US 20080283238A1

(19) **United States**

(12) **Patent Application Publication**

Richards et al.

(10) **Pub. No.: US 2008/0283238 A1**

(43) **Pub. Date: Nov. 20, 2008**

(54) **APPARATUS FOR AUTONOMOUSLY CONTROLLING THE INFLOW OF PRODUCTION FLUIDS FROM A SUBTERRANEAN WELL**

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(21) Appl. No.: **11/803,835**

(22) Filed: **May 16, 2007**

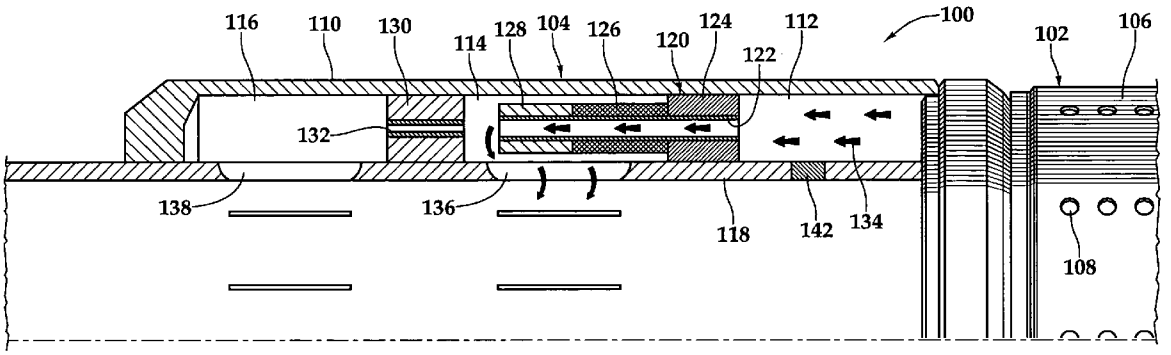
Publication Classification

(51) **Int. Cl.**
E21B 34/14 (2006.01)
E21B 43/08 (2006.01)

(52) **U.S. Cl.** **166/228**; 166/205; 166/332.1

(57) **ABSTRACT**

A flow control apparatus (**100**) for controlling the inflow of production fluids (**134**, **140**) from a subterranean well includes a tubular member (**118**) having at least one opening (**138**) that allows fluid flow between an exterior of the tubular member (**118**) and an interior flow path of the tubular member (**118**) and a flow restricting device (**120**) operably positioned in a fluid flow path between a fluid source and the at least one opening (**138**). The flow restricting device (**120**) includes a valve (**128**, **130**) and an actuator (**126**). The actuator (**126**) includes a material that swells in response to contact with an undesired fluid (**140**), such as water or gas. The flow restricting device (**120**) is operable to autonomously reduce the fluid flow through the flow control apparatus (**100**) in response to contact between the material and the undesired fluid (**140**).



