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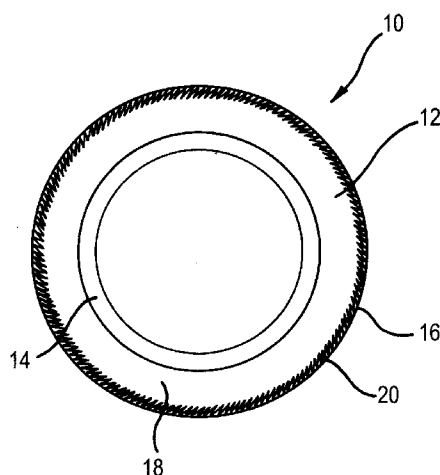


Fig. 1

(57) Abstract: A swellable apparatus for filling a space in oil or gas apparatus and method of forming an apparatus is described. The apparatus comprises a hydrocarbon swellable body formed from an elastomeric material selected to expand on exposure to a hydrocarbon fluid such as EPDM. The swellable body has a first surface which is exposed to a hydrocarbon fluid, a first (inner) portion, and a second portion disposed between the first portion and the surface. The first portion comprises a fluid permeability structure which differs from the fluid permeability structure of the second portion. In one embodiment, the cross-linking density of an outer portion of the body is greater than the cross-linking density of an inner portion of the body.



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Method and Apparatus

The present invention relates to a swellable apparatus for filling a space in oil or gas apparatus and a method of forming such a swellable apparatus.

Well packers are used to create seals in downhole environments. Typically, a well packer is used to form a seal in the annular space between a casing and a tubular located in the casing or between a drilled hole and a tubular located in the drilled hole. Instead of mechanical or inflatable well packers, it is known to form well packers from a material that swells upon contact with hydrocarbons present in the downhole environment.

The material is selected to expand on exposure to at least one predetermined fluid, which may be a hydrocarbon fluid or an aqueous fluid. The packer may be run to a downhole location in its unexpanded state, where it is exposed to a wellbore fluid and caused to expand. The design, dimensions, and swelling characteristics are selected such that the swellable mantle expands to create a fluid seal in the annulus, thereby isolating one wellbore section from another. Swellable packers have several advantages over conventional packers, including passive actuation, simplicity of construction, and robustness in long term isolation applications. Examples of swellable packers and suitable materials are described in GB 2411918.

Typically a packer will be constructed for a specific application and incorporated into a casing string or other tool string by means of threaded couplings. Swellable packers are typically constructed from multiple layers of uncured elastomeric material, such as ethylene propylene diene monomer (EPDM) rubber. Multiple layers are overlaid on a mandrel or

1 tubular in an uncured form to build up a mantle of the required dimensions. The mantle is
2 subsequently cured, e.g. by heat curing or air curing. The outer surface of the swellable
3 mantle is then machined using a lathe to create a smooth cylindrical surface. This method
4 produces a fully cured, unitary swellable mantle capable of sealing large differential
5 pressures.

6
7 It is important to control the swell rate of the swellable material of the packer. Swellable
8 materials used to form the expanding portion of the packer will begin to swell as soon as
9 they are exposed to triggering fluids. Thus the packers may begin to expand as they
10 contact drilling oil wellbore fluids during run-in to their desired location in the wellbore.
11 However, it is desirable for the packer outer diameter (OD) to be small during run-in to
12 avoid contact with obstructions, for example washout zones. When the packer is in its
13 desired location, it is advantageous for the packer to swell to its fully swelled condition
14 providing a seal in the wellbore in a short time. It is therefore advantageous to have a
15 swelling rate profile which takes account of the run-in time of the packer and the possible
16 exposure of the packer to triggering fluid during run in. In particular, it may be desirable to
17 impede or retard the swelling of the packer during an early stage of exposure to a
18 triggering fluid, but increase the rate of during a later stage of exposure.

19
20 EP 1315883 discloses a packer system comprising a core of a first elastomer, and an
21 external elastomer which consists of a material having a lower diffusion rate of
22 hydrocarbons compared with the elastomer which constitutes the core.

23
24 In certain applications it is desirable to have a well packer that swells on exposure to
25 hydrocarbons and water. Such well packers comprise material that is capable of swelling
26 upon contact with hydrocarbons and material that is capable of swelling upon contact with
27 water or brine. Such materials may be referred to as "hybrid" swelling materials. A well
28 packer that swells upon contact with both hydrocarbons and water may provide a proper
29 seal during both the initial and the subsequent stages of production. More specifically,
30 during an early stage of production the production fluid may be comprised essentially of
31 hydrocarbons and during later stages of production the water content of the production
32 fluid may increase.

33
34 WO 05/012686 discloses a swellable material for downhole applications comprising an
35 elastomeric matrix material to which has been added super absorbent polymer (SAP)

1 particles. Such SAP particles can be classified into starch systems, cellulose systems and
2 synthetic resin systems. The SAPs have hydrophilic characteristics by virtue of the
3 presence of alcohols, carboxylic acids, amides or sulphuric acids. Cross-linking between
4 the particles creates a three dimensional network. A compound is mixed with and bound
5 to the material to maintain the desired diffusion gradient and allow for continued absorption
6 of water (and thus continued swelling) in aqueous conditions.

7
8 US 2007/0027245 discloses oilfield elements and assemblies comprising elastomeric
9 compositions capable of swelling in oil and water. The compositions comprise the reaction
10 product of linear or branched polymers having residual ethylenic unsaturation with an
11 unsaturated organic monomer having at least one acidic reactive moiety.

12
13 One object of the invention is to provide an alternative swellable apparatus which
14 facilitates control or selection of swelling characteristics such as swelling rate during
15 exposure to wellbore fluids.

16
17 The present inventor has appreciated certain shortcomings of known well packers formed
18 of material capable of swelling upon contact with hydrocarbons and water. In particular,
19 swelling of hybrid materials may be inadequate or slow in aqueous (water or brine)
20 conditions.

21
22 One drawback of blending water swellable bodies such as superabsorbent polymers with
23 elastomers is that the bodies which are embedded in the elastomer may migrate towards
24 the surface of the elastomer that is exposed to water. This can cause the swellable
25 material to have non uniform swelling. In some cases, blisters may develop on the surface
26 of the elastomer that is exposed to water. If these blisters burst open, they will leave
27 cracks or openings in the elastomer.

28
29 It is therefore an object of the present invention to provide a swellable apparatus
30 configured to fill a space in oil or gas apparatus that addresses such shortcomings.

31
32 It is a further object for the present invention to provide a method of forming swellable
33 apparatus for filling a space in oil or gas apparatus.

34

1 According to a first aspect of the invention, there is provided a swellable apparatus for
2 filling a space in oil or gas apparatus, the swellable apparatus comprising a unitary
3 hydrocarbon swellable body formed from an elastomeric material selected to expand on
4 exposure to a hydrocarbon fluid, the hydrocarbon swellable body having a first surface
5 which, in use, is exposed to a hydrocarbon fluid, a first portion, and a second portion
6 disposed between the first portion and the first surface, wherein the first portion comprises
7 a fluid permeability structure which differs from the fluid permeability structure of the
8 second portion.

9
10 In this context, the term "unitary" means cured or otherwise formed into a single body or
11 mass. In this specification, elastomeric material means a synthetic or natural material
12 displaying elastomeric or rubber-like characteristics, and includes compositions comprising
13 polymeric and non-polymeric additives including stabilisers, fillers, co-agents and others.

14
15 The first surface is preferably an outer surface exposed to a wellbore fluid, but in an
16 alternative configuration the first surface is exposed to a triggering fluid, which may be
17 delivered internally or via a fluid delivery system.

18
19 The permeability of the hydrocarbon swellable body may be varied by varying the cross-
20 linking density of the elastomeric material in parts of the hydrocarbon swellable body. The
21 cross-linking density of the first portion may be less than the cross-linking density of the
22 second portion. The composition of the elastomeric material may otherwise be the same
23 in the first and second portions.

24
25 Thus according to a second aspect of the invention, there is provided a swellable
26 apparatus for filling a space in oil or gas apparatus, the swellable apparatus comprising a
27 hydrocarbon swellable body formed from a cross-linked elastomeric material selected to
28 expand on exposure to a hydrocarbon fluid, the hydrocarbon swellable body having a first
29 surface which, in use, is exposed to a hydrocarbon fluid, wherein the cross-linking density
30 of the elastomeric material varies in the hydrocarbon swellable body.

31
32 Embodiments of the second aspect of the invention may comprise preferred and optional
33 features of the first aspect of the invention and vice versa.

34

1 Different parts of the hydrocarbon swellable body may therefore have different cross-
2 linking densities. By varying the cross-linking density of the material which makes up the
3 body, the diffusion rate, and thus the swelling rate, of the swellable apparatus is affected.
4 A higher cross-linking density reduces the diffusion rate of hydrocarbon fluid when
5 compared with a lower cross-linking density. The apparatus thus has a permeability
6 structure which varies in the body. The invention may therefore provide a unitary body of
7 cured elastomeric material which facilitates control and/or selection of swelling
8 characteristics.

