressure limit with the use of a minimum quantity, weight or concentration of microspheres 34. Exemplary collapse pressures of glass, ceramic, polymer and/or metal encased microspheres 34 include, but are not limited to, 250 psi, 1000 psi. 2000 psi, 3000 psi, 4000 psi, 6000 psi, 10,000 psi and greater than 10,000 psi.

[0029] In another example embodiment, the pressure actuated collapsing closed capsules are pozzolan or glass encased microspheres 34 provided from the waste stream of a coal-fired power plant. Hollow pozzolan or glass encased microspheres 34 known as floaters or cenospheres are formed in the coal burning process of coal-fired power plants. Cenospheres collect on the surface of disposal ponds where waste fly ash is deposited as part of the waste stream of a coal-fired power plant. Cenospheres are essentially thin-walled pozzolan or glass encased microspheres with a similar composition of fly ash. Pozzolan or glass encased microspheres 34 produced from cenospheres are cheaper than manufactured microspheres 34. Pozzolan or glass encased microspheres 34 produced from cenospheres also have non-uniform or variable collapse pressures.

[0030] To accommodate a wide range of pressures in a particular subterranean containment space, it is desirable to introduce a pressured operating fluid 30 having pozzolan or glass encased microspheres 34 that have non-uniform or graduated collapse pressures. For instance, it may be desirable to introduce a pressured operating fluid 30 into a plurality of subterranean containment spaces in a plurality of subterranean zones having dissimilar temperatures and pressures at varying depths within the subterranean well. The plurality of subterranean containment spaces may be at least partially filled with a pressured operating fluid 30 having a composition of pozzolan or glass encased microspheres 34 that have non-uniform or graduated collapse pressures to accommodate thermal expansion of downhole fluids at varying temperatures and pressures within each subterranean zone. In one example embodiment, pozzolan or glass encased microspheres 34 produced from cenospheres rupture, implode or collapse between 8000 psi and 10,000 psi. In another example embodiment, pozzolan or glass encased microspheres 34 produced from cenospheres rupture, implode or collapse between 10,000 psi and 12,000 psi.

[0031] Tables I through III provide example embodiments of pressured operating fluids having glass encased microspheres suspended in water. The addition of a negligible volume of polymer to aid in suspension of microspheres was assumed. A constant volume subterranean containment space was assumed. The well temperature was increased to cause thermal expansion of the pressured operating fluid.

Table I: 3000 psi Collapse Rated Spheres Heated From 80^{0}F (26 ^{0}C)

Pressured Operating Fluid	Water (kg)	Glass Spheres (kg)	Final Temperature (°F)	Final Temperature (°C)	Percent Spheres Collapsed (%)
1	1	0.2	260	126.7	14
1	1	0.2	360	182.2	28
1	1	0.2	460	237.8	48
1	1	0.2	560	293.3	76
2	1	0.3	260	126.7	9
2	1	0.3	360	182.2	19
2	1	0.3	460	237.8	32
2	1	0.3	560	293.3	51
3	1	0.4	260	126.7	7
3	1	0.4	360	182.2	14
3	1	0.4	460	237.8	24
3	1	0.4	560	293.3	38

[0032] Table I provides the predicted collapse percentage of glass encased microspheres suspended in three operating fluids heated to final temperatures of 126.7°C, 182.2°C, 237.8°C and 293.3°C. The percentage of glass encased spheres collapsing at a given temperature is an indication of the volume change necessary to accommodate the thermal expansion of the water present in the pressured operating fluid. Operating Fluid 1 contains 1 kg of water and 0.2 kg of 3000 psi collapse rated glass encased microspheres. Operating Fluid 2 contains 1 kg of water and 0.3 kg of 3000 psi collapse rated glass encased microspheres. Operating Fluid 3 contains 1 kg of water and 0.4 kg of 3000 psi collapse rated glass encased microspheres. An initial temperature of 26^{0}C was assumed. The percentage of microsphere collapse necessary to accommodate the thermal expansion of the pressured operating fluid increases as temperature increases. At temperatures approaching and above 25O^{0}C the percentage of microsphere collapse necessary to accommodate the thermal expansion of the pressured operating fluid substantially increases.

Table II: 6000 psi Collapse Rated Spheres Heated From 80°F (26°C)

Pressured Operating Fluid	Water (kg)	Glass Spheres (kg)	Final Temperature (°F)	Final Temperature (°C)	Percent Spheres Collapsed (%)
1	1	0.2	260	126.7	18
1	1	0.2	360	182.2	36
1	1	0.2	460	237.8	62
1	1	0.2	560	293.3	99
2	1	0.3	260	126.7	12
2	1	0.3	360	182.2	24
2	1	0.3	460	237.8	42
2	1	0.3	560	293.3	66
3	1	0.4	260	126.7	9
3	1	0.4	360	182.2	18
3	1	0.4	460	237.8	31
3	1	0.4	560	293.3	49

[0033] Table II provides the predicted collapse percentage of glass encased microspheres suspended in three operating fluids heated to final temperatures of 126.7°C, 182.2°C, 237.8°C and 293.3°C. The percentage of glass encased spheres collapsing at a given temperature is an indication of the volume change necessary to accommodate the thermal expansion of the water present in the pressured operating fluid. Operating Fluid 1 contains 1 kg of water and 0.2 kg of 6000 psi collapse rated glass encased microspheres. Operating Fluid 2 contains 1 kg of water and 0.3 kg of 6000 psi collapse rated glass encased microspheres. Operating Fluid 3 contains 1 kg of water and 0.4 kg of 6000 psi collapse rated glass encased microspheres. An initial temperature of 26°C was assumed. At temperatures approaching and above 250°C the percentage of microsphere collapse necessary to accommodate the thermal expansion of the pressured operating fluid substantially increases. The theoretical percentage of microsphere collapse in Operating Fluid 1 is 99% at 293.3°C. Therefore, a greater composition of microspheres must be suspended in Operating Fluid 1 to accommodate the potential thermal expansion and resulting over-pressure created at temperatures above 293.3°C.

Table III: 10,000 psi Collapse Rated Spheres Heated From 80°F (26°C)

Pressured Operating Fluid	Water (kg)	Glass Spheres (kg)	Final Temperature (°F)	Final Temperature (°C)	Percent Spheres Collapsed (%)
1	1	0.2	260	126.7	25
1	1	0.2	360	182.2	50
1	1	0.2	460	237.8	87
1	1	0.2	560	293.3	138
2	1	0.3	260	126.7	17

2	1	0.3	360	182.2	33
2	1	0.3	460	237.8	58
2	1	0.3	560	293.3	92
3	1	0.4	260	126.7	12
3	1	0.4	360	182.2	25
3	1	0.4	460	237.8	43
3	1	0.4	560	293.3	69

[0034] Table III provides the predicted collapse percentage of glass encased microspheres suspended in three operating fluids heated to final temperatures of 126.*TC,* 182.2°C, 237.8°C and 293.3 ^{0}C. The percentage of glass encased spheres collapsing at a given temperature is an indication of the volume change necessary to accommodate the thermal expansion of the water present in the pressured operating fluid. Operating Fluid 1 contains 1 kg of water and 0.2 kg of 10,000 psi collapse rated glass encased microspheres. Operating Fluid 2 contains 1 kg of water and 0.3 kg of 10,000 psi collapse rated glass encased microspheres. Operating Fluid 3 contains 1 kg of water and 0.4 kg of 10,000 psi collapse rated glass encased microspheres. An initial temperature of 26^{0}C was assumed. At temperatures approaching and above 25O^{0}C the percentage of microsphere collapse necessary to accommodate the thermal expansion of the pressured operating fluid substantially increases. The theoretical percentage of microsphere collapse in Operating Fluid 1 is over 100% at 293.3°C. Therefore, Operating Fluid 1 is not designed to compensate for the potential thermal expansion and resulting over-pressure created at 293.3°C. The theoretical percentage of microsphere collapse in Operating Fluid 2 is over 92% at 293.3 ^{0}C. Therefore, a greater composition of microspheres must be suspended in Operating Fluid 2 to accommodate the potential thermal expansion and resulting over-pressure created at temperatures above 293.3 ^{0}C.