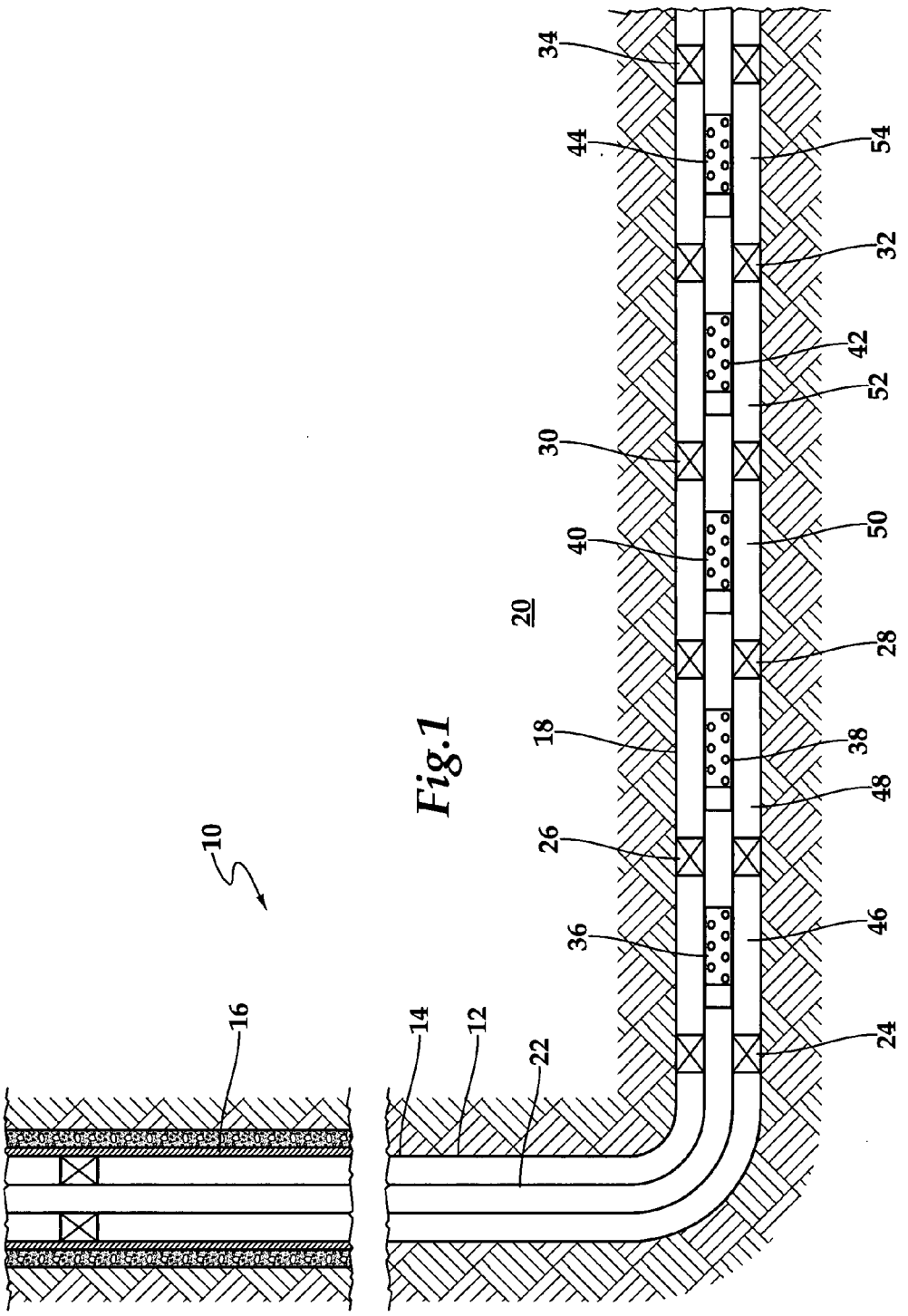


Fig.1

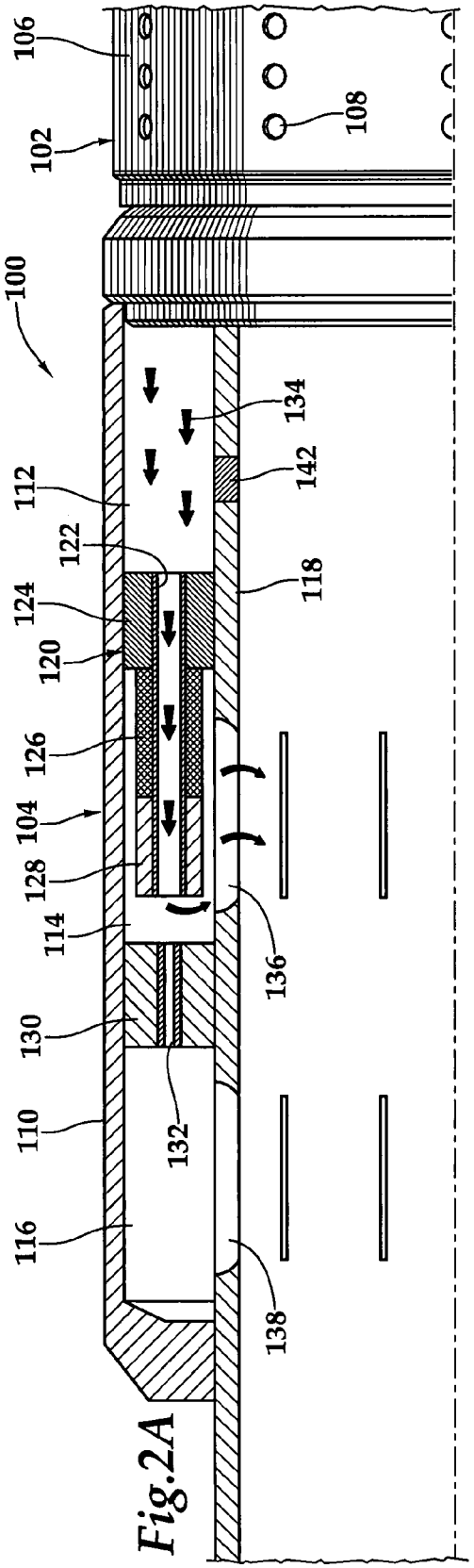

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Fig.2A

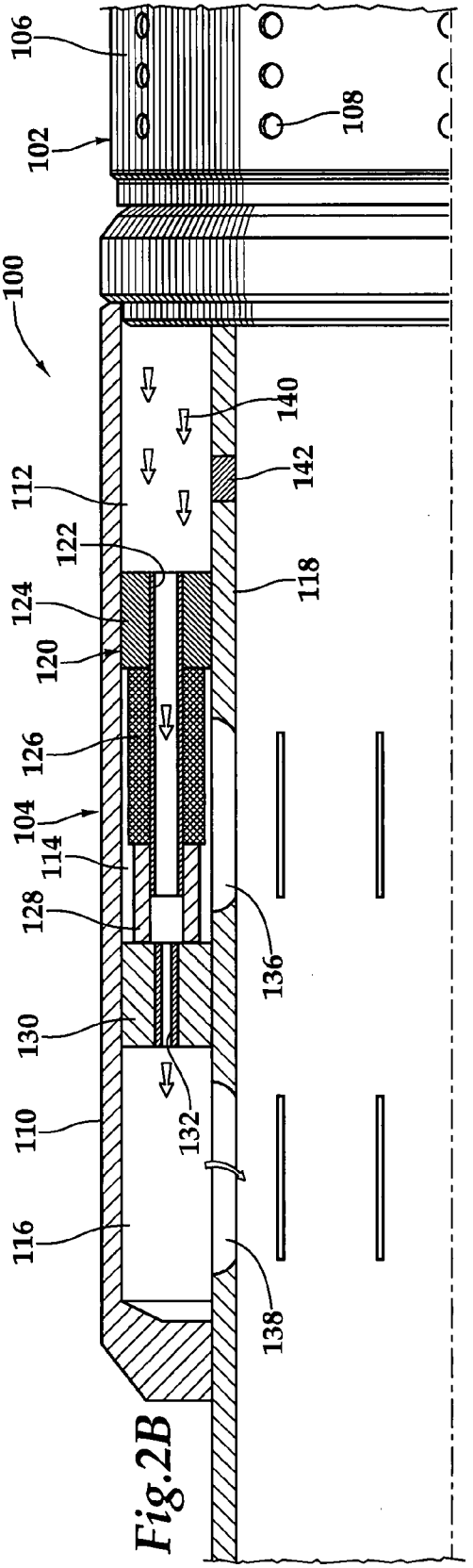
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Fig.2B

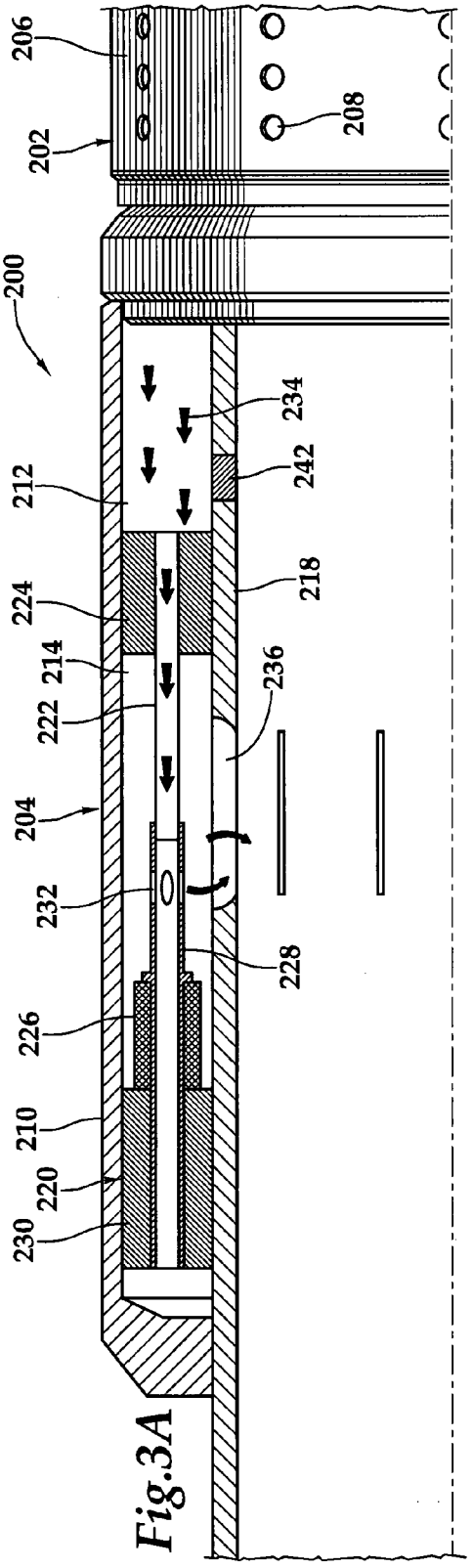
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Fig.3A

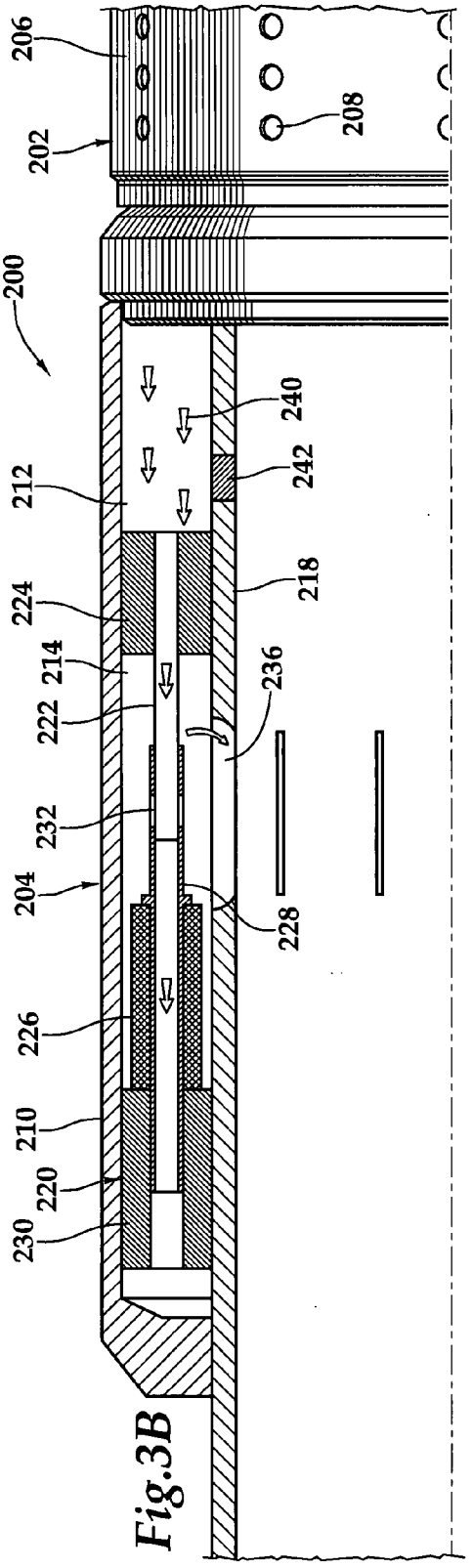
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Fig.3B

