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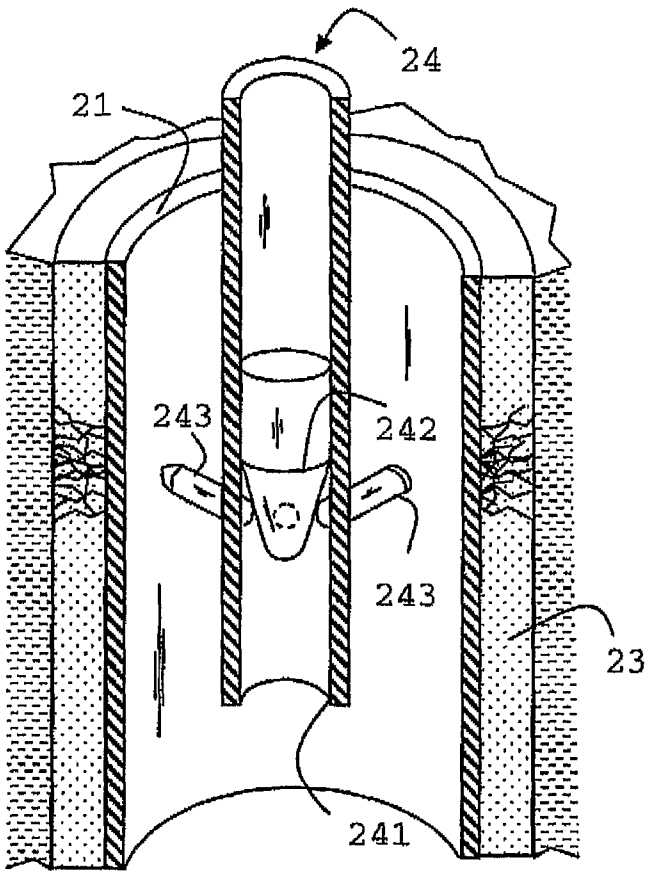
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(54) Title: METHODS AND APPARATUS FOR COMPLETING A WELL



(57) Abstract: Methods and tools are described to reduce sanding including the steps of fracturing the cement sheath (13) in a localized zone around the casing (111) and having the fractured zone act as sand filter between the formation and openings (113) in the casing (111), with the openings being best pre-formed but temporarily blocked so as to allow a conventional primary cementing of the casing. The fracturing step can also be used for remedial operation to reopen blocked formation or screens.

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METHODS AND APPARATUS FOR COMPLETING A WELL

BACKGROUND OF THE INVENTION

[0001] This invention relates to methods and apparatus for completing a well, including but not limited to a production or an injection well. More specifically, certain embodiments of the present invention relate to methods and apparatus for reducing the amount of abrasive or blocking solid particles such as sand from subterranean formation entering the wellbore in either an initial completion of the well or in remedial operations to improve an initial completion. Similarly, in other embodiments of the present invention, systems and methods are provided for control the inflow/outflow of fluids into/out of a wellbore through localized fractures in a settable material associated with the wellbore. As such, this invention may facilitate localized areas of drawdown and production in a production well or selective outflow control in an injection well.

[0002] Certain underground formations encountered in the drilling of wells such as oil and gas wells are sometimes prone to sanding during the production phase. Sand when produced along with the fluids from the formation can cause severe problems with the ability of the well to produce the desired fluids due to blockage by the produced solids and damage done to installations due to the abrasive nature of such particles.

[0003] Wellbores drilled in sanding-prone reservoirs can be completed either in a cased hole configuration or in an uncased (open-hole) configuration. For cased hole completions, a casing string, typically formed from a series of steel tubes joined end to end, is cemented in place in the wellbore. The simplest cement placement is primary cementing where a fluid train comprising a cement slurry is pumped from the surface into the wellbore through the casing string, returning towards the surface along the annular gap between the casing and the formation. The cement sets in the annulus behind the casing to form a material that supports and protects the casing and provides zonal isolation.

[0004] At present, open hole (uncased) reservoir completion of a sanding-prone reservoir is often a complicated and expensive procedure requiring the use of hardware to prevent the sand production from the reservoir during the production phase.

[0005] Common current ways to prevent sanding include;

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- gravel packing after placing tools and screens in the hole;
- placement of a prepacked screen in the open hole;
- use of expandable screen completions; and
- reservoir sandface consolidation, for example using resin.

[0006] The gravel packing process requires the use of a special tool and incomplete placement of gravel is a well-known risk particularly in horizontal reservoirs. Pre-packed screens eliminate the risk of voids but require special complex placement.

[0007] United States patent No. 3 026 936 proposes to facilitate well production through the use of fractures in cement. Fracturing of cement in a vertical well is proposed by use of bullets, mechanical hammers, hydraulically activated pistons and casing deformation through increased hydraulic pressure. Additionally, increasing permeability is proposed by chemical treatment.

[0008] The use of casing liner with pre-weakened (plugged holes) zones is proposed in United States patent No. 4 531 583 which describes a cement placement method for remediation of channels between casing and cement. Another use of casing liner with pre-cut holes is described in the United States published patent application No. 2005/0121203 A1 as expanded liner to be brought into direct contact with the wellbore wall.

SUMMARY OF THE INVENTION

[0009] This invention aims to improve on the previously proposed techniques by localizing the fracturing of the cement. In particular US 3 026 936 to Teplitz has early recognized the potential of producing a well through a shattered sheath of cement and perforated casing. The proposal of Teplitz however has been largly ignored in favor of the above described apparatus and techniques which dominate the industry in the area of well production and sand control.

[0010] The present invention improves certain aspects which have been identified as major obstacles in implementing the method according to Teplitz. For example Teplitz fails to limits the propagation of cracks in the cement sheath thus creating the potential of unwanted crossflow between formation layers and loss of zonal isolation. Though referring to casing perforated prior to its placement in the well, Teplitz also fails to teach ways to place cement slurry through pre-perforated casing tubes.

[0011] The present invention provides apparatus and methods to localize the zone of fractured cement and in another aspect provides improved pre-perforated casing for the primary placement of cement slurries in the annulus between casing and formation.

[0012] In order to localize the fractured zone, the invention applies localized and preferably controlled forces or pressure on the sheath of cement (or any other settable material used to establish zonal isolation) along the wellbore. Preferably, the method comprises expanding the casing in the zone of interest so as to fracture the cement in the zone of interest by means of force- or pressure-transmitting elements.

[0013] Alternatively the zone or volume of fractured settable material is limited by a zone or volume of more compliant, and hence less brittle material located within the annulus. Perforated sections of the casing or liner are placed such that fluids from the surrounding formation passing through the fractured zones can enter the well through the perforations of the casing.

[0014] The zone or layer of fragmented material separating the casing and the producing formation is designed to prevent the entry of sand and other solid particles into the well. In other words, the fractured material between formation and casing acts as sand filter or sand screen.

[0015] At least a section of the casing can have a plurality of opening such as slots, screens, meshs and the like. The opening are preferably filled or blocked with removable filling elements or plugs during the primary placing of the settable material. The method according to this variant includes the further step of removing the filling elements or the plugs in the casing in the zone of interest prior to or during production of the well. Preferably, the removal of the filling elements or plugs occurs prior to fracturing the cement or after fracturing the cement but before producing the well. In a variant of this embodiment, however, the filling material may be removed using produced formation fluids. Alternatively, casing containing open ports may be lowered into the well containing cement or with cement subsequently pumped into the well. In such aspects, cement located in the wellbore may be drilled out of the wellbore leaving the wellbore clear for further operations such as fracturing or the like.

[0016] These various aspects of the invention can be combined according to operational requirements. It is seen as being particularly advantageous to combine the aspects of localizing the fractures in the cement with the use of a pre-perforated

casing to facilitate production. The invention can be applied to vertical and non-vertical or horizontal wells.

[0017] Another aspect of the invention comprises apparatus for fracturing locally the cement surrounding a casing in a well.

[0018] In certain embodiments, by controlling the location of the fractures in the cement, settable material and/or the like, inflow of fluids into the wellbore from a reservoir and/or outflow of fluids from the wellbore to the reservoir may be controlled. This control of fluid flow using localized fractures in the settable material may be used as a substitute for perforating the wellbore/wellbore casing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The invention will now be described in relation to the accompanying drawings, in which:

[0020] FIGs. 1A and 1B show one embodiment of the invention before and after fracturing;

[0021] FIGs. 1C and 1D show another embodiment of the invention before and after fracturing;

[0022] FIGs. 2A and 2B show views of an apparatus according to one embodiment of the invention;

[0023] FIGs. 3A – 3D shows various forms of casing and adapted tools for use in the present invention;

[0024] FIG. 4 shows a tool for generating shock waves to fracture cement;

[0025] FIGs. 5A-5C show casing with force- or pressure localizing elements in accordance with the invention;

[0026] FIG. 6 shows casing with pre-formed openings;

[0027] FIG. 7 illustrates another example of casing adapted in accordance with the invention; and

[0028] FIG. 8 is a flowchart of steps in accordance with an example of the present invention.