[0035] FIG. 3 illustrates an exemplary system for protecting a containment space 218 in an annulus 210 of a subterranean well 200 from over-pressure according to one embodiment. A plurality of casing strings including an inner casing string 204 and an outer casing string 206 are disposed in the wellbore 202. To secure the inner casing string 204 against the wellbore wall 212, the inner annulus 208 between the inner casing string 204 and the wellbore wall 212 is filled with cement 214 below the mud line 216. To secure the outer casing string 206 against the wellbore wall 212, the outer annulus 210 between the outer casing string 206 and the wellbore wall 212 is filled with cement 214 below the mud line 216. Due to insufficient volume and circulation of cement 214, subterranean pressured fluid receiving containment spaces 218 form in the inner annulus 208 and the outer annulus 210 between the cement 214 and the mud line 216. Downhole fluids may become trapped in subterranean containment spaces 218 during drilling, completion, production, injection or other well operations.

[0036] If trapped downhole fluids are heated while in the subterranean containment spaces 218, the thermal expansion of the fluid can cause the inner casing string 204 to burst or the outer casing string 206 to collapse. A pressured operating fluid 220 having a mixture of substantially incompressible liquid and pressure actuated collapsing capsules may be pumped or circulated into the subterranean containment spaces 218 to prevent casing collapse. The pressure actuated collapsing capsules rupture, implode or collapse when the pressure in the subterranean containment space 218 exceeds a predetermined limit, thus releasing pressure in the containment space 218. The pressured operating fluid 220 may be circulated into subterranean containment spaces 218 to prevent casing collapse before, during and/or after cement is circulated into the inner annulus 208 or outer annulus 210 of the wellbore 202. The pressured operating fluid 220 may also be circulated into subterranean containment spaces 218 as part of the cement 214.

[0037] FIGS. 4A through 4F illustrate an exemplary system for protecting a subterranean containment space 320 in the annulus 306 of a subterranean well 300 from over-pressure according to another embodiment. A two stage cement process is used to secure well casing 308 to the wellbore wall 304. Cement 318 is pumped or circulated into the first stage 324 through the inner diameter of the well casing 308 and back up the annulus 306 near or above a stage tool 310. Pressure may be applied to the wellbore 302 through the inner diameter of the well casing 308 to open the stage tool 310. An opening dart 312 may also be dropped into the well casing 308 on top of the stage tool 310 before pressure is applied to the wellbore 302 to open the stage tool 310. Once the stage tool 310 is opened, the annulus 306 above the tool 310 is circulated clean back to the surface.

[0038] After permitting the cement 318 in the first stage to set, a first stage plug 314 is launched into the well casing 308 to plug off the first stage 324. Cement 318 is circulated into the second stage 322 through the inner diameter of the well casing 308 and up the annulus 306 of the wellbore 302. A displacement plug 316 may be launched into the well casing 308 to further facilitate displacement and circulation of cement 318 into the annulus 306. Ideally, spaces, gaps or voids do not form in the annulus 306 in the first stage 324 or the second stage 322 during circulation of cement 318. However, subterranean containment spaces 320 including gaps, voids and cavities are often created due to lack of volume or lost circulation of cement 318 in the first stage 324 or second stage 322. Downhole fluids may become trapped in subterranean containment spaces 320 in first stage 324, the second stage 322 or between the first stage 324 and the second stage 322 of the annulus 306.

[0039] If temperature in the well 300 increases substantially during production of hotter fluids, such as oil, gas, geothermal water, brine and/or steam, thermal expansion of trapped fluid can cause the casing 308 to collapse. A pressured operating fluid 326 having a mixture of substantially incompressible liquid and pressure actuated collapsing capsules may be pumped or circulated into the subterranean containment spaces 320 in the first stage 324, the second stage or between the first stage 324 and the second stage 322 of the annulus 306. The pressure actuated collapsing capsules rupture, implode or collapse when the pressure in the subterranean containment space 320 exceeds a predetermined limit, thus accommodating thermal expansion of fluid in the subterranean containment space 320. The pressured operating fluid 326 may be circulated into subterranean containment spaces 320 to prevent casing collapse before, during and/or after cement 318 is circulated into the first stage 324 or second stage 322 of the annulus 306. The pressured operating fluid 326 may also be circulated into subterranean containment spaces 320 as part of the cement 318.

[0040] FIGS. 5A through 5E illustrate an subterranean containment system for protecting a downhole packer 406 from over-pressure according to one embodiment. A downhole packer 408 including an expandable bladder 412 and packer body 410 is positioned within a wellbore 400. The expandable bladder 412 is attached to the packer body 410 which includes port sleeves 416, sleeve receiving apertures 418 and inflation ports 420 in fluid communication with the expandable bladder 412 attached thereto. The expandable bladder 412 is positioned in the wellbore annulus 404 between a tubular 406 and the wellbore wall 402. The tubular 406 may be well casing, casing liner, drill pipe, production conduit or other downhole tubular known in the art. A dart seat 414 may be positioned inside the tubular 406 and/or attached to the packer body 410. A seating dart 422 is launched into the tubular 406 to plug the dart seat 414.

[0041] Pressure is applied to the well packer 408 by pumping or circulating pressured operating fluid 424 having a mixture of substantially incompressible liquid and pressure actuated collapsing capsules through the tubular 406. The pressure drives the port sleeves 416 into the sleeve receiving apertures 418, causes the inflation ports 420 to align and permits the pressured operating fluid 424 to fill the expandable bladder 412. The inflated bladder 412 forms a seal in the annulus 404 between the tubular 406 and the wellbore wall 402. After the downhole packer 408 is filled, any additional pressure applied to the packer 408 through the tubular 406 will cause the port sleeves 416 to withdraw from the sleeve receiving apertures 418 and close the inflation ports 420.

[0042] The seating dart 422 may also be pushed through the dart seat 414 by applying pressure to the tubular 406. The inflated downhole packer 408 provides hydraulic isolation in the annulus 404 to allow for pumping or circulation of fluids below the packer 408. Temperature in the well may increase during production of hotter fluids, such as oil, gas, geothermal water, brine and/or steam. The temperature of the well and fluids therein may also increase in a geothermal well approaching the geostatic temperature. The expandable bladder 412 of the downhole packer 408 can be at least partially filled with the pressured operating fluid 424 to protect the expandable bladder 412 from over-pressure. Pressure actuated collapsing capsules suspended in the pressured operating fluid 424 rupture, implode or collapse when the pressure in the expandable bladder 412 exceeds a predetermined limit, thus accommodating for thermal expansion of fluids in the expandable bladder 412. The wellbore 400 and packer 408 may be cooled with cooling fluid 426 to cause contraction of the pressured operating fluid 424 in the expandable bladder 412. The volume of the pressured operating fluid 424 within the expandable bladder 412 may be reduced substantially (e.g. 10-20 percent reduction in volume) by cooling the pressured operating fluid 424 after a portion of the pressure actuated collapsing capsules have ruptured, imploded or collapsed. This allows easy removal of the packer 408 from the wellbore 400 without the need to drill out the packer 408 or remove the pressured operating fluid 424 from the expandable bladder 412.

[0043] FIG. 6 illustrates an exemplary system for protecting a subterranean containment space in a geothermal well 500 from over-pressure according to one embodiment. A geothermal well 500 is created by drilling a wellbore 502 into a geothermal formation 504 capable of producing heat from fractures 506 within the formation 504. The wellbore wall 524 is lined with casing 510 and a production conduit 512 is positioned within the wellbore 504 interior of the casing 510. An annulus 508 may exist between the casing 510 and the wellbore wall 524 or between the casing 510 and the production conduit 512. A downhole packer 514 including an expandable bladder 516 may be positioned in the well 500 to provide hydraulic or zonal isolation within the annulus 508 between the casing 510 and the wellbore wall 524 or between the casing 510 and the production conduit 512.

[0044] Annular cavities 518 may form in the annulus 508 between the casing 510 and the wellbore wall 524 or between the casing 510 and the production conduit 512 during drilling, completion, production and/or other well operations. Downhole fluids may become trapped within subterranean containment spaces including, but not limited to, an annular cavity 518, an expandable packer bladder 516, or a naturally occurring fracture 506 in the formation 504. Geothermal wells completed in deep granite basement rock can have well temperatures greater than 300^{0}C. The thermal expansion of water or other substantially incompressible fluids used in well operations could cause severe damage to the geothermal well and formation at temperatures as low as 100^{0}C.