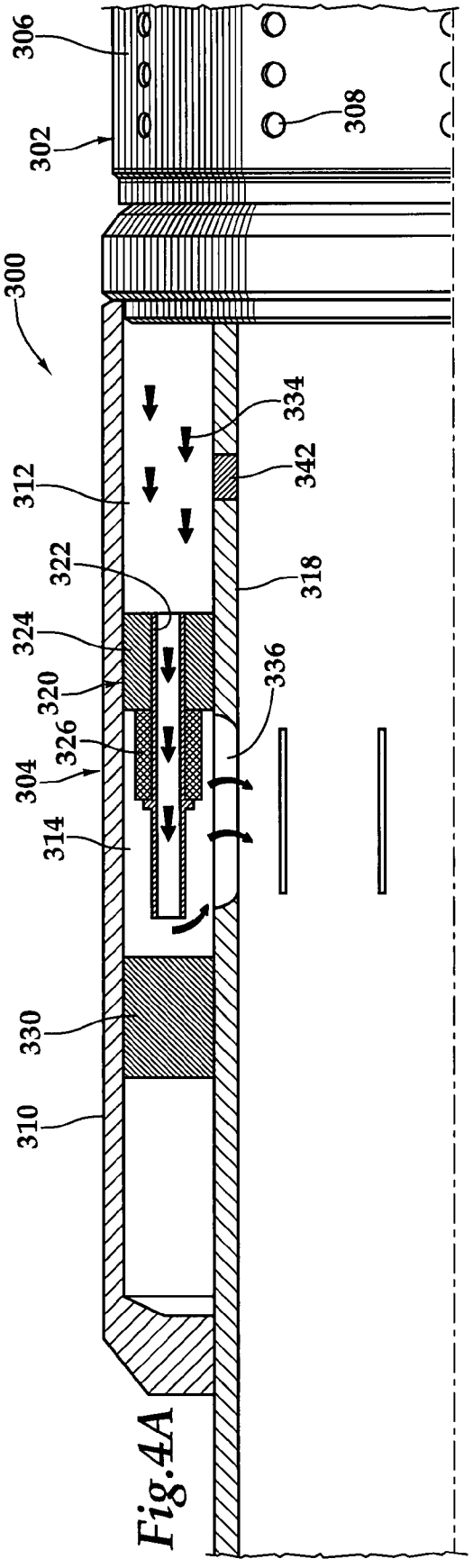
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Fig.4A

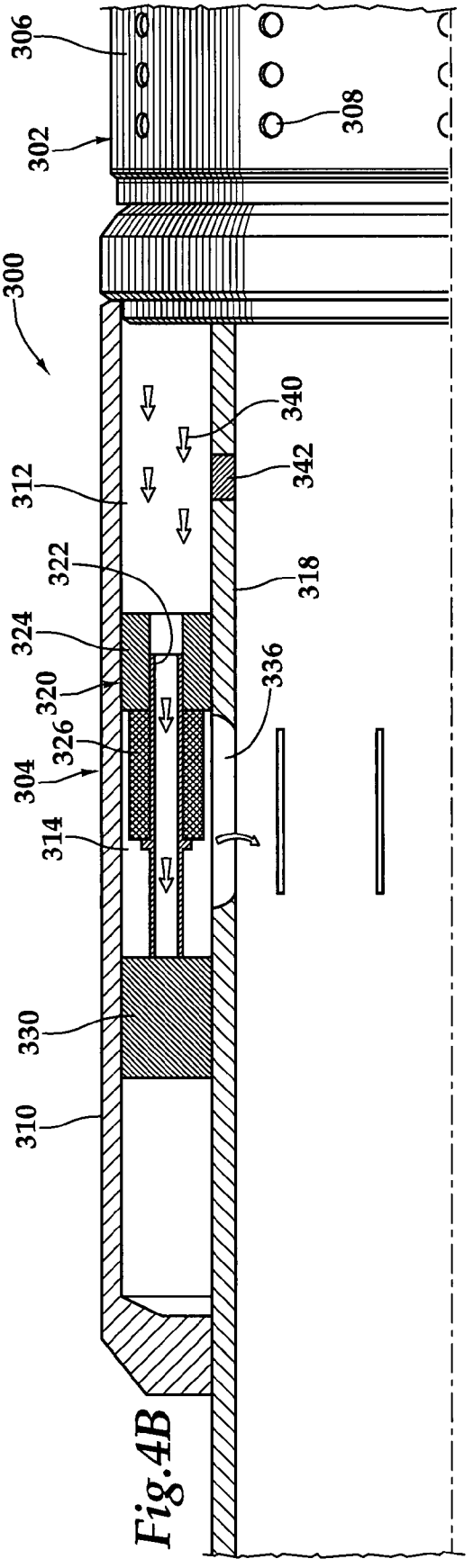
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Fig.4B

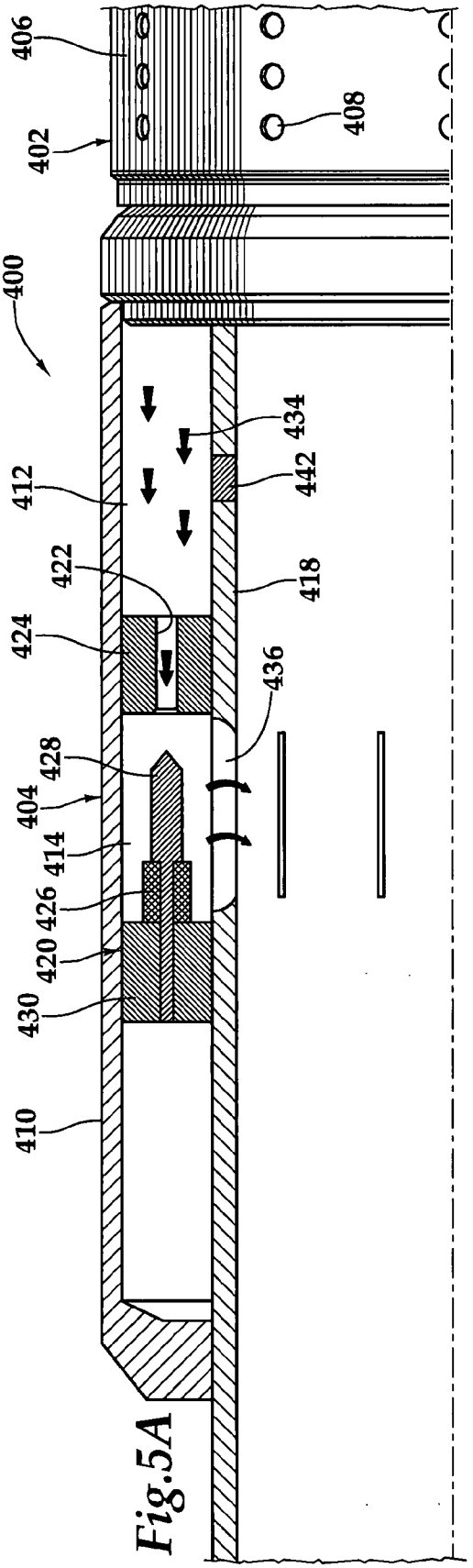
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Fig.5A

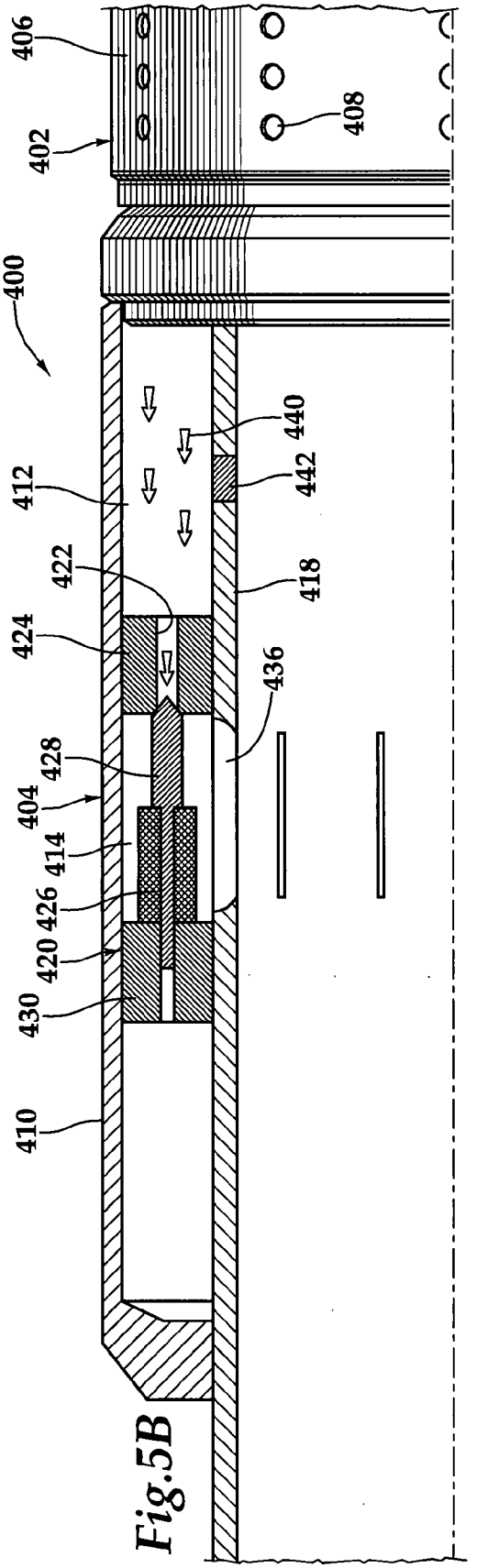
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Fig.5B

