Abstract:

Conformance control through stimulus-responsive materials and methods, particularly in the context of wellbore integrity and flow control in oil and gas production. The technologies described enable automatic and responsive operations in environments where conventional methods are insufficient, such as in oil spills, drilling operations, and reservoir management.

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CONFORMANCE CONTROL THROUGH
STIMULUS-RESPONSIVE MATERIALS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/772,087, filed 10 February 2006.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] This invention relates generally to managing sand, water, and hydrocarbon production from a wellbore. More particularly, but not exclusively, this invention relates to the application of stimulus-responsive materials for controlling production and injection profiles in wellbores, commonly known as "conformance control."

Discussion of Background Information

[0003] This section is intended to introduce various aspects of the art, which may be associated with exemplary embodiments of the present techniques. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present techniques. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

[0004] The production of hydrocarbons, such as oil and gas, has been performed for numerous years. To produce these hydrocarbons, a production system may utilize various devices, such as sand control devices, flow control devices and other tools, for specific tasks within a well. Typically, these devices are placed into a wellbore completed in either cased-hole or open-hole completion. In cased-hole completions, wellbore casing is placed in the wellbore and perforations are made through the casing into subterranean formations to provide a flow path for formation fluids, such as hydrocarbons, into the wellbore. Alternatively, in open-hole completions, a production string is positioned inside the wellbore without wellbore casing. The
formation fluids flow through the annulus between the subsurface formation and the production string to enter the production string.

[0005] Regardless of the completion type, producing hydrocarbons from some subterranean formations is challenging because solid materials, such as particles or sand, and water may be produced along with the formation hydrocarbons. For example, some subterranean formations may include high pressure/temperature reservoirs, long intervals, poorly consolidated formations and/or weakened formations. While the production of solid particles may be controlled by typical sand control techniques, the production of water may present problems that increase the individual well cost dramatically. That is, the cost of managing the unwanted gas and water from the subterranean formation may result in fewer wells being operated.

[0006] As an example, costs may be associated with the production of undesired gas and water from some subterranean formation. These costs may include direct costs associated with the lifting, handling and disposal of excess fluids as well as indirect costs associated with reduced production rates and reduced recovery of more desirable fluids, such as hydrocarbons. According to an article by Seright et al., seven barrels of water are produced for each barrel of oil in United States, while three barrels of water are produced for each barrel of oil worldwide. See Seright et al., "A Strategy for Attacking Excess Water Production", SPE Permian Basin Oil and Gas Recovery Conference, Midland, Texas (May 2001). The annual cost of disposing of the water is estimated at $5-$10 billion in the United States and $40 billion worldwide. Also, unwanted gas may cause additional losses of value for a subterranean formation. For instance, a high gas to oil ratio may lead to either curtailed oil production or reserve losses. The additional costs associated with the unwanted gas production may include the costs to repair a compressed formation or losses of gases to a flare stack. Thus, the production of undesired gas and water from subterranean formations may limit or stop the production of hydrocarbons from the subterranean formation.

[0007] Similarly, injection applications may suffer from various profile control problems. For instance, in pressure maintenance applications, uncontrolled injection
profiles may lead to over injection of one interval or under injection in another interval of a subterranean formation. In fact, the over injection may even lead to premature breakthrough and unwanted water or gas production in nearby production wells. Further, well treatment applications are another problem area for injection applications. With these well treatment applications, profile control of treatment fluids, such as acids, tracers, scale inhibitors, etc., is utilized to effectively treat certain well conditions. Failure to maintain profile control may lead to excessive treatment volumes increasing costs because the well treatment has failed. Thus, the production of undesired gas and water from subterranean formations may limit the effectiveness for injection applications.

[0008] A variety of methods have been developed and used for reducing the flow of water produced with hydrocarbons from a subterranean formation. Such methods have generally involved pumping a fluid into the formation which forms a water blocking material therein. For example, U.S. Patent No. 3,334,689 discloses a water control method wherein an aqueous solution of a polymerizable composition containing a monoethylenically unsaturated acrylate monomer and a cross-linking agent are injected into the portion of a hydrocarbon producing formation that also produces water. The monomer and cross-linking agent form a stable cross-linked gel in the formation to thus reduce the water permeability of the formation and thereby terminate or at least decrease the rate of flow of water from the formation.

[0009] U.S. Patent No. 5,358,051 discloses another method of water control. In this method, a gel is formed in the water producing portion of a subterranean formation having hydrocarbons to reduce or prevent the production of water from the subterranean formation. In accordance with this method, a self cross-linking monomer selected from hydroxy unsaturated carbonyl compounds is polymerized in the formation by a suitable initiator.

[0010] Other methods using various other water blocking agents including cross-linked gels, cement compositions and various polymers have been utilized to reduce the production of water from subterranean formations producing both hydrocarbons and water. However, such methods usually only reduce the water production and are
not utilized until after the water has invaded the oil zones in the subterranean formation. As such, these other methods are not utilized until the water production has become a problem that increases operational costs for separation and disposal.

[0011] U.S. Patent No. 6,109,350 discloses a method of water control by packing an interval with particulate solids coated with an organic polymer that swells when contacted by water. The swelling chokes off the flow of water through the pack. However, there is no disclosure of a material that swells when acted upon by other media, coating well tools with such a polymer, reversing the swelling process, or intentionally shrinking a particulate for water control purposes.

SUMMARY OF THE INVENTION

[0012] According to one aspect of the invention, a method of changing a flow profile along a length of a completed well is disclosed comprising coating a particulate solid with at least one stimulus-responsive material, wherein the at least one stimulus-responsive material swells or shrinks in volume in the presence of at least one stimulus, wherein the at least one stimulus consists primarily of contact by non-aqueous fluids, changes in concentration of the at least one stimulus-responsive material, changes in pH of a media contacting the at least one stimulus-responsive material, changes in temperature, changes in electric current, changes in the magnetic polarity of the media contacting the at least one stimulus-responsive material; and placing a pack of particulate solids coated with the at least one stimulus-responsive material in or adjacent to a formation, wherein at least a portion of the pack of particulate solids is coated with the at least one stimulus-responsive material. The swelling or shrinking of the stimulus-responsive materials in the presence of at least one stimulus may be reversible. The particulate solid may comprise one of graded sand or gravels. The stimulus-responsive material may be at least one of crosslinked polyacrylamide, polyacrylate, or other similar materials.

[0013] In one alternative embodiment of the invention, a method of changing a flow profile along a length of a completed well is disclosed. The method includes coating a particulate solid with at least one stimulus-responsive material, wherein the
at least one stimulus-responsive material swells in volume when contacted with a first stimulus and shrinks in volume when contacted with a second stimulus; and placing a pack of particulate solids coated with the at least one stimulus-responsive material in or adjacent to a formation, wherein at least a portion of the pack of particulate solids is coated with the at least one stimulus-responsive material.

