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(54) Title: A METHOD FOR PLUGGING A HYDROCARBON WELL

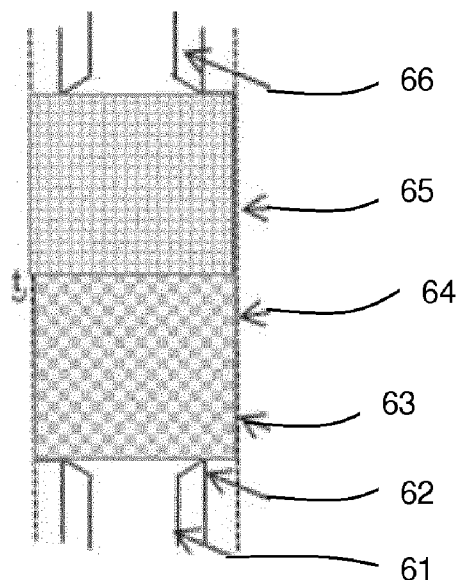


Fig. 6

(57) Abstract: A method of plugging a hydrocarbon well, the method comprising expanding a section of a tubular within the well wherein the expanded section of the tubular comes into contact with a casing lining the well, melting at least part of the expanded section of the tubular and the casing, and forming a plug within a region of the well where the tubular and the casing have been melted.



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A method for plugging a hydrocarbon well

The present invention relates to a method for plugging a hydrocarbon well to facilitate permanent abandonment of the well.

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Wells used in gas and oil recovery need to be satisfactorily plugged and sealed after the wells have reached their end-of life and it is not economically feasible to keep the wells in service. Oil and gas wells have in general three different purposes, as producers of hydrocarbons; injectors of water or gas for reservoir pressure support or for depositing purposes; or as exploration wells. Plugging of wells is performed in connection with permanent abandonment of wells due to decommissioning of fields or in connection with permanent abandonment of a section of well to construct a new wellbore (known as side tracking or slot recovery) with a new geological well target.

15 A well is constructed by a hole being drilled down into the reservoir using a drilling rig and then sections of steel pipe, casing or liner are placed in the hole to impart structural integrity to the wellbore. Cement is placed between the outside of the casing or liner and the bore hole and then tubing is inserted into the casing to connect the wellbore to the surface. Once the reservoir has been abandoned, a permanent well barrier must be established across the full cross-section of the well. This is generally achieved by removal of the inner tubulars from the well bore by means of a workover rig which pulls the tubulars to the surface. The casing is then section milled to create an area in the casing with an increased internal diameter for receiving a well barrier. Well barriers are then established across the full cross-section of the well, in order to isolate the reservoir(s) and prevent flow of formation fluids between reservoirs or to the surface. It is necessary to remove the inner tubulars from the wellbore in order to set the cement plug against the outer casing or liner and to verify the casing or liner cement. This method is time consuming and expensive since it requires a rig for pulling the tubing, performing section milling and placing a barrier.

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Improperly abandoned wells are a serious liability so it is important to ensure that the well is adequately plugged and sealed. However, the number of steps and equipment involved, such as a rig and drillpipe, results in this stage of the life of the well being costly and time-consuming, at a time when the well no longer generates revenue.

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Attempts have been made to increase the efficiency of the method of abandonment. For example, GB2407835 (Head) describes wellbore sealing wherein explosive charges are used to perforate a lower end of the tubing and then sealing fluid is then pumped through the perforations so as to plug the well around the bottom end of the tubing.

US2591807 (Greene) relates to an apparatus that uses relatively low and high velocity explosive charges spaced at opposing ends of a container full of cement for placing in a zone of a wellbore whereby upon ignition cement is forced downwardly and outwardly to release cement into the cavity between the tubing and formation. US2696258 and US2696259 (also to Greene) relate to an apparatus for depositing cement in a zone wherein the cement is contained within an elongated container and a gas generating charge is ignited to displace the cement through a lower outlet of the container into the zone. The charge expands the container into sealing contact with the casing, while at the same time rupturing the end of a tubular body to release cement into the wellbore.