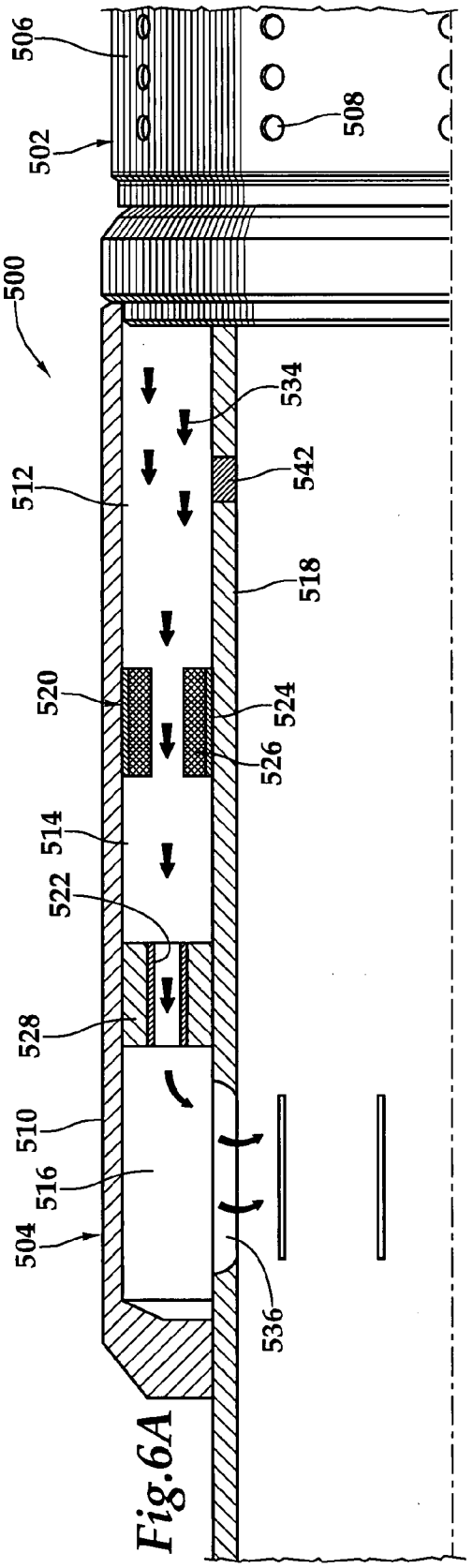
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Fig.6A

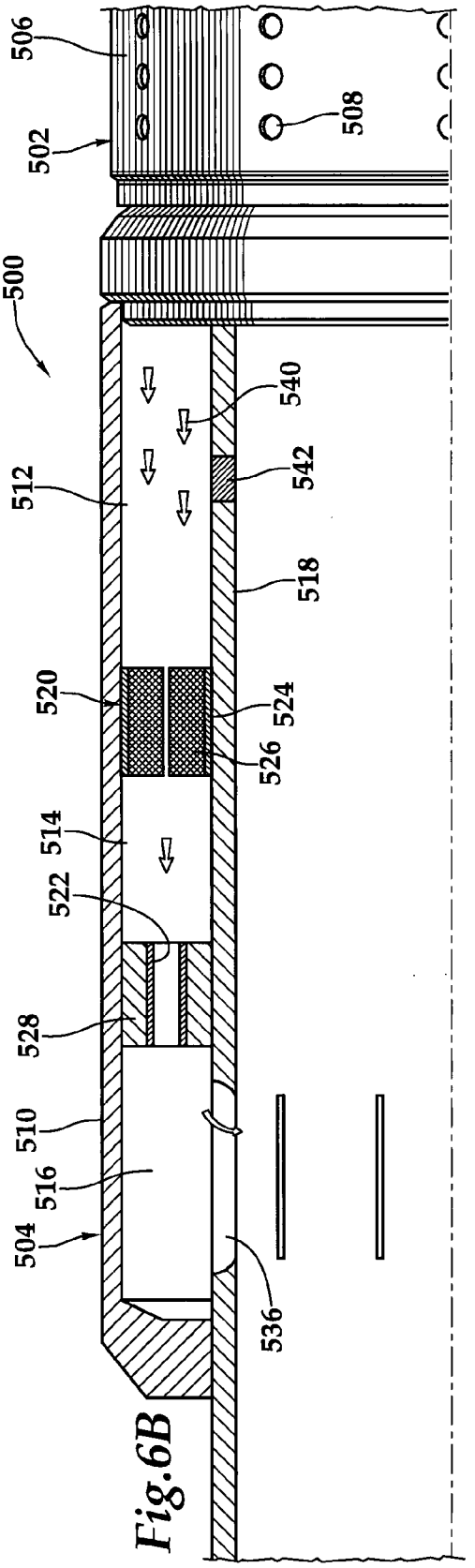
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Fig.6B

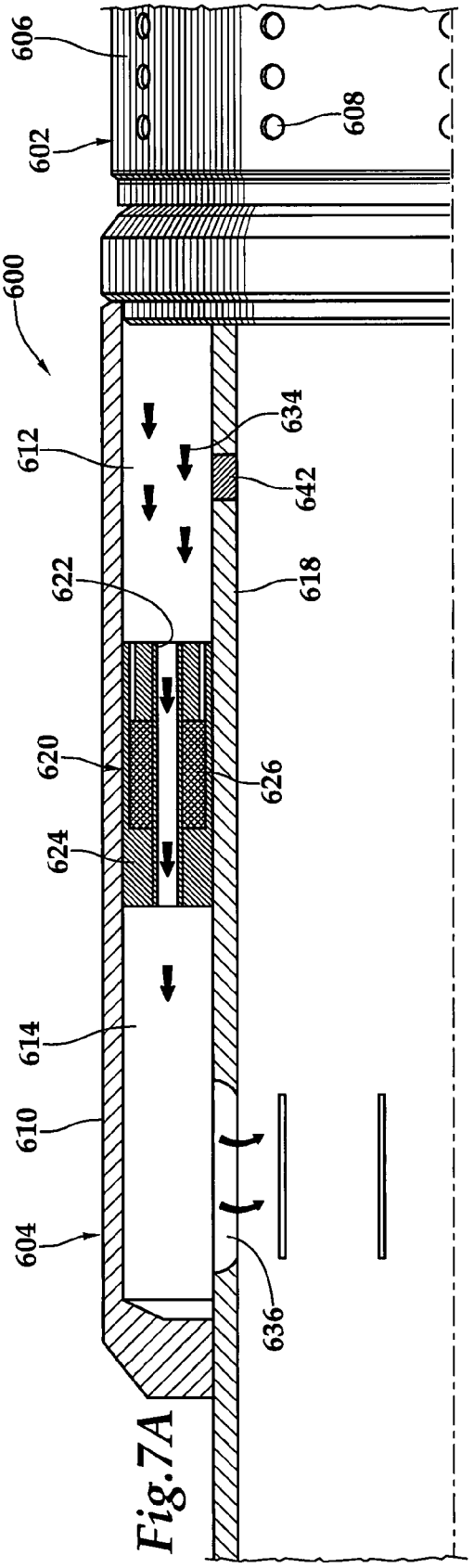
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Fig.7A

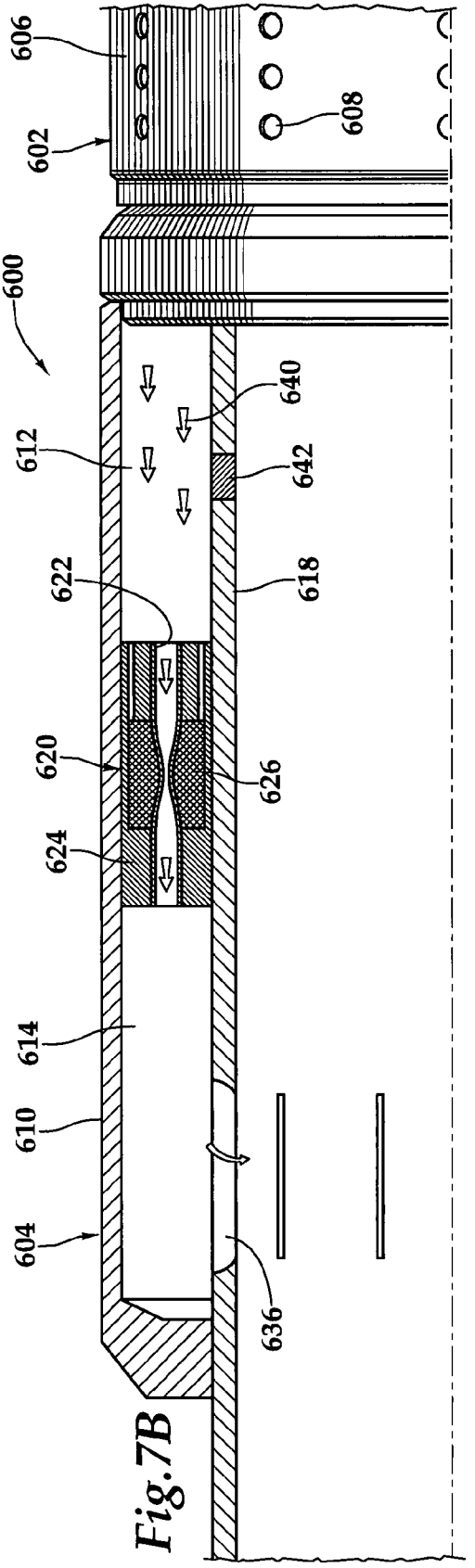
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Fig.7B