[0045] It is undesirable to propagate fractures 506 beyond the efficient heat recovery rate of the geotheπnal well 500. The thermal expansion of incompressible fluids trapped in fractures 506 in the formation 504 can cause undesirable fracture propagation. The pressured operating fluids having a mixture of substantially incompressible liquid 32 and pressure actuated collapsing capsules 32 herein disclosed are capable of accommodating thermal expansion and resulting over-pressure in subterranean containment spaces. To protect the geothermal well 500 and formation 504 from over-pressure a pressured operating fluid 522 comprising a mixture of substantially incompressible liquid and pressure actuated collapsing capsules may be pumped or circulated into annular cavities 518, the expandable packer bladder 516, or naturally occurring fractures 506 in the formation 504. The pressure actuated collapsing capsules rupture, implode or collapse when the pressure in the subterranean containment space exceeds a predetermined limit, thus accommodating thermal expansion of liquid in the subterranean containment space.

[0046] Example embodiments have been described hereinabove regarding improved systems and methods for use of microspheres suspended in a thermally expanding fluid. Various modifications to and departures from the disclosed example embodiments will occur to those having ordinary skill in the art. The subject matter that is intended to be within the spirit of this disclosure is set forth in the following claims.

CLAIMS

What is claimed is:

1. A system comprising:

a subterranean pressured fluid receiving containment space located in a wellbore of a subterranean well; and

a pressured operating fluid filling at least a portion of the containment space and comprising a mixture of substantially incompressible liquid and pressure actuated collapsing capsules wherein at least a portion of the pressure actuated collapsing capsules implode as pressure in the containment space exceeds a predetermined limit.

2. The system as recited in claim 1, wherein the pressured fluid receiving containment space is an expandable bladder of a downhole packer.

3. The system as recited in claim 1, wherein the pressured fluid receiving containment space is an annulus space between a drilled wellbore and a casing string.

4. The system as recited in claim 1, wherein the pressured fluid receiving containment space is an annulus space between a plurality of casing strings.

5. The system as recited in claim 1, wherein the pressure actuated collapsing capsules are hollow and encased in a frangible material.

6. The system as recited in claim 5, wherein the pressure actuated collapsing capsules are of substantially fixed volume and at least partially gas-filled.

7. The system as recited in claim 5, wherein the frangible material is one of glass, ceramic, polymer, metal or pozzolan.

8. The system as recited in claim 7, wherein the pressure actuated collapsing capsules are microspheres.

9. The system as recited in claim 8, wherein the microspheres have a substantially uniform collapse pressure.

10. The system as recited in claim 9, wherein the microspheres have a collapse pressure within 1000 psi of one another.

11. The system as recited in claim 8, wherein the microspheres have a non-uniform collapse pressure.

12. The system as recited in claim 11, wherein the microspheres have at least two different collapse pressures.

13. The system as recited in claim 11, wherein the difference in collapse pressure of a plurality of the microspheres is at least 1000 psi.

14. A method comprising:

defining a subterranean pressured fluid receiving containment space in a wellbore of a subterranean well; and

filling at least a portion of the containment space with a pressured operating fluid comprising a mixture of substantially incompressible liquid and pressure actuated collapsing capsules wherein at least a portion of the pressure actuated collapsing capsules implode as pressure in the containment space exceeds a predetermined limit.

15. The method as recited in claim 14, wherein the pressured fluid receiving containment space is an expandable bladder of a downhole packer.

16. The method as recited in claim 14, wherein the pressured fluid receiving containment space is an annulus space between a drilled wellbore and a casing string.

17. The method as recited in claim 14, wherein the pressured fluid receiving containment space is an annulus space between a plurality of casing strings.

18. The method as recited in claim 14, wherein the pressure actuated collapsing capsules are hollow and encased in a frangible material.

19. The method as recited in claim 18, wherein the pressure actuated collapsing capsules are of substantially fixed volume and at least partially gas-filled.

20. The method as recited in claim 18, wherein the frangible material is one of glass, ceramic, polymer, metal or pozzolan.

21. The method as recited in claim 20, wherein the pressure actuated collapsing capsules are microspheres.

22. The method as recited in claim 21, wherein the microspheres have a substantially uniform collapse pressure.

23. The method as recited in claim 22, wherein the microspheres have a collapse pressure within 1000 psi of one another.

24. The method as recited in claim 21, wherein the microspheres have a non-uniform collapse pressure

25. The method as recited in claim 24, wherein the microspheres have at least two different collapse pressures.

26. The method as recited in claim 24, wherein the difference in collapse pressure of a plurality of the microspheres is at least 1000 psi.

27. An system comprising:

a subterranean pressured fluid receiving containment space located in a wellbore of a subterranean well; and

a pressure take-up means for establishing an upper-pressure limit with a pressured operating fluid filling at least a portion of the containment space and comprising a mixture of substantially incompressible liquid and pressure actuated collapsing capsules wherein at least a portion of the pressure actuated collapsing capsules implode as pressure in the containment space approaches the upper-pressure limit.

28. The system as recited in claim 27, wherein the pressured fluid receiving containment space is one of either an expandable bladder of a downhole packer or an annulus space between a plurality of casing strings.

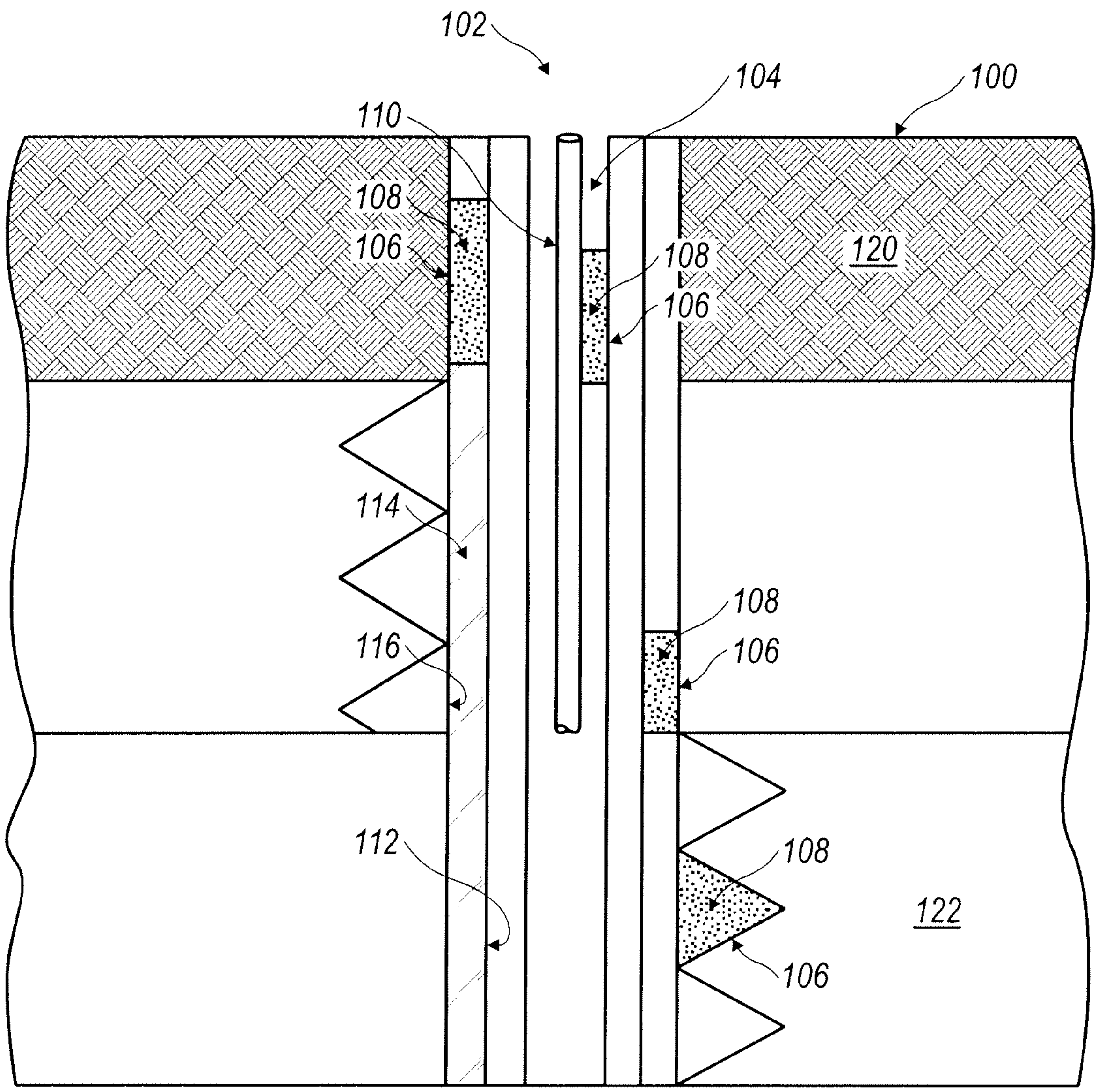
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FIG. 1

