SHAPE MEMORY MATERIALS FOR DOWNHOLE TOOL APPLICATIONS

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ABSTRACT

A technique utilizes shape memory materials in wellbore applications. Well components are formed with shape memory materials able to transition to a desired state when activated. The well components are moved downhole with the shape memory material in one state. Upon introduction of an activating agent, the automatic transition of the shape memory material is initiated and the well component is changed to a state in which it is able to perform a desired downhole function.
SHAPE MEMORY MATERIALS FOR DOWNHOLE TOOL APPLICATIONS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present document is based on and claims priority to U.S. Provisional Application Ser. No. 60/914,569, filed Apr. 27, 2007.

BACKGROUND

[0002] In many downhole applications, one or more components are actuated to achieve a desired result. For example, a flow control valve can be actuated to open or close a fluid flow path. Similarly, a packer or an expandable sand screen can be actuated to seal off a desired region of a wellbore. Actuating these and other devices often requires movement of a component, a change in component shape, or some other type of conversion that transitions the component to a desired functional state.

[0003] Depending on a variety of factors, including environment and well equipment structure, actuation of certain components can be difficult or time-consuming. For example, mechanical actuation may require movement of large downhole equipment strings. Similarly, hydraulic or electrical actuation often requires the routing of control lines over substantial distances along the wellbore.

SUMMARY

[0004] In general, the present invention provides a method and system for utilizing shape memory materials in wellbore applications. Well components requiring actuation are formed of or combined with shape memory materials able to transition to a desired state when actuated. An activating agent can be utilized downhole to initiate automatic transition of the shape memory material to a state in which the well component is able to perform a desired function.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Certain embodiments of the invention will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements, and:

[0006] FIG. 1 is a front elevation view of a well system deployed in a wellbore, according to an embodiment of the present invention;

[0007] FIG. 2 is a cross-sectional view of a well component formed from a shape memory material manufactured in a first memorized state, according to an embodiment of the present invention;

[0008] FIG. 3 is a cross-sectional view of the well component of FIG. 2 following deformation into an alternate state, according to an embodiment of the present invention;

[0009] FIG. 4 is a cross-sectional view of the well component of FIG. 3 following the use of an activating agent to return the shape memory material and the well component to the memorized state, according to an embodiment of the present invention;

[0010] FIG. 5 is a cross-sectional view of a packer comprising shape memory material and deployed in a wellbore in the deformed state, according to an embodiment of the present invention;

[0011] FIG. 6 is a cross-sectional view of the packer of FIG. 5 following activation of the shape memory material to the memorized state, according to an embodiment of the present invention;

[0012] FIG. 7 is a cross-sectional view of another embodiment of a flow control device comprising shape memory material and deployed in a wellbore in the deformed state, according to an embodiment of the present invention;

[0013] FIG. 8 is a cross-sectional view of the flow control device of FIG. 7 following activation of the shape memory material to the memorized state, according to an embodiment of the present invention;

[0014] FIG. 9 is a cross-sectional view of a well component having a threaded connector comprising shape memory material and deployed in a wellbore in the deformed state, according to an embodiment of the present invention;

[0015] FIG. 10 is a cross-sectional view of the well component of FIG. 9 following activation of the shape memory material to the memorized state, according to an embodiment of the present invention;

[0016] FIG. 11 is a cross-sectional view of a seal device incorporating shape memory material, according to an embodiment of the present invention; and

[0017] FIG. 12 is a cross-sectional view of another embodiment of a seal device incorporating shape memory material, according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0018] In the following description, numerous details are set forth to provide an understanding of the present invention. However, it will be understood by those of ordinary skill in the art that the present invention may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

[0019] The present invention generally relates to downhole or wellbore tool applications that utilize shape memory materials. One or more well components are formed from shape memory material and deployed downhole in a wellbore. The shape memory material is readily transformable from one state to another state and thus can be selectively transitioned while downhole to perform a desired function. The change of states can be induced by an appropriate activating agent.