9
10 Preferably, the extent of cross-linking in the hydrocarbon swellable body decreases in an
11 inward direction from the first surface. The hydrocarbon swellable body may have a first
12 surface directed towards a hydrocarbon fluid and a second surface, wherein the extent of
13 cross-linking in the hydrocarbon swellable body decreases in a direction from the first
14 surface to the second surface.

15
16 More specifically, an extent of cross-linking at an outer surface of the hydrocarbon
17 swellable body may be higher than an extent of cross-linking within the hydrocarbon
18 swellable body, the outer surface, in use, coming into contact with the first fluid. In use, a
19 high extent and/or density of cross-linking at the outer surface may control or retard an
20 uptake of hydrocarbon molecules by the hydrocarbon swellable body whilst allowing a part
21 of the hydrocarbon swellable body having a lower extent of cross-linking to have faster
22 penetration of the hydrocarbon molecules and thus faster swelling.

23
24 A greater extent of cross-linking at the first surface may reduce a rate of uptake of
25 hydrocarbon molecules by the hydrocarbon swellable body. Therefore, an extent of cross-
26 linking at the first surface may be predetermined to set a predetermined rate of uptake of
27 hydrocarbon molecules. This has advantages in certain wellbore environments where it is
28 desirable for swelling of the apparatus to be retarded, for example during run-in of the
29 apparatus to its required depth. An elastomer having an increased cross-linking density
30 may have a reduced tendency to suffer from migration of the water swellable body towards
31 the surface of the elastomer that is exposed to water and thus reduce non-uniform
32 swelling.

33
34 More specifically, the extent of cross-linking at the surface of the hydrocarbon swellable
35 body may be between about 10 and about 100 times higher than at a location in the

1 hydrocarbon swellable body spaced apart from the first surface of the hydrocarbon
2 swellable body.

3
4 Alternatively or in addition, the permeability of the hydrocarbon swellable body may be
5 varied by varying the macroscopic bond structure of the elastomeric material. Thus
6 different parts of the body may have different macroscopic bond structures. This may be
7 achieved by incorporating in a part of the swellable body of a polymer additive or a plurality
8 of specific polymer additives, which may comprise a semi-crystalline rubber and/or
9 polyoctenamer such as Vestenamer®.

10
11 The preferred additive is Vestenamer®, but the additive may comprise one or more
12 rubbers as described in *trans-Polyoctenamer* by Draxler, Marl A. & Kautschuk, Gummi,
13 Kunststoffe, 34, Nr. 3/1981, pp. 185-190; and *25 Jahre Polyoctenamer - der*
14 *Entwicklungsgang eines Synthesekautschuks vom Laborpraparat zum industriellen*
15 *Rohstoff*, by Draxler, Marl A., Kautschuk, Gummi Kunststoffe, 42, Nr. 10/1989, pp. 868-
16 874, incorporated herein by reference.

17
18 Thus the inner portion of the swellable body may incorporate a semi-crystalline rubber or
19 polyoctenamer to provide a macroscopic bond structure, whereas an outer portion of the
20 swellable body disposed towards the outer surface of the body may not have a semi-
21 crystalline rubber or polyoctenamer incorporated therein.

22
23 It is believed that the addition of a semi-crystalline rubber polyoctenamer results in a
24 macroscopic bond structure which increases the permeability of the apparatus to increase
25 the access of the water to the water swellable bodies. Thus access pathways are
26 provided by the macroscopic bond structure of the material. The macroscopic bond
27 structure also improves the retention of the water swellable body in the hydrocarbon
28 swellable body.

29
30 More specifically, the polymer additive, such as Vestenamer®, may comprise between
31 about 5% and about 15% of a volume of the swellable apparatus.

32
33 In an alternative embodiment of the invention, the swellable apparatus comprises one or
34 more foaming agents or blowing agents. A chemical foaming agent decomposes to
35 release a gas when heated to its activation temperature. A range of different chemical

1 foaming agents may be used with the invention. One example is a
2 dinitrosopentamethylene tetraamine (DNPT) such as Opex® 80, available from Uniroyal
3 Chemical. Another suitable additive is based on the family of azodicarbonamide type
4 chemicals, for example, those provided by Lanxess Group under the Porofor® brand.

5
6 The foaming agent may be incorporated into the swellable apparatus during mixing, and
7 subsequently treated, for example by heating to decompose and impart a cellular structure
8 to the EPDM matrix material. Preferably, the cellular structure is an open cellular
9 structure. Thus the cellular structure may provide one or more fluid pathways within the
10 hydrocarbon swellable body, which increases the permeability of the swellable apparatus.

11
12 The swellable apparatus may comprise a plurality of water swellable bodies. The plurality
13 of water swellable bodies may, for example, be embedded in the hydrocarbon swellable
14 body such that the water swellable bodies are spaced apart from each other. The water
15 swellable bodies may be evenly and uniformly spaced apart from each other.

16
17 Alternatively or in addition, the hydrocarbon swellable body may comprise at least one
18 pathway therethrough. Thus, the at least one pathway may provide for the passage of
19 water comprised in the second fluid through the hydrocarbon swellable body. The
20 provision of at least one pathway may provide for ease of access of water to the water
21 swellable body, e.g. compared with known swellable apparatus.

22
23 The at least one pathway may be configured to permit the passage of water molecules but
24 prevent the passage of hydrocarbon molecules contained in the first fluid. This limits or
25 eliminates the effect that providing pathways in the apparatus has on the hydrocarbon-
26 swelling characteristics of the apparatus.

27
28 Thus, the at least one pathway may allow for the passage of water molecules.
29 Alternatively or in addition, the at least one pathway may have a diameter of less than
30 about 1000 microns. Thus, the at least one pathway may prevent the passage of the at
31 least one water swellable body, when the at least one water swellable body is embedded
32 in the hydrocarbon swellable body.

33

1 More specifically, the at least one pathway may have a diameter of less than about 100
2 microns, and may preferably be about 40 microns. Such a dimension means that
3 hydrocarbon molecules may not readily pass through the pathway.

4
5 Alternatively or in addition, the swellable apparatus may be configured such that the at
6 least one pathway may extend from an outer surface of the hydrocarbon swellable body
7 through the hydrocarbon swellable body to the at least one water swellable body, the outer
8 surface, in use, coming into contact with the first and second fluids.

9
10 Alternatively or in addition, the pathway may comprise a bore. The bore may, for example,
11 be formed by perforation of the hydrocarbon swellable body. The perforation may be a
12 mechanical perforation, and may be formed by penetrating the hydrocarbon swellable
13 body with a pin, needle or spike, or may be a perforation formed by a laser, for example in
14 a micro-drilling process.

15
16 Alternatively or in addition, the pathway may comprise a macroscopic bond structure
17 between the hydrocarbon swellable body and the at least one water swellable body. Such
18 a macroscopic bond structure may, for example, be formed by the inclusion of a polymer
19 material, which may be a semi-crystalline rubber and/or polyoctenamer such as
20 Vestenamer®.

21
22 More specifically, the polymer material, such as Vestenamer®, may comprise between
23 about 5% and about 15% of a volume of the swellable apparatus.

24
25 Changing at least one of a number of pathways and a density of pathways per unit area of
26 the outer surface of the hydrocarbon swellable body may provide for control of access of
27 water molecules to the at least one water swellable body. Thus, at least one of the
28 number of pathways and the pathway density may be increased to increase access of a
29 selected fluid to the at least one swellable body. Hence, changing at least one of the
30 number of pathways and the pathway density may control an uptake of an aqueous fluid
31 by the water swellable body whilst not affecting an uptake of a hydrocarbon fluid by the
32 hydrocarbon swellable body.

33
34 Alternatively or in addition, the hydrocarbon swellable body may comprise a polymer.

35 Alternatively or in addition, the hydrocarbon swellable body may comprise an elastomer.

1
2 Alternatively or in addition, the hydrocarbon swellable body may comprise ethylene
3 propylene diene monomer rubber (EPDM). Alternatively or in addition, the hydrocarbon
4 swellable body may be operative to swell upon contact with the first fluid by diffusion of
5 hydrocarbon molecules into the hydrocarbon swellable body. Alternatively or in addition,
6 the water swellable body may comprise a polymer.

7
8 More specifically, the water swellable body may comprise a Super Absorbent Polymer
9 (SAP), which may be an acrylic acid and sodium acrylate copolymer such as Aqualic®.
10 Alternatively or in addition, the water swellable body may comprise a salt, such as NaCl or
11 CaCl_2 . Alternatively or in addition, the water swellable body may be operative to swell
12 upon contact with water by means of diffusion of water molecules into the water swellable
13 body. More specifically, where the water swellable body comprises a salt, the water
14 swellable body may be operative to swell upon contact with water by means of osmosis.