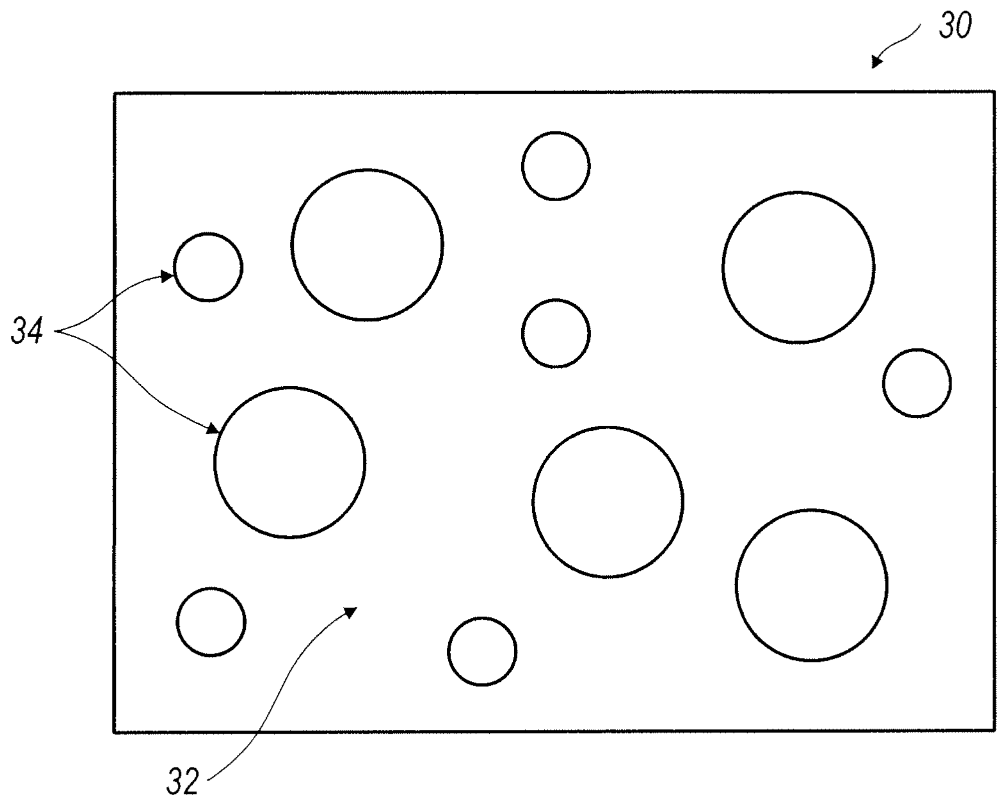

FIG. 2A

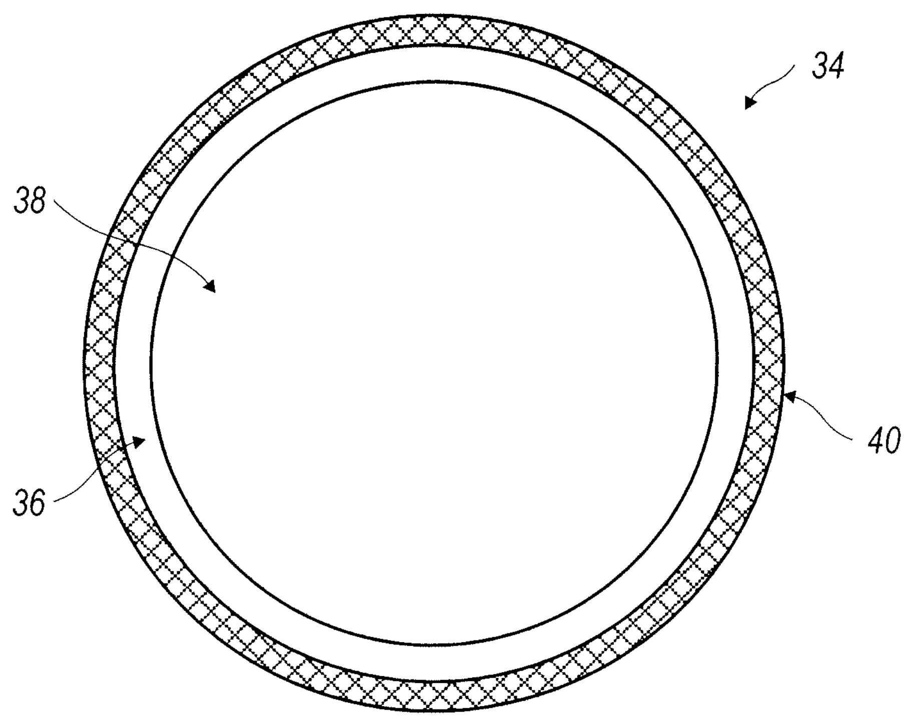

FIG. 2B

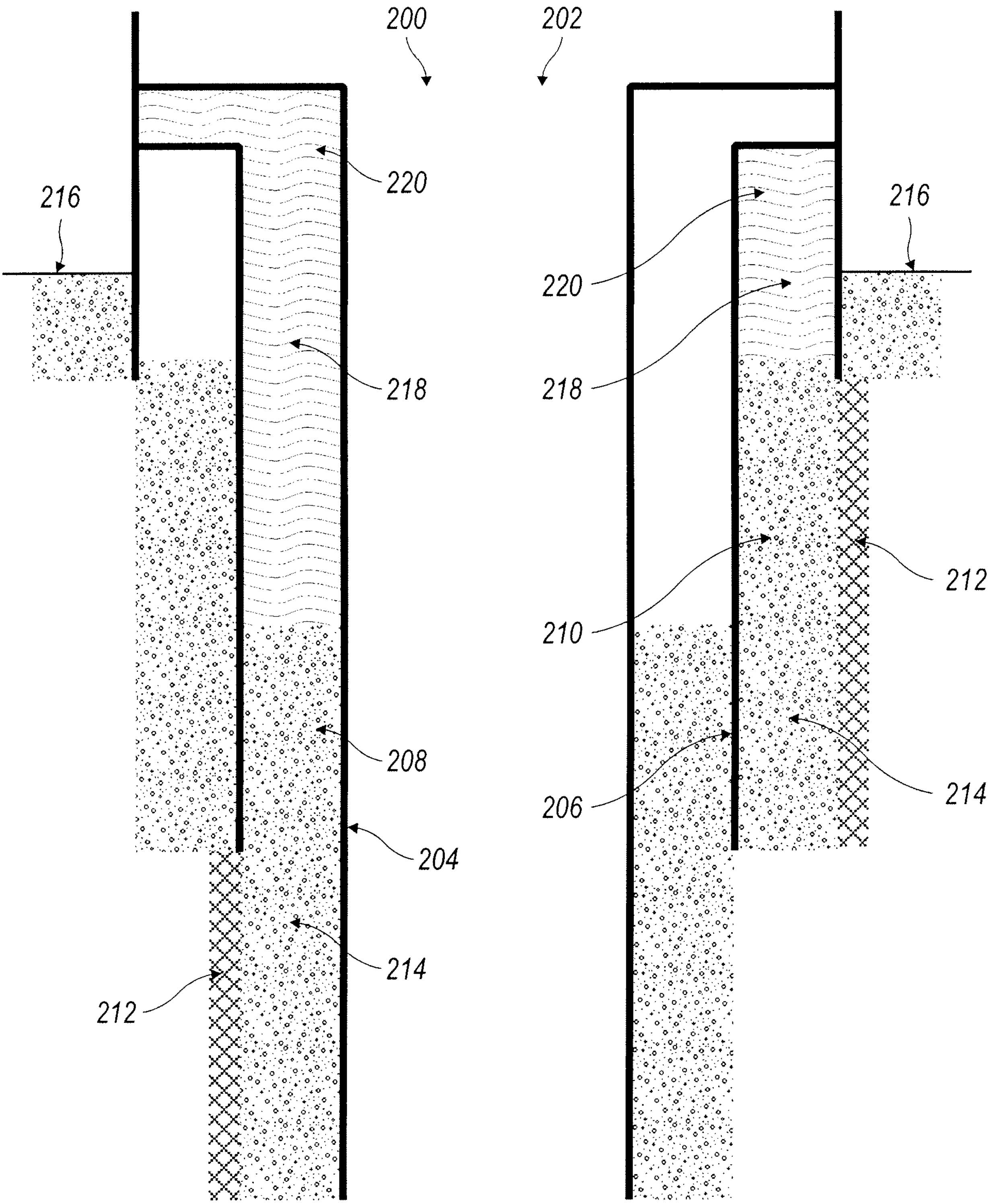

FIG. 3

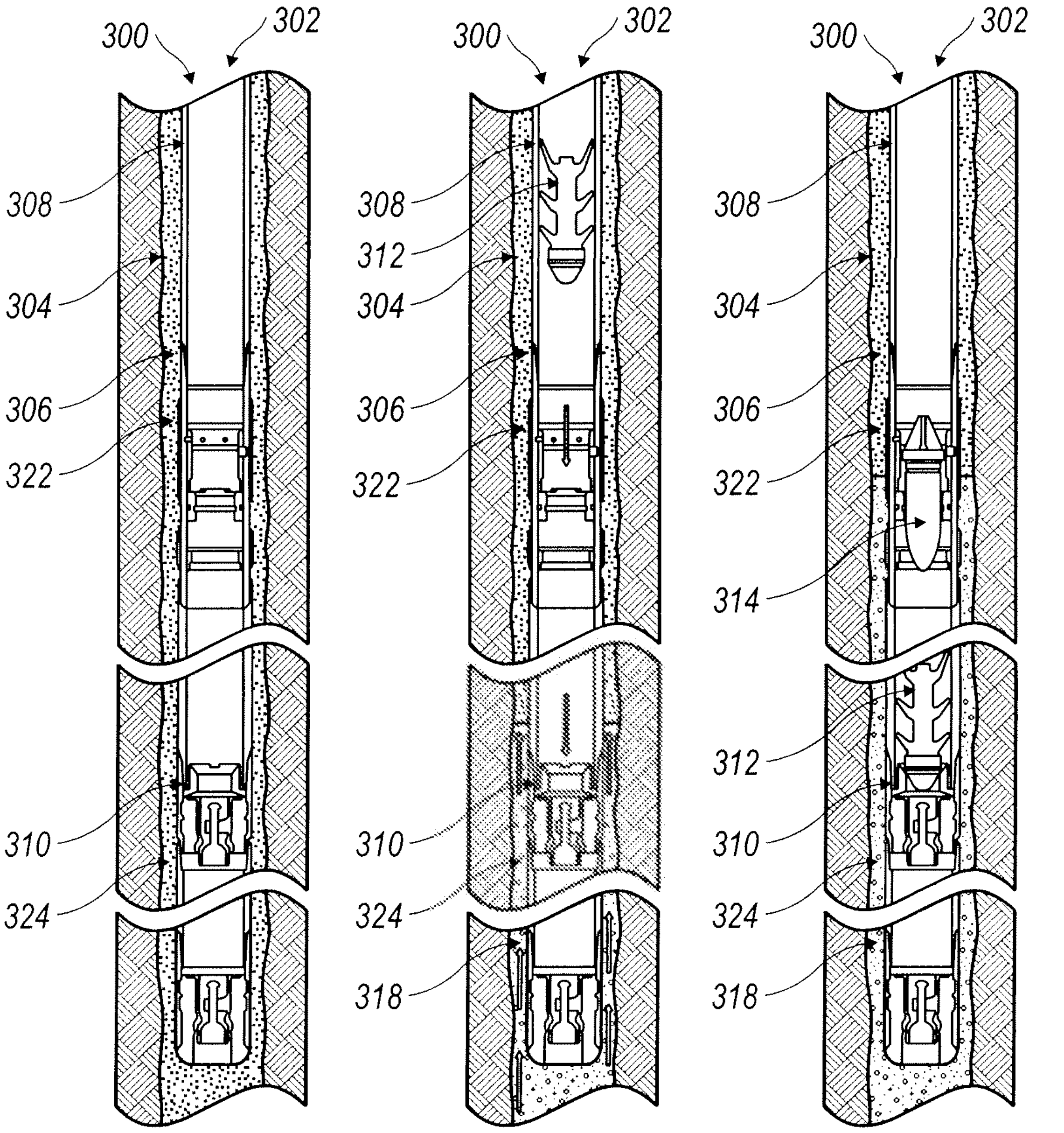