DETAILED DESCRIPTION OF EXAMPLES AND VARIANTS

[0029] One aspect of the invention concerns a primary cementing process that will provide a permeable material in front of producing zone. This process may happen in one stage or multiple stages. One embodiment of the invention is shown schematically in FIG. 1A. A casing string **11** is positioned in the well **10**, with conventional steel casing **111** in front of the cap rock **121** or impermeable formation, and slotted casing **112** with a plurality of slots **113** in front of a permeable zone **122**. In one embodiment of the present invention, the plurality of slots **113** may be arranged in a perpendicular direction/orientation relative to the slotted casing **112**. In other embodiments, the plurality of slots **113** may be arranged in any direction/orientation relative to the slotted casing **112** and one or more slots in the plurality of slots may in fact have different directions/orientations relative to the slotted casing **112** then other slots in the plurality of slots **113**. A fluid train, comprising a cement slurry appropriate for the wellbore conditions is pumped from the surface along the casing **11** to fill the annulus between the casing **11** and the formation **12** thus forming an impermeable sheath **13** around the well. A cementing plug **131** may also be placed in the fluid train between the fracturable cement slurry and fluids remaining in the casing. This process will leave the hole either free to continue drilling, run tools, or to be filled with oil.

[0030] In FIG. 1B a fracturing force is applied to the cement to generate fractures **132** the set cement **13** locally in the zone around the slots **113**. Details of suitable methods to confine the fractures within the desired zone will be described below.

[0031] For example, in FIG. 1C a fluid train comprising a conventional cement slurry, followed by a more compliant sealant formulation, followed by easily fracturable cement is pumped along the casing **11**. The fluid train (described in more detail below) is placed behind the casing **11** into the annular gap between the casing **11** and the formation **12**. Thus, the standard cement **133** is placed above the compliant sealant **134** and the fracturable cement **135** in the zone of interest. At some time after setting of the materials behind the casing **11**, the fracturable cement **135** and in some cases the formation will be fractured/cracked to allow production from the reservoir formation **122** through the fractures **132**, as is shown in FIG. 1D. The compliant zone **134** prevents the cracks **132** from propagating beyond the cement **135** adjacent to the producing formation **122**. Suitable materials for the sealant are described below.

[0032] In variants of this embodiment (not shown), the properties of the cement **133** and **135** are chosen such that the fractures stop at the interface between the two cements, without requiring an intermittent zone of sealant material **134**. Cements with compliant and elastic properties are known as such in the art, for example under the tradename FlexSTONE (RTM) by Schlumberger. Alternatively, it may be possible to use the same type of cement in both zones **133** and **135**, provided the sealant **134** prevents the propagation of fractures **132**. Suitable materials for the sealant are described below.

[0033] The details which follow describe various methods to apply a fracturing force or pressure to cause the cement to fracture at the desired locations within the wellbore.

[0034] A controlled load can be applied through the casing and/or sealing plugs for inducing cracks in the cement by means of one or more force or pressure transmitting elements. A contact element can vary in shape, number and position to optimise the process. In one embodiment, the tool applying the force can could be repositioned in the casing and the process repeated or a device could be configured as an (vertical) array of such elements.

[0035] An example of one such downhole tool **24** is shown in FIGs. 2A and 2B. In this example a hydraulic pressure is applied to the top of a conical wedge **242** mounted in a carrier tube **241**. Alternatively the wedge can be loaded mechanically via a screw driven by an electric or hydraulic motor (not shown). The wedge in turn transmits a force to the casing **21** by pins **243** fed through the carrier tube **241**. The position and number of pins **243** can be designed to optimise the number of fractures **232** in the cement **23**. The pins could also be used to puncture the casing **21** When using a casing with plugged slots similar to the casing **11** of FIG. 1, the tool **24** can be used to push through plugs which seal openings in the casing during placement and pumping of the cements as described below.

[0036] In FIG. 3, there are shown further examples of methods and tools for fracturing the cement locally. In FIG. 3A, the casing **31** is surrounded by set cement **33**. The casing has one or more spikes **311** on the cement side, and has an indent **312** on the inside. The cement fracturing tool **34** includes a piston **341** joined to a probe **342** that projects through the tool through O-ring **343** designed to prevent stray materials fouling the spring **344** The piston **341** is sealed by the O-ring **345** and can be activated against the spring **344** by compressed oil or water acting on its face. On

activation the probe-tip **342** enters the indent **312**, and forces the spike **311** into the set cement **33**, causing the fracture **332**. The piston **341** is prevented from retracting by a wedge or circlip **346**. The tool **34** then travels to the next spike/indent of the casing and repeats the operation as required.

[0037] In FIG. 3B shows a modified casing which includes movable elements to fracture the cement locally. The set cement **33** abuts casing **31** holding one or more cavities **311**, each containing a piston **312** normally held against backstop **313** by spring **314**. The assembly is held in position by a circlip **315**. The cement side of the piston **312** has spike **316** and a soft plug material **317** which prevents the ingress of the unset cement into the piston/spring region **311**. Following the cement set, the the piston is pushed by a tapered plug **351** (shown in part), housed in a tool **35**, under the action of hydraulic pressure. Any other available force, e.g. derived electrically in wireline conveyance, or hydraulically in coiled tubing conveyance could be envisaged to generate the force to push the spike **316** against the cement **33**. The spike **316** causes the cement to fracture. Fluids produced through the fracture may flow either through slots in the casing such as shown in FIG. 1 above, or, using the cavity **311** in the casing **31**, through a hole (not shown) in the centre of the piston **312** and or a combination of the two. In all cases the modified casing may contain spikes of different protrusion allowing selection of fracture size, position and number. These spikes may also sit along side holes containing oil soluble resin as plugging material.

[0038] In simplified embodiment, shown in FIG 3C, the spike **316** protrudes from the casing **31** either partially or fully embedded into a plug of elastomeric material **318** which provides an elastic but fluid tight mount for the spike.

[0039] In the embodiments of FIGs. 3A – 3C the spike could be held in position after the cement has been fractured initially by means of a frictional material, or a device containing grooves (dents) or seats in the piston. Such a variation in the surface of the piston has been presented by in FIG. 3D as **319**. Other variations to locate the spike without retraction while maintaining stress could be envisaged.

[0040] In some situations these spikes may contain sensors that would monitor the flow, temperature and composition of produced fluid.

[0041] Alternatively when the casing is of reduced thickness an elastomer may be used stand alone to position the insert and prevent cement leakage (see Figure 3B). The insert, spike or pin could protrude into the cement on the outside of the casing prior to applying a load.

[0042] Another alternative to apply controlled pressure is to use explosive devices to increase the hydraulic pressure inside the casing to shatter the cement in the annulus or shaped charges which create a local pressure wave. The suggestion of Teplitz in US 3 026 936 to use bullets to punch holes in the casing or shatter the cements does not afford a similar control over the pressure ranges and location of the force when compared to the methods of the present invention operating explosive charges without bullets. The explosive devices could penetrate or not penetrate the casing. In the example of FIG. 4, a coiled tubing conveyed gun **44** is shown lowered in the wellbore. The gun carries a plurality of explosive charges. The explosive charges could be encapsulated in small pressure chambers **441** which are exposed to the fluid and efficiently couple the shock wave to the casing **41**. This creates a large hydraulic shock to the casing, which is beneficial in shattering the cement **43**.

[0043] Perforating devices (explosives) have been used to punch holes in the casing and penetrate the formation to enhance production. There has been some evidence of the cement shattering especially near the perforated hole and when used in high density. Tubing punchers, which are simple perforating charges with very low penetration, could be used to just penetrate the casing.

[0044] The explosives may be replaced by electromagnetically operated hammer deployed on a wireline tool. The hammer is placed close to the casing, and is activated, ringing on the casing, the shock waves causing the cement to crack in a known manner.

[0045] Controlled vibrational energy can also be used to crack the cement. Again, using a wireline deployed device a ring can be expanded from a small collar and clamped to the casing. A shaker device of a known or optimized frequency can then excite the casing with sufficient high frequency energy to cause radial cracks. The frequency and magnitude of the vibration can be tailored to the depth and ambient pressure and temperature to optimize the size of the cracks that are formed. The acoustic source could have the secondary and beneficial effect of reducing the viscosity of produced oil.