[0020] Shape memory materials may comprise one or more materials. For example, shape memory materials can be metallic and/or polymeric. The metallic type of shape memory material comprises a shape memory alloy that gains its shape memory effect from a solid-state phase change, i.e., molecular rearrangement. This type of phase change is similar to the phase change that occurs in transitioning from solid to liquid and vice versa in that a molecular rearrangement occurs, but the molecules remain closely packed. However, the substance remains in a solid-state. In many applications, a temperature change around 10°C is adequate to initiate a solid-state phase change. Examples of suitable metallic shape memory materials are nickel-titanium alloys. Other shape memory materials comprise copper-aluminum-nickel alloys, copper-zinc-aluminum alloys, and iron-manganese-silicon alloys. Additionally, composite shape memory materials can be used. For example, the shape memory material may comprise polymeric shape memory composites, metal/polymer shape memory materials, e.g., metal bonded polymer parts, polymer or metal coated/layered shape memory materials, e.g., rubber coated shape memory polymer parts, and other composite memory materials.

[0021] The polymeric type of shape memory material often exhibits radical change from a normal rigid polymer to a very stretchy, elastic material and back upon input of a proper activating agent. The change between states can be repeated without substantial degradation of the material. The “memory” or recovery quality comes from the stored mechanical energy attained during the reconfiguration and cooling of the material. Above its transition temperature, the polymeric shape memory material transitions from a rigid, plastic state to a flexible, elastic state. When cooled, the
material again becomes rigid and can be constrained in a new shape configuration. Shape memory characteristics can be engineered into several polymers, such as epoxy-based polymers, methacrylate polymers, and styrene-based polymers.

[0022] Depending on the desired downhole objective, an appropriate shape memory material can be selected for use in connection with downhole oilfield applications. Components of downhole well tools can be made of shape memory materials that undergo a desired change of state. For example, the shape memory material can be selected to undergo a change of shape, stiffness, position, or other mechanical characteristics in response to an appropriate activating agent. Examples of activating agents comprise application of heat, matter absorption, UV exposure, electromagnetic field exposure, and other stimuli.

[0023] Components constructed with shape memory materials can be used in a variety of equipment types and well applications. For example, shape memory material can be used in the construction of packers. In one embodiment, a polymeric shape memory material or composite shape memory material is used in the formation of the packer sealing element. The packer element is manufactured in a desired shape, referred to as the memory or memorized shape with the selected shape memory material. The component is then heated to a higher temperature and deformed to a second shape, referred to as the deformed shape. After cooling, the component, e.g., packer element, is installed on an appropriate tool string and sent downhole. Upon heating of the packer element to a certain temperature, the element returns to the first memorized shape. This memorized shape can be an expanded shape selected to seal off an annulus between a tubing and a casing. In this embodiment, heat is used as the activating agent, and the heat can be obtained from downhole fluid heating.

[0024] A variety of other well components can be formed from shape memory material and utilized in downhole applications to perform a desired function. For example, the shape memory material can be used to construct a variety of sealing elements that can be used in inflatable packers, expandable packers, mechanically set packers, bridge plugs and other sealing devices. The shape memory materials also can be used in constructing sealing elements on sand screens and other downhole components. The activating agent supplied can be in the form of heat, moisture, changing pH, light, or an electromagnetic field. The components can be un-set or changed back by changing the corresponding stimuli, e.g., activating agent. For these types of sealing applications, the seal elements can be made solely from shape memory material, from composites of elastomer and shape memory material, e.g., elastomeric membrane supported by a shape memory material frame, or from other material composites.

[0025] Additional embodiments of well components formed in whole or in part from shape memory materials comprise flow control valves. The shape memory material can be used to shut off flow, for example, between an inner tubing and an annulus space upon selective activation with an appropriate activating agent. In other applications, components may be constructed with threaded regions formed of shape memory material. The threaded region is used to connect the component with a corresponding component. However, upon activation, the shape memory material changes shape in a manner that disengages the threaded region from the corresponding component. This type of mechanism can be very useful in, for example, the retrieval of packers. The use of shape memory material enables avoidance of the conventional practice of cutting apart the packer body to disengage connected components. When shape memory material is used, only an appropriate heating source or other activating agent is necessary to cause the desired disengagement between connected components.