FIG.4 A FIG. 4B FIG. 4C

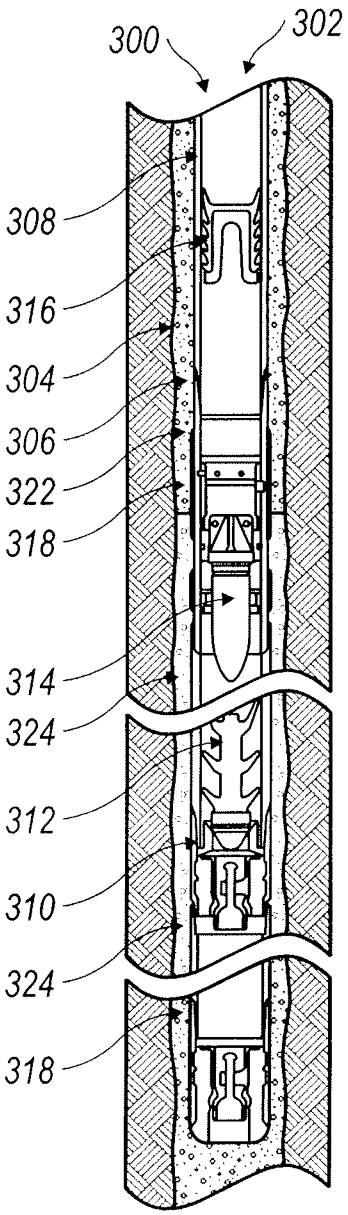

FIG.4 D

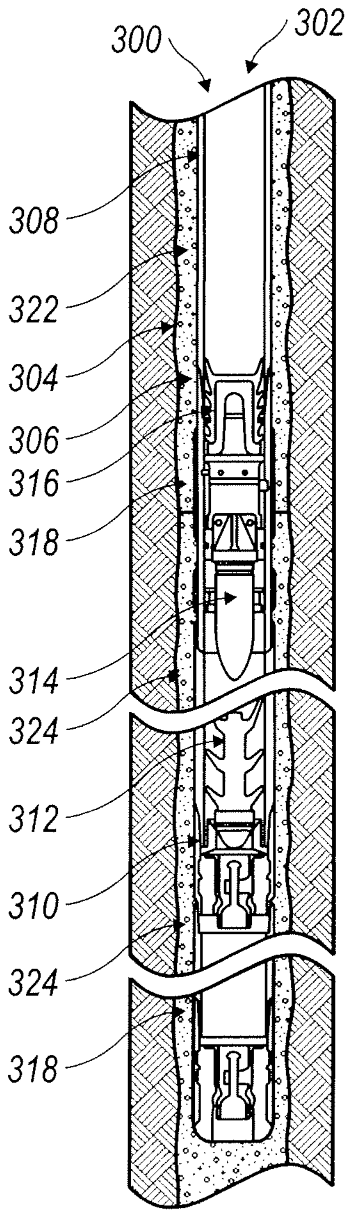

FIG. 4E

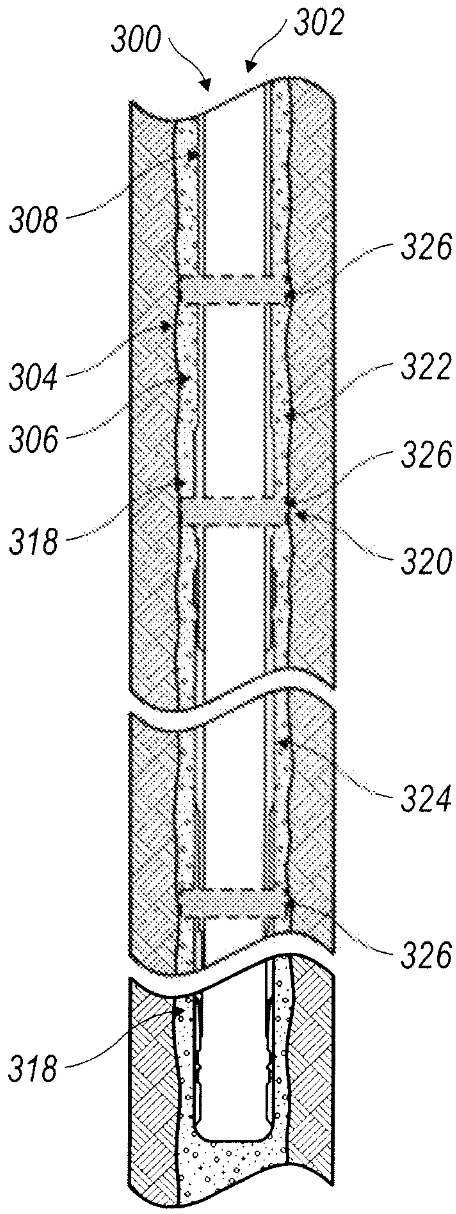