[0046] Another approach is to apply heat to the casing surface to encourage the cement to expand and crack, while reducing the viscosity of the hydrocarbon fluid. For example, localized heating using radiation or induction can be deployed to crack the cement in predetermined zones. In this case a tool is lowered on a wireline to deliver 9 kW (and even higher bursts) of energy. This energy can be converted to

heat with focused probes (in a manner similar to the pins described above). The pins focus the thermal energy into the cement in a very precise manner.

[0047] Another solution is to use a mandrel, similar to those used for expandable casing. The mandrel is pulled from the surface thus deforming a section of the casing as desired. The shape of the mandrel can be tailored to induce a permanent amount of deformation of the casing, ensuring not only that fractures will be created but also that they will remain open. The amount of deformation can be tailored to induce cracking in the cement in both tension and shear, and to increase the density of fractures when such a feature would be beneficial. More than one mandrel can also be used for further casing expansion and cement cracking if required. In some situations the mandrel may contain chemicals that can alter the surface properties of and or all of the casing, the cement and the filtercake.

[0048] A controlled expansion of the casing may also be achieved by using hydraulic pressure applied inside the casing.

[0049] In addition to the steps described above electrical fields, gamma rays, or X rays may be used to degrade the cement prior or after the fracturing.

[0050] Of these potential alternatives as sources of a fracturing force, some, for example hydraulic pressure, heat or other means of expanding the casing are not easily confineable and are likely to lead to fractures outside the desired zones. In such cases, the distribution of cracks in the cement can be localized and controlled by the surface topography of the casing **51** in contact with the set cement. Examples of some of the casing configurations suitable for such a purpose are presented in FIGs. 5A – 5C and include axial knife-edge ribs **511**, circumferential knife-edge ribs **512** and pointed protrusions **513**, respectively. In accordance with certain embodiments of the present invention, other force or pressure transmitting elements – including but not limited to a groove in the casing, a modified centralizer or the like -- and combinations of any of the above, may be used.

[0051] If using a conventional casing string such casing is perforated or cut after placing and setting the cement. Such alteration of the casing would require the use of a perforation tool as described above, a casing drilling tool or a water jet. The water jet can be held close to the casing surface by magnetic arms and rotated in contact with various positions on the casing. The nozzle diameter and speed of displacement can be used to control the slot width. The jet may be provided by a downhole pump and a tractor conveyed on a wireline. In another variation of this approach it could be

possible to increase the power available by pumping fluid down a coiled tubing to power a downhole pump.

[0052] However, it is preferable that the casing is modified to allow the carrying out of a completion in accordance with the present invention as a part of the primary cementing process.

[0053] Hence, any of the above variants benefit from the use of casing such as described in FIG. 1 having slots or milled weak regions or mesh-type openings, which are covered, plugged or cut to less than the casing thickness to hold a minimum amount of pressure differential. The cover or plug would rupture or be punctured when the fracturing force is activated. Alternatively, the cover or plug is dissolved by fluids which can either be pumped from the surface or are effluents from the formation. An example of such a casing or screen is shown in FIG. 6.

[0054] In FIG 6, the lower half of casing tube **61** has a plurality of openings **613** each filled during placement and pumping of the cement with a plug **614** as shown in the enlarged view.

[0055] The plug material can be an oil soluble resin, a brittle material or a material with a high thermal expansivity. Such plugs can be arranged to crack or melt during the hydration of the cement or dissolve in contact with oil or water. Alternatively they may be melted or broken on casing expansion or dragged out of position by a tool run in the hole after the cement has gelled but before it has set.

[0056] In general, the openings in the casing or screen will preferably have a width less than the domains in the fractured cement (as an extra safeguard against complete failure and sand production), preferably at most 2.5 times the diameter of the sand particles of the formation. The remaining cement fragments are likely to be much larger than the particles (probably in the range of 0.3 mm to 1 mm) and will then not be produced through the casing or screen. The screen or casing has a permeability greater than the fractured cement but it can have areas that remain unperforated to prevent collapse and eliminate the need for extra circular (ring) supports in the wellbore. These areas without openings may contain multiple surfaces that are conical or wedged in shape as are described above in an example above.

[0057] Though conventional casing is made of steel, other metallic and/or non metallic (e.g., polymeric or composite material) casings can be envisioned for the present application.

[0058] A schematic of an alternative modified casing is presented in FIG. 7. In this approach a wire mesh **711** is attached to the back of the perforated or slotted casing **71**. The mesh can be coated on the outside with an oil or water soluble polymer **712** which allows the placement of the cement **73** as slurry during the primary cementing at the back of the casing. As the oil or water penetrates the holes/slots **713** in the screen it will reach the polymer coating and solubilise it. The pressure is applied to the cement through the holes in the screen which will reduce the required fracture stress.

[0059] Alternatively the coating **712** will be altered by the high pH (≈13) environment of the cement and fracture when extra stress is applied in the wellbore. This variation on the screen allows for primary cementing, reduced cement failure pressures, increased permeability (connectivity) behind the screen, and maximize the effect of shrinkage stresses in the cement.

[0060] Referring now to desirable and preferred properties of the cement material for use in the present invention, the important properties of the cement are its shrinkage, compressive strength, elastic properties and hydraulic permeability. These properties will determine the properties of the cement and the way it can be fractured.

[0061] Merely by way of example, shrinkage (after gelation) of a standard class G cement slurry has been observed with a resultant strain on the casing of 0.01%. A laboratory experiment showing this was carried out in the absence of excess water and the result was the generation of a tangential tensile stress and tensile fractures developed from the outer surface towards the casing. While the foregoing analysis concerned class G cement slurry, embodiments of the present invention are not limited to use with such cements and may be used with other cements, cement slurries, cement like mixtures and or the like. Maximising the shrinkage of a cement slurry while reducing the tensile strength can lead to natural fractures in the cement. After placement of cement, the bottom hole temperature will rise (sometimes by as much as 20°C) increasing the tangential tensile stress in the cement. Software simulations were carried out using standard cement slurry inputs and sandstone as the formation and a 7 inch (178 mm) casing. The set cement had a Young's modulus E of 5 GPa and a tensile strength of 3 MPa and failed in tension if the casing was expanded by 0.13%. The stress required for fracturing the cement may also be altered, preferably reduced, by the presence of a layer of filter cake between the formation and the cement, the presence of a gap or micro-annulus between the

formation and the cement or an unconsolidated formation. Such a gap can be caused by a significant shrinkage of the cement during setting.

[0062] Using an approximation to a thin walled cylinder for a free standing 7 inch casing, such an expansion would require a pressure differential of *ca* 15 MPa. Using the software simulation and allowing for strain in the cement and rock, a pressure increase of 37 MPa would be required for tensile failure and higher stresses for a combined tensile hoop stress and compressive radial stress. Altering the Young's modulus E and Poisson's ratio ν of the modified casing to values for cement would reduce the required pressure to around 15 MPa and changing the steel to non-metallic material (e.g. plastic) ($E = 200$ MPa, $\nu = 0.45$) reduces the wellbore pressure required for fracture to around 13 MPa.

[0063] A flexible cement is not required for this completion technique. Instead, a brittle material with the lowest possible tensile strength is preferred. However, in some embodiments of the present invention, a flexible cement may be used. In some situations the rock will be fractured at the same time as the set cement is fractured, giving the potential of bypassing the internal or external filter cake which often forms an additional layer between cement and formation.

[0064] The design of a cement based material in which multiple radial fractures can be induced and microcracking established while limiting the crack tortuosity is important. This material may be a conventional cement slurry, i.e., cement and water mixed with or without other additives. Alternatively it can be a cement designed to be permeable that can be remediated by refracturing. After fracturing, the resulting permeability is however much greater than the initial values of permeability. The cement could also be vibrated by an acoustic source to remove debris from the fractures. The formulations would allow variation in the density range and the addition of fluid loss additives. Free water development could be minimised or maximised as required depending on the well orientation. The water to cement ratio will vary between 0.2 and 0.6 and other additives will be used to alter the stress response. Included in the formulation would be a dispersant, retarder and antifoam agent as for conventional systems. Approaches to maximising fracture distribution could be

- non bonding particles with oil soluble or hydrophobic layer
- aggregate addition
- fibres or plates for fracture propagation and solubilisation

- coalescence of emulsion droplets
- oil swelling particles to give fractures by osmotic swelling
- maximised shrinkage

[0065] In some variation of the above list hydrophobic particles or polymer can be added to the matrix to reduce the impact of water production on the cement matrix, such as scaling or matrix dissolution.