It is an object of the present invention to provide an improved method for plugging an abandoned well that reduces the number of steps involved in the process and/or removes the need for a rig.

Accordingly, a first aspect of the present invention provides a method of plugging a hydrocarbon well, the method comprising expanding a section of a tubular within the well wherein the expanded section of the tubular comes into contact with a casing lining the well, melting at least part of the expanded section of the tubular and the casing; and forming a plug within a region of the well where the tubular and the casing have been melted.

The step of forming a plug may at least partially be carried out by said melting and melted portions of the tubular and the casing may be included in the plug. The melting may expose at least part of the borehole wall. At least part of said plug may be directly adjacent the borehole wall. Said melting may be achieved by igniting thermite, which comprises iron-III-oxide and aluminium. The plug may be the reaction product of thermite.

An explosive force may cause expansion of a section of the tubular. The explosives may be introduced into a section of the tubing on a wire-line. Alternatively, the tubular may be expanded using mechanical expansion means such as a hydraulic mechanism or a cone forced against a section of the tubular.

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The method may be used in the plugging of a production well, injector well or an exploration well. The method may also be used in the plugging of offshore wells.

10 A second aspect of the present invention provides a method of plugging a hydrocarbon well to facilitate permanent abandonment of the well, the method comprising:

expanding a section of inner or outer tubular within the well wherein the expanded section of an inner tubular comes into sealing contact with a casing lining the well to at least partially seal the tubular to the casing or wherein the expanded section of the outer tubular comes into sealing contact with the formation; and

15 filling the expanded section of tubular, in whole or in part, with a material so as to form a sealing plug within the tubular.

The present invention is particularly suitable for plugging of oil and gas wells, especially offshore wells.

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In the context of this disclosure, the term "tubular" refers generally to any kind of pipe contained within a well, including an inner or outer casing within the well, tubing, such as production tubing and liners.

25 Expansion of the tubular may be accomplished by any suitable means that causes the tubular to expand sufficiently for it to deform into sealing contact with the surrounding casing or formation of the well. Preferably, explosives are provided within the tubular, for example, attached to a wire line that is inserted into the tubular to deliver explosives to the section to be expanded against the casing or formation. In this embodiment of
30 the invention, an appropriate detonator should also be provided. Explosives may be used to expand a section of the inner tubular to cause at least partial fusion of the tubular with the outer casing.

35 Additional and/or alternative means may be used to effect expansion of the tubular, such as hydraulics or other mechanical means, for example a cone, provided said

means generates enough force to expand the tubular against the casing or formation to fuse the two together to result in the formation of a single barrier element .

5 Generally, the expanded section of the tubular will be filled with cement to form a permanent plug within the tubular. However, alternative sealing materials may be used.

10 It may be preferable to improve the seal between the casing and the tubular by the introduction of a sealant or adhesive between the casing and the tubular. The sealant may comprise a polymer composite, such as epoxy resin, or cement.

For a better understanding of the present invention and to show more clearly how it may be carried into effect, reference will now be made by way of example only, to the accompanying drawings in which:

15 Figure 1A is a schematic diagram of a well section;
 Figure 1B is the well section of Figure 1 provided with a wireline;
 Figure 1C illustrates detonation of explosive charges along the wireline causing expansion of the tubular towards the casing;
 Figure 1D illustrates plugging of the expanded section using cement; and
20 Figure 2 is an illustrative flow chart showing the steps of a method of plugging a hydrocarbon well according to an aspect of the present invention.
 Fig. 3 illustrates a vertical cross section through a portion of a well;
 Fig. 4 illustrates a vertical cross section through a portion of the well of Fig. 3 in which a portion of an inner tubular has been expanded;
25 Fig. 5 illustrates a vertical cross section through a portion of the well of Fig. 4 in which a heating means is lowered;
 Fig. 6 illustrates a vertical cross section through a portion of the well of Fig. 5 in which a plug is formed;
 Fig. 7 is an illustrative flow chart showing the steps of a method of plugging a
30 hydrocarbon well according to an aspect of the present invention.