15
16 Alternatively or in addition, the hydrocarbon swellable body may comprise between about
17 35% and about 50% of a volume of the swellable apparatus and the water swellable body
18 may comprise between about 15% and about 40% of the volume of the swellable
19 apparatus. In use, such a composition may provide for an increase in volume for the
20 swellable apparatus from the unswollen condition to the swollen condition of up to about
21 300% in an environment such as that found in a downhole oil well. For example, within 2-3
22 weeks of exposure to a 100 degree Celsius fluid mixture containing both a hydrocarbon-
23 based liquid and low salinity aqueous solution.

24
25 More specifically, the hydrocarbon swellable body may comprise between about 40% and
26 about 45% of the volume of the swellable apparatus.

27
28 Alternatively or in addition, the water swellable body may comprise between about 25%
29 and about 35% of the volume of the swellable apparatus.

30
31 Alternatively or in addition, the swellable apparatus may comprise a filler, such as carbon
32 black or silica oxide. More specifically, the filler may comprise between about 15% and
33 about 30% of a volume of the swellable apparatus.

34

1 Alternatively or in addition, the swellable apparatus may comprise an activator, which is
2 operative to form a sulphurating compound. More specifically, the activator may comprise
3 at least one of zinc oxide and stearic acid. When zinc oxide and stearic acid are present a
4 zinc sulphurating compound may be formed. More specifically, the stearic acid may
5 comprise less than about 2% of a volume of the swellable apparatus.

6
7 Alternatively or in addition, the swellable apparatus may comprise a metal oxide, such as
8 zinc oxide. In the curing process the zinc oxide may activate an organic accelerator.
9 Suitable organic accelerators include zinc diacrylate (ZDA), zinc dimethacrylate (ZDMA),
10 triallyl cyanate (TAC), or triallylisocyanate (TAIC®), including those available from
11 Sartomer Company, Inc of Pennsylvania, USA. An unreacted portion of the zinc oxide
12 may remain available to neutralize sulphur-bearing acidic decomposition products formed
13 during vulcanization. Adequate levels of zinc oxide can contribute markedly to chemical
14 reinforcement, scorch control and resistance to heat-aging and compression fatigue.

15
16 More specifically, the metal oxide may comprise less than about 5% of a volume of the
17 swellable apparatus.

18
19 Alternatively or in addition, at least one of the first fluid and the second fluid may be
20 comprised in a downhole fluid present in a downhole environment. More specifically, the
21 downhole fluid may comprise at least one of: a completion brine; a water-based drilling
22 mud; an oil-based drilling mud; formation water; and a production fluid, e.g. oil or gas from
23 a well being produced.

24
25 Thus, the swellable apparatus may be used, e.g. in a well packer, where it may be
26 activated by water based completion fluids. After a completion operation and during a well
27 production phase, the swellable apparatus may be used to form a seal, even though the
28 swellable may then be mainly exposed to hydrocarbons.

29
30 Alternatively or in addition, the swellable apparatus may be operative to increase in
31 volume from an unswollen condition to a swollen condition by up to about 300% when in
32 contact with at least one of the first fluid and the second fluid. Thus, the swellable
33 apparatus may be operative to swell based on simultaneous swelling of both the
34 hydrocarbon swellable body and the water swellable body.

35

1 According to a third aspect of the invention, there is provided a swellable material for filling
2 a space in oil or gas apparatus, the swellable material selected to swell on exposure to a
3 wellbore fluid, wherein the swellable material comprises an elastomeric material and an
4 additive comprising a semi-crystalline rubber and/or a polyoctenamer.

5
6 The preferred additive is Vestenamer®, but the additive may comprise one or more
7 rubbers as described in *trans-Polyoctenamer* by Draxler, Marl A. & Kautschuk, Gummi,
8 Kunststoffe, 34, Nr. 3/1981, pp. 185-190; and *25 Jahre Polyoctenamer - der*
9 *Entwicklungsgang eines Synthesekautschuks vom Laborpräparat zum industriellen*
10 *Rohstoff*, by Draxler, Marl A., Kautschuk, Gummi Kunststoffe, 42, Nr. 10/1989, pp. 868-
11 874, incorporated herein by reference.

12
13 Thus the swellable material may incorporate a semi-crystalline rubber or polyoctenamer to
14 provide a macroscopic bond structure. It is believed that the addition of a semi-crystalline
15 rubber and/or a polyoctenamer results in a macroscopic bond structure which increases
16 the permeability of the material to increase the access of wellbore fluids into the swellable
17 material or a body formed therefrom. Thus access pathways are provided by the
18 macroscopic bond structure of the material. The macroscopic bond structure also
19 improves the retention of a water swellable body such as an SAP in a swellable body.

20
21 The elastomeric material may be an ethylene propylene copolymer such as EPDM.

22
23 More specifically, the polymer additive, such as Vestenamer®, may comprise between
24 about 5% and about 15% of a volume of the swellable apparatus.

25
26 Embodiments of the third aspect of the invention may comprise preferred and optional
27 features of the first or second aspects of the invention and vice versa.

28
29 According to a fourth aspect of the invention, there is provided an oil or gas tool
30 comprising the swellable apparatus of the first, second or third aspects of the invention.
31 The tool may be a downhole tool, and may be a wellbore packer, anchor or centraliser.

32
33 Embodiments of the fourth aspect of the invention may comprise preferred and optional
34 features of the first to third aspects of the invention and vice versa.

35

1 According to a fifth aspect of the invention, there is provided a method of forming a
2 swellable apparatus for filling a space in oil or gas apparatus, the method comprising the
3 steps of:
4 providing an elastomeric material selected to expand on exposure to a hydrocarbon fluid;
5 curing the elastomeric material to form a unitary hydrocarbon swellable body;
6 treating the elastomeric material such that a first portion of the hydrocarbon swellable body
7 comprises a fluid permeability structure which differs from the fluid permeability structure
8 of a second portion of the hydrocarbon swellable body.

9
10 The method may include the steps of providing a sheet of hydrocarbon swellable material,
11 forming a substantially cylindrical mantle from the sheet of hydrocarbon swellable material.
12 The method may comprise the steps of forming multiple layers of the hydrocarbon
13 swellable material on a mandrel or tubular.

14
15 The multiple layers may be formed by wrapping a sheet of hydrocarbon swellable material
16 onto the mandrel or tubular. A cross-linking agent may be applied to the surface of one or
17 more layers. For example, the outermost layers may be coated with a cross-linking agent.
18 The multiple layers may be of an uncured elastomeric material.

19
20 Alternatively, or in addition, the method may comprise the step of incorporating an additive
21 into the elastomeric material. The additive may be a pathway forming material with the
22 hydrocarbon swellable material and the water swellable material. Alternatively, or in
23 addition, the additive may be a chemical foaming agent. The pathway forming material
24 may comprise a polymer, which may be a semi-crystalline rubber and/or polyoctenamer
25 such as Vestenamer®.

26
27 Alternatively or in addition, the method may comprise treating the hydrocarbon swellable
28 material such that an outer surface of the hydrocarbon swellable body has a higher extent
29 of cross-linking than within the hydrocarbon swellable body. The elastomeric material may
30 be treated by applying a cross-linking agent. The cross-linking agent may be selectively
31 applied to parts of the hydrocarbon swellable body. More specifically, treating the
32 hydrocarbon swellable material may comprise providing a curing material on an uncured
33 outer surface of the hydrocarbon swellable body.

1 More specifically, the curing material may comprise at least one of: a cure accelerator; and
2 a curing agent. Cure accelerators or curing agents are well and widely known to those
3 skilled in the art of elastomer or polymer science.

4
5 Alternatively or in addition, providing the curing material may comprise at least one of
6 spraying and painting at least one application (e.g. such that it forms a temporary coating
7 to be absorbed by the swellable material) of the curing material onto the outer surface of
8 the hydrocarbon swellable member.

9
10 More specifically, the curing material may be provided on the outer surface before the
11 swellable member is cured. The process of curing the swellable member will be well
12 known to persons skilled in the art. More specifically, skilled persons will have a full
13 understanding of parameters associated with temperatures and pressures required to cure
14 swellable members formed of an elastomer; such a process will be familiar to skilled
15 persons as vulcanisation. It will be appreciated that peroxide curing and/or sulphur curing
16 may be used with the present invention.

17
18 Alternatively or in addition, the curing material may be dissolved as an aqueous solution or
19 in a solvent.

20
21 More specifically, the curing material may have a predetermined concentration when in the
22 form of an aqueous solution or solvent. Thus, the concentration may be changed from one
23 curing step to another such that when the curing material is applied to an outer surface of
24 the hydrocarbon swellable member an extent of cross-linking may be controlled.

25
26 In one embodiment of the invention a curing material is provided on the outer surface of a
27 fully or substantially cured material prior to a re-curing process to change the cross-linking
28 structure of the material.

29
30 Embodiments of the fifth aspect of the invention may comprise preferred and optional
31 features of the first to fourth aspects of the invention and vice versa.