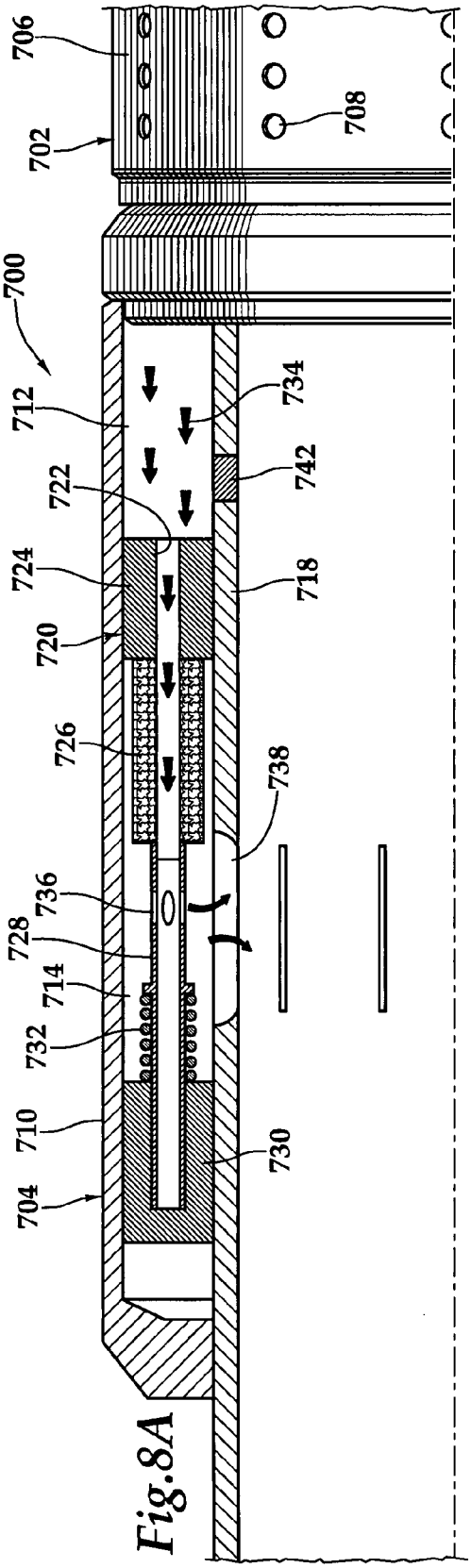
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Fig.8A

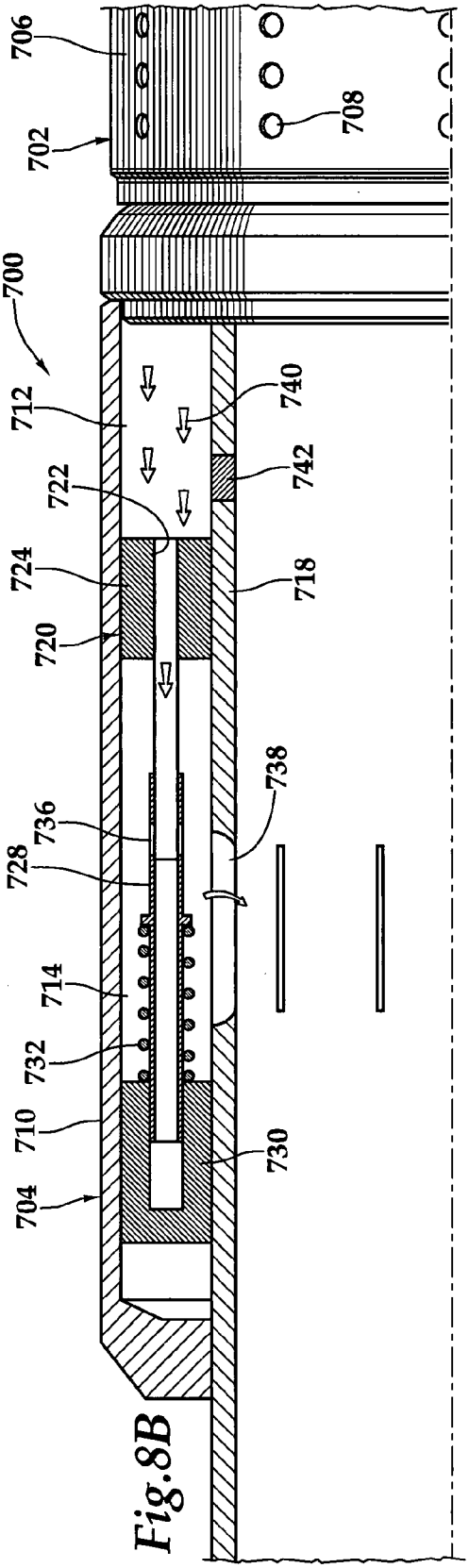
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Fig.8B

APPARATUS FOR AUTONOMOUSLY CONTROLLING THE INFLOW OF PRODUCTION FLUIDS FROM A SUBTERRANEAN WELL

TECHNICAL FIELD OF THE INVENTION

[0001] This invention relates, in general, to controlling the production of fluids from a well that traverses a hydrocarbon bearing subterranean formation and, in particular, to an apparatus for autonomously controlling the inflow of production fluids from the subterranean well in response to contact with an undesired fluid.

BACKGROUND OF THE INVENTION

[0002] Without limiting the scope of the present invention, its background will be described with reference to producing fluid from a subterranean formation, as an example.

[0003] During the completion of a well that traverses a hydrocarbon bearing subterranean formation, production tubing and various equipment are installed in the well to enable safe and efficient production of the formation fluids. For example, to prevent the production of particulate material from an unconsolidated or loosely consolidated subterranean formation, certain completions include one or more sand control screens positioned proximate the desired production intervals. In other completions, to control the flow rate of production fluids into the production tubing, it is common practice to install one or more flow control devices within the tubing string.

[0004] Recently, attempts have been made to utilize fluid flow control devices within completions requiring sand control. For example, in one such device, after production fluids flows through the filter media of the sand control screen, the fluids are directed into a flow control labyrinth. A slidable sleeve on the labyrinth controls the fluid velocity therethrough. The slidable sleeve is moved by a remotely and electrically-operated device placed in the sand control screen. The fluid leaving the labyrinth passes to the tubing string for carrying to the surface. While certain benefits have been achieved through the use of such devices, many of these devices are complicated to operate, have suffered from poor reliability and require certain intervention for operation.

[0005] Accordingly, need has arisen for a fluid flow control device for controlling the inflow of formation fluids in a completion requiring sand control. A need has also arisen for such a fluid flow control device that is not difficult or expensive to manufacture. Further, a need has arisen for such a fluid flow control device that is reliable in a variety of flow conditions and does not require intervention to control inflow.

SUMMARY OF THE INVENTION

[0006] The present invention disclosed herein comprises a flow control apparatus for controlling the inflow of formation fluids. The flow control apparatus of the present invention is not difficult or expensive to manufacture. In addition, the flow control apparatus of the present invention is reliable in a variety of flow conditions and does not require intervention to control inflow.

[0007] In one aspect, the present invention is directed to a flow control apparatus for controlling the inflow of production fluids from a subterranean well that includes a tubular member having at least one opening that allows fluid flow between an exterior of the tubular member and an interior flow path of the tubular member and a flow restricting device operably positioned in a fluid flow path between a fluid source and the at least one opening. The flow restricting device includes a valve and an actuator. The actuator includes a material that swells in response to contact with an undesired fluid, such as water or gas. The flow restricting device is operable to autonomously reduce the fluid flow through the flow control apparatus in response to contact between the material and the undesired fluid.