The present invention according to a first embodiment enables the establishment of permanent wellbore barriers by the expansion of an inner tubing (or other tubular, such as an inner casing) causing it to fuse with an outer casing to allow for simplified
35 plugging and abandonment of a well. The method involves the expansion of the inner

tubular of a production well towards the outer casing to form a single tubular steel pipe, as illustrated in Figures 1A to 1D of the accompanying drawings. This removes the need to remove the inner tubular by means of a rig prior to the formation of a barrier across the wellbore. In the illustrated example, expansion is achieved using explosives. A well comprises a casing 2 lining a wellbore drilled through a formation 1. A tubular 4 extends through the casing 2. A cement bond 6 is provided between the steel casing and the wellbore. When the well is to be abandoned and hence requires plugging and sealing, a wireline 8 with explosive charges 10 is fed down the tubular into a section of the well (see Fig. 1B). The explosive charges are then detonated to cause expansion of the tubular 4 towards the casing. This must be carried out in such a manner as to ensure that the tubular 4 is welded into the casing 2 to form a single solid pipe section, as shown in Figure 1D. The creation of a single barrier element is achieved by metallurgically joining the two metal tubings by explosive welding, a well-known method for joining a wide variety of similar or dissimilar metals. The expanded section is then permanently plugged with cement 12. A squeeze operation may also be performed to establish a permanent seal behind the casing, if logging shows poor cement bond. This may be achieved by squeezing cement or other sealant into the annular space behind the casing.

It is to be appreciated that the type of explosive used in the procedure may comprise any chemical explosive that generates sufficient energy to accelerate the inner tubular 4 to collide at high velocity into the outer casing so that they are fused together. The tubular itself must be comprised of a material that allows for such expansion. In oil and gas wells, the tubular generally consist of various steel grades. Steel is a material that can be expanded by the application of stresses above the yield point and into a plastic region to create permanent deformation. Such steel pipes should be able to expand by 20-30% without fracturing.

Alternative methods for expansion of the tubular include hydraulic means, mechanically by a cone or any other means that generates the necessary force to expand the tubular against the outer casing. Explosives may be used in conjunction with the other expansion means whereby the need for high velocity explosives is reduced, making a broader selection of explosives available for selection.

The sealant may be injected into the annulus between the casing and the tubular before expansion using a punch-tool or annulus injection. The sealant consists of a material that is qualified as part of a permanent barrier element. For example, a polymer composite type material, such as epoxy.

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Figure 2 of the accompanying drawings is an illustrative flow chart showing the steps of plugging a hydrocarbon well according to an aspect of the present invention, comprising (a) expansion of an inner or outer tubular; (b) obtaining sealing contact of the expanded tubular with a casing or formation; and (c) filling the expanded section of tubular with a material to form a sealing plug.

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The barrier element formed according to the process of the present invention should be tested for integrity. This may be carried out by perforating into the annulus below and above the expanded section of tubular and pressure testing across the barrier element.

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It is clear that the present invention removes the need for a rig to remove the inner tubular and enables the use of light well intervention vessels or coiled-tubing vessels to perform permanent plug and abandonment of offshore wells, leading to a quicker and cheaper procedure.

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Whilst the illustrated embodiment demonstrates the expansion of an inner tubular to fuse it to the outer casing followed by plugging of the tubular, an outer casing or liner may be expanded against the formation in order to achieve a permanent barrier. The inner casing/tubing may be pulled out by conventional means. This embodiment removes the need to mill out the casing from the well.