[0026] Referring generally to FIG. 1, an example of a well system utilizing one or more well components constructed with shape memory material is illustrated. In the illustrated embodiment, a well system 20 comprises a well equipment string 22, e.g., a completion assembly, deployed in a wellbore 24 via a tubing 26, e.g., coiled tubing or jointed tubing. The wellbore 24 is drilled into a geological formation 28 and extends downwardly from a wellhead 30 positioned at a surface 32, such as a seabed floor or a surface of the earth. The wellbore 24 may be oriented generally vertically or with combined vertical and deviated sections. Furthermore, the wellbore 24 may be open or lined with a casing 34 depending on the specific environment and application. If wellbore 24 is lined with casing 34, a plurality of perforations 36 are formed through the casing to accommodate flow of fluid between formation 28 and wellbore 24.

[0027] In the embodiment illustrated, wellbore equipment string 22 comprises a well component 38 formed from a shape memory material 40. The well component 38 is utilized in wellbore 24 and may be transitioned between states. For example, the shape memory material 40 enables the transition of well component 38 between a first, e.g., deformed, shape illustrated in solid lines and a second, e.g., memorized, shape illustrated in dashed lines in FIG. 1. The transition between two functional states, e.g., shapes, is readily achievable while the well component is positioned downhole. The transition can be induced simply by providing or enabling the appropriate activation agent proximate the shape memory material.

[0028] One embodiment of well component 38 comprises a packer having a packer sealing element. Referring generally to FIG. 2, a packer sealing element 42 is illustrated as formed with shape memory material 40. Packer element 42 is initially manufactured from shape memory material 40 in the memory or memorized shape illustrated in FIG. 2. In this example, the memorized shape comprises an expanded sealing region 44 that extends radially outward from a base region 46. The expanded sealing region 44 is formed with sufficient size and shape to seal off the annulus of wellbore 24. For example, sealing region 44 may be designed to extend radially outward a sufficient distance to seal against casing 34.

[0029] Following manufacture of packer element 42 in the expanded, memorized state, the shape memory material 40 is heated to an increased temperature and deformed to another shape, as illustrated in FIG. 3. In this embodiment, the deformed shape may be a radially contracted shape similar to the tubular shape of base region 46. When the shape memory material 40 cools, the deformed shape is retained and the packer element 42 can be moved and manipulated in this deformed shape. However, upon introduction of the appropriate activating agent, e.g., sufficient heat, the shape memory material 40 causes packer sealing element 42 to return to its memorized shape, as illustrated in FIG. 4. In some applications, the shape memory material can be shifted back and forth between states by providing appropriate stimuli. For example, the shape memory material 40 may have a first material property when exposed to a first stimulus and a second material property, e.g., new shape or consistency, when exposed to a second stimulus. At least one of the first stimulus and the second stimulus may be presented downhole to cause a desired transition in the shape memory material.

[0030] In an actual well application, packer sealing element 42 may be mounted on a tubing 48 or on another appropriate structure of well equipment string 22, as illustrated in FIG. 5. The packer sealing element 42 is mounted to well equipment string 22 in its deformed state so that it does not interfere with the surrounding casing 34 (or the wellbore wall in an open
wellbore) during deployment of well equipment string 22 downhole. Once well equipment string 22 and well component 38 are deployed to a desired location in wellbore 24, an appropriate activating agent is used to cause the shape memory material to transition to its memorized shape. In the embodiment illustrated, this transition results in the expansion of packer element 42 such that sealing region 44 expands radially outward to seal off the annulus 50 surrounding tubing 48, as illustrated in FIG. 6.

0031] The expansion of packer element 42 can be induced by an activating agent in the form of sufficient heat due to downhole fluid heating. The heat increases the temperature of the shape memory material 40 to a level that causes transition to the memorized expanded shape. However, the shape memory material also may be selected so the packer sealing element 42 is caused to change shape upon the introduction of other activating agents. For example, the sealing element can be induced to change shape upon the introduction of sufficient moisture, a specific pH value, light or a specific type of light, or an electromagnetic field. In some applications, the shape memory material also can be changed back to the initial shape by changing corresponding stimuli. It should be noted that the transition of the sealing component illustrated in FIGS. 5 and 6 also is representative of the expansion of one or more sealing elements positioned on a sand screen. In this latter embodiment, tubing 48 comprises a sand screen on which one or more sealing elements are mounted.