FIG.4 F

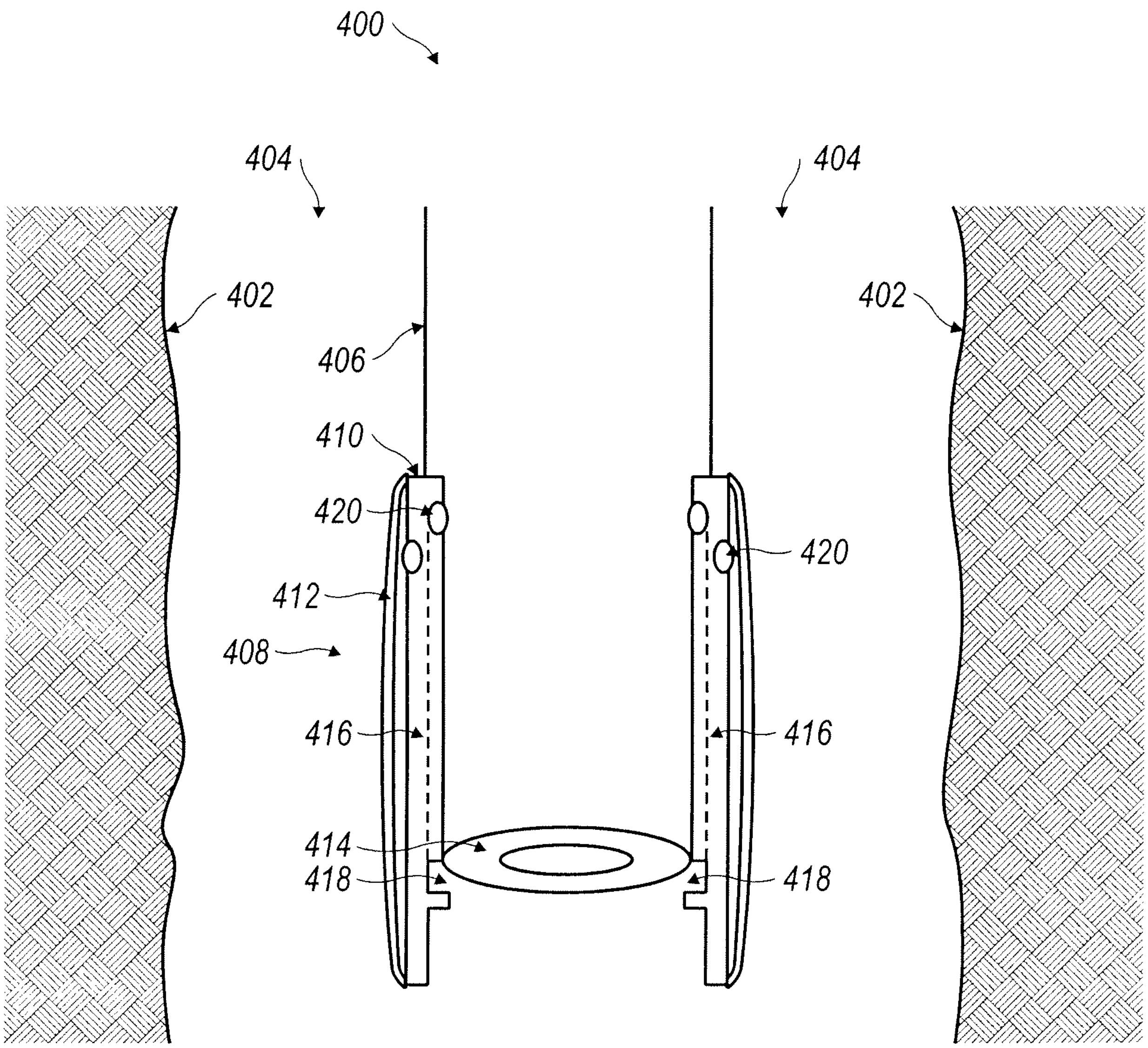

FIG. 5A

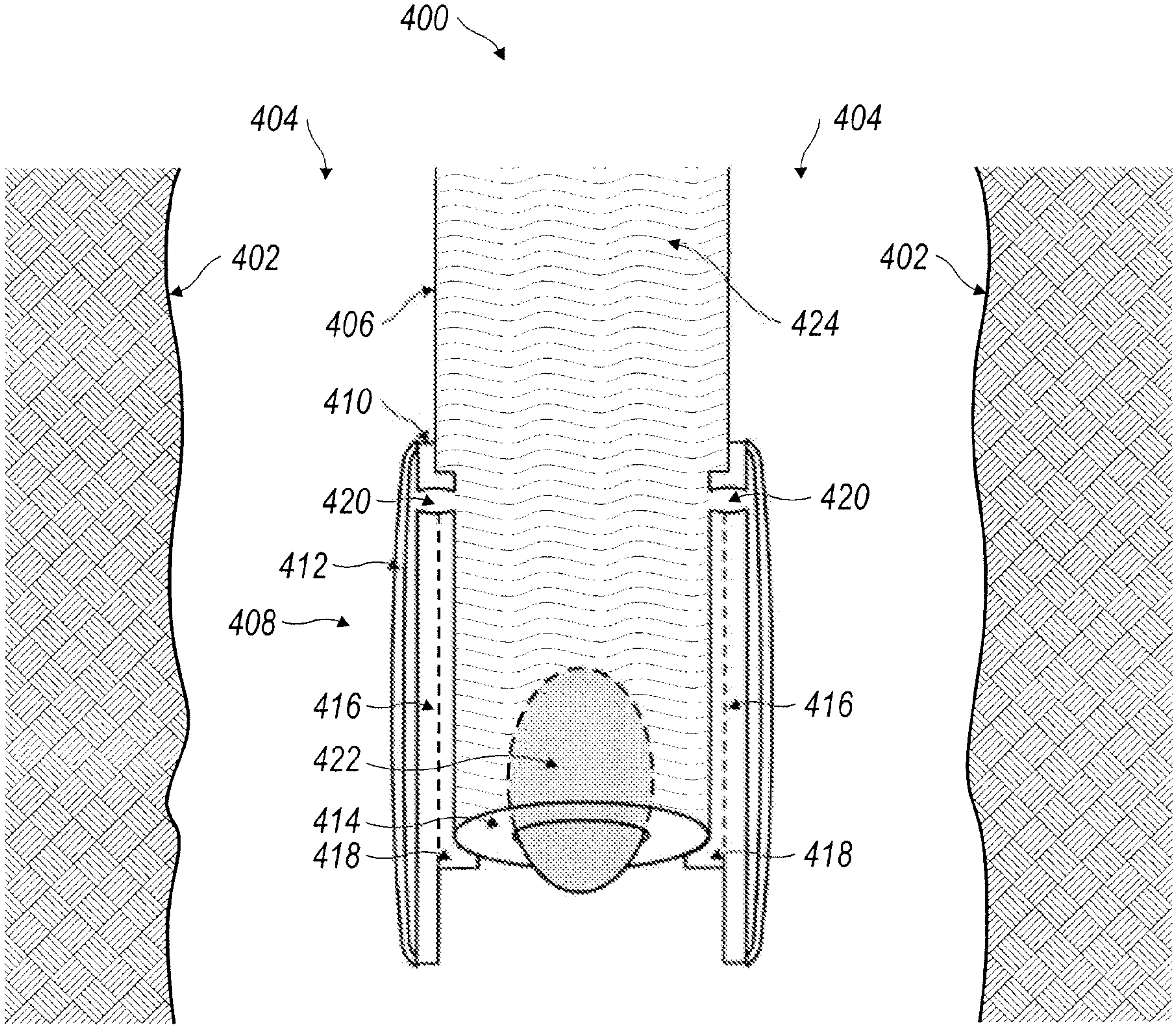
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FIG. 5B