[0014] In a third embodiment of the present techniques, a method of changing a flow profile along a length of a completed well is disclosed. The method includes coating at least a portion of well equipment with at least one stimulus-responsive material, wherein the stimulus-responsive material swells in volume when contacted with a first stimulus and shrinks in volume when contacted with a second stimulus; and placing the at least a portion of well equipment coated with the at least one stimulus-responsive material in or adjacent to a formation.

[0015] In a fourth embodiment of the present techniques, an apparatus for changing a flow profile along a length of a completed well is disclosed. The apparatus comprises a length of production tubing comprising well equipment and disposed in a well substantially adjacent to a formation, wherein at least a portion of the well equipment is coated with at least one stimulus-responsive material, wherein the at least one stimulus-responsive material swells or shrinks in volume in the presence of at least one stimulus.

[0016] In a fifth embodiment of the present techniques a production well system for hydrocarbon production is disclosed. The system comprising at least one stimulus-responsive material placed in or adjacent to a formation accessed by a well, wherein the at least one stimulus-responsive material swells in volume when contacted with a first stimulus and shrinks in volume when contacted with a second stimulus.

[0017] In a sixth embodiment of the present techniques an apparatus for passive wellbore conformance control is disclosed. The apparatus comprising a tubular member having at least one flow orifice; a particle comprising a flow control
material, wherein the flow control material swells in the presence of a first stimulus and shrinks in the presence of a second stimulus; a flow control material retainer at or near the at least one flow orifice, wherein the flow control material is retained at or near the at least one flow orifice so as to permit the flow of a first fluid in the swollen state and substantially restrict the flow of a second fluid in the shrunken state.

[0018] Other exemplary embodiments and advantages of the present invention may be ascertained by reviewing the present disclosure and the accompanying drawings.

**BRIEF DESCRIPTION OF THE FIGURES**

[0019] The foregoing and other advantages of the present techniques may become apparent upon reviewing the following detailed description and drawings of non-limiting examples of embodiments in which:

FIG. 1 illustrates an exemplary production system in accordance with certain aspects of the present techniques;

FIG. 2 illustrates a conventional Open Hole Gravel Pack (OHGP) completed in multiple zones with water production coming from one of the intervals;

FIGs. 3A and 3B illustrate various behaviors of intelligent polymer under different stimuli;

FIG. 4 illustrates a cross section of a typical screen section;

FIG. 5 illustrates an OHGP application where the screens are run in clear brine;

FIG. 6 illustrates an OHGP application where screens are run in a solids weighted fluid system;

FIG. 7 illustrates the production configuration with the screen/base pipe annulus packed with either consolidated gravel or an expanded fluid sensitive material;
FIG. 8 illustrates the addition of a plug in the base pipe inner diameter (ID) to control the fluid inflow profile and limit production of undesirable fluids from an interval downstream;

FIG. 9 illustrates the addition of a straddle assembly in the base pipe ID to control the fluid inflow profile and limit production of undesirable fluids from an interval upstream;

FIG. 10 illustrates the estimated water cut reductions as a function of well productivity;

FIG. 11 illustrates a mesh screen for preventing water production;

FIG. 12 illustrates coated perforations or disks for restricting water flow into tubulars;

FIGs. 13A-13B illustrate the initial state of a flow control material in swollen, non-blocking configuration;

FIGs. 14A-14B illustrate the control state of a flow control material in semi-swollen, partially-blocking configuration; and

FIGs. 15A-15B illustrate the shut-off state of a flow control material in shrunken, fully-blocking configuration.

**DETAILED DESCRIPTION OF THE PRESENT INVENTION**

[0020] In the following detailed description section, the specific embodiments of the present techniques are described in connection with preferred embodiments. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the invention is not limited to the specific embodiments described below, but rather, it includes all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.
[0021] Turning now to FIG. I, an exemplary production system 100 in accordance with certain aspects of the present techniques is illustrated. In the exemplary production system 100, a floating production facility 102 is coupled to a subsea tree 104 located on the sea floor 106. Through this subsea tree 104, the floating production facility 102 accesses one or more subsurface formations, such as subsurface formation 107, which may include multiple production intervals or zones 108a-108n having hydrocarbons, such as oil and gas. Beneficially, sand control devices, such as sand control devices 138a-138n, may be utilized to enhance the production of hydrocarbons from the production intervals 108a-108n. However, it should be noted that the production system 100 is illustrated for exemplary purposes and the present invention may be used in the production or injection of fluids from any subsea, platform or land location.

[0022] The floating production facility 102 is configured to monitor and produce hydrocarbons from the production intervals 108a-108n of the subsurface formation 107. The floating production facility 102 may be a floating vessel capable of managing the production of fluids, such as hydrocarbons, from subsea wells. These fluids may be stored on the floating production facility 102 and/or provided to tankers (not shown). To access the production intervals 108a-108n, the floating production facility 102 is coupled to a subsea tree 104 and control valve 110 via a control umbilical 112. The control umbilical 112 may include production tubing for providing hydrocarbons from the subsea tree 104 to the floating production facility 102, control tubing for hydraulic or electrical devices, and a control cable for communicating with other devices within the wellbore 114.

[0023] To access the production intervals 108a-108n, the wellbore 114 penetrates the sea floor 106 to a depth that interfaces with the production interval 108a-108n at different intervals within the wellbore 114. The production intervals 108a-108n, which may be referred to as production intervals 108, may include various layers or intervals of rock that may or may not include hydrocarbons and may be referred to as zones. The subsea tree 104, which is positioned over the wellbore 114 at the sea floor 106, provides an interface between devices within the wellbore 114 and the floating production facility 102. Accordingly, the subsea tree 104 may be
coupled to a production tubing string 128 to provide fluid flow paths and a control cable (not shown) to provide communication paths, which may interface with the control umbilical 112 at the subsea tree 104.

[0024] Within the wellbore 114, the production system 100 may also include different equipment to provide access to the production intervals 108a-108n. For instance, a surface casing string 124 may be installed from the sea floor 106 to a location at a specific depth beneath the sea floor 106. Within the surface casing string 124, an intermediate or production casing string 126, which may extend down to a depth near the production interval 108, may be utilized to provide support for walls of the wellbore 114. The surface and production casing strings 124 and 126 may be cemented into a fixed position within the wellbore 114 to further stabilize the wellbore 114. Within the surface and production casing strings 124 and 126, a production tubing string 128 may be utilized to provide a flow path through the wellbore 114 for hydrocarbons and other fluids. Along this flow path, a subsurface safety valve 132 may be utilized to block the flow of fluids from the production tubing string 128 in the event of rupture or break above the subsurface safety valve 132. Further, packers 134a-134n may be utilized to isolate specific zones within the wellbore annulus from each other. The packers 134a-134n may include external casing packers, such as the SWELLPACKER™ (EasyWell Solutions) and the MPAS PACKER® (Baker Oil Tools), or any other suitable packer for an open or cased hole well, as appropriate.