[0066] Generally particles are added to cement in the oil industry to alter density and enhance strength and flexibility. These particles can be mineral based or polymer based. The particles can have any shape from fibres to plates to spheres. Other complex geometries may apply.

[0067] Aggregates alter the stress distribution in the cement matrix and also the structure of the set cement at the interface. Fracture redirection at the aggregate-cement interface can lead to an increased permeability especially if the particles were dislodged during oil production. Aggregate particles can have a diameter as large as 1 mm. These aggregates can be minerals from silts, clay, granite, pyrex, slag, fly ash, crushed concrete, wood or carbon black. These particles may be added to increase the brittleness of the cement.

[0068] Alternatively at temperature the fracturing of the cement based composite could be facilitated by the differences in coefficients of expansion between the cement and aggregate, pore pressure reduction leading to increased effective stress and at extreme temperatures the decomposition of hydrates. The fracture of cement without filler could also be achieved if a percentage of the cement remains unhydrated. Then the fractures would form through the silicate gel, calcium hydroxide crystals and around the unhydrated cement particles.

[0069] In an alternative formulation non bonding particles with oil soluble layers could be added. This oil soluble layer could result from an asphaltene and/or resin emulsion added to the initial formulation.

[0070] The fracturable cement may consist of oil droplets as well as Portland cement, an emulsifier, cement retarder and water. The density of the formulation may be adjusted as necessary. The surfactant may be unstable at high pH and temperature resulting in coalescence. During a fragmentation process cement matrix fragments and the oil filled pores are connected. These oil-wet pores fill with oil from the reservoir and surface layers may prevent the precipitation of calcite or other minerals should water be produced.

[0071] Particles of wood, polymer, clay, polypropylene, rubber and hydrogel may be chosen at high volume fraction such that the swelling stresses when in contact with oil could assist in the fracture of the remaining cement matrix.

[0072] Cement shrinks on setting because the volume fraction of products is less than that of the reactants. Once gelation has taken place the absence of excess water can further increase the shrinkage of the cement. Water uptake from a permeable formation can be prevented by the addition of permeability reducing agents in the cement slurry. Such shrinkage could lead to cracking in a radial geometry. This shrinkage could be maximised by increasing the concentration of aluminate phases in the cement or by altering the water to cement ratio. Alternatively expanding agents such as calcium and magnesium oxides may be added to increase the stress in the cement matrix further.

[0073] The concept of permeable cement for reservoir completions is not new in the oil industry. These materials contain foam, oil droplets or degradable particles. These materials could form the basis of the special cement for this application.

[0074] The sealant depicted as **134** in FIG. 1C and 1D is designed to prevent the transmission of fractures upstream and/or downstream behind the annular gap or to act as a pressure seal. This material can be a modified cement or an organic material. Suitable materials for such a seal are described for example in detail in the United Kingdom Patent Application No. GB 2398582. The material is a set material that is flexible and has a Young's modulus of around 1000 MPa or lower. The material can be placed in compression or can swell in contact with oil.

[0075] In case the fracturing of the cement requires a layer of filter cake between the cement and the formation, existing drilling fluids and/or methods of removing the filter cake may have to be modified so as to ensure the presence of such a layer. However, in other cases the presence of the filter cake may reduce the flow through the fractured cement and hence, the complete removal of the filter cake may be warranted.

[0076] In conventional horizontal cementing, centralizers may be required to be placed at 6 m intervals to achieve the recommended API stand-off of at least 67% and allow proper cement placement. For these applications, a centralized casing is preferred. However, standoff is not critical as perfect hole cleaning is not necessary. Centralizers can be further apart than 6 m and can be reduced friction rollers or specialized filtercake removers. Alternatively the centralizers might be designed and

placed so as to allow turbulent placement of the cement to facilitate filtercake removal.

[0077] Drilling mud filtercake is formed on the outside of the reservoir rock and if the rock permeability is above ≈ 50 mD polymers (xanthan, starch, scleroglucan) from the reservoir drilling fluid could invade the rock. This invasion would lead to reduced productivity. It may not be possible to carry out any of the conventional cleanup practices after the cement has been placed. One option is to drill the zone of interest underbalanced reducing invasion and thus the creating of a filter cake. Alternatively the shrinkage of the cement on setting can leave the filtercake unsupported with a pressure between the filtercake and the cement. Produced oil can rupture the filtercake and possibly displace the internal solids. There is also the potential for the filtercake to be modified during the expansion of the cement. In another approach the filtercake may be embedded into the cement during fracture and dislodged by the use of an acoustic cleanup tool. Alternatively a fluid carrying an enzyme-based breaker can be injected through the cement. Alternatively the cake may be partially removed by the passage of cementing fluid. The invasion of cement filtrate into the formation can be prevented by the addition of fluid loss additives to all the cement based formulations. In this situation the use of acoustics to clean up the fractures in cement and dislodge the internal cake is a possibility. A fracturable cement containing fluid loss additives can limit the invasion of the cement solids into the formation.

[0078] The permeability of the fractures generated in accordance with any of the methods described above can be enhanced or recovered using an acidizing treatment. Optimised acidic solutions can be squeezed into the fractured cement for clean up or used to increase the permeability of the cement prior to further fracturing. Such acids, for example a mixture of 12%HCl/3% HF, can be spotted along the surface of the casing. The acid can also comprise acetic, formic or citric acids or mixtures of the above.

[0079] Alternatively, materials such as those used for squeeze treatments can be used to block unwanted or large fractures in the cement. The material can be cement based or an organic material or a combination of both. The material can be injected during water production or in exceptional circumstances when sand is produced through the screen. Such remediation allows complete control and drilling ahead if necessary.

[0080] The remedial fluids can be conveyed downhole in coiled tubing or it could be presented to the casing inside a spike or pin (as described above) used for fracturing.

[0081] The scope of the present invention may be extended for use in gravel pack tools for cased hole remediation or prepacked gravel packs. Variants of the present invention may include the step of placing a layer of settable material inside a perforated casing and using any of the above described methods to fracture solid blocks or sheath of settable material and thus converts them into functional equivalents of the conventional gravel packers. The placement and fracturing of the cement in this case may require the use of packer technology to isolate the sections of the well in which a gravel packer is to be placed.

[0082] Gravel packs typically have a permeability of 40 – 50 Darcy. Although being much larger than typical formation permeabilities, this is designed to allow for a reduction in permeability of the pack during its service lifetime owing to partial blockage by particulates such as produced sand or filter cake residues. In a simple model of linear and constant-width radial fractures in the cement that connect the casing to the formation, it is readily shown that the permeability for radial flow is given by $k = \varepsilon w^2/12$, where w is the width of a fracture and ε is the fracture porosity, i.e. ε = (volume of linear fractures) ÷ (total volume of the cement). The particle sizes of produced sand are typically from 0.1 to 5 mm, so that the cement fracture width should optimally be about 0.1 mm, although larger widths may be allowable if it is known that the produced sand is larger. Taking a crack width w = 0.2 mm and a typical crack porosity of 0.01 gives $k = 30 \times 10^{-12}$ m^2, or ~30 Darcy, close to conventional gravel pack permeability. This crack porosity can be accounted for given the shrinkage levels expected from a cement in the wellbore of 0.5 % or higher. This is subject to the same degradation by particle blocking over time as described above for gravel packs. Hence, cements sheath or blocks when placed inside the cased wellbore and cracked or fractured using any of the above methods can replace convention gravel packers in wellbore completions. One of the advantages of such a new gravel packer is its potential to be initially placed downhole as a slurry and can also be subject to subsequent remediation (or refracturing) treatment when being blocked as described above.

The flow chart of FIG. 8 describes some steps in accordance with an example of the present invention including the step **81** of fracturing locally cement being the casing

of a well, the step **82** of retaining a layer of such fractured cement as a sand filter and the step **83** of producing the well through the filter and (optionally preformed but initially blocked) openings in the casing. As observed in the Sumnmary of the Invention, above, in step **82**, in addition to acting as a sand filter, the localized fractures in the cement casing may be used to provide for controlling the flow of fluids into and or out of the wellbore. In this way, embodiments of the present invention may provide an alternative to localized perforating of the wellbore, which may be performed to provide for injecting fluids into injection zones in a formation and/or control of inflow of fluids into the wellbore from a reservoir.

WE CLAIM

1 A method of establishing a fluid communication in a well between a formation and a tubular casing, said method comprising the steps of providing a settable material in an annulus between a casing and the formation and fracturing the settable material after setting, thereby establishing the fluid communication through openings in the casing, characterized in that the location of the fractures is defined and the fractured material blocks the passage of formation sand and other solid particles.