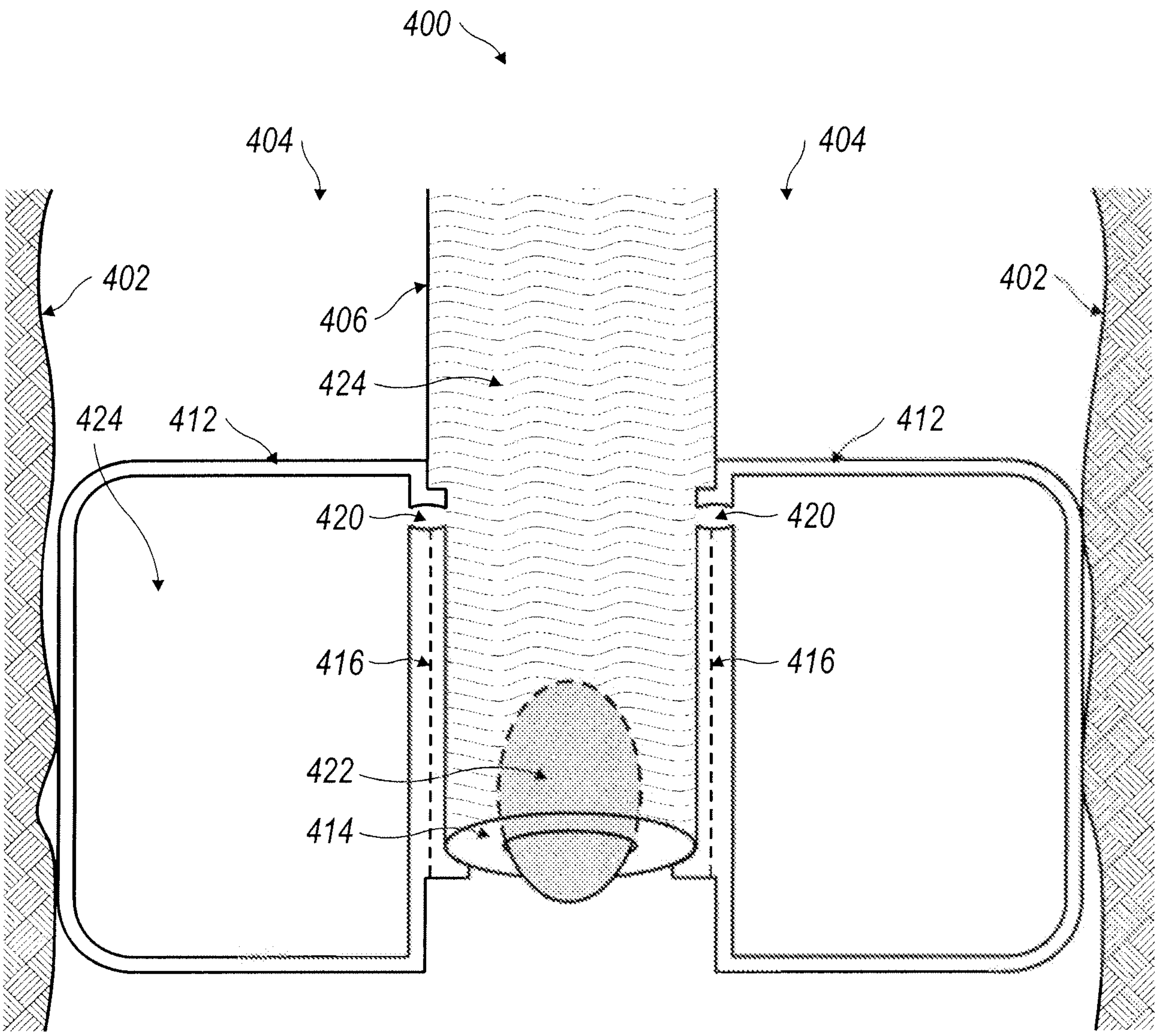

FIG. 5C

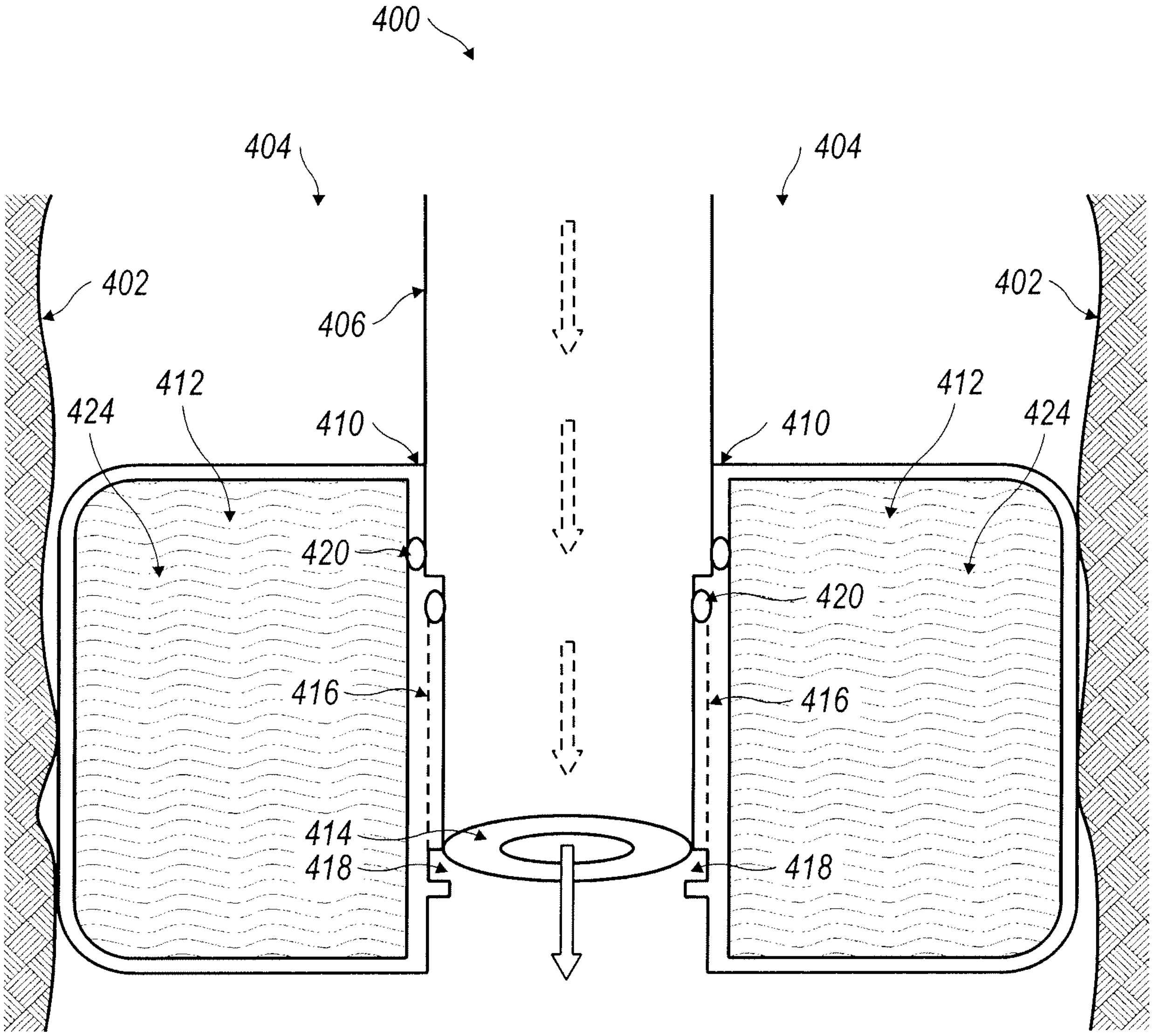
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FIG. 5D