0032] An alternate embodiment of well component 38 is illustrated in FIGS. 7 and 8. In this embodiment, another type of flow control device is constructed at least in part from shape memory material. In FIG. 7, the well component 38 is illustrated as a flow control valve 52 that may be positioned in well equipment string 22 to control flow between regions in wellbore 24. For example, the flow control valve 52 can be used in controlling flow between an interior of a tubing 53 and the surrounding annular space.

0033] Flow control valve 52 may be formed with a memorized state that is either open or closed. By way of example, valve 52 is illustrated in FIG. 7 as deformed to an open state that allows a flow of fluid 54 to move from a tubing interior 56 to an annulus or other external region 58. Upon introduction of a suitable activating agent, e.g., heat, moisture, change in pH value, light or electromagnetic field, the shape memory material 40 forming flow control valve 52 transitions to the memorized state, as illustrated in FIG. 8. In this particular example, the memorized state is one in which the change in shape memory material 40 blocks the flow of fluid 54 between interior region 56 and exterior region 58.

0034] The shape memory material 40 also can be used to construct a variety of other components in a manner that allows downhole activation simply through the introduction of a suitable activating agent. For example, shape memory material 40 may be used to construct well components 38 that may be connected and/or disconnected upon undergoing a change in state, e.g., a change in shape.

0035] As illustrated in FIGS. 9 and 10, for example, a first component 60 may be connected to a second component 62 by a suitable engagement region 64, such as a threaded engagement region. The transition of the shape memory material is used either in forming the connection or in causing disengagement of components 60, 62. Additionally, one or both of the components can be formed at least in part with the shape memory material 40. In the embodiment illustrated in FIG. 9, at least a portion of second component 62 has been constructed with shape memory material 40 in a manner that allows first component 60 and second component 62 to be threaded together or otherwise engaged via engagement region 64. However, second component 62 transitions to a second state, e.g., a second shape, that causes disengagement of region 64, as illustrated in FIG. 10. The ability to disconnect components by inducing a change of state is helpful in a variety of well equipment applications. For example, this method of disconnecting is substantially simpler and cheaper than current methods for disconnecting and retrieving packers from downhole locations. The packer can be disconnected simply by providing the appropriate activating agent to cause disconnection of a threaded or otherwise interlocked engagement region.

0036] In other applications, the shape memory material 40 can be used to construct well components 38 that act as sealing devices. For example, shape memory material 40 may be used to construct well components 38 that form seals between a variety of component surfaces in downhole applications. The transition of shape memory material 40 can be selectively initiated to form a better seal.

0037] As illustrated in FIG. 11, for example, well component 38 comprises a sealing device 66. In this embodiment, sealing device 66 comprises layers of shape memory material 40 arranged in an alternating relationship with sealing layers 68. By way of example, sealing device 66 may be formed as a chevron seal in which layers of shape memory material 40 and alternating sealing layers 68 are formed in a generally chevron shape. Upon introduction of an appropriate activating agent, the layers of shape memory material 40 are transitioned to a second state, such as an expanded shape, that acts to further squeeze sealing layers 68. Thus, the alternating layers of shape memory material 40 can be used to create a seal stackable to exert greater sealing force which, in turn, facilitates sealing against higher differential pressures.

0038] In another embodiment of sealing device 66, shape memory material 40 is used to create an energized seal, as illustrated in FIG. 12. In this embodiment, shape memory material 40 is formed in an arcuate shape as a seal energizer 70 deployed within a seal body 72 formed of a suitable sealing material. By way of example, seal body 72 may comprise a seal base region 74 from which extends a pair of sealing lips 76, 78 separated by a gap 80. The sealing lips 76, 78 are designed to form seals with adjacent surfaces, and seal energizer 70 is deployed within gap 80 between sealing lips 76 and 78. Upon introduction of an appropriate activating agent, the shape memory material 40 of seal energizer 70 transitions to a second state in which the arcuate seal energizer 70 expands to bias sealing lips 76 and 78 in opposed directions. The expansion of seal energizer 70 effectively energizes sealing device 66 by creating greater force between sealing lips 76, 78 and their adjacent seal surfaces, thereby creating a better seal against higher differential pressures.