32
33 The present inventor has appreciated the feature of varying an extent of cross-linking
34 across the hydrocarbon swellable body has particular application to a hybrid swellable
35 material. Thus, from a sixth aspect of the present invention there is provided a swellable

1 apparatus for filling a space in oil or gas apparatus, the swellable apparatus comprising a
2 hydrocarbon swellable body and at least one water swellable body,

3 the swellable apparatus, in use, being operative to fill the space in oil or gas
4 apparatus when in a swollen condition, the swellable apparatus adopting the swollen
5 condition when at least one of the hydrocarbon swellable body and the at least one water
6 swellable body are swollen,

7 the hydrocarbon swellable body swelling upon contact with a first fluid comprising a
8 hydrocarbon; and

9 the at least one water swellable body swelling upon contact with a second fluid
10 comprising water,

11 the hydrocarbon swellable body having a structure that varies as to an extent of
12 cross-linking across the hydrocarbon swellable body.

13

14 More specifically, an extent of cross-linking at an outer surface of the hydrocarbon
15 swellable body may be higher than an extent of cross-linking within the hydrocarbon
16 swellable body, the outer surface, in use, coming into contact with the first fluid.

17

18 Alternatively or in addition, the swellable apparatus may be configured such that the
19 hydrocarbon swellable body is operative to control access of the second fluid to the at
20 least one water swellable body.

21

22 Embodiments of the sixth aspect of the invention may comprise preferred and optional
23 features of the first to fifth aspects of the invention and vice versa.

24

25 According to a seventh aspect of the present invention, there is provided a method of
26 forming a swellable apparatus for filling a space in oil or gas apparatus, the method
27 comprising:

28 incorporating a hydrocarbon swellable material and a water swellable material, the
29 hydrocarbon swellable material forming a hydrocarbon swellable body and the water
30 swellable material forming at least one water swellable body,

31 the hydrocarbon swellable material and the water swellable material being
32 incorporated such that, in use, the formed hydrocarbon swellable body swells upon contact
33 with a first fluid comprising a hydrocarbon and the at least one water swellable body swells
34 upon contact with a second fluid comprising water, and

1 treating the hydrocarbon swellable body such that an extent of cross-linking of the
2 hydrocarbon swellable body varies across the hydrocarbon swellable body.

3
4 More specifically, the hydrocarbon swellable body may be treated such that an outer
5 surface of the hydrocarbon swellable body has a higher extent of cross-linking than within
6 the hydrocarbon swellable body.

7
8 Alternatively or in addition, the hydrocarbon swellable material and the water swellable
9 material may be further incorporated such that, in use, the hydrocarbon swellable body is
10 operative to control access of the second fluid to the at least one water swellable body.

11
12 Embodiments of the seventh aspect of the invention may comprise preferred and optional
13 features of the sixth aspect of the invention and vice versa.

14
15 According to an eighth aspect of the invention, there is provided a method of forming a
16 swellable material for filling a space in oil or gas apparatus, the swellable material selected
17 to swell on exposure to a wellbore fluid, the method comprising the step of combining an
18 elastomeric material and an additive comprising a semi-crystalline rubber and/or a
19 polyoctenamer.

20
21 The method may comprise the additional step of curing the combined elastomeric material
22 and additive.

23
24 Embodiments of the eighth aspect of the invention may comprise preferred and optional
25 features of the third aspect of the invention and vice versa.

26

27

There will now be described, by way of example only, embodiments of the invention with reference to the following drawings, of which:

Figure 1 is a cross-section of a wellbore packer comprising swellable apparatus in accordance with an embodiment of the invention;

Figure 2 is a longitudinal section of a downhole tool comprising swellable apparatus in accordance with an embodiment of the invention;

Figure 3 is a schematic line drawing of a material for the swellable apparatus of Figure 2;

Figure 4 is a schematic view of the swellable apparatus of the downhole centraliser tool of Figure 2;

Figure 5 is a graph of swelling profile for samples of a swellable apparatus in accordance with embodiments of the invention;

Figure 6A is a graph of swelling profile for two samples of swellable material in water;

Figure 6B is a graph of swelling profile for two samples of swellable material in a hydrocarbon fluid; and

Figure 7 is a cross-section of a wellbore packer in accordance with an alternative embodiment of the invention.

Referring firstly to Figure 1, there is shown in cross section a wellbore packer which comprises a swellable material in accordance with an embodiment of the invention. The packer, generally shown at 10, comprises a swellable mantle 12 disposed on a tubular 14. The packer is configured to be disposed in a wellbore such that its outer surface 16 is exposed to wellbore fluids. In this example, the swellable mantle 12 is formed from an elastomeric material comprises an ethylene propylene diene monomer (EPDM) rubber, selected to swell on exposure to a hydrocarbon fluid. The swellable mantle 12 has a cross-linking density which varies across its cross section. An inner volume or core 18 comprises a relatively low density of cross-linking of the elastomeric material. An outer

1 volume 20, disposed between the outer surface 16 and the inner volume 18, has a
2 relatively high cross-linking density. The volume 20 has a lower permeability and swell
3 rate to wellbore fluids by virtue of its increased cross-linked density. Thus the diffusion of
4 the well fluids into the body is retarded by the relatively highly cross-linked volume 20.

5
6 The volume 20 of high cross-linking is achieved by coating the outer surface of the formed
7 swellable mantle with a cross-linking accelerator such as zinc diacrylate (ZDA). The
8 cross-linking accelerator is coated on to the outer surface by spraying or brushing, and
9 allowed to penetrate into the swellable mantle 12. Subsequently, the swellable mantle
10 may be cured or re-cured to cause the cross-linking to occur and create a unitary
11 hydrocarbon swellable body with the relatively high density cross-linked region 20.

12
13 Although in Figure 1 the high cross-linked region 20 appears to have a discrete boundary
14 with the relatively low cross-linked region 18, in practice there is a region of continuous
15 change in cross-linking density due to the gradual penetration of the cross-linking agent
16 into the swellable mantle 12. The relative thickness of the high cross-linked region 20, and
17 the relative densities of cross-linking in the volumes can be varied by changing the amount
18 of cross-linking accelerator applied to the outer surface, and the time it is allowed to
19 penetrate into the swellable mantle before the curing or re-curing process is performed.

20
21 Figure 2 shows generally at 100 a swellable centraliser of an alternative embodiment of
22 the invention, located downhole in a subterranean wellbore 112. The centraliser 100 is
23 provided with a swellable apparatus 116, which can swell in the presence of hydrocarbon
24 and aqueous wellbore fluids to fill the annular space 118. To achieve this, the swellable
25 apparatus 116 is formed from a "hybrid" material containing both hydrocarbon and water
26 swellable bodies, as described in more detail with reference to Figure 3. Access to the
27 water and hydrocarbon swellable bodies by hydrocarbons and water, which will be present
28 in wellbore fluids, is controlled by the structure of the swellable material.

29
30 The swellable material 120 has a hydrocarbon swellable body in the form of an ethylene
31 propylene diene monomer rubber (EPDM) elastomer matrix, together with water swellable
32 bodies 132 in the form of super absorbent polymers (SAPs) embedded within the matrix
33 122. The polymer bodies 132 are evenly distributed and spaced apart from each other
34 throughout the material. Upon being brought into contact with hydrocarbon molecules, the
35 EPDM matrix is caused to swell, while the super absorbent polymers swell upon contact

with water. This ensures proper performance of the swellable apparatus to seal the wellbore annulus 118 around the centraliser tool in the presence of both water and hydrocarbon based well fluids, and in the presence of fluids consisting of water and hydrocarbons are mixed together.

In this example, hydrocarbon molecules diffuse into the EPDM matrix and water molecules diffuse into the super absorbent polymers. The EPDM matrix makes up about 40% of the material volume, while the super absorbent polymers make up a further 20% of the volume. This helps to achieve the desired swelling behaviour. Further, the material volume includes a silica oxide filler, a zinc oxide and stearic acid.

Relative quantities of the above mentioned components used in forming the swellable material of this example are specified in Table A below:

Component	Phr	%
EPDM (calendering grade)	100	39.2%
HAF N330 Carbon Black	48	18.8%
Processing Oil	20	7.8%
Zinc Oxide	5	2.0%
Peroxide (pure)	5	2.0%
Co-agent (TAC or TAIC)	2	0.8%
Stearic Acid	1	0.4%
Vestenamer®	10	3.9%
Water Absorbent Resin (Aqualic®)	64	25.1%
TOTAL	255	100.0%

Figure 4 provides a more detailed view of the apparatus shown in Figures 2 and 3. The apparatus is formed from the material 120 described with reference to Figure 3.

In Figure 4 the apparatus is additionally shown having a number of sub-micron pathways 140 through the material 120. The pathways 140 provide access for water molecules from the wellbore environment 142 through the surface region 144 of the wellbore apparatus 100 to the water absorbing polymers. In this example, the pathways 140 are created by

1 mechanical perforations through the material 120. The pathways 140 are sized to permit
2 water molecules to pass readily through the bores. However, hydrocarbon molecules do
3 not readily pass through the pathways. The density of pathways 140 is selected to provide
4 adequate access of water for the required swelling properties, such as rate and volume
5 expansion, of the swellable apparatus 100.