[0025] In addition to the above-mentioned equipment, other devices or tools, such as sand control devices 138a-138n, may be utilized to manage the flow of particles into the production tubing string 128. The sand control devices 138a-138n, which may herein be referred to as sand control devices 138, may include slotted liners, stand-alone screens (SAS), pre-packed screens, wire-wrapped screens, membrane screens, expandable screens and/or wire-mesh screens. For exemplary purposes, the sand control devices 138 are herein described as being slotted basepipe with a wire-wrapped screen. Also, around the sand control devices 138, gravel packs 140a-140n, such as a natural sand pack or frac pack, may be disposed to provide additional mechanism to manage the flow of particles into the production tubing
string 128. The sand control devices 138 and gravel packs 140a-140n may be utilized to manage the flow of hydrocarbons from the production intervals 108 to the production tubing string 128.

[0026] Commercial gravel pack systems using external packers are available from a variety of sources, including Baker and Schlumberger. For example, Baker's BETA BREAKER SYSTEM® has been used for open-hole gravel packs and utilizes packing gravel around the screen with carefully placed voids where external casing packers are then expanded into the void areas. Also, Schlumberger's MZ PACKER®, for example, has been used with ALTERNATE PATH® technology (APT) to provide interval isolation in cased hole gravel pack completions.

[0027] Because many different causes of excess water production exist, the nature of the excess water production is typically identified and different materials/methods are used to treat the excess water production. Generally, the methods utilized to address excess water production may be divided into chemical and mechanical methods. For instance, one mechanical method may include mechanical isolation that utilizes bridge plugs, straddle packers, tubing patches, cement plugs, etc. The chemical methods typically involve gel treatment. The gels in the gel treatment are generally formed by chemically crosslinking water-soluble organic polymers. The present techniques may work for a variety of applications, such as unwanted gas, water or gas from multiple intervals, and similar situations. An example of a conventional OHGP for water production is shown in greater detail in FIG. 2.

[0028] FIG. 2 illustrates a conventional OHGP completion profile 200 in multiple zones with water production coming from one of the intervals 205-207. Typically, permeability along a first flow path 214 during the gravel pack installation process is utilized to ensure effective placement of gravel packs 140a-140c. However, with standard screens 202-204, attempts to isolate flow from the water-producing interval, such as interval 206 with an internal plug 208 may only restrict flow slightly. For instance, due to pressure inside the basepipe, flow is diverted from the first flow path 214 to a second flow path 216 through an annular space outside the screen 203 around the plugged section and into the bottom of the next section of
Flow is slightly impeded because the annular space between the screen 202-204 and the base pipe 210-212 provides the second flow path 216 through the wellbore. That is, the second flow path 216 may be utilized because the pressure differential in the second flow path 216 is small and flow is not restricted along this path. As such, the restriction or elimination of this second, unrestricted flow path is effectively resolved by the present techniques.

Accordingly, some embodiments of the present techniques describe the use of at least one stimulus-responsive material to alter production or injection profiles along the length of the completed interval. While the location and form of the stimulus-responsive material may vary with the specifics of the well configuration and type of desired conformance control (gas, water, oil, acids, emulsions, and/or other treating fluids), each application is enabled by altering the pressure drop along a flow path through the enlargement (swelling) or reduction (shrinking) of the polymer volume within the material through the presence of stimuli such as changes in concentration, pH of the media the stimulus-responsive material is in contact with, salinity, or temperature; changes in current; changes in polarity of the media the stimulus-responsive material is in contact with; and any combination thereof. Further, the stimulus-responsive materials, such as polymeric materials, may include crosslinked polyacrylamide or polyacrylate (commonly referred to as "water absorbent polymers" or "hydrogels"). Also, the stimulus-responsive materials may include different particulate solids utilized for the stimulus-responsive polymeric materials, one preferred particulate solid being graded sand.

The stimulus-responsive polymeric materials may take many common forms including: whole particles; particulate coatings; equipment components; equipment coatings; valve parts; valve coatings; orifice coatings; well head, tubing, casing, screen, and inflow conformance device coatings; fibers; and/or fiber coatings. The stimulus-responsive polymeric materials in any one of these forms may reversibly, and/or irreversibly swell or shrink when exposed to changes in: water concentration, hydrocarbon concentration, pH, salinity, temperature; changes in electric current; changes in magnetic polarity of the media the stimulus-responsive polymeric material is in contact with. A more in-depth explanation of some of the
behaviors and types of the materials disclosed here is included in the article GELS by Toyoichi Tanaka in SCIENTIFIC AMERICAN, Vol. 244, pp 124-138 (1981), which is hereby incorporated by reference.

[0031] For example, as shown in FIGs. 3A and 3B, an intelligent polymer is shown in various configurations. In FIG. 3A, an intelligent polymer 302 is shown in a compressed or first configuration 304, and in an expanded or second configuration 306 once a stimulus has been introduced. The stimulus may include changes in: temperature, solvent composition, pH, ions, electric field, ultraviolet light (UV), and light specific molecules or chemicals and any combination thereof. An example of this transition for temperature may be seen in the chart 310 of FIG. 3B. The chart 310 includes a response curve 312 that provides the changes in the intelligent polymer 302 against a volume axis 314 and a temperature axis 316. As shown by the response curve 312, the intelligent polymer 302 has an expanded configuration 306 for low temperatures with slight changes in volume as the temperature increases. However, at a transition temperature \( T_{\text{trans}} \), the volume of the intelligent polymer 302 decreases to the compressed configuration 304. Beyond the transition temperature \( T_{\text{trans}} \), the volume of the intelligent polymer 302 continues to decrease at a gradual rate along the response curve 312 as the temperature increases. This type of volume change may also occur with other stimuli, such as changes in salinity; pH; electric current; or in the magnetic polarity of the media contacting the stimulus-responsive polymeric material.

[0032] In some aspects of the present techniques, the different response of stimulus-responsive materials, such as the intelligent polymer 302, may be utilized to enhance the operation of a well. For instance, components that are designed to swell when exposed to various stimuli generally inhibit (reduce) flow by increasing the pressure drop along a flow path by reducing the cross-sectional area available for flow. In particular, water shut-off may be one application of the present technique. In water shut-off applications, when exposed to water under certain conditions, particle packs containing the water-swellable (stimulus-responsive) particles or coated particulates, swell and reduce flow through the particle packs. This may be applicable to: gravel packs, frac-packs, pre-packed screens, and other particulate packs. In other
applications, when exposed to water under certain conditions, mechanical devices with orifice components constructed of, or coated with stimulus-responsive polymers, swell and reduce the critical area for flow (in effect "swell shut") and thereby reduce flow through the device. This is applicable to various apparatuses, such as inflow control devices (ICDs), slotted liners slot (via slot surface coatings), pre-perforated screens (via perforation surface coatings), and other flow restriction devices.