2 The method of claim 1 wherein the defined location of the fractures in the settable material provides for controlling inflow of formation fluids into the well.

3 The method of claim 2 wherein the control of inflow of formation fluids into the well is provided without perforating the well.

4 The method of claim 2 fractures in the settable material are located to correspond with one or more production zones.

5 The method of claim 1 wherein the defined location of the fractures in the settable material provides for controlling flow of injection fluids out of the well into the formation.

6 The method of claim 1 wherein the location of the fractures is defined using localized force or pressure.

7 The method of claim 2 wherein the step of fracturing the settable material comprises applying localized deformation to the casing adjacent the material to be fractured.

8 The method of claim 2 wherein the step of fracturing the settable material comprises applying localized shock waves to the casing adjacent the material to be fractured.

9 The method of claim 4 wherein the localised shock waves are caused by firing explosive charges.

10 The method of claim 5 wherein the localized shock waves are caused by firing shaped explosive charges without projectiles.

11 The method of claim 1 wherein the location of the fractures is defined using force or pressure localizing elements on the casing.

12 The method of claim of 7 wherein the force or pressure localizing elements are openings in the casing or protruding elements within or on the outer surface of the casing.

13 The method of claim of 7 wherein the protruding elements include pointed or blade-like elements.

14 The method of claim 1 wherein the location of the fractures is defined using heat or radiation localizing elements on the casing.

15 The method of claim 1 wherein the location of the fractures is defined by introducing into the settable material between casing and formation zones of reduced fracturability.

16 The method of claim 11 wherein the location of the fractures is defined by introducing into the settable material between casing and formation zones of reduced fracturability by injecting from the surface a fluid train comprising at least two different settable materials.

17 The method of claim 12, wherein one of the settable materials is more elastic than the other.

18 The method of claim 12, wherein one of the settable materials includes additives that promote the formation of fractures or cracks.

19 The method of claim 1 wherein the settable material is a cementious material.

20 The method of claim 1 wherein the fluid communication is enhanced using settable material being permeable after setting.

21 The method of claim 1 wherein the fluid communication is enhanced using an acidizing treatment.

22 The method of claim 1 performed during the primary cementing of the casing after the placement casing but prior to the initial production.

23 The method of claim 1 performed as remedial treatment after the onset of production.

24 A method of establishing a fluid communication in a well between a formation and a tubular casing, said method comprising the steps of providing a settable material in an annulus between the casing and the formation and fracturing the settable material after setting, thereby establishing the fluid communication through openings in the casing, characterized in that the casing includes pre-formed openings temporally blocked for the settable material during placement in the well and in that after placement the openings of the casing are separated from the formation by a layer of fractured set material designed to prevent sand or solid production.

25 The method of claim 20 wherein the blocking is removed after the settable material is set.

26 The method of claim 20 using the fracturing step to simultaneously remove the blocking.

27 The method of claim 20 using fluids produced from the formation to remove the blocking.

28 The method of claim 20 using plugs of dissolvable material to block the pre-formed openings.

29 Casing tube for sand control having pre-formed openings temporally blocked during placement in the well and the injection of settable material into the wellbore said opening being removable to allow the flow of formation fluid through a layer of fractured set material into the well.