6
7 The perforations are produced in an automated process using a perforating roller body,
8 such as described in US 3,646,639. In alternative embodiments the perforations may be
9 formed using a laser or micro-drilling process using a system of CO₂ lasers.

10
11 The swellable hybrid material is vulcanised to produce cross-linking of the EPDM matrix
12 122. In this example, the swellable apparatus has a strongly cross-linked surface region
13 146, followed below by a region 148 of intermediate cross-linking, and a further main
14 region 150 that is cross-linked to a still lesser degree. The extent of cross-linking controls
15 access of hydrocarbon molecules to the hydrocarbon swellable matrix 122, such that the
16 swelling behaviour of the apparatus in the presence of hydrocarbons can be selected
17 appropriately.

18
19 In this case, the cross-linking at the surface is strong to retard the uptake of hydrocarbon
20 molecules and the degree and/or speed of hydrocarbon-activated swelling, while in other
21 regions, which are cross-linked to a lesser extent, hydrocarbon molecules that have been
22 taken up are allowed to diffuse more effectively throughout the material.

23
24 In order to create such a cross-linked structure, a cross-linking or curing agent such as
25 zinc diacrylate (ZDA) is coated onto the outer surface by spraying or brushing. The
26 variable cross-linking profile in this example is substantially continuous, due to the
27 diffusion of the cross-linking agent into the swellable body.

28
29 In order to create such a cross-linked structure, a cross-linking or curing agent such as
30 zinc diacrylate (ZDA) is deposited onto the outer surface by spraying or brushing. This
31 may be carried out during the construction of the packer apparatus before curing to adjust
32 the cross-linking characteristics and, in turn, the nature of the swelling. The EPDM
33 component of the material is cross-linked upon curing of the EPDM.

34

1 Samples of the swellable material with the composition specified in Table A were placed in
2 tap water at a controlled temperature of 80 degrees Celsius, and the mass changes were
3 measured over a period of several days. Figure 5 is a graph of water-swell profile for
4 samples having a number of different perforation densities. In each case the perforations
5 were mechanically formed in the sample using a perforating needle. The data show that
6 perforating the material has a marked effect on the swell profile. For example, at around
7 15 days, the sample with 1050 perforations per square inch (approximately 6.45 square
8 cm) had increased in mass by around 200%, compared with an increase of around 75%
9 for the unperforated case. The sample with 132 perforations per square inch
10 (approximately 6.45 square cm) had increased in mass by around 112%. The data also
11 show the maximum mass increases to be higher where the perforation density is higher.
12

13 To measure the effect on the swelling profile in a hydrocarbon fluid, samples of the same
14 material composition with no perforations, 16 perforations, 64 perforations and 132
15 perforations per square inch (approximately 6.45 square cm) were placed in the special
16 kerosine Clairsol 350MHF™ at a controlled temperature of 80 degrees Celsius. The
17 mass increase of the samples was measured, and the data showed no significant effect on
18 swelling profile, i.e. the perforations did not significantly affect the penetration of the
19 hydrocarbon into the body.
20

21 Samples of the material composition specified in Table A were compared with a similar
22 composition with the Vestenamer® omitted. Samples of each composition were placed in
23 tap water at a controlled temperature of 80°C. Figure 6A is a plot of percentage mass
24 change versus time for the respective samples. The data show a clear increase in swell
25 profile for the swellable material containing Vestenamer® compared to the swellable
26 material with no Vestenamer®.
27

28 Identical samples were placed in Clairsol 350 MHF™ at a controlled temperature of 80°C
29 to model the effect of the Vestenamer® in a hydrocarbon well fluid environment, with the
30 measured mass increase plotted in Figure 6B. The data show an improved swell rate and
31 improved maximum swell increase for the swellable material with the Vestenamer®,
32 compared to the swellable material without Vestenamer®.
33

34 It is believed that the addition of the Vestenamer® results in a macroscopic bond structure
35 within the material which increases the permeability to wellbore fluids. This increases the

1 access of water contained in a wellbore fluid to the water swellable bodies in the
2 elastomer. In addition, the macroscopic bond structure increases the permeability of the
3 apparatus to hydrocarbon fluids. The data also show that the addition of the Vestenamer®
4 increases the maximum swell increase of the material. Although the examples shown
5 relate to Vestenamer®, the addition of other semi-crystalline rubbers and/or
6 polyoctenamers also falls within the scope of the invention. Thus in particular
7 embodiments, the access pathways providing access for water molecules to the super
8 absorbing polymer bodies may be formed by the macroscopic bond structure of the
9 material itself.

10
11 Figure 7 is a cross sectional view through a packer in accordance with an alternative
12 embodiment of the invention. The packer, generally shown at 200, is similar to the packer
13 10 of Figure 1, but differs in its construction. The packer comprises an expanding portion
14 215 of cylindrical form located on a tubular 214. The packer is formed by forming multiple
15 wraps 202a, 202b, and 202c of an elastomeric material 230 on the tubular 214. The
16 elastomeric material 230 consists of a substantially rectangular sheet. In this example, the
17 elastomeric material 230 is extruded EPDM and is uncured. The elastomeric material will
18 typically be formed in a continuous length of several tens of metres, and may conveniently
19 be deployed from a storage reel.

20
21 The lowermost layer 202a of the material is secured to the tubular 214 by a bonding agent,
22 which may be a cyanoacrylate based adhesive. The multiple layer construction allows
23 treatments to be applied to different parts of the swellable mantle. In this embodiment, the
24 outer surfaces of the two outermost layers 202b, 202c of the material are coated with a
25 cross-linking agent such as ZDA. This may be applied to the material prior to its
26 application to the tubular over selected areas of the material. Alternatively, the treatment
27 may be applied to the different layers during application on to the tubular.

28
29 When the expanding portion is formed it is cured, for example by a heat curing process, to
30 form a unitary body of hydrocarbon swellable material. A cross-linking accelerator has
31 been selectively applied to an outer volume of the expanding portion, resulting in an inner
32 volume 218 with relatively low cross-linking density, compared with an outer volume 220
33 with relatively high cross-linking density.

34

1 In an alternative embodiment (not illustrated), the elastomeric material 230 is replaced by
2 a sheet material of a hybrid swellable material, such as that described with reference to
3 Figures 2 to 4. In a further alternative embodiment, the permeability structure of the
4 swellable body is affected by creating a macroscopic bond structure. This is achieved by
5 incorporating a semi-crystalline rubber such as Vestenamer® in a part of the sheet
6 material. For example, the innermost layers of the expanding portion may incorporate
7 Vestenamer®, whereas the outermost layers do not. Curing of the material to a unitary
8 body of hydrocarbon swellable material results in a varying macroscopic structure across
9 the cross-section of the body, and thus a variation in permeability to hydrocarbon fluids,
10 even if molecular cross-linking density is the same across the body.

11
12 The invention provides a swellable apparatus for filling a space in oil or gas apparatus and
13 method of forming an apparatus is described. The apparatus comprises a hydrocarbon
14 swellable body formed from an elastomeric material selected to expand on exposure to a
15 hydrocarbon fluid such as EPDM. The swellable body has a first surface which is exposed
16 to a hydrocarbon fluid, a first (inner) portion, and a second portion disposed between the
17 first portion and the surface. The first portion comprises a fluid permeability structure
18 which differs from the fluid permeability structure of the second portion. In one
19 embodiment, the cross-linking density of an outer portion of the body is greater than the
20 cross-linking density of an inner portion of the body.

21
23 The presently described invention provides a number of benefits. Importantly, it provides
24 apparatus which facilitates control or selection of swelling characteristics such as swelling
25 rate during exposure to wellbore fluids. It allows for controlled swelling behaviour in the
26 presence of both hydrocarbon and water that may typically be encountered in operations
27 in wells. It provides for reliability of performance of swellable apparatus in different
28 conditions.

29
30 Various modifications and improvements may be made without departing from the scope
31 of the invention herein described. Combinations of features other than those specifically
32 claimed are within the scope of the invention.