[0033] Yet in some other applications, either a gel or a carrier fluid containing stimulus-responsive polymer fraction may be injected into and enter a water-producing zone, the polymeric materials swell, bridge off the leaks/channels/pore throats and effectively reduce the permeability of the water producing zones. This application may be applied in the following situations: casing leaks with flow restrictions, flow behind pipe with flow restrictions, two dimensional coning through a hydraulic fracture from an aquifer, natural fracture system leading to an aquifer, single fracture causing channeling between wells, open-hole or cased-hole completion with sand control.

[0034] As an example of this functionality, one embodiment of the present techniques reduces unwanted fluids (gas/water) in production applications, modifies injection profiles for improved pressure support and sweep efficiency in pressure maintenance and flood applications, and diverts treatments for improved treatment efficiency in chemical treatment applications.

[0035] Components that are designed to shrink, however, when exposed to various stimuli can either enhance (increase) flow by creating a larger cross-sectional area for flow (with a correspondingly lower pressure drop) or inhibit (reduce) flow by becoming free to move after decreasing in size, and changing position (generally along the flow direction) into a location where the smaller size more effectively blocks flow through an orifice (valve, pore throat, channel, seat). The swelling/shrinking of the polymers may be automatic or passive because swelling/shrinking may be controlled by an equilibrium process that may be dependent on the local water concentration. These systems react to changes in the environment in real time providing dynamic and automatic changes to the fluid flow.
profiles. It is position specific because the swelling is controlled by the local environment, and any volume changes only occur in those areas that have undergone sufficient changes in their environment. It is reversible because if the condition reverts away from the triggering environment, the swelling/shrinking processes are reversed, restoring the original flow conditions. The swelling or shrinking may also be reversed by introduction of a second stimulus into the environment that reverses the swelling or shrinking process. The introduction may be a result of operator intervention or a change in the wellbore environment.

[0036] For example, FIG. 4 illustrates a cross section of a typical screen section, which may be a cross-section of one of the sand control devices 138a-138n. In one embodiment of the method, the annular flow areas 408 between the base pipe 402, the screen 404 and the support ribs 406 are filled with flow restricting (stimulus-responsive) material. The flow restricting material may include any of several commercially available materials that exist for restricting or plugging off flow in the annular flow area 408. As there are a variety of gravel pack techniques, the preferred material may be application specific. Material options include consolidated sand and fluid sensitive elastomers configured to swell after contact with the undesirable fluid and water/gas sensitive polymer gels.

[0037] Fluid sensitive swelling materials may be used in applications where the screens are run in mud systems or in brine systems where the chemistry can be altered to be sufficiently different from the formation water. While running the screens and pumping the gravel, the material may remain in the unexpended condition providing sufficient flow area to place the gravel pack. After packing, exposure to the specified fluid with sufficient time, the material expands to block the annular space. With the onset of unwanted fluids, plugs and straddles may be set in the base pipe's inner diameter (ID) forcing flow through the packed annular flow area 408.

[0038] Consolidated gravel pack sand may be used to restrict flow when gravel packing in clear brine systems where the polymer response to exposure of the undesirable fluids and the brine systems cannot be engineered to be sufficiently different (through changes in pH of the media the stimulus-responsive material is in
contact with, salinity, inhibitors, or other). With the onset of unwanted fluids, plugs
and straddles can be set in the base pipe's ID forcing flow through the gravel packed
annular flow area 408.

[0039] A few preferred embodiments are described for exemplary purposes in
different applications, such as water or gas shut-off in a sand-control completion via
completion design: stimulus-responsive particles; water or gas shut-off via completion
design: stimulus-responsive coatings; water shut-off via fluid injection; and water or
gas shut-off via completion design: inflow control devices. Accordingly, the
embodiments, which are discussed in greater detail below, are merely illustrative
embodiments of the present techniques for different applications.

A) Water or gas shut-off in a sand-control completion via completion design:
Stimulus-Responsive Particles.

[0040] In these examples, water or gas ingress is expected during the operation of
the well prior to installation of the completion. As such, this embodiment may be
utilized for natural sand pack, open-hole gravel pack or cased-hole gravel pack
completion types.

Example 1:

[0041] This exemplary embodiment is based on the concept of diverting flow
from "normal" radial flow (from the sand face, through the gravel pack, through the
screen) where pressure drops are small, to a restricted linear flow path through the
annular space outside the screen where the pressure drops are much larger, which may
be further explained with reference to FIG. 7. This embodiment entails a method for
isolating flow paths in both the sand face or casing-by-gravel pack screen annulus and
the gravel pack screen-by-base pipe annulus. Blocking either of these annuli allows
control of the production (or injection) profile using plugs and/or straddle packers in
the base pipe's inner diameter (ID). The present methods for blocking the flow paths
include filling the spaces with consolidated sand composites (containing some
fraction of stimulus-responsive polymer beads or gravel coated with stimulus-
responsive polymer) or other fluid (hydrocarbon or water) sensitive materials designed to swell and plug the space when contacted by the appropriate fluid/gas.

**Example 2:**

[0042] An alternate exemplary embodiment includes pumping a pack of particulate solids, a first portion of which comprises a particulate coated with a polymer that swells in the presence of formation water, and a second portion of which comprises a particulate coated with a polymer that "shrinks" when contacted with crude oil. This "double acting" gravel pack may improve permeability in the areas of the wellbore that produced oil and reduce permeability in the areas of the wellbore that produced water.

[0043] The exemplary embodiments described in Examples 1 and 2 may be utilized in any gravel pack application where gravel is tightly packed and the gravel pack is substantially free of voids. The elimination of voids in the gravel pack or addition of stimulus-responsive particles that swell in the presence of water eliminate unrestricted annular flow paths by ensuring that flow is forced through low permeability gravel packs. The flow rate is then controlled by the length of the flow path, the permeability of the gravel pack and the cross sectional area of flow. Open-hole and cased-hole gravel pack applications, using any ALTERNATE PATH®, shunt tube, or frac-pack technology, provide the greatest assurance of achieving a tight gravel pack that does not have voids. More examples to further describe such applications are provided in FIGs. 5-9.

1) Installation Configuration - Gravel Pack ("GP") applications with sand control device having screens run in clear brines

[0044] FIG. 5 illustrates an exemplary OHGP embodiment where the sand control devices are run in clear brine. In this embodiment, the present techniques are utilized in a screen/base pipe annulus 506 formed within the sand control device 138b being pre-packed with a consolidated gravel, such as consolidated sand 510. The sand control devices 138a-138c, each of which include a sand screen 502a-502c and base pipe 504a-504c, are run into a wellbore 114 having clear brine in the
conventional manner. Each of the sand control devices 138a-138c are associated with different intervals 108a-108c, such as productive intervals 108a and 108c and non-productive interval 108b. During the gravel placement process, gravel slurry, which may include a carrier fluid and gravel 508, is pumped into the annulus 512 formed between wellbore 114 and the screens 502a-502c. The carrier fluid in the gravel slurry leaks into the formation or passes through the screen 502a-502c and is returned to the surface, while the gravel 508 is packed against the screens 502a-502c to form the gravel packs 140a-140c. To restrict the alternative flow path, the sand control device 138b has pre-packed consolidated sand 510 between the screen 502b and the base pipe 504b. In this configuration, the pre-packed consolidated sand 510 in sand control device 138b may increase pump pressures in comparison to other typical sand control devices. Also, during the installation process, the pressure increases around the pre-packed section of consolidated sand 510 are small because the radial flow area is large and the radial thickness is small, i.e. a fraction of an inch.