[0008] In one embodiment of the flow control apparatus, fluid flow through the flow control apparatus is increasingly restricted in response to contact between the material and the undesired fluid. In another embodiment, fluid flow through the flow control apparatus is substantially completely restricted in response to contact between the material and the undesired fluid.

[0009] In certain embodiments of the flow control apparatus, the valve includes a sliding sleeve that is operated from the open position to a choking or closed position by the actuator. In other embodiments, the valve includes a longitudinally shiftable valve element that is operated from the open position to a choking or closed position by the actuator. In still other embodiments, the valve includes a valve element having a fluid flow passageway with a cross sectional area that is reduced in response to contact between the material and the undesired fluid. In yet another embodiment, the actuator includes a biasing member that biases a valve element in a first direction. In this embodiment, the material prevents movement of the valve element in the first direction until the material is contacted by the undesired fluid.

[0010] In one embodiment of the flow control apparatus, once the material contacts the undesired fluid, the material permanently remains in a swelled state. In another embodiment of the flow control apparatus, once the material contacts the undesired fluid, the material remains in a swelled state as long as the material stays in contact with the undesired fluid but returns to an unswelled state if contact with the undesired fluid ceases.

[0011] In another aspect, the present invention is directed to a sand control screen that is positionable within a wellbore. The sand control screen includes a base pipe having at least one opening that allows fluid flow between an exterior of the base pipe and an interior flow path of the base pipe and a filter medium positioned exteriorly of the base pipe. The filter medium selectively allows fluid flow therethrough and prevents particulate flow of a predetermined size therethrough. A flow restricting device is operably positioned in a fluid flow path between the filter medium and the at least one opening. The flow restricting device including a valve and an actuator. The actuator includes a material that swells in response to contact with an undesired fluid such that the flow restricting device is operable to autonomously reduce the fluid flow through the screen in response to contact between the material and the undesired fluid.

[0012] In a further aspect, the present invention is directed to a sand control completion for installation in a wellbore. The completion includes first and second seal assemblies that define a production zone in the wellbore and a sand control screen operably positioned between the first and second seal assemblies. The sand control screen includes a base pipe having at least one opening that allows fluid flow between an exterior of the base pipe and an interior flow path of the base pipe, a filter medium positioned exteriorly of the base pipe, the filter medium selectively allowing fluid flow therethrough

and preventing particulate flow of a predetermined size therethrough and a flow restricting device operably positioned in a fluid flow path between the filter medium and the at least one opening. The flow restricting device includes a valve and an actuator. The actuator includes a material that swells in response to contact with an undesired fluid such that the flow restricting device is operable to autonomously reduce the fluid flow from the production zone in response to contact between the material and the undesired fluid.

[0013] In yet another aspect, the present invention is directed to a multizone sand control completion for installation in a wellbore. The completion includes at least two sets of first and second seal assemblies that define at least two production zones in the wellbore and a sand control screen positioned between each of the first and second seal assemblies. Each of the sand control screens includes a base pipe having at least one opening that allows fluid flow between an exterior of the base pipe and an interior flow path of the base pipe, a filter medium positioned exteriorly of the base pipe, the filter medium selectively allowing fluid flow therethrough and preventing particulate flow of a predetermined size therethrough and a flow restricting device operably positioned in a fluid flow path between the filter medium and the at least one opening. Each flow restricting device includes a valve and an actuator. The actuators include a material that swells in response to contact with an undesired fluid such that each of the flow restricting devices is operable to autonomously reduce the fluid flow from the respective production zones in response to contact between the material and the undesired fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

[0015] FIG. **1** is a schematic illustration of a well system operating a plurality of fluid flow control devices according to the present invention;

[0016] FIG. **2**A is side view partially in quarter section of a fluid flow control device according to the present invention in its least restricting configuration;

[0017] FIG. **2**B is side view partially in quarter section of a fluid flow control device according to the present invention in its most restricting configuration;

[0018] FIG. **3**A is side view partially in quarter section of a fluid flow control device according to the present invention in its least restricting configuration;

[0019] FIG. **3**B is side view partially in quarter section of a fluid flow control device according to the present invention in its most restricting configuration;

[0020] FIG. **4**A is side view partially in quarter section of a fluid flow control device according to the present invention in its least restricting configuration;

[0021] FIG. **4**B is side view partially in quarter section of a fluid flow control device according to the present invention in its most restricting configuration;

[0022] FIG. **5**A is side view partially in quarter section of a fluid flow control device according to the present invention in its least restricting configuration;

[0023] FIG. **5**B is side view partially in quarter section of a fluid flow control device according to the present invention in its most restricting configuration;

[0024] FIG. **6**A is side view partially in quarter section of a fluid flow control device according to the present invention in its least restricting configuration;

[0025] FIG. **6**B is side view partially in quarter section of a fluid flow control device according to the present invention in its most restricting configuration;

[0026] FIG. **7**A is side view partially in quarter section of a fluid flow control device according to the present invention in its least restricting configuration;

[0027] FIG. **7**B is side view partially in quarter section of a fluid flow control device according to the present invention in its most restricting configuration;

[0028] FIG. **8**A is side view partially in quarter section of a fluid flow control device according to the present invention in its least restricting configuration; and

[0029] FIG. **8**B is side view partially in quarter section of a fluid flow control device according to the present invention in its most restricting configuration.

DETAILED DESCRIPTION OF THE INVENTION

[0030] While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts which can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention, and do not delimit the scope of the present invention.

[0031] Referring initially to FIG. **1**, therein is depicted a well system including a plurality of fluid flow control devices embodying principles of the present invention that is schematically illustrated and generally designated **10**. In the illustrated embodiment, a wellbore **12** extends through the various earth strata. Wellbore **12** has a substantially vertical section **14**, the upper portion of which has installed therein a casing string **16**. Wellbore **12** also has a substantially horizontal section **18** that extends through a hydrocarbon bearing subterranean formation **20**. As illustrated, substantially horizontal section **18** of wellbore **12** is open hole.

[0032] Positioned within wellbore **12** and extending from the surface is a tubing string **22**. Tubing string **22** provides a conduit for formation fluids to travel from formation **20** to the surface. Positioned within tubing string **22** are a plurality of seal assemblies **24**, **26**, **28**, **30**, **32**, **34** and a plurality of fluid flow control devices **36**, **38**, **40**, **42**, **44**. Each of the seal assemblies **24**, **26**, **28**, **30**, **32**, **34** provides a fluid seal between tubing string **22** and the wall of wellbore **12**. Each pair of seal assemblies defines a production interval. As illustrated, seal assemblies **24**, **26** define production interval **46**, seal assemblies **26**, **28** define production interval **48**, seal assemblies **28**, **30** define production interval **50**, seal assemblies **30**, **32** define production interval **52** and seal assemblies **32**, **34** define production interval **54**.

[0033] Through use of the fluid flow control devices **36**, **38**, **40**, **42**, **44** of the present invention and by providing numerous production intervals **46**, **48**, **50**, **52**, **54**, precise control over the volume and composition of the produced fluids is enabled. For example, in an oil production operation if an undesired fluid component, such as water or gas, is entering one of the production intervals, the fluid flow control device in that interval will autonomously restrict the production of that

undesired fluid component and in some cases the entire fluid stream from that production interval. Accordingly, when a production interval corresponding to a particular one of the fluid flow control devices produces a greater proportion of an undesired fluid, the fluid flow control device in that interval will increasingly or entirely restrict flow from that interval. Thus, the other production intervals which are producing a greater proportion of desired fluid, in this case oil, will contribute more to the production stream entering tubing string **22**. In particular, there will be a greater pressure drop from formation **20** to tubing string **22**, resulting in a greater production of the desired fluid, due to the increased restriction to flow from the production interval that would otherwise be producing a greater proportion of the undesired fluid.

[0034] In the illustrated embodiment, each of the fluid flow control devices **36**, **38**, **40**, **42**, **44** provides not only fluid flow control capability but also sand control capability. The sand control screen elements or filter media associated with fluid flow control devices **36**, **38**, **40**, **42**, **44** are designed to allow fluids to flow therethrough but prevent particulate matter of sufficient size from flowing therethrough. The exact design of the screen element associated with fluid flow control devices **36**, **38**, **40**, **42**, **44** is not critical to the present invention as long as it is suitably designed for the characteristics of the formation fluids and any treatment operations to be performed. For example, the sand control screen may utilize a nonperforated base pipe having a wire wrapped around a plurality of ribs positioned circumferentially around the base pipe that provide stand off between the base pipe and the wire wrap. Alternatively, a fluid-porous, particulate restricting, metal material such as a plurality of layers of a wire mesh that are sintered together to form a fluid porous wire mesh screen could be used as the filter medium. As illustrated, a protective outer shroud having a plurality of perforations therethrough may be positioned around the exterior of the filter medium.