33

Claims

1. A swellable apparatus for filling a space in oil or gas apparatus, the swellable apparatus comprising a unitary hydrocarbon swellable body formed from an elastomeric material selected to expand on exposure to a hydrocarbon fluid, the hydrocarbon swellable body having a first surface which, in use, is exposed to a hydrocarbon fluid, a first portion, and a second portion disposed between the first portion and the first surface, wherein the first portion comprises a fluid permeability structure which differs from the fluid permeability structure of the second portion.
2. The apparatus as claimed in claim 1, wherein the cross-linking density of the elastomeric material in the first portion of the hydrocarbon swellable body differs from the cross-linking density of the elastomeric material in the second portion of the hydrocarbon swellable body.
3. The apparatus as claimed in claim 2, wherein the cross-linking density of the elastomeric material in the second portion is greater than the cross-linking density of the elastomeric material in the first portion.
4. The apparatus as claimed in claim 2 or claim 3, wherein the hydrocarbon swellable body comprises a second surface, and the extent of cross-linking in the hydrocarbon swellable body decreases in a direction from the first surface to the second surface.
5. The apparatus as claimed in any preceding claim, wherein the macroscopic bond structure of the elastomeric material in the first portion of the hydrocarbon swellable body differs from the macroscopic bond structure of the elastomeric material in the second portion of the hydrocarbon swellable body.
6. The apparatus as claimed in any preceding claim, wherein one of first or second portions of the hydrocarbon swellable body comprises an additive comprising a semi-crystalline rubber and/or a polyoctenamer.
7. The apparatus as claimed in claim 6, wherein one of first or second portions of the hydrocarbon swellable body comprises Vestenamer®.

- 1 8. The apparatus as claimed in claim 7, wherein Vestenamer® comprises between
2 about 5% and about 15% of a volume of the first or second portion of the
3 hydrocarbon swellable body.
4
- 5 9. The apparatus as claimed in any preceding claim, wherein one of first or second
6 portions of the hydrocarbon swellable body comprises an additive comprising one or
7 more chemical foaming agents.
8
- 9 10. The apparatus as claimed in claim 9, wherein the chemical foaming agent imparts an
10 open cellular structure to one of first or second portions of the hydrocarbon swellable
11 body.
12
- 13 11. The apparatus as claimed in any preceding claim, further comprising a plurality of
14 water swellable bodies embedded in the hydrocarbon swellable body.
15
- 16 12. The apparatus as claimed in any preceding claim, wherein the hydrocarbon
17 swellable body comprises at least one pathway for the passage of water comprised
18 in a wellbore fluid through the hydrocarbon swellable body.
19
- 20 13. The apparatus as claimed in claim 12, wherein the pathway comprises a bore.
21
- 22 14. The apparatus as claimed in claim 13, wherein the bore is formed by perforation of
23 the hydrocarbon swellable body.
24
- 25 15. The apparatus as claimed in any preceding claim, wherein the hydrocarbon
26 swellable body comprises ethylene propylene diene monomer rubber (EPDM).
27
- 28 16. The apparatus as claimed in any of claims 11 to 15, wherein the water swellable
29 bodies comprise a Super Absorbent Polymer (SAP),
30
- 31 17. An oil or gas tool comprising the swellable apparatus of any preceding claim.
32
- 33 18. A wellbore packer comprising the swellable apparatus of any preceding claim.
34

- 1 19. A method of forming a swellable apparatus for filling a space in oil or gas apparatus,
2 the method comprising the steps of:
- 3 – providing an elastomeric material selected to expand on exposure to a
4 hydrocarbon fluid;
 - 5 – curing the elastomeric material to form a unitary hydrocarbon swellable body;
 - 6 – treating the elastomeric material such that a first portion of the hydrocarbon
7 swellable body comprises a fluid permeability structure which differs from the fluid
8 permeability structure of a second portion of the hydrocarbon swellable body.
- 9
- 10 20. The method as claimed in claim 19, comprising the additional steps of providing a
11 sheet of hydrocarbon swellable material and forming a substantially cylindrical
12 mantle from the sheet of hydrocarbon swellable material.
- 13
- 14 21. The method as claimed in claim 20, comprising the additional step of forming
15 multiple layers of the hydrocarbon swellable material on a mandrel or tubular.
- 16
- 17 22. The method as claimed in claim 20 or claim 21, comprising the additional step of
18 wrapping a sheet of hydrocarbon swellable material onto a mandrel or tubular.
- 19
- 20 23. The method as claimed in any of claims 19 to 22, comprising the additional step of
21 incorporating an additive into the elastomeric material, the additive comprising a
22 chemical foaming agent.
- 23
- 24 24. The method as claimed in any of claims 19 to 23, comprising the additional step of
25 incorporating an additive into the elastomeric material, the additive comprising a
26 semi-crystalline rubber and/or polyoctenamer.
- 27
- 28 25. The method as claimed in any of claims 19 to 24, comprising the additional step of
29 treating the hydrocarbon swellable material such that a second portion of the
30 hydrocarbon swellable body has a higher extent of cross-linking than a first portion of
31 the hydrocarbon swellable body.
- 32
- 33 26. The method as claimed in claim 25, comprising the additional step of applying a
34 cross-linking agent selectively parts of the hydrocarbon swellable body.
- 35

- 1 27. The method as claimed in claim 26, comprising the additional step of providing a
2 cross-linking agent on an outer surface of the hydrocarbon swellable body.
3
- 4 28. The method as claimed in claim 26 or claim 27, comprising the additional step of
5 applying a cross-linking agent to the surface of one or more layers prior to curing the
6 elastomeric material.
7
- 8 29. A swellable apparatus for filling a space in oil or gas apparatus, the swellable
9 apparatus comprising a hydrocarbon swellable body formed from a cross-linked
10 elastomeric material selected to expand on exposure to a hydrocarbon fluid, the
11 hydrocarbon swellable body having a first surface which, in use, is exposed to a
12 hydrocarbon fluid, wherein the cross-linking density of the elastomeric material
13 varies in the hydrocarbon swellable body.
14