2) Installation Configuration - GP Applications with sand control devices having screens run in solids laden muds

FIG. 6 illustrates an exemplary OHGP embodiment where sand control devices are run in a solids weighted fluid system, such as an oil based mud. In this embodiment, which may include various components of FIG. 5, the present techniques are utilized in the screen/base pipe annulus of the sand control device 138b pre-packed with a fluid sensitive material 602 in an unexpanded configuration. Upon installation, the fluid sensitive material 602, which may be a stimulus-responsive material, is in the unexpanded configuration to provide an unrestricted path during the gravel placement. Accordingly, during gravel placement, gravel 510 as part of a gravel carrier fluid is pumped into the annulus formed between the wellbore 114 and the screens 502a-502c to form the gravel packs 140a-140c. The gravel carrier fluid enters the intervals 108a-108c or passes through the screens 502a-502c and is returned to the surface depositing the dehydrated gravel tightly against the screen 502a-502c. Following gravel placement, the fluid sensitive material 602 swells when it contacts an undesirable fluid, such as water, to fill and plug off the annulus 506 formed by the screen 502b and the base pipe 504b. Thus, the fluid sensitive material
602 may be utilized to provide fluid communication paths until a stimulus, such as an undesirable fluid contacts the stimulus-responsive material 602, at which time the material 602 swells, thereby at least partially inhibiting flow through the annulus 506.

3) Production Configuration - Screen/base pipe annulus restricted - ID unrestricted

[0046] FIG. 7 illustrates the production configuration with the screen/base pipe annulus 506 packed with a stimulus-responsive material 702, which may be either the consolidated sand 510 of FIG. 5 or the fluid sensitive material 602, in the expanded configuration. Accordingly, this figure may be best understood by concurrently viewing FIGs. 5 and 6. In this embodiment, flow resistance through the stimulus-responsive material 702 is increased because the annulus between the screen 502b and the base pipe 504b is packed off (i.e. the stimulus-responsive material 702 has expanded to block flow into the base pipe 504b). Accordingly, the flow paths 704 and 706 for fluids in the intervals 108a and 108c continues into the respective base pipes 504a and 504c. However, the flow path 708 for fluids in the production interval 108b flows axially along the wellbore 114 until it reaches another sand control device 138a or 138c. This flow path 708 may be restricted because the differential pressure along the flow path 708 may be large enough to prevent flow. As such, fluids (unwanted or not) may flow directly into the base pipes 502a and 502c from the interval 108b.

4) Production Configuration - Screen/base pipe annulus restricted - ID restricted

[0047] FIG. 8 illustrates the addition of a plug into the interior of the sand control device 138b to control the fluid inflow profile and to limit production of undesirable fluids from a first, or downstream interval. Accordingly, this figure may be best understood by concurrently viewing FIGs. 5-7. In this embodiment, a plug 802 is utilized within the inner diameter of base pipe 502b to change the inflow profile. By installing the plug 802, the fluid flow paths 804, 806 and 808 from the respective intervals 108a, 108b and 108c may flow through the annulus between the wellbore 114 and the sand screens 502a-502c. As a result, the fluid flow path 804 may be relatively unrestricted, while fluid flow paths 806 and 808 may be limited because of
the differential pressure drop through the gravel packs 140b and 140c. Thus, the plug 802 and stimulus-responsive material 702 may be utilized to block or restrict flow from the intervals 138c-138n below the sand control device 138b.

[0048] FIG. 9 illustrates the addition of a straddle assembly 902 in the inner diameter of the base pipes 502a and 502b. The straddle assembly 902 is utilized to control the fluid inflow profile and to limit production of undesirable fluids from a second or upstream interval, such as interval 108a. The straddle assembly 902 includes two plugs and a section of pipe that fits within the base pipes 502a-502c. With the straddle assembly 902 installed, the fluid paths 904, 906 and 908 from the respective intervals 108a-108c are diverted into the sand control device 138c in a downstream interval. As a result, the fluid flow path 908 may be relatively unrestricted, while fluid flow paths 904 and 906 may be limited because of the differential pressure drop through the gravel packs 140a and 140b. Thus, combining the use of conventional plugs/straddles in the base pipe 502a-502b with the present techniques provides flexibility in the control of the flow profile.

[0049] Plugging the alternate path forces flow through the annular pack for the full length of screen section or sand control device, which may result in lower rates from the water-producing intervals. The degree of conformance control is a function of several factors including, but not limited to: flow path length, permeability and area, and the productivity of the producing intervals. In some applications, water cut reductions of about 90% or more may be possible for medium and high productivity wells.

[0050] For instance, FIG. 10 is an example chart of estimated water cut reductions as a function of well productivity for a simple application. In this chart, which is herein referred to by reference numeral 1000, typical values for pack permeability and area are used and the assumed flow path length is 40 ft (approximately equal to a standard screen length). The assumptions for this chart 1000 are uniform flow distribution; zone A is 100% oil; zone B is 100% water; Kpack is 100 darcies; A (cross sectional flow area) is 331ft²; L (length of sand control device) is 40ft and 20ft; viscosity of oil is 0.6 cp (centipoises); and viscosity of water
is 1.0 cp. Based on these assumptions, various response curves 1006-1008 are shown against water cut axis 1002 and a productivity index axis 1004.

[0051] In FIG. 10, an unrestricted water cut response curve 1006 is the percentage of water cut within a wellbore based on the amount of production without any additional flow control mechanisms, such as the use of stimulus-responsive material 702. This percentage of water cut does not change for different production rates, but is substantially constant for various production levels. However, if a sand control device, such as sand control device 138b with the stimulus-responsive material 702, has an L of 20 ft, then the reduction response curve 1007 is the percentage of water cut within a wellbore based on the amount of production. The use of the stimulus-responsive material 702 decreases the percentage of water cut along the water cut axis 1002 as the productivity increases along the productivity index axis 1004. Similarly, if the sand control device is increased to have an L of 40 ft, then the reduction response curve 1008 is the percentage of water cut within a wellbore based on the productivity index. The use of the stimulus-responsive material 702 along with the increases in the length that fluids have to travel along the alternative flow paths decrease the percentage of water cut for the response curve 1008.