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A further embodiment will now be described in which a combination of expanding and heating is used for creating a plug. After expanding the inner tubular, the inner tubular and the casing are in direct contact with each other in the expanded region of the tubular. The two layers will not be melted together when hydraulic means are used for expanding the inner tubular. The tubular and casing may partially be melted together due to the heat generated by the explosion when explosive means are used for expanding the inner tubular. However, the expansion process may not entirely unite the two layers of steel of the tubular, but may mainly create a press fit, whereby one layer is squeezed into the other without being entirely melted together and without

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creating a uniform seal across the area of contact between the tubular and the casing. The presence of any cables between the inner tubular and the casing may also prevent the formation of a seal. The seal between the expanded portion of the tubular and the casing may be improved by exposing the expanded portion of the inner tubular to a heat source. Thermite may be used as a source of heat for melting the steel tubular and casing. Thermite is a mixture of a metal powder fuel and metal oxide. When ignited, the thermite will generate a high temperature, for example up to 2500 °C when using iron-(III)-oxide in combination with aluminium powder. After the chemical reaction has ended, the reaction product will be a barrier plug consisting of an iron plug at the bottom and a slag plug (such as aluminium oxide) on top. The barrier plug forms a seal extending across the well in the direction perpendicular to the longitudinal direction of the well. The heating process may be repeated two or more times. During the production of the plug, the well may be ventilated on top to remove gas such as H₂.

The combination of expanding the inner tubular and heating enables the formation of a seal by using a wire-line, coiled tubing or a jointed pipe without needing to take the inner tubular out of the well. The initial step of expanding the inner tubular will remove fluids in the region between the inner tubular and the casing in the expanded section, thereby improving the heat transfer between the inner tubular and the casing during the next step of heating the expanded portion. Any cables present in between the inner tubular and the outer casing, or within the inner tubular, will also melt during the heating process and will become part of the seal. The strong heat generated during the heating step will also reduce or remove the material present in the casing, such as any mixture of cement, barite or mud.

Figure 3 illustrates a vertical cross section through a portion of a well which is to be plugged. The well has an inner tubular 31 and an outer tubular 32. The outer tubular is separated from a borehole wall 33 by a region 34 of mud, barite or cement, or a mixture of those materials. The region 35 between the inner tubular and the outer tubular is filled with mud or brine.

Figure 4 illustrates a vertical cross section through a portion of the well of Fig. 3, in which a portion of the inner tubular 41 is expanded and is partially in direct contact with the outer tubular 42. The mud or brine is displaced in the region where the inner and outer tubular are in direct contact with each other. The region between the borehole

wall 43 and the outer tubular 42 is still filled with mud, barite or cement 44. An expansion tool 45 is provided within the inner tubular in the region where the inner tubular is expanded. The tool is suspended from a wire-line 47. Mud or brine is still present in the region 46 between the inner- and outer tubular above the expanded section.

Figure 5 illustrates a vertical cross section through a portion of the well of Fig. 4 in which the expansion tool has been removed and in which a heating means has been lowered. As in Figures 3 and 4, the well comprises an inner tubular 51, an outer tubular 52, a borehole wall 53, a region 54 between the outer tubular and the borehole wall which is filled with mud, barite or cement. A thermite pack 55 is lowered into the expanded region by means of a wire-line 57. The annulus 56 between the inner and outer tubular is filled with mud or brine in the region which has not been expanded.

The expanded region may be closed from below (not shown) by a high temperature resistant plug to prevent melted metal from falling down the tubular during formation of the plug. The expanded region may also be closed from above (not shown) by a high temperature resistant plug to prevent heat which is generated by the thermite from escaping the heated region.

Figure 6 illustrates a vertical cross section through a portion of the well of Fig. 4 after the thermite has been ignited and the chemical process has ended. Parts 61, 62, 63 and 66 correspond to parts 51, 52, 53 and 56 of Fig. 5. The high temperature generated by the thermite has displaced the mud, barite or cement in region 54 of Fig. 5 and a plug is directly adjacent the borehole wall 63. A plug has been formed which has a lower portion 64 of iron and an upper portion 65 of aluminium oxide. In the region of the plug, the inner tubular, the outer tubular and any further materials such as mud, barite, cement or wires which were initially provided in the region of the plug have melted away and may be part of the plug.