0039] Depending on the specific application and environmental factors, each of the components formed with shape memory material 40 as described above can be formed from polymeric shape memory materials, metallic shape memory materials, or composite shape memory materials. Components formed in whole or in part with composite shape memory materials can be formed with, for example, polymeric shape memory composites. In other applications, the composite component can be formed from metal/polymer shape memory materials. For example, metal bonded polymer parts can be used to form the shape memory material portion of a given component. The component also can be formed with polymer or metal coated/layered shape memory materials, such as rubber coated shape memory polymer components.

0040] Shape memory material 40 can be incorporated into the construction of many types of downhole components used in a variety of well environments. The ability to transition the shape memory material between two different states enables
simple well tool activation by the provision of an activating agent. Well components formed of shape memory material can be designed to enable simple creation of seals or the breaking of previously created seals. Such components also can be used to control flow between components or along a wellbore. The shape memory material components also can be used to mechanically connect, disconnect, activate, deactivate, shift, pressurize or otherwise control well equipment utilized in a variety of well related applications.

[0041] Accordingly, although only a few embodiments of the present invention have been described in detail above, those of ordinary skill in the art will readily appreciate that many modifications are possible without materially departing from the teachings of this invention. Such modifications are intended to be included within the scope of this invention as defined in the claims.

What is claimed is:

1. A method of operation in a well, comprising:
   forming a well component from a shape memory material;
   deploying the well component downhole into a wellbore;
   and
   providing an activating agent downhole to transition the shape memory material so as to change the shape of the well component.

2. The method as recited in claim 1, wherein forming comprises manufacturing the shape memory material in a shape and deforming the shape memory material to a deformed shape.

3. The method as recited in claim 1, wherein deploying comprises running the well component downhole with an equipment string.

4. The method as recited in claim 1, wherein providing comprises providing the activating agent in the form of heat.

5. The method as recited in claim 1, wherein providing comprises providing the activating agent in the form of moisture.

6. The method as recited in claim 1, wherein providing comprises providing the activating agent in the form of a change in the pH value of the environment surrounding the shape memory material.

7. The method as recited in claim 1, wherein providing comprises providing the activating agent in the form of light.

8. The method as recited in claim 1, wherein providing comprises providing the activating agent in the form of an electromagnetic field.

9. The method as recited in claim 1, wherein forming comprises forming a sealing element.

10. The method as recited in claim 9, wherein forming the sealing element comprises forming a packer.

11. The method as recited in claim 1, wherein forming the sealing element comprises forming a threaded region of the well component from the shape memory material.

12. A well device, comprising:
   a downhole tool formed at least in part of a shape memory material, the shape memory material having a first material property when exposed to a first stimulus and a second material property when exposed to a second stimulus, wherein at least one of the first stimulus and the second stimulus may be applied downhole to transition the shape memory material between the first and the second material properties.

13. The well device as recited in claim 12, wherein the shape memory material comprises a polymer.

14. The well device as recited in claim 12, wherein the shape memory material comprises a metal.

15. The well device as recited in claim 12, wherein the downhole tool comprises a packer having a sealing element formed of the shape memory material.

16. The well device as recited in claim 12, wherein the downhole tool comprises a packer having a threaded engagement region formed of the shape memory material.

17. The well device as recited in claim 12, wherein the downhole tool comprises a control device formed of the shape memory material.

18. A well system, comprising:
   a well device having a sealing element formed of a shape memory material selectively transitionable between a non-sealing and a sealing shape within a wellbore.

19. The well system as recited in claim 18, wherein the well device comprises a seal device.

20. The well system as recited in claim 18, wherein the well device comprises a packer.

21. A method, comprising:
   preparing a shape memory material in a first state;
   combining the shape memory material with well equipment;
   deploying the well equipment into a wellbore; and
   initiating a change in the shape memory material to a memorized second state while deployed in the wellbore.

22. The method as recited in claim 21, wherein preparing comprises preparing the shape memory material as a composite memory material formed with a metal and a polymer.

23. The method as recited in claim 21, wherein preparing comprises preparing the shape memory material as a layered shape memory material.

24. The method as recited in claim 21, wherein preparing comprises using the shape memory material to form a chevron seal.

25. The method as recited in claim 21, wherein preparing comprises using the shape memory material to form a seal energizer.