[0052] As shown by these response curves, the stimulus-responsive material 702 and the additional length of the sand control device increases the hydrocarbon production from the well. For low production rates, the longer the sand control device, the greater the production rates because water production from the intervals is decreased. This increase in production is shown by the difference between the response curves 1007 and 1008. However, as production rates increase, the length of the sand control device does not provide as large an increase in production rates. Regardless, the stimulus-responsive material 702 increases production levels by reducing the water cut percentage, as shown by the difference between the response curves 1007 and 1008 and the unrestricted water cut response curve 1006.
Example 3: - Natural Sand Packs (NSP)

[0053] In an alternative example, sand control screens may also be installed without a gravel pack. In these installations, unconsolidated sand from the formation fills in the annular space as the well is produced over time. The present techniques may be utilized in a manner similar to the discussion above, to control inflow profiles as long as the natural sand pack is free of voids (i.e., has sufficiently low permeability) between the installation of stimulus-responsive particles or materials according to the present techniques and the interval where profile control is beneficial.

B) Water or gas shut-off via completion design: Stimulus-Responsive Coatings.

[0054] In these examples, water or gas ingress may be expected during the operation of the well prior to the installation of the completion. These examples may also be applicable for natural sand pack, open-hole gravel pack or cased-hole gravel pack completion type.

Example 4:

[0055] The present techniques may also be used to divert flow from "normal" radial flow (i.e. from the sand face, through the gravel pack, through the sand screen) where pressure drops are small, to a restricted linear flow path through the annular space outside the sand screen where the pressure drops are larger. To divert the flow, a coating of stimulus-responsive materials may be formed on the sand screen with the intelligent or smart polymers that swell in the presence of formation water. This coating of stimulus-responsive material may be placed at least partially on wire segments of the screen, ribs of the screen, or any combination. An example of this embodiment is shown in FIG. 11. FIG. 11 illustrates the swelling of an intelligent polymer coating 1102 between the ribs 1104 of a sand screen 1106, which may be part of the sand control device 138a-138n. The intelligent polymer coating 1102 is utilized to prevent or eliminate water entry into the production tubing or inner diameter of the sand control device's base pipe 1108. In addition, the intelligent polymer coating may cover a portion or all of the exposed portions of the ribs, wire
screen segments, or orifices in the base pipe as well. For instance, the intelligent polymer coating may cover areas of the sand screen offsetting the intervals of the formation that are expected to produce water.

Example 5:

[0056] An alternate embodiment of stimulus-responsive coatings may cover the surfaces around the perforations in pre-perforated liners, or on the surfaces of specialty tubulars containing disks with coated orifices placed inside the screens of the sand control devices 138a-138n of FIG. 1. The holes or orifices in the disks may provide tubulars with a variety of flow points, which is shown in FIG. 12. FIG. 12 illustrates coated perforations or disks for restricting water flow into tubulars. In this embodiment, a disk 1200 having one or more orifices 1202 is shown. Each of these orifices 1202 is coated with a stimulus-responsive coating, such as an intelligent polymer coating 1204. As the water cut increased, the intelligent polymer in the intelligent polymer coating 1204 may swell to fill the perforation holes or orifices 1202 to reduce water production. In one embodiment, the disk 1200 may be positioned inside a tubular member between production intervals 108. This application may be capable of blocking off entire sections of a wellbore that are producing water or other stimulus that activate the intelligent polymer coating 1204.

[0057] Beneficially, the use of stimulus-responsive material coating along with stimulus-responsive materials in the gravel applications discussed above, may be more effective than either one used alone. The present methods for blocking the gravel-filled flow paths include filling the spaces with consolidated sand composites (containing some fraction of stimulus-responsive polymer beads or gravel coated with stimulus-responsive material, such as the intelligent polymers) or other fluid (hydrocarbon or water) sensitive materials configured to swell and plug the space when contacted by the appropriate fluid/gas.

Example 6:

[0058] Stimulus-responsive polymers can also be adapted or configured to swell in the presence of methane gas or free reservoir gas. These intelligent polymer
particles or coatings may be used in place of or in conjunction with water-responsive polymers. For example, screens closer to the water intervals or contact zones may be coated with a water-swellable polymer (i.e. or be filled with a water-swellable pack), while screens closer to a gas interval or contact zone may be coated with gas-swellable polymer (i.e. or be filled with a gas-swellable pack). In this manner, gas cap breakthrough or coning in various well types may be managed by limiting free gas entry into the wellbore.

C) Water shut-off via fluid injection.

[0059] This is applicable when an existing completion design cannot mitigate water ingress (in situations where incorporating conformance control in the completion was either not necessary or economically prohibitive). This is also applicable when there is current water ingress and is applicable for multiple completion types.

Example 7: Conformance control

[0060] This exemplary embodiment may include water-sensitive polymer gels with a non-aqueous carrier fluid in an injection program. In the non-aqueous environment, polymer gels (typically in spherical/granular form) remain in the collapsed or compressed configuration which may allow the polymer gels to enter pinholes, cement channels, natural/induced fractures, or pore throats. As the polymer gels contact fresh to brackish formation water, the polymer gels swell into the expanded configuration, which may be 10 to 100 times the original volume, to bridge off the pathway, and to create a low permeability zone. The treatment may reduce the mobility of water in the water producing intervals or zones.

[0061] In an alternative embodiment, with knowledge of the formation water chemistry, an aqueous carrier fluid may be used if 1) it has significantly different ion concentrations or pH than the formation water and the stimulus-responsive polymer is configured to be insensitive to these conditions; 2) if the polymer coatings have an outer diffusion barrier that effectively delay swelling until the injected fluid is in place; or 3) if the polymer is only activated at downhole temperatures after a
sufficient amount of time to enable getting the injected fluid in place. Thus, by knowing the formation water chemistry, the carrier fluid or pre-coat polymer gels may be optimized to remain in the collapsed state (i.e. un-swollen state), which may reduce premature swelling of the polymer gel.

[0062] When pumping the treatment to reduce excess water production, polymer gels pass through the pinholes in the casing, cement channels behind casing, fractures, or pore throats prior to expanding into the expanded configuration. If the polymer gels are utilized to isolate/bridge off these leaks/channels/fractures/permeable formations, the size of the expanded configuration of polymer gels may be utilized to effectively perform this function. Generally, the polymer gels are sized to less than about 1/7 of the pinhole diameter in casing, width of cement channels, or pore throat size of water producing formations to ensure passage.