Figure 7 of the accompanying drawings is an illustrative flow chart showing the steps of plugging a hydrocarbon well according to an aspect of the present invention, comprising (a) expanding a section of a tubular within the well wherein the expanded section of the tubular comes into contact with a casing lining the well; (b) melting at

least part of the expanded section of the tubular and the casing; and (c) forming a plug within a region of the well where the tubular and the casing have been melted.

5 Although the invention has been described in terms of preferred embodiments as set forth above, it should be understood that these embodiments are illustrative only and that the claims are not limited to those embodiments. Those skilled in the art will be able to make modifications and alternatives in view of the disclosure which are contemplated as falling within the scope of the appended claims. Each feature disclosed or illustrated in the present specification may be incorporated in the
10 invention, whether alone or in any appropriate combination with any other feature disclosed or illustrated herein.

CLAIMS:

1. A method of plugging a hydrocarbon well, the method comprising:
expanding a section of a tubular within the well wherein the expanded section of
5 the tubular comes into contact with a casing lining the well;
melting at least part of the expanded section of the tubular and the casing; and
forming a plug within a region of the well where the tubular and the casing have
been melted.
- 10 2. A method according to claim 1, wherein said forming a plug is at least partially
carried out by said melting and wherein melted portions of the tubular and the casing
are included in the plug.
- 15 3. A method according to claim 1, wherein said melting exposes at least part of
the borehole wall.
4. A method according to claim 3, wherein at least part of said plug is directly
adjacent the borehole wall.
- 20 5. A method according to claim 1, wherein said melting is achieved by igniting
thermite.
6. A method according to claim 5, wherein the thermite comprises iron-III-oxide
and aluminium.
- 25 7. A method according to any one of claims 1 to 6, wherein at least part of the plug
is the reaction product of thermite.
8. A method according to claim 1 wherein an explosive force causes expansion of
30 a section of the tubular.
9. A method according to claim 1 wherein explosives are introduced into a section
of the tubing on a wire-line.

10. A method according to claim 1 wherein the tubular is expanded using mechanical expansion means.

5 11. A method according to claim 10, wherein the mechanical expansion means comprises a hydraulic mechanism.

12. A method according to claim 1 wherein a cone forced against a section of the tubular causes expansion of the tubular.

10 13. A method according to claim 1 for use in the plugging of a production well, injector well or an exploration well.

14. A method according to claim 1 for use in the plugging of offshore wells.

15 15. A method of plugging a hydrocarbon well, the method comprising:
expanding a section of an inner or outer tubular within the well wherein the expanded section of the inner tubular comes into sealing contact with a casing lining the well to at least partially seal the tubular to the casing or wherein the expanded section of the outer tubular comes into sealing contact with the formation; and
20 filling the expanded section of tubular, in whole or in part, with a material so as to form a sealing plug within the tubular.

16. A method according to claim 15 wherein the inner tubular comprises a production tubing, inner casing or lining for coming into sealing contact with a casing
25 lining the well.

17. A method according to claim 15 wherein the outer tubular comprises an outer casing or liner for coming into sealing contact with the formation.

30 18. A method according to claim 15, 16 or 17 wherein an explosive force causes expansion of a section of the tubular.

19. A method according to claim 18 wherein explosives are introduced into a section of the tubing on a wireline.
35

20. A method according to any one of claims 15 to 19 wherein hydraulics expand the tubular.

5 21. A method according to any one of claims 15 to 20 wherein a cone forced against a section of the tubular causes expansion of the tubular.

22. A method according to any one of claims 15 to 21 wherein the expanded section of the tubular is filled with cement to form the sealing plug within the tubular.