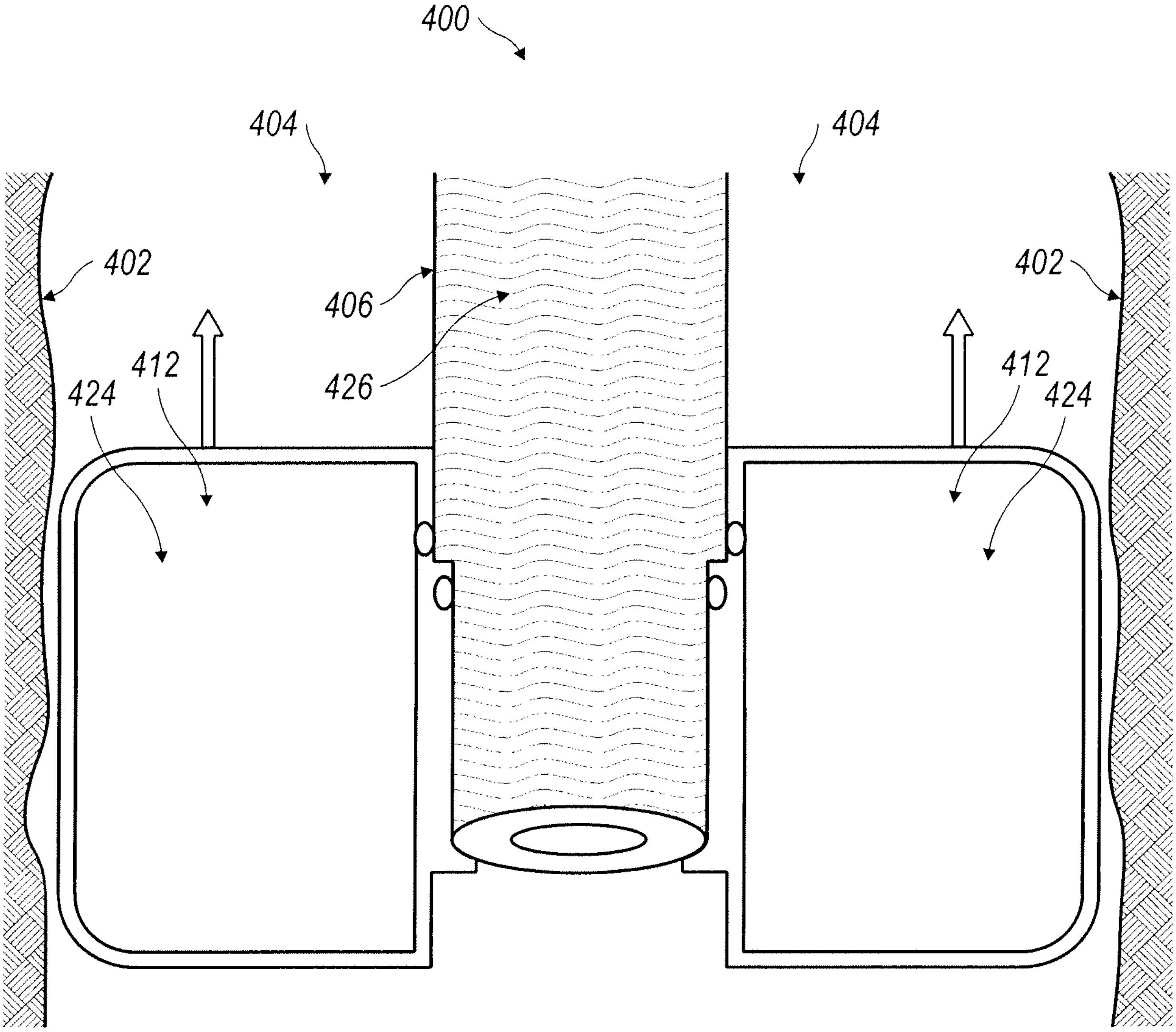

FIG. 5E

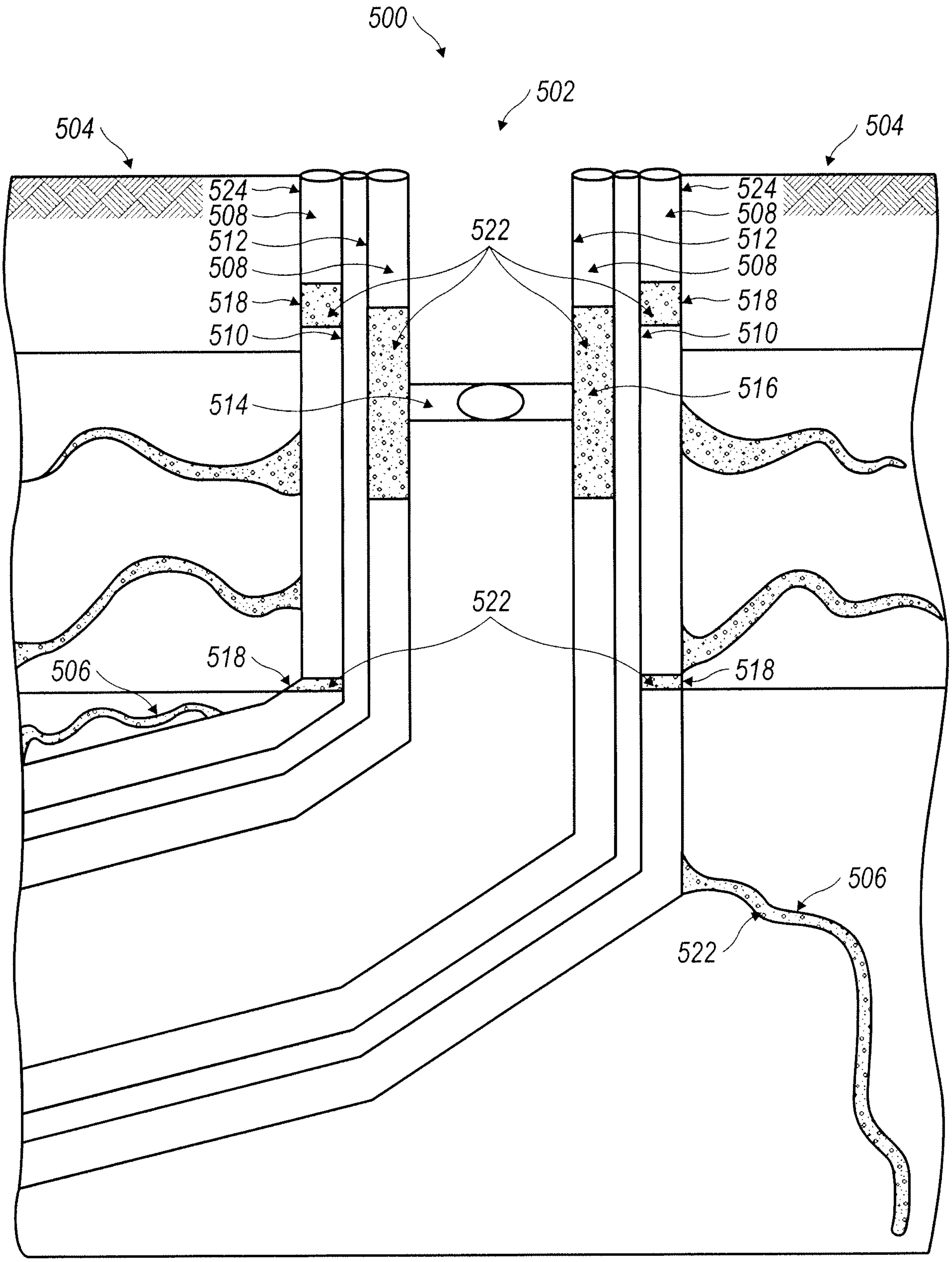
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FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/042137

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B33/12 E21B41/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
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A	EP 0 435 430 Al (COOPER IND INC [US]) 3 July 1991 (1991-07-03) column 1, lines 47-55; figures 2, 2A, 3, 4 column 2, lines 6-11 column 3, lines 11-14, 29-34, 45-50, 57-58 column 4, lines 1-12, 20-25 -----	1-28
A	EP 0 338 154 Al (CAMERON IRON WORKS INC [US]) 25 October 1989 (1989-10-25) column 3, lines 26-31; figure 1 -----	1-28
A	US 4 573 537 A (HIRASUNA ALAN R [US] ET AL) 4 March 1986 (1986-03-04) column 2, lines 8-16 -----	1-28

D Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents

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"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance, the claimed Invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 August 2009	21/08/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P B 5818 Patentlaan 2 NL - 2280 HV RijSWljk Tel (+31-70) 340-2040, Fax (+31-70) 340-3016	Georgescu, Mihnea

INTERNATIONAL SEARCH REPORT

Information on patent family members

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