[0063] The aperture size of the leaks and channels may be qualitatively determined by pump-in tests. For leaks or channels without flow restriction, a conventional cement squeeze may be a cost effective solution to the problem. For leaks with flow restrictions (pinhole less than 1/8 inch) and cement channel behind pipe with flow restrictions (less than 1/16 inch), the use of polymer gels may be the preferred method for treating the problem. For coning problems, it may be beneficial to know the distribution of pore throat sizes in the formation. This information may be utilized to select the "size" or configure the polymer gels for a specific application. Core data or injectivity testing may provide this information. Additionally, within any single pumping operation, the size of polymer gels could be increased as the operation is progressed. One can initiate the operation by pumping the smallest polymer gels (micron to sub-micron) that can be manufactured first. That should permit these gels to penetrate furthest into the reservoir and through the smallest pore throats. As one increases the size (diameter) of the gels, one improves the probability of ultimately blocking successively larger pore throats. Knowing the distribution of pore throat diameters aids this process. Because the polymer gels are configured to swell when contacted with formation water, the backflow of the well may activate the polymer gels. This allows the formation water to better contact and swell the polymer gels. One of the premises of this embodiment is based upon the assumption that gels
may withstand or are strong enough to resist "shearing" forces caused by the drawdown associated with production.

**Example 8:** - Gravel pack injection applications for pressure maintenance or water flood

[0064] Profile control may be used in production and injection applications. It is often beneficial to alter the injection profile in gas or water pressure maintenance applications to sweep previously bypassed intervals. In injection wells with adequate gravel packs installed, the present techniques may be used to limit fluid volumes injected into intervals upstream and downstream to improve sweep efficiency and pressure support in previously under-injected intervals.

**Example 9:** - Gravel pack injection applications for chemical treatment

[0065] Some embodiments of the present techniques may be conducive to placing treatment chemicals in both producing and injection well applications. In addition, packers and straddles may be used to temporarily restrict treating fluids from entry into intervals as desired for the purpose of improving treatment efficiency or reducing the treatment volumes to lower treatment costs.

**Example 10:** - Application for enhancing acid diversion

[0066] Stage water- and pH- sensitive polymer gels with acid preflush may be utilized in this exemplary embodiment. At low-pH (less than 3) environments, polymer gels remain in the collapsed form or compressed configuration to enter the pore throats. As the polymer gels come into contact with water or higher pH fluid, the polymer gels swell/expand to 10 to 100 times the original volume, bridging off the pore throats and creating a low permeability zone. The acid treatment is then diverted from the water bearing zones to the oil-bearing zones. The same process also reduces the mobility of water in the water producing horizons when the well is returned to production.

[0067] When pumping the treatment to reduce the permeability of water productive zones, polymer gels may pass the pore throats prior to swelling. If the
polymer gels are to reduce permeability of water-bearing zones, they may enter the pore structure, swell, and then "bridge off" the pore throats. To enhance this operation, the distribution of pore throat sizes in the formation may be determined. The information may be utilized to "size" the polymer gels for pumping to reduce the permeability of water productive zones. Core data or injectivity testing may again provide this information. Additionally, within any single pumping operation, one can ramp up the polymer gel size during the operation. One may initiate the operation by pumping the smallest available gels (micron to sub-micron size) first. That should permit these polymer gels to penetrate deeper into the reservoir and through the smallest pore throats. As the size (diameter) of the polymer gels increases, the probability of ultimately bridging off successively larger pore throats is increased. Accordingly, knowing the distribution of pore throat diameters enhances this process. Because the polymer gels are designed to swell when contacted with formation water, the well may flow back prior to pumping the stimulation treatment. This allows the formation water to contact and swell the gels prior to the actual stimulation treatment. An enhanced diversion may be achieved when the polymer gel swells/expands to 100 to 1000 times the original volume in the compressed configuration. One of the premises of this embodiment is based upon the assumption that polymer gels are strong enough to resist "shearing" forces induced by the pumping of the stimulation treatment.

D) Water or gas shut-off via completion design: Inflow Control Devices.

[0068] Some embodiments of the present techniques may be utilized when future water or gas ingress is expected prior to installation of the completion and this is also applicable for completion types compatible with inflow control devices.

[0069] This wellbore conformance approach utilizes the volumetric changes of a material to passively (e.g. without active conformance problem identification and intervention) provide wellbore conformance. The passive flow control device is generally composed of three items: the modified production tubular with the flow channel or orifice; the flow control or stimulus-responsive material that swells and/or shrinks in the presence of the unwanted production fluid; and the flow control
material retainer. Accordingly, these different shapes are shown in FIGs. 13A-B, 14A-B, and 15A-B below.

[0070] The initial state or compressed configuration of the flow control material is in one extreme volumetric condition (e.g., a swollen ethylene propylene (EPDM) ball within hydrocarbon fluids). FIGs. 13A-B illustrate the initial state of a flow control material in swollen, non-blocking configuration. FIG. 13B is a top view of the flow orifice without the particle 1304 and including a shaded area 1320 showing the area of contact between the particle 1304 and the orifice 1306. In this embodiment 1300, a production tubular 1302 is modified so that the initial state of the flow control material, such as a swollen EPDM particle or ball 1304 within an enclosure 1306, does not block the reservoir inflow or flow channel 1308. The EPDM ball 1304 is in the swollen state from the flow of hydrocarbons along the flow path 1310 into the production tubular 1302.

[0071] Once water or another stimulus is introduced, the EPDM ball 1304 may begin to change into another configuration or state, as shown in FIGs. 14A-B. FIGs. 14A-B illustrates the control state of a flow control material in semi-swollen, partially-blocking configuration. In this embodiment 1400, which may include similar elements to the discussion of FIGs. 13A-B, the EPDM particle or ball 1402 is in the semi-swollen configuration. The EPDM ball 1402, which had been in hydrocarbon fluids, may shrink when exposed to water and reduce the flow of fluids into the flow channel 1308. This reversible volumetric change controls the flow through the modified production tubular's flow channel and orifice. Accordingly, the EPDM ball 1402 is in the semi-swollen state from the flow of hydrocarbons and water along the flow path 1404 into the production tubular 1302.

[0072] In a final configuration, FIGs. 15A-B illustrates the shut-off state of a flow control material in shrunken, fully-blocking configuration. In this embodiment 1500, the other stimulus or water may contact the EPDM particle or ball 1502 to contract it into a compressed configuration. The volumetric change in the EPDM ball 1502 may block a fluid path 1504 into the flow channel 1308. As a result, the EPDM ball 1502 may shut-off the flow of fluid into the production tubular 1302.
[0073] EPDM is an elastomer that has the following properties for a hydrocarbon-swelling polymer: high temperature resistance for peroxide cured grades, good resistance to hot water, steam, dry heat, and ozone; good resistance to hydraulic fluids, inhibitors, biocides and other treatment chemicals; good H₂S resistance; low cost; low resistance to hydrocarbons (swelling occurs) and operational temperature range of -60°F to 300°F.