10 23. A method according to any one of claims 15 to 21 further comprising introducing a sealant between the tubular and the casing to enhance the seal therebetween.

15 24. A method according to claim 23 wherein the sealant is cement.

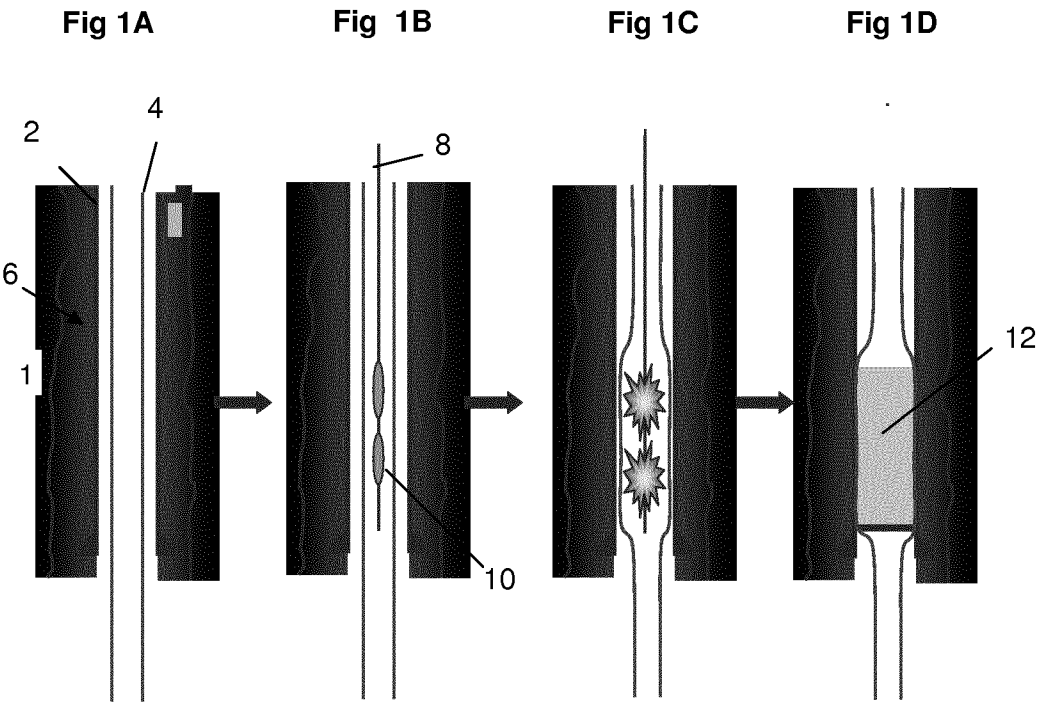
25. A method according to claim 23 wherein the sealant is a polymer composite.

20 26. A method according to claim 25 wherein the polymer composite is an epoxy resin.

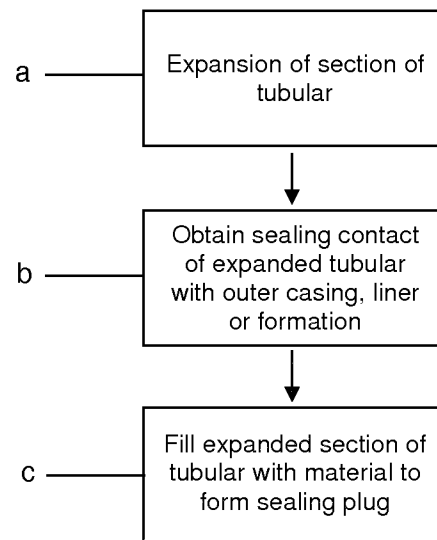
27. A method according to any one claims 15 to 26 for use in the plugging of a production well, injector well or an exploration well.

25 28. A method according to any one of claims 15 to 27 for use in the plugging of offshore wells.