[0035] Even though FIG. **1** depicts the fluid flow control devices of the present invention in an open hole environment, it should be understood by those skilled in the art that the fluid flow control devices of the present invention are equally well suited for use in cased wells. Also, even though FIG. **1** depicts one fluid flow control device in each production interval, it should be understood by those skilled in the art that any number of fluid flow control devices of the present invention may be deployed within a production interval without departing from the principles of the present invention.

[0036] In addition, even though FIG. **1** depicts the fluid flow control devices of the present invention in a horizontal section of the wellbore, it should be understood by those skilled in the art that the fluid flow control devices of the present invention are equally well suited for use in deviated or vertical wellbores. Accordingly, it should be understood by those skilled in the art that the use of directional terms such as above, below, upper, lower, upward, downward and the like are used in relation to the illustrative embodiments as they are depicted in the figures, the upward direction being toward the top of the corresponding figure and the downward direction being toward the bottom of the corresponding figure. Further, even though FIG. **1** depicts the fluid flow control devices of the present invention as including sand control screen elements, it should be understood by those skilled in the art that the fluid flow control devices of the present invention are equally well suited for use in completions that do not require sand control.

[0037] Referring next to FIGS. **2**A-**2**B, therein is depicted a fluid flow control device according to the present invention that is representatively illustrated and generally designated **100**. Fluid flow control device **100** may be suitably coupled to other similar fluid flow control devices, seal assemblies, production tubulars or other downhole tools to form a tubing string as described above. Fluid flow control device **100** includes a sand control screen section **102** and a flow restrictor section **104**. Sand control screen section **102** includes a suitable sand control screen element or filter medium, such as a wire wrap screen, a woven wire mesh screen or the like, designed to allow fluids to flow therethrough but prevent particulate matter of sufficient size from flowing therethrough. In the illustrated embodiment, a protective outer shroud **106** having a plurality of perforations **108** is positioned around the exterior of the filter medium.

[0038] Flow restrictor section **104** is configured in series with sand control screen section **102** such that fluid must pass through sand control screen section **102** prior to entering flow restrictor section **104**. Flow restrictor section **104** includes an outer housing **110**. Outer housing **110** defines an annular chamber **112**, an annular chamber **114** and an annular chamber **116** with base pipe **118**. Disposed between annular chamber **112** and annular chamber **114** and partially within annular chamber **114** is a valve assembly **120**. Valve assembly **120** includes a tubular fluid passageway **122**, a support member **124**, an actuator **126** and a sliding sleeve **128**. Disposed between annular chamber **114** and annular chamber **116** is a support member **130** having a tubular fluid passageway **132**.

[0039] As best seen in FIG. **2**A, tubular fluid passageway **122** serves as a first stage flow restrictor to control fluid flow through fluid flow control device **100** when a desired fluid, such as oil, depicted as arrows **134**, is being produced. As illustrated, once desired fluid **134** enters flow restrictor section **104**, desired fluid **134** passes through annular chamber **112** and encounters tubular fluid passageway **122** which restricts the flow of desired fluid **134**. After passing through tubular fluid passageway **122**, desired fluid **134** enters annular chamber **114** before passing into the interior flow path of base pipe **118** via openings **136**, which are depicted in the form of slots. Once inside the interior flow path of base pipe **118**, desired fluid **134** flows to the surface within the tubing string. In addition, a portion of desired fluid **134** (not pictured) also passes through tubular fluid passageway **132**, that serves as a second stage flow restrictor, before passing into base pipe **118** via openings **138**. As tubular fluid passageway **132** provides a greater restriction to flow than openings **136**, the majority of desired fluid **134** enters base pipe **118** via openings **136**.

[0040] As best seen in FIG. **2**B, when an undesired fluid, such as water, depicted as arrows **140**, is produced, valve assembly **120** is actuated to its closed or choking position. In the illustrated embodiment, this actuation is achieved by longitudinally shifting sliding sleeve **128** into contact with support member **130** in response to the expansion of actuator **126**. Once sliding sleeve **128** contacts support member **130** all or a majority of the undesired fluid **140** must now pass through tubular fluid passageway **132** before entering base pipe **118** via openings **138**. As tubular fluid passageway **132** provides a greater restriction to flow than tubular fluid passageway **122**, the production of undesired fluid **140** through fluid flow control device **100** is reduced as compared to the production of desired fluid **134** in FIG. **2**A. The increased pressure drop caused by tubular fluid passageway **132** not only reduces the production of undesired fluid **140** from the

production interval corresponding to fluid flow control device **100** but may also tend to increase production from other production intervals which are producing a desired fluid. Specifically, as there will be a greater pressure drop from the formation to the tubing string for all fluids, with a greater restriction to flow only being applied to undesired fluids, a greater production of fluids from intervals not producing the undesired fluid will occur.

[0041] As noted above, the actuation of valve assembly **120** is achieved in response to the expansion of actuator **126**. More specifically, actuator **126** is formed from a material that expands when it comes in contact with an activating agent. For example, the material of actuator **126** may be a polymer that swells multiple times its initial size upon activation by an activating agent that stimulates the polymer chains to expand both radial and axially. In an autonomous implementation of fluid flow control device **100**, the undesired fluid serves as the activating agent. For example, when the undesired fluid is water, the material of actuator **126** may be a water-swellable polymer such as a water-swellable elastomer or water-swellable rubber. More specifically, the material of actuator **126** may be a water-swellable hydrophobic polymer or water-swellable hydrophobic copolymer and preferably a water-swellable hydrophobic porous copolymer. As another example, the material of actuator **126** may be a salt polymer such as polyacrylamide or modified crosslinked poly(meth) acrylate that has the tendency to attract water from salt water through osmosis wherein water flows from an area of low salt concentration, the formation water, to an area of high salt concentration, the salt polymer, across a semi permeable membrane, the interface between the polymer and the production fluids, that allows water molecules to pass therethrough but prevents the passage of dissolved salts therethrough. Other embodiments of actuator **126** may employ different types of swelling polymers or materials that are activated by other activating agents. For example, in certain implementations, it may be desirable to have the material of actuator **126** swell upon activation by a hydrocarbon gas component of the production fluids.

[0042] As best seen in FIG. **2**B, once actuator **126** is exposed to the activating agent, actuator **126** swells to longitudinally shift sliding sleeve **128** into contact with support member **130**. Once this operation is complete, actuator **126** retains the activating fluid therein. As a result, after actuator **126** has transformed from its unswelled state (FIG. **2**A) to its swelled state (FIG. **2**B), actuator **126** retains its expanded size. If required, full access through fluid flow control device **100** can be reestablished via removal of plug **142**. For example, plug **142** may be mechanically removed from base pipe **118** or chemically attacked such that a fluid flow path is created upstream of valve assembly **120**. It should be noted that the use of plug **142** or other similar removeable device in this and the other embodiments of the present invention is an additional feature which may be included or excluded optionally. Alternatively, in certain embodiments, actuator **126** may be deactivated upon removal of the activating agent from contact with actuator **126**. This implementation is useful in the scenario in which an oil producing production zone temporarily produces the unwanted fluid of water that acts as the activating agent for actuator **126**, then later reverts back to oil production. In this case, actuator **126** is transitioned back from its swelled state to its unswelled state due to the removal of the activating agent.

[0043] Depended upon the specific composition of actuator **126**, the swelling process may take place over a relatively short period of time, several minutes, or a relatively long period of time, several days or weeks. As flow control device **100** is typically installed in a well that contains drilling fluids, which may include the activating agent of actuator **126**, a composition for the material of actuator **126** with a relatively long swelling process may be desirable to enable the installation of actuator **126** without immediate actuation of flow control device **100**, thus enabling the drilling fluid to be removed from contact with actuator **126** before actuation takes place. The removal of the drilling fluids could be done by displacing the drilling fluids with other fluids form the surface of by flowing reservoir fluids through flow control device **100**. Additionally or alternatively, an outer skin may be applied to actuator **126** prior to installation that protects actuator **126** from any activation agent in the drilling fluids. For example, the skin may be relatively impermeable to the activating agent such that contact between the activating agent and actuator **126** is initially limited or the skin may entirely prevent contact between the activating agent and actuator **126** until such skin is removed, for example, due to the passage of time or a treatment used to remove the skin from actuator **126**.