[0074] While the present techniques of the invention may be susceptible to various modifications and alternative forms, the exemplary embodiments discussed above have been shown only by way of example. However, it should again be understood that the invention is not intended to be limited to the particular embodiments disclosed herein. Indeed, the present techniques of the invention include all alternatives, modifications, and equivalents falling within the true spirit and scope of the invention as defined by the following appended claims.
What is claimed is:

1. A method of changing a flow profile along a length of a well, the method comprising:
   - coating a particulate solid with at least one stimulus-responsive material, wherein the at least one stimulus-responsive material swells or shrinks in volume in the presence of at least one stimulus, wherein the at least one stimulus consists primarily of contact by non-aqueous fluids, changes in concentration of the at least one stimulus-responsive material, changes in pH of a media contacting the at least one stimulus-responsive material, changes in temperature, changes in electric current, changes in the magnetic polarity of the media contacting the at least one stimulus-responsive material; and
   - placing a pack of particulate solids in or adjacent to a formation, wherein at least a portion of the pack of particulate solids is coated with the at least one stimulus-responsive material.

2. The method according to claim 1, wherein the swelling or shrinking of the at least one stimulus-responsive materials in the presence of at least one stimulus is reversible.

3. The method according to claim 1, wherein the particulate solid comprises one of graded sands, gravels and any combination thereof.

4. The method according to claim 1 comprising using alternate path technology to place the pack of particulate solids, deliver stimuli to the stimulus-responsive material, or any combination thereof.

5. The method of claim 1 comprising producing hydrocarbons from the well.

6. A method of changing a flow profile along a length of a well, the method comprising:
   - coating a particulate solid with at least one stimulus-responsive material, wherein the at least one stimulus-responsive material swells in volume when acted upon by a first stimulus and shrinks in volume when acted upon by a second stimulus;
and placing a pack of particulate solids in or adjacent to a formation, wherein at least a portion of the pack of particulate solids is coated with the at least one stimulus-responsive material.

7. The method of claim 6, wherein the at least one stimulus comprises at least one of: aqueous fluids, non-aqueous fluids, changes in salinity, changes in concentration of the at least one stimulus-responsive material, changes in pH of a media contacting the at least one stimulus-responsive material, changes in temperature, changes in electric current, changes in the magnetic polarity of the media contacting the at least one stimulus-responsive material.

8. The method of claim 6, wherein the particulate solid comprises one of graded sands, gravels, and any combination thereof.

9. The method of claim 6, wherein the at least one stimulus-responsive material is at least one of ethylene propylene, crosslinked polyacrylamide, polyacrylate, and any combination thereof.

10. The method according to claim 6 comprising using alternate path technology to place the pack of particulate solids, deliver stimuli to the stimulus-responsive material, or any combination thereof.

11. The method according to claim 6 comprising producing hydrocarbons from the well.

12. A method of changing a flow profile along a length of a completed well comprising:

coating at least a portion of well equipment with at least one stimulus-responsive material, wherein the stimulus-responsive material swells in volume when acted upon by a first stimulus and shrinks in volume when acted upon by a second stimulus; and

placing the at least a portion of well equipment coated with the at least one stimulus-responsive material in or adjacent to a formation.
13. The method according to claim 12, wherein the at least one stimulus comprises at least one of: changes in concentration of the at least one stimulus-responsive material; changes in pH of a media contacting the at least one stimulus-responsive material; changes in salinity; changes in temperature; changes in electric current; changes in the magnetic polarity of the media contacting the at least one stimulus-responsive material, and any combination thereof.

14. The method according to claim 12, wherein the swelling and shrinking of the at least one stimulus-responsive material in the presence of the at least one stimulus is reversible.

15. The method according to claim 12, wherein the well equipment comprises at least one of valve parts, valve coatings, orifice coatings, well head, tubing, casing, screen, inflow conformance device coatings, and fibers.

16. The method according to claim 12, wherein the at least one stimulus-responsive material is at least one of ethylene-propylene, crosslinked polyacrylamide, and polyacrylate.

17. An apparatus for changing a flow profile along a length of a completed well comprising:

   a length of production tubing comprising well equipment and disposed in a well substantially adjacent to a formation, wherein at least a portion of the well equipment is coated with at least one stimulus-responsive material, wherein the at least one stimulus-responsive material swells or shrinks in volume in the presence of at least one stimulus.

18. The apparatus of claim 17, wherein the at least one stimulus comprises at least one of: changes in concentration of the at least one stimulus-responsive material; changes in pH of a media contacting the at least one stimulus-responsive material; changes in salinity; changes in temperature; changes in electric current; changes in the magnetic polarity of the media contacting the at least one stimulus-responsive material, and any combination thereof.
19. The apparatus of claim 17, wherein the swelling and shrinking of the at least one stimulus-responsive material in the presence of the at least one stimulus is reversible.

20. The apparatus according to claim 17, wherein the well equipment comprises at least one of valve parts, valve coatings, orifice coatings, well head, tubing, casing, screen, inflow conformance device coatings, and fibers.

21. The apparatus according to claim 17, wherein the at least one stimulus-responsive material is at least one of ethylene-propylene, crosslinked polyacrylamide, and polyacrylate.

22. A production well system for hydrocarbon production comprising:

   at least one stimulus-responsive material placed in or adjacent to a formation accessed by a well, wherein the at least one stimulus-responsive material swells in volume when contacted with a first stimulus and shrinks in volume when contacted with a second stimulus.

23. The system according to claim 22, wherein the at least one stimulus-responsive material is coated on a solid particulate.

24. The system according to claim 22, wherein the at least one stimulus-responsive material is placed inside the well as at least a portion of a pack of solid particulates.

25. The system according to claim 22, wherein the at least one stimulus-responsive material is coated on a portion of well equipment placed inside the well.

26. The system according to claim 25, wherein the well equipment comprises valve parts, valve coatings, orifice coatings, well head, tubing, casing, screen, inflow conformance device coatings and fibers.

27. The system according to claim 22, wherein the swelling and shrinking of the at least one stimulus-responsive material in the presence of at least one stimulus is reversible.
28. The system of claim 22, wherein the at least one stimulus consists primarily of non-aqueous fluids, changes in concentration of the at least one stimulus-responsive material, changes in pH of a media contacting the at least one stimulus-responsive material, changes in temperature, changes in electric current, changes in the magnetic polarity of the media contacting the at least one stimulus-responsive material.

29. The system according to claim 22, wherein the at least one stimulus-responsive material is at least one of ethylene propylene, crosslinked polyacrylamide, and polyacrylate.

30. An apparatus for passive wellbore conformance control comprising:
   a tubular member having at least one flow orifice;
   a particle comprising a flow control material, wherein the flow control material swells in the presence of a first stimulus and shrinks in the presence of a second stimulus;
   a flow control material retainer at or near the at least one flow orifice, wherein the flow control material is retained at or near the at least one flow orifice so as to permit the flow of a first fluid in the swollen state and substantially restrict the flow of a second fluid in the shrunken state.

31. The apparatus of claim 30, wherein the first fluid is hydrocarbons and the second fluid is water.

32. The apparatus of claim 30, wherein the flow control material is ethylene-propylene.

33. The apparatus of claim 30, wherein the particle is spherical in shape.
FIG. 2

FIG. 3A

FIG. 3B