30 29. A method according to any one of the preceding claims, wherein the method is used for abandonment of the well.



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Fig 2

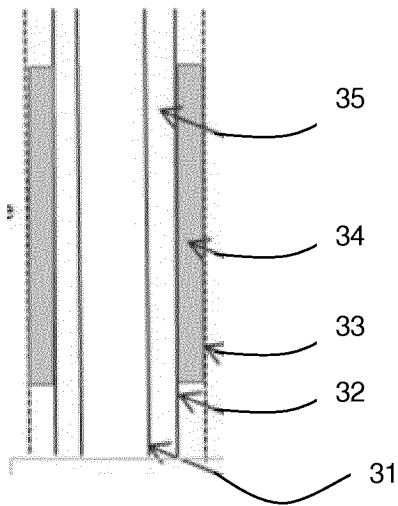


Fig. 3

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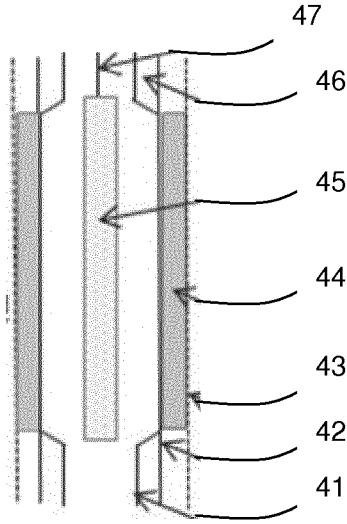


Fig. 4

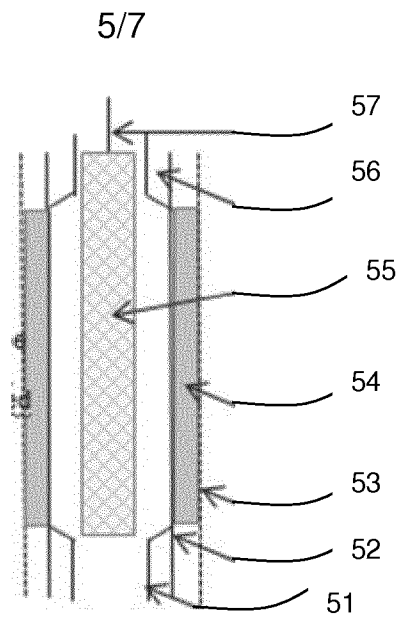


Fig. 5

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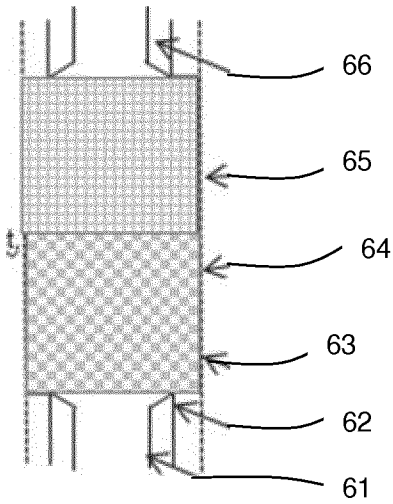


Fig. 6

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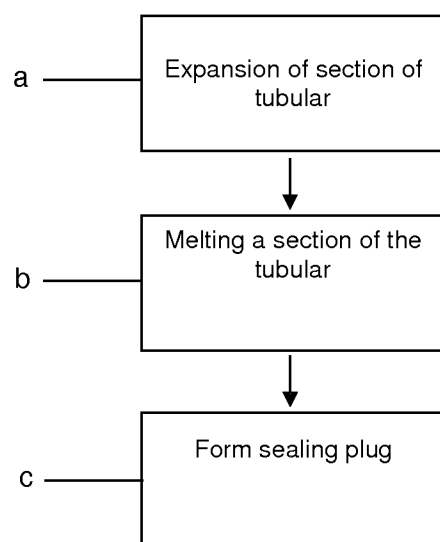


Figure 7