1/6

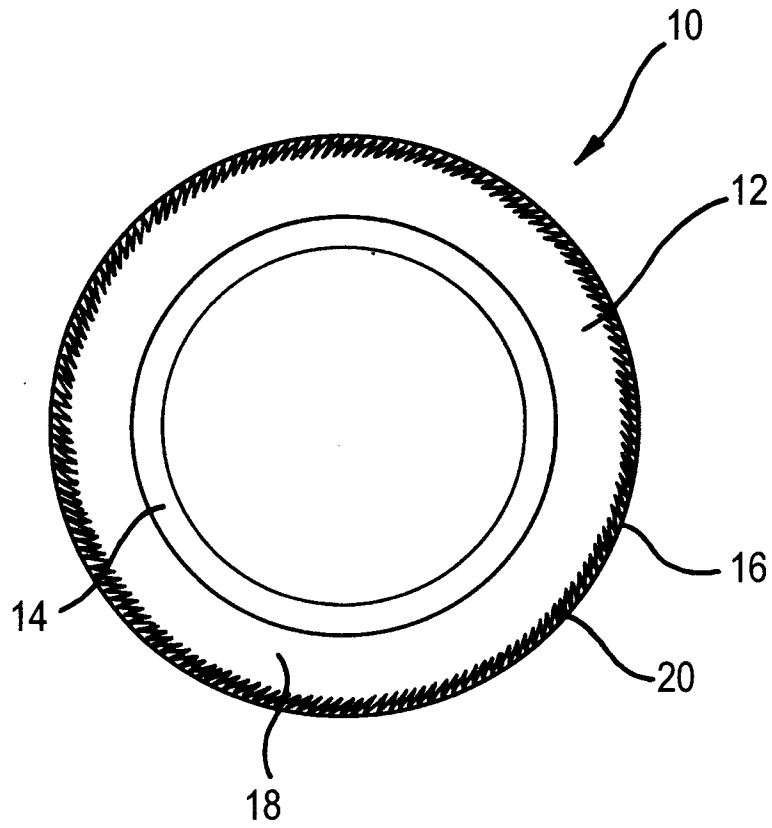


Fig. 1

2/6

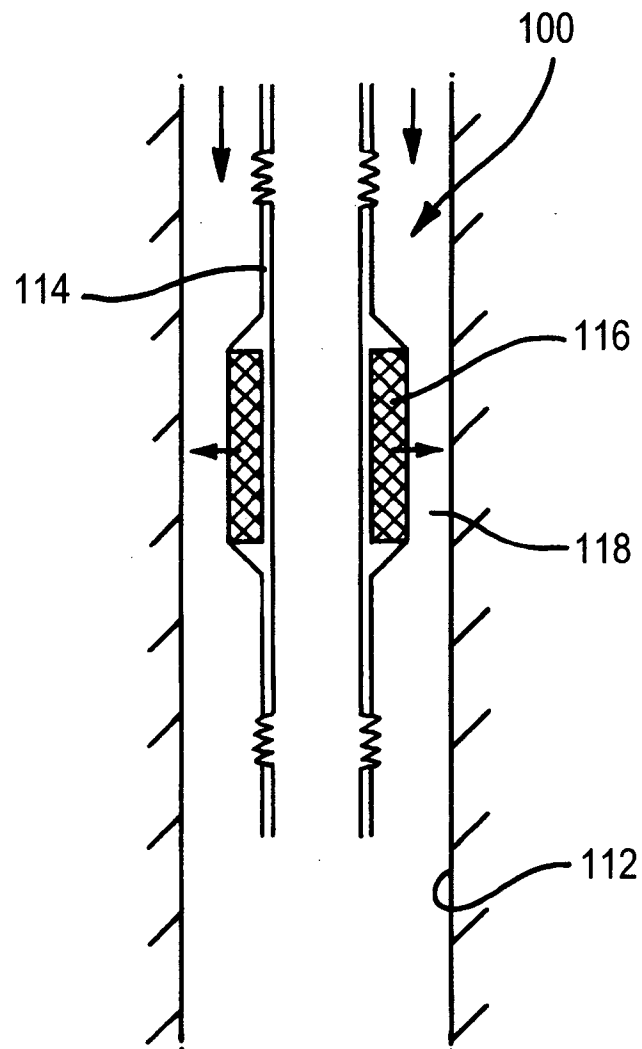


Fig. 2

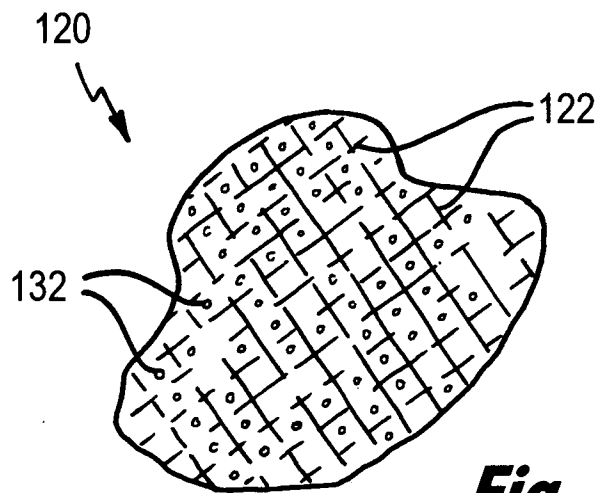
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Fig. 3

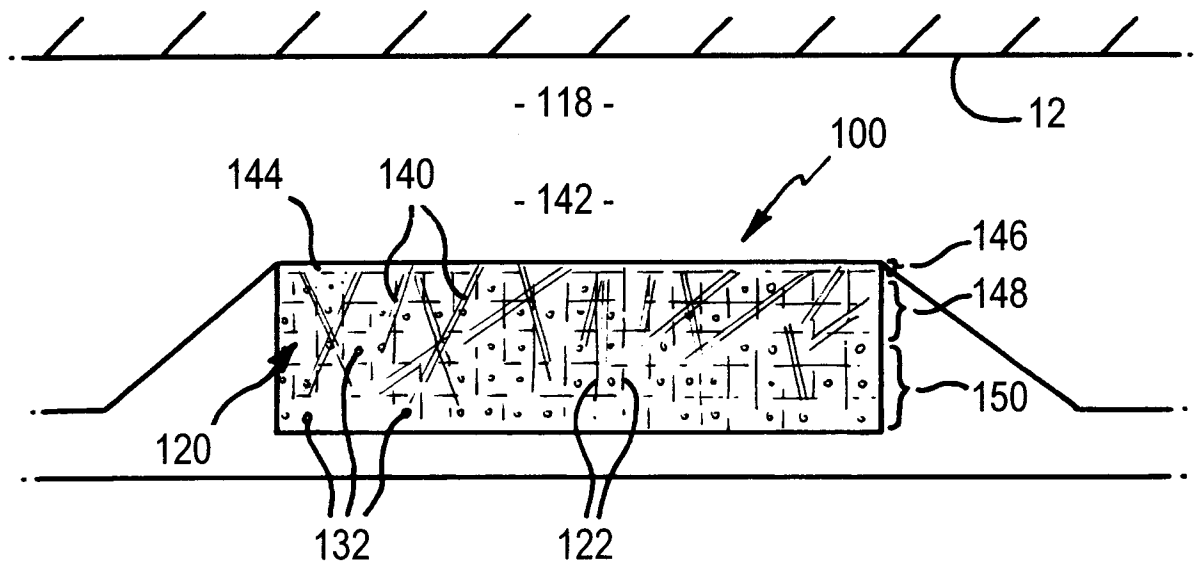
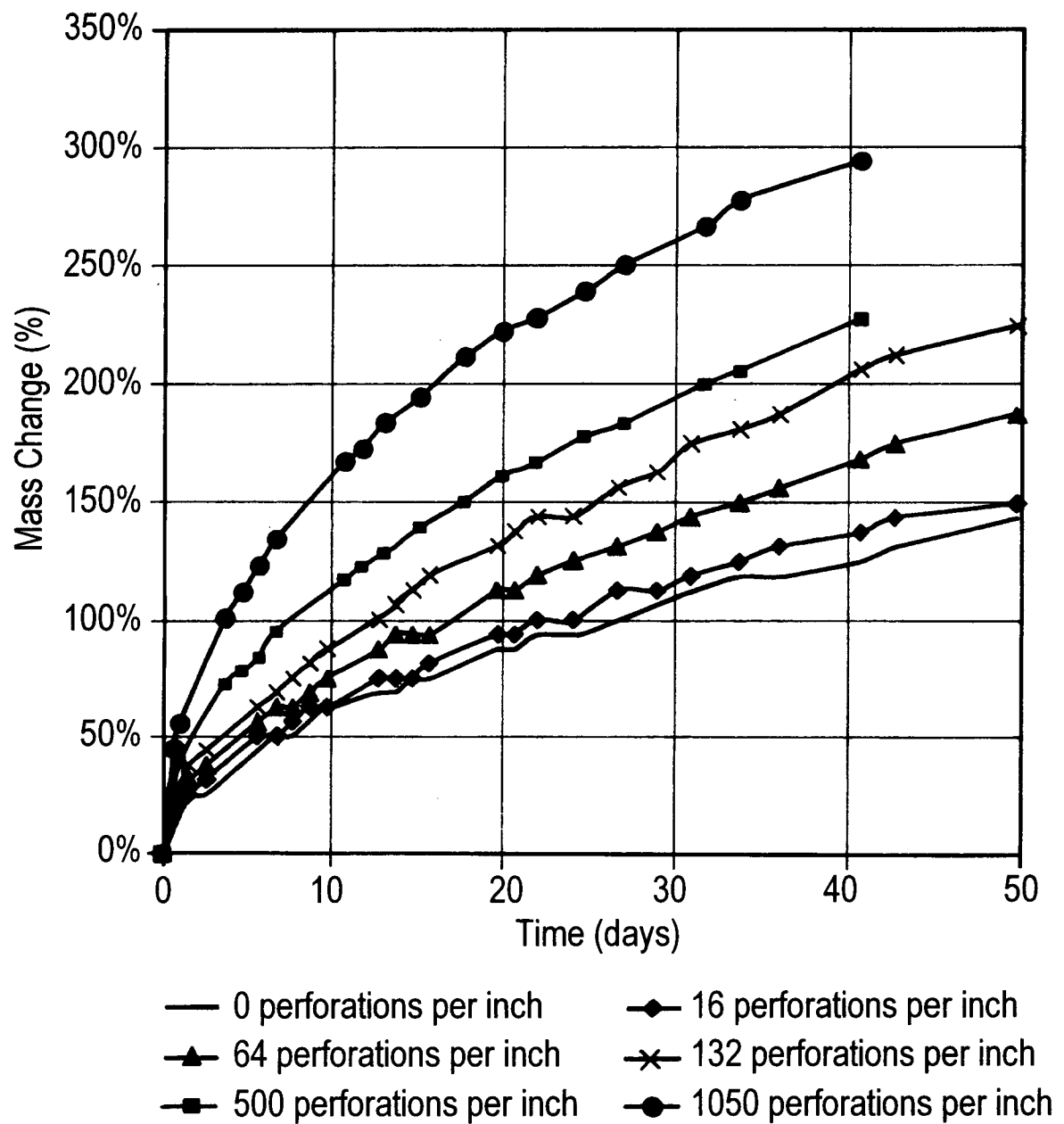
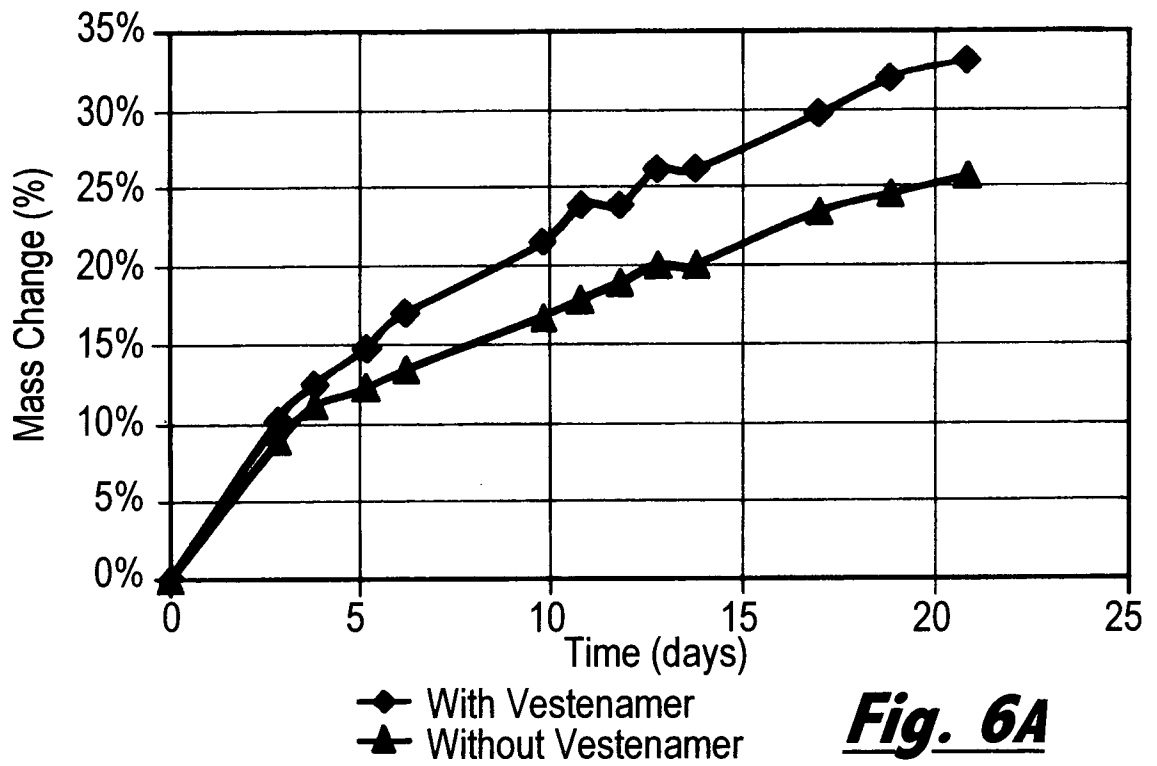
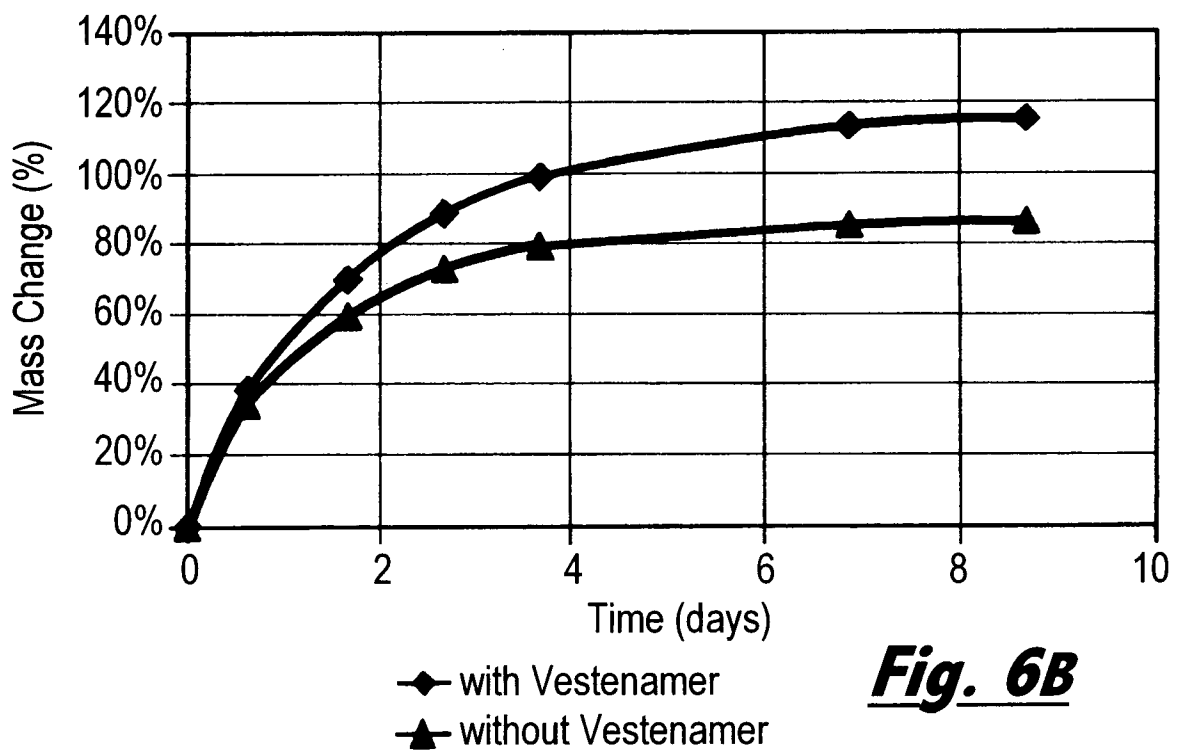