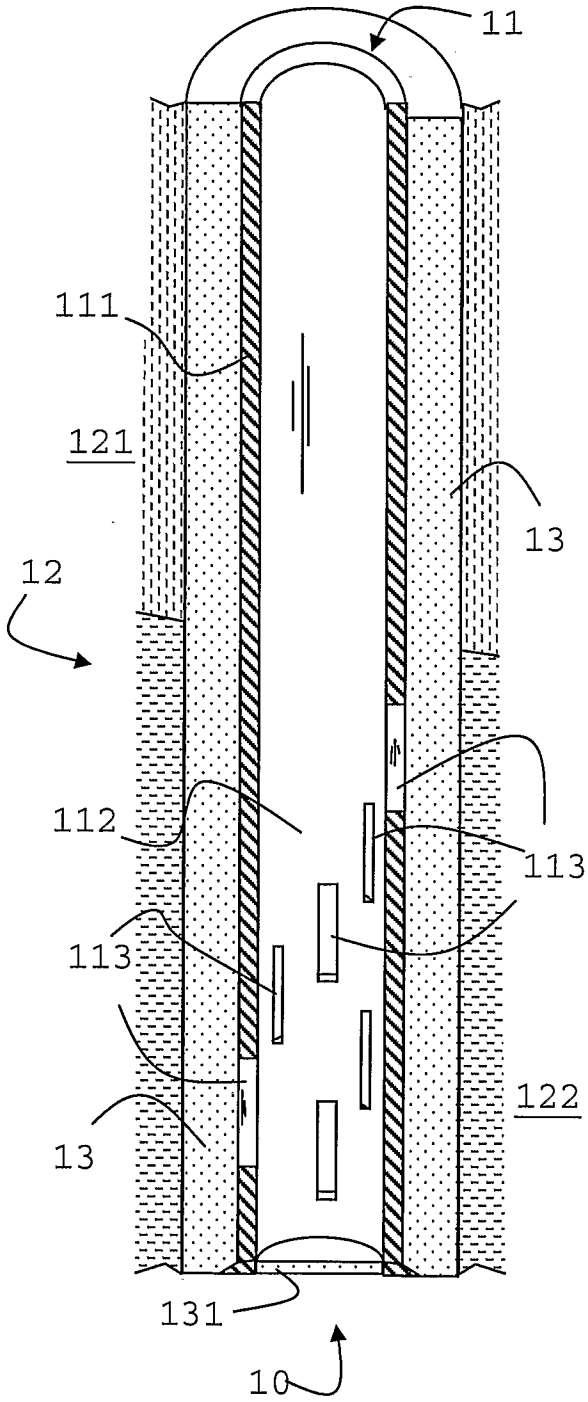

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FIG. 1A

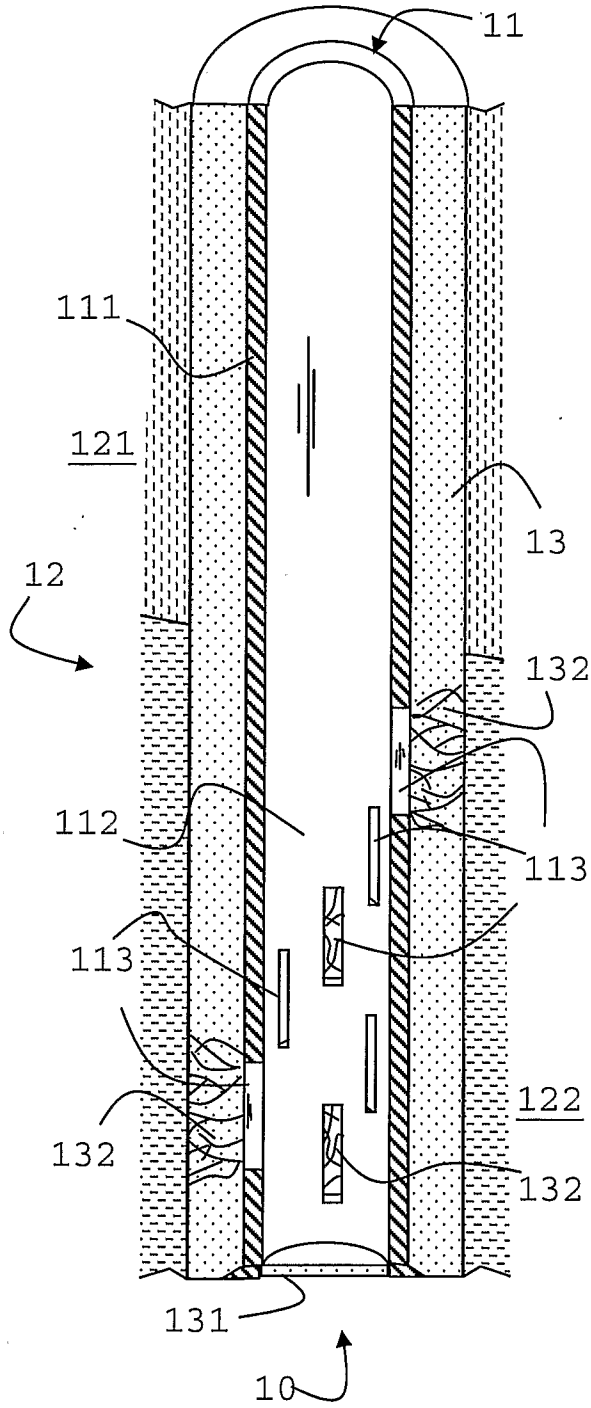

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FIG. 1B

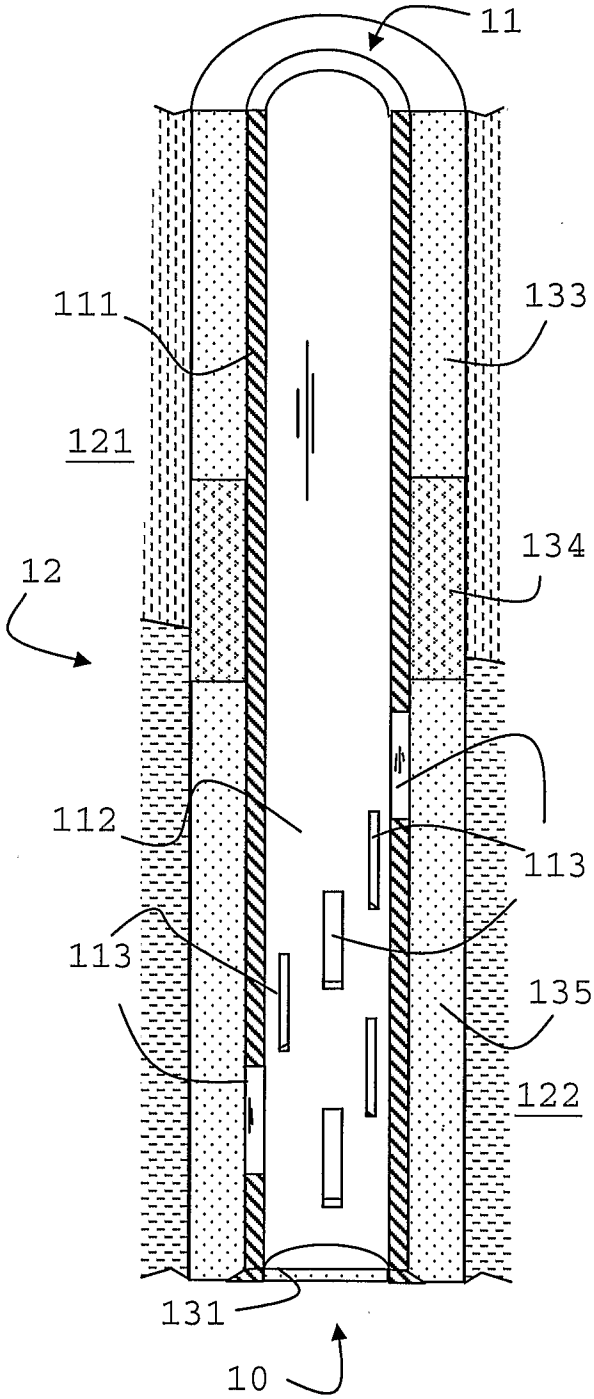

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FIG. 1C

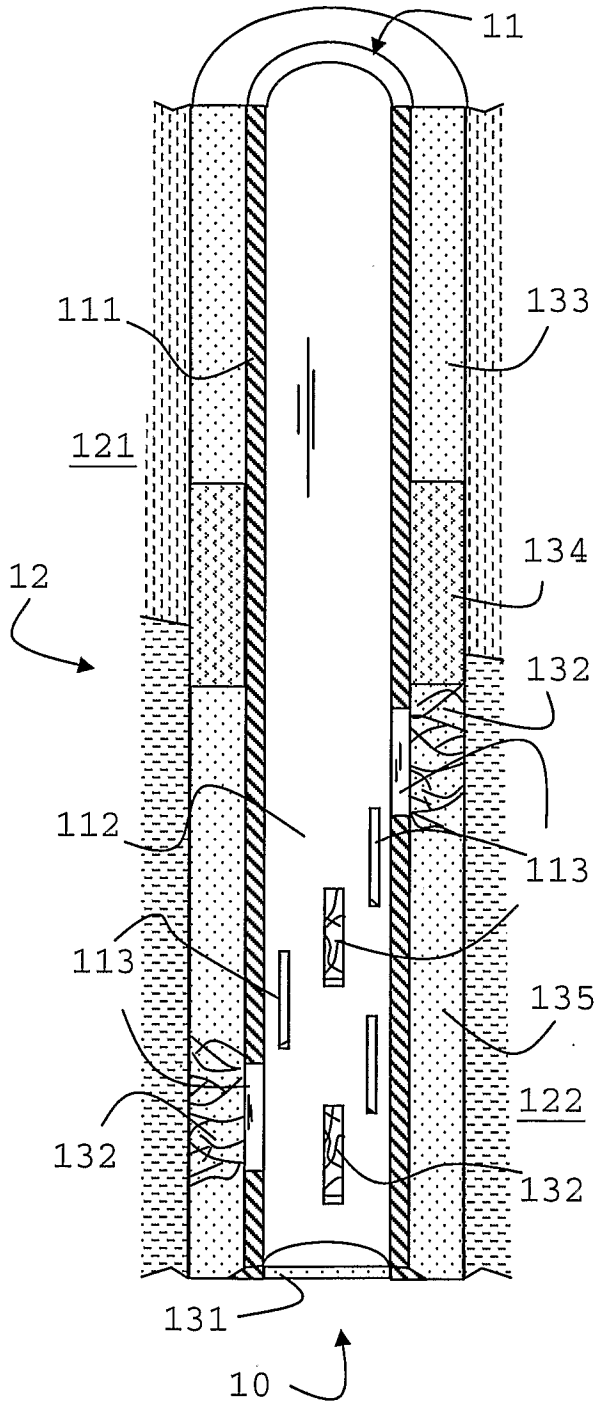

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FIG. 1D

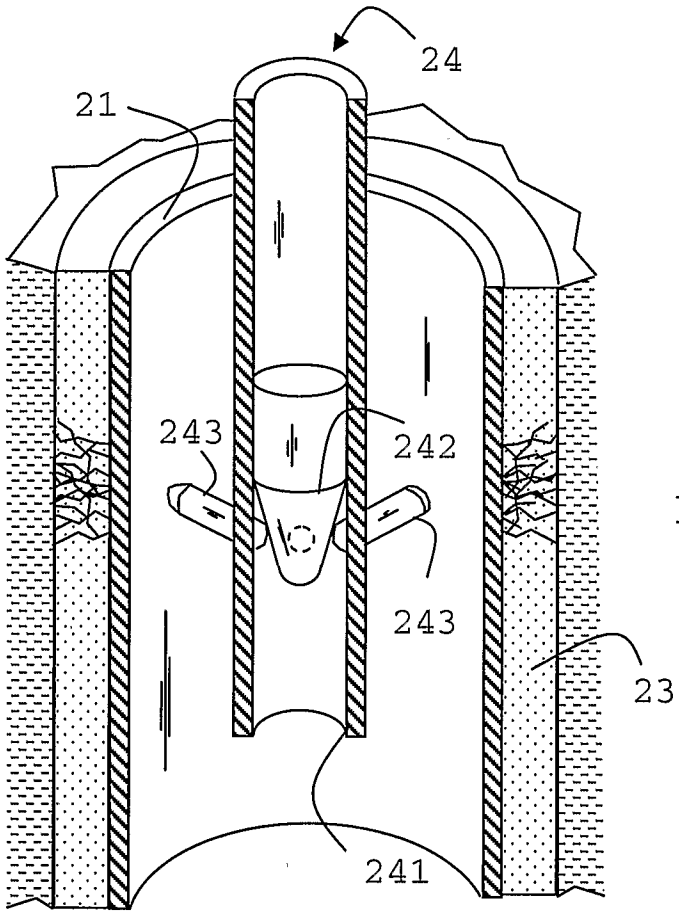


FIG. 2A

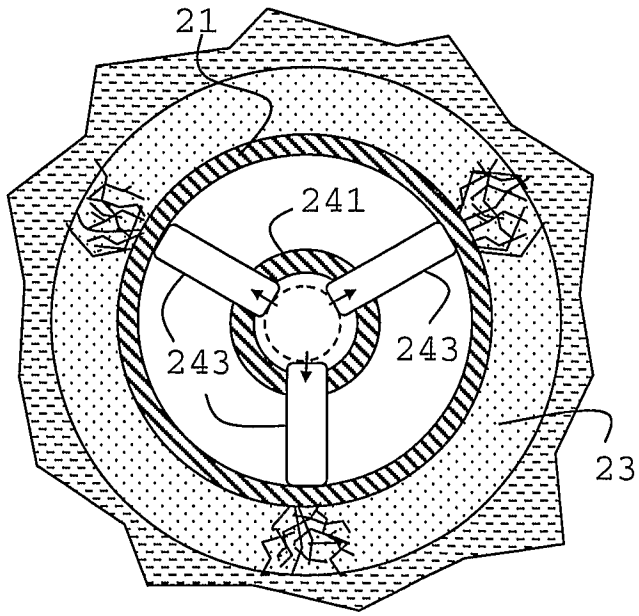


FIG. 2B

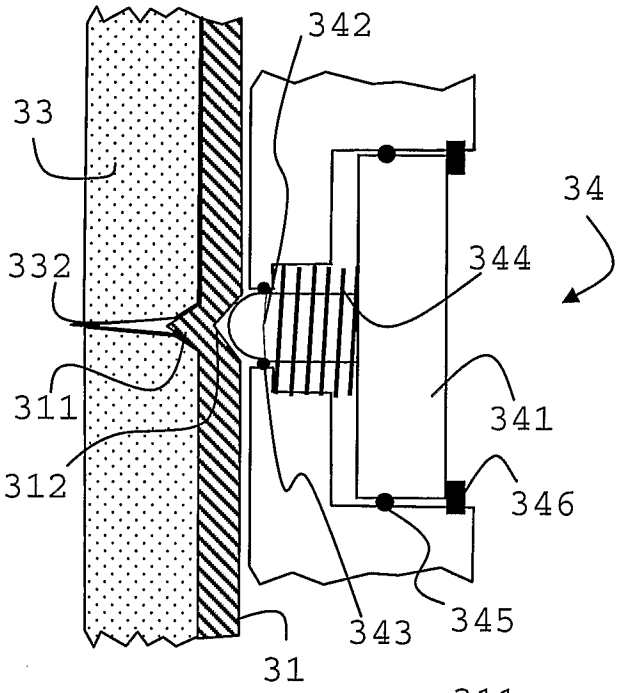


FIG. 3A

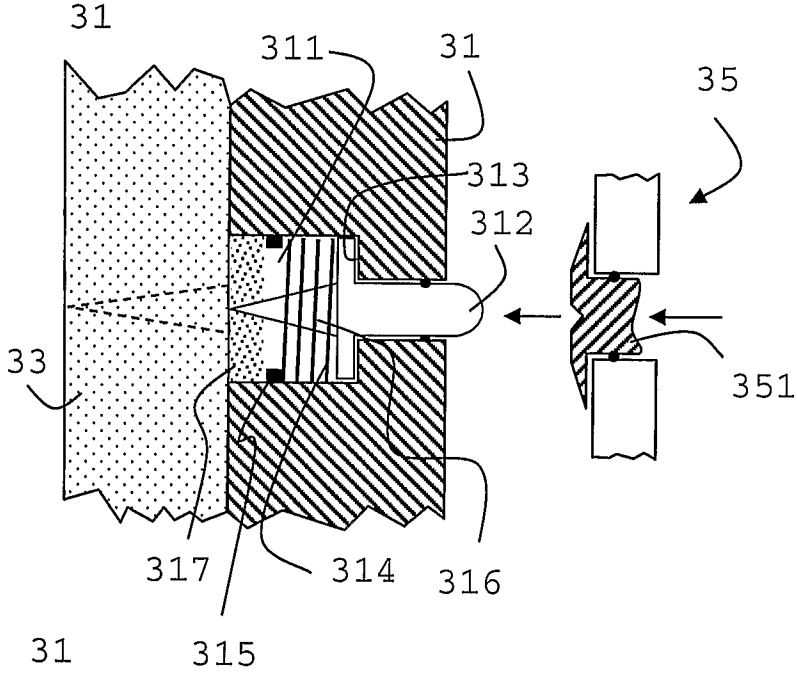


FIG. 3B

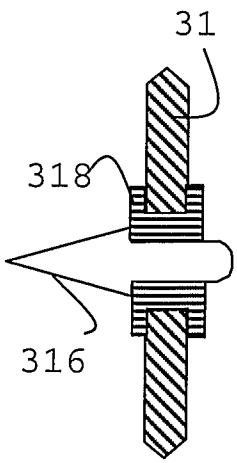


FIG. 3C

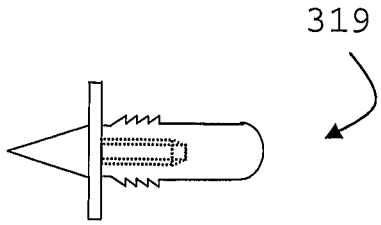


FIG. 3D

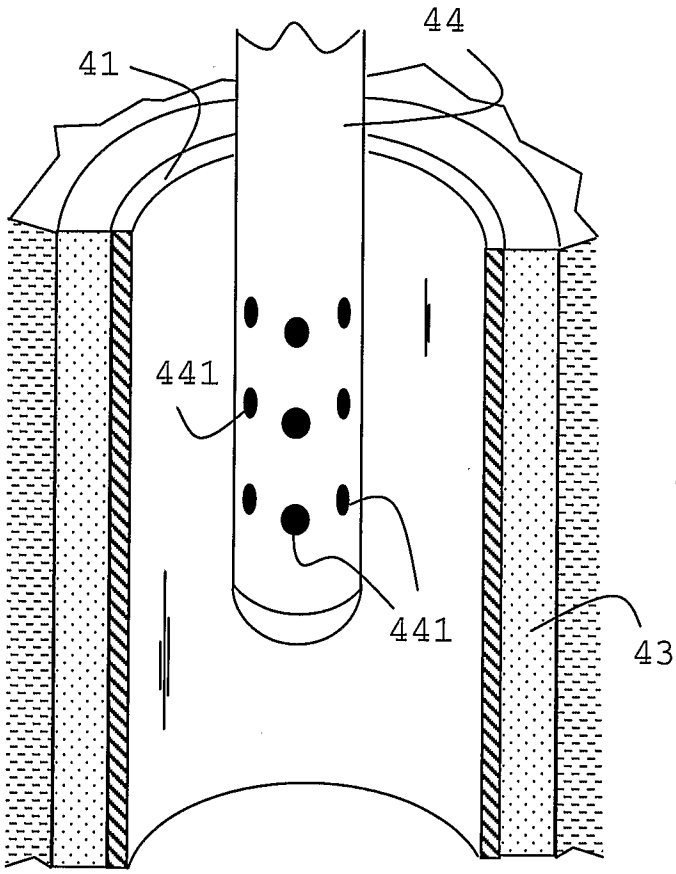


FIG. 4

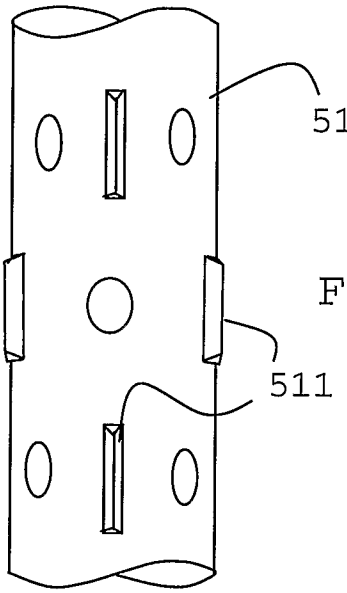


FIG. 5A

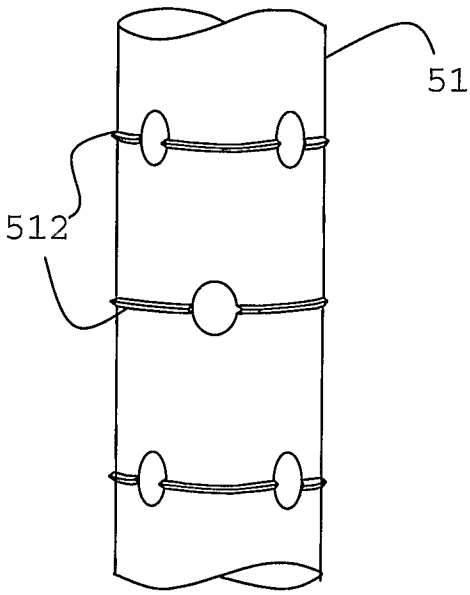


FIG. 5B