Fig. 4

$\frac{4}{6}$ **Fig. 5**

5/
6***Fig. 6A******Fig. 6B***

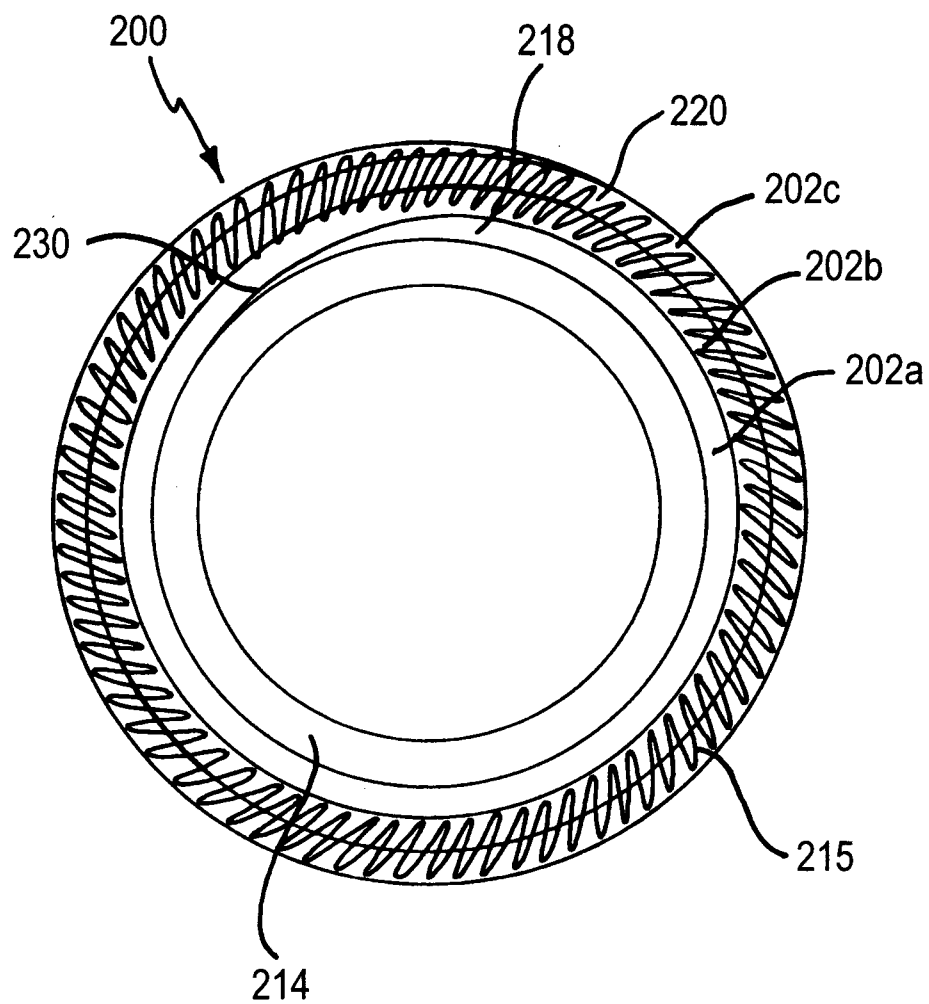


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2008/002159

A. CLASSIFICATION OF SUBJECT MATTER

INV. E21B33/12 C08C19/00 C08K5/14

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 C08C C08K F16L

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 554 599 A (US RUBBER CO) 12 July 1943 (1943-07-12) page 1, column 2, line 65 - page 2, column 1, line 34	1-29
X	WO 02/20941 A (FREYER JAN [NO]) 14 March 2002 (2002-03-14) cited in the application figures 2,3 & EP 1 315 883 A (HALLIBURTON CO [US]) HALLIBURTON ENERGY SERV INC [US]) 4 June 2003 (2003-06-04)	1, 19, 29
A	GB 2 421 527 A (SCHLUMBERGER HOLDINGS [VG]) 28 June 2006 (2006-06-28) claims 1-12; figures 2-7 the whole document	1, 19, 29



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

6 November 2008

Date of mailing of the international search report

13/11/2008

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/002159

C(Continuation). 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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P, A	WO 2007/094897 A (EXXONMOBIL UPSTREAM RES CO [US]; YEAGER DONALD L [US]; BUNNELL FRANZ D) 23 August 2007 (2007-08-23) the whole document -----	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2008/002159

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