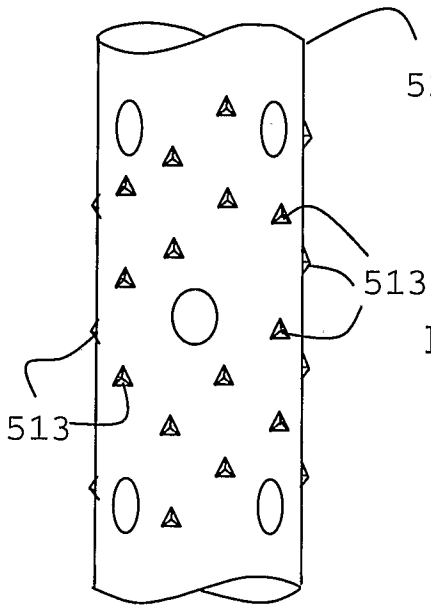


FIG. 5C

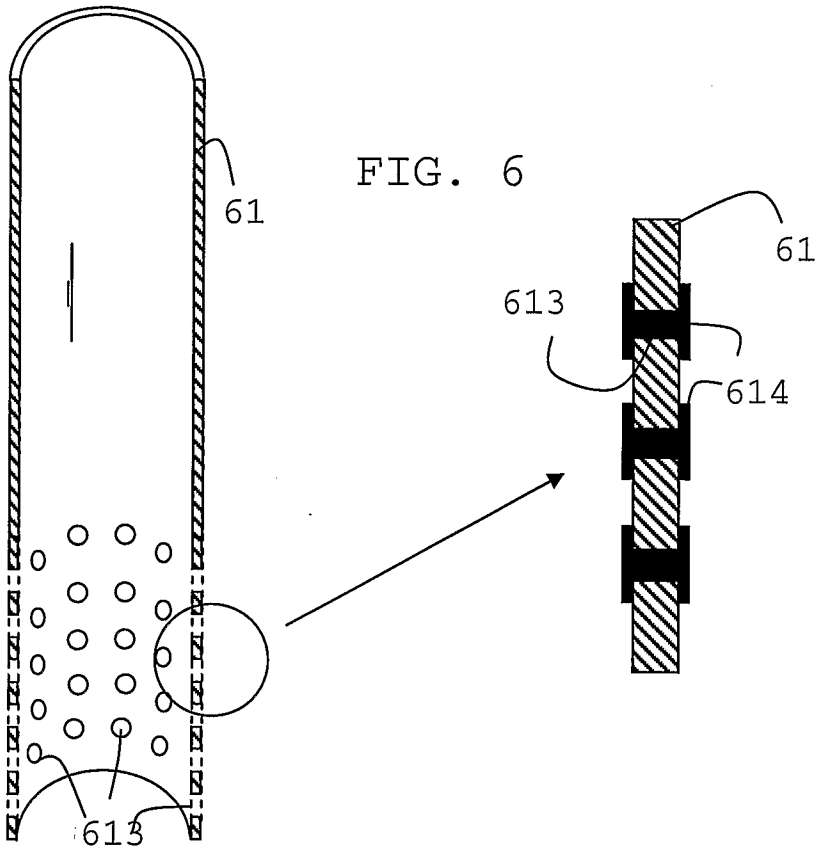


FIG. 6

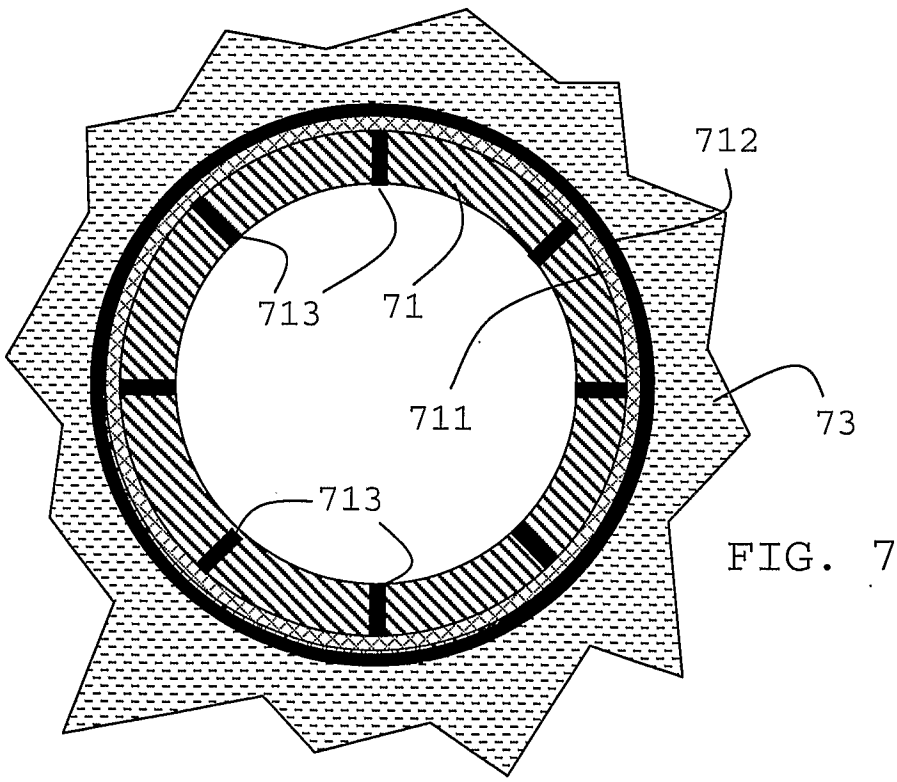


FIG. 7

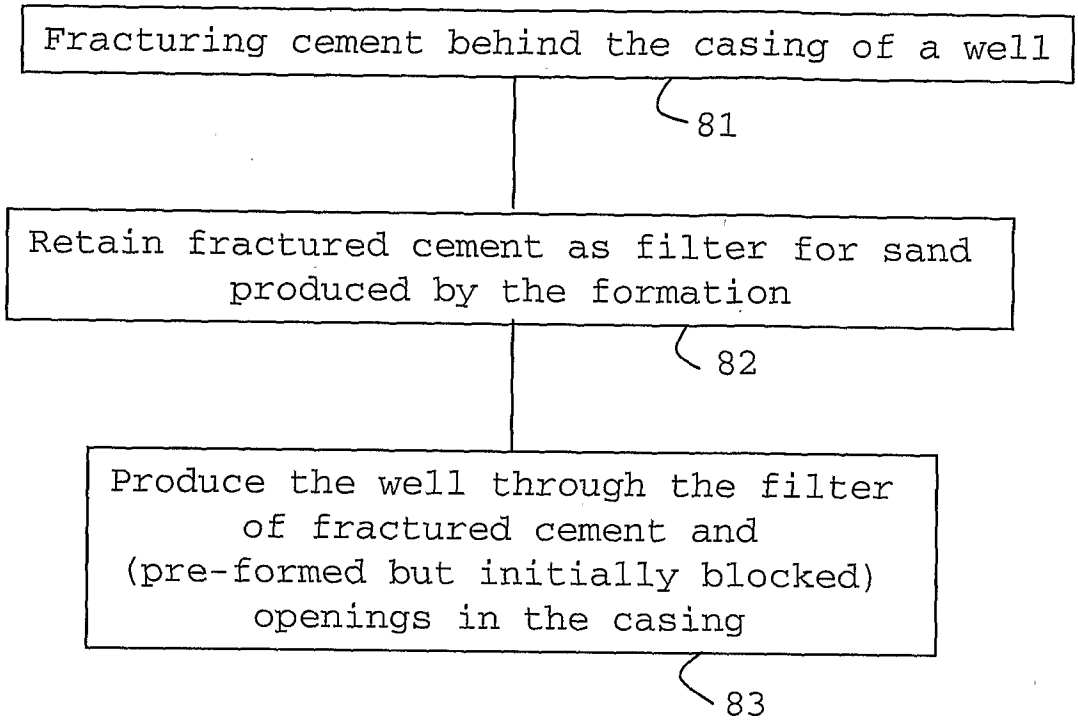

Fracturing cement behind the casing of a well
81
Retain fractured cement as filter for sand produced by the formation
82
Produce the well through the filter of fractured cement and (pre-formed but initially blocked) openings in the casing
83

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2006/002683

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B43/26 E21B43/263

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.
X	US 3 026 936 A (TEPLITZ ABRAHAM J) 27 March 1962 (1962-03-27) cited in the application column 4, line 15 - line 20 column 5, line 19 - line 34; claims 1,4; figure 2	1-29
X	US 4 673 039 A (MOHAUPT HENRY H [US]) 16 June 1987 (1987-06-16) column 3, line 28 - column 4, line 19; claim 1; figures 1-4	1-29
X	EP 0 426 427 A (HALLIBURTON CO [US]) 8 May 1991 (1991-05-08) column 6, line 37 - column 8, line 2; claim 1; figure 2	1,24,29

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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
5 December 2006	13/12/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Str mmen, Henrik

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2006/002683

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 380 749 A (HALLIBURTON ENERGY SERV INC [US]) 16 April 2003 (2003-04-16) page 9, line 1 - page 11, line 8; figures 5a,5b	1,24,29

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Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2006/002683

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US 4673039	A	16-06-1987	NONE		
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