[0044] Even though fluid flow control device **100** has been described as having one valve assembly **120**, it should be understood by those skilled in the art that a fluid flow control device of the present invention could alternatively have more than one valve assembly positioned in the flow restrictor section thereof. The number of valve assemblies and the exact location and circumferential distribution of the valve assemblies will be determined based upon a number of factors including the volume of desired fluid to be produced through fluid flow control device **100**, the types or types of fluid that comprise the desired fluid and undesired fluid, the mechanical space requirements within fluid flow control device **100** and the like. In addition, even though the fluid passageways **122**, **132** have been described as being tubular, it should be understood by those skilled in the art that the passageways or nozzles that restrict fluid flow through fluid flow control device **100** could alternatively have different configurations including different cross sectional shapes and different directional pathways such as labyrinth type pathways, without departing from the principles of the present invention.

[0045] Referring next to FIGS. **3**A-**3**B, therein is depicted a fluid flow control device according to the present invention that is representatively illustrated and generally designated **200**. Fluid flow control device **200** includes a sand control screen section **202** and a flow restrictor section **204**. Sand control screen section **202** includes a suitable sand control screen element or filter medium. In the illustrated embodiment, a protective outer shroud **206** having a plurality of perforations **208** is positioned around the exterior of the filter medium.

[0046] Flow restrictor section **204** is configured in series with sand control screen section **202** such that fluid must pass through sand control screen section **202** prior to entering flow restrictor section **204**. Flow restrictor section **204** includes an outer housing **210**. Outer housing **210** defines an annular chamber **212** and an annular chamber **214** with base pipe **218**. Disposed at least partially within annular chamber **214** is a valve assembly **220**. Valve assembly **220** includes a tubular fluid passageway **222**, a support member **224**, an actuator **226**, a sliding sleeve **228** and a support member **230**.

[0047] As best seen in FIG. **3**A, tubular fluid passageway **222** serves as a flow restrictor to control fluid flow through fluid flow control device **200** when a desired fluid **234** is being produced. As illustrated, once desired fluid **234** enters flow restrictor section **204**, desired fluid **234** passes through annular chamber **212** and encounters tubular fluid passageway **222** which restricts the flow of desired fluid **234**. After passing through tubular fluid passageway **222**, desired fluid **234** enters the interior of sliding sleeve **228**, passes through openings **232** into annular chamber **214** before passing into base pipe **218** via openings **236** for transport to the surface.

[0048] As best seen in FIG. **3**B, when an undesired fluid **240** is produced, valve assembly **220** is actuated to its closed or choking position. In the illustrated embodiment, this actuation is achieved by longitudinally shifting sliding sleeve **228** such that openings **232** are blocked by the outer surface of the tubular including tubular fluid passageway **222**. Depending upon the sealing therebetween, this may result in a complete shut off of flow through fluid flow control device **200**. In some instances a complete closedown of production is not wanted. In the illustrated embodiment an incomplete seal is created between sliding sleeve **228** and tubular fluid passageway **222**. In this manner, the actuation of actuator **226** creates an increased restriction to flow, without completely preventing flow. Thus, some of unwanted fluid **240** is permitted to flow through openings **236** into base pipe **218**.

[0049] Actuator **226** is formed from a material that expands when it comes in contact with an activating agent. In an autonomous implementation of fluid flow control device **200**, undesired fluid **240** serves as the activating agent. As best seen in FIG. **3**B, once actuator **226** is exposed to the activating agent, actuator **226** swells to longitudinally shift sliding sleeve **228**. Once this operation is complete, actuator **226** retains the activating fluid therein. As a result, after actuator **226** has transformed from its unswelled state (FIG. **3**A) to its swelled state (FIG. **3**B), actuator **226** retains its expanded size. If required, full access through fluid flow control device **200** can be reestablished via removal of plug **242**. Alternatively, in certain embodiments, actuator **226** may be deactivated upon removal of the activating agent from contact with actuator **226**. Alternatively or additionally, an outer skin may be applied to actuator **226** prior to installation that protects actuator **226** from premature actuation.

[0050] Referring next to FIGS. **4**A-**4**B, therein is depicted a fluid flow control device according to the present invention that is representatively illustrated and generally designated **300**. Fluid flow control device **300** includes a sand control screen section **302** and a flow restrictor section **304**. Sand control screen section **302** includes a suitable sand control screen element or filter medium. In the illustrated embodiment, a protective outer shroud **306** having a plurality of perforations **308** is positioned around the exterior of the filter medium.

[0051] Flow restrictor section **304** is configured in series with sand control screen section **302** such that fluid must pass through sand control screen section **302** prior to entering flow restrictor section **304**. Flow restrictor section **304** includes an outer housing **310**. Outer housing **310** defines an annular chamber **312** and an annular chamber **314** with base pipe **318**. Disposed at least partially within annular chamber **314** is a valve assembly **320**. Valve assembly **320** includes a tubular fluid passageway **322**, a support member **324**, an actuator **326** and a support member **330**.

[0052] As best seen in FIG. **4**A, tubular fluid passageway **322** serves as a flow restrictor to control fluid flow through fluid flow control device **300** when a desired fluid **334** is being produced. As illustrated, once desired fluid **334** enters flow restrictor section **304**, desired fluid **334** passes through annular chamber **312** and encounters tubular fluid passageway **322** which restricts the flow of desired fluid **334**. After passing through tubular fluid passageway **322**, desired fluid **334** enters annular chamber **314** before passing into base pipe **318** via openings **336** for transport to the surface.

[0053] As best seen in FIG. **4**B, when an undesired fluid **340** is produced, valve assembly **320** is actuated to its closed or choking position. In the illustrated embodiment, this actuation is achieved by longitudinally shifting the tubular that defines tubular fluid passageway **222** such that it comes in contact with support member **330**. Depending upon the sealing therebetween, this may result in a complete shut off of flow through fluid flow control device **300**. In some instances a complete closedown of production is not wanted. In the illustrated embodiment an incomplete seal is created between the tubular and support member **330**. In this manner, the actuation of actuator **326** creates an increased restriction to flow, without completely preventing flow. Thus, some of unwanted fluid **340** is permitted to flow through openings **336** into base pipe **318**.

[0054] Actuator **326** is formed from a material that expands when it comes in contact with an activating agent. In an autonomous implementation of fluid flow control device **300**, undesired fluid **340** serves as the activating agent. As best seen in FIG. **4**B, once actuator **326** is exposed to the activating agent, actuator **326** swells to longitudinally shift the tubular. Once this operation is complete, actuator **326** retains the activating fluid therein. As a result, after actuator **326** has transformed from its unswelled state (FIG. **4**A) to its swelled state (FIG. **4**B), actuator **326** retains its expanded size. If required, full access through fluid flow control device **300** can be reestablished via removal of plug **342**. Alternatively, in certain embodiments, actuator **326** may be deactivated upon removal of the activating agent from contact with actuator **326**. Alternatively or additionally, an outer skin may be applied to actuator **326** prior to installation that protects actuator **326** from premature actuation.

[0055] Referring next to FIGS. **5**A-**5**B, therein is depicted a fluid flow control device according to the present invention that is representatively illustrated and generally designated **400**. Fluid flow control device **400** includes a sand control screen section **402** and a flow restrictor section **404**. Sand control screen section **402** includes a suitable sand control screen element or filter medium. In the illustrated embodiment, a protective outer shroud **406** having a plurality of perforations **408** is positioned around the exterior of the filter medium.

[0056] Flow restrictor section **404** is configured in series with sand control screen section **402** such that fluid must pass through sand control screen section **402** prior to entering flow restrictor section **404**. Flow restrictor section **404** includes an outer housing **410**. Outer housing **410** defines an annular chamber **412** and an annular chamber **414** with base pipe **418**. Disposed at least partially within annular chamber **414** is a valve assembly **420**. Valve assembly **420** includes a tubular fluid passageway **422**, a support member **424**, an actuator **426**, a plunger **428** and a support member **430**.

[0057] As best seen in FIG. **5**A, tubular fluid passageway **422** serves as a flow restrictor to control fluid flow through

fluid flow control device **400** when a desired fluid **434** is being produced. As illustrated, once desired fluid **434** enters flow restrictor section **404**, desired fluid **434** passes through annular chamber **412** and encounters tubular fluid passageway **422** which restricts the flow of desired fluid **434**. After passing through tubular fluid passageway **422**, desired fluid **434** enters annular chamber **414** before passing into base pipe **418** via openings **436** for transport to the surface.

[0058] As best seen in FIG. **5**B, when an undesired fluid **440** is produced, valve assembly **420** is actuated to its closed or choking position. In the illustrated embodiment, this actuation is achieved by longitudinally shifting plunger **428** such that it comes in contact with a seat in support member **424**. Depending upon the sealing therebetween, this may result in a complete shut off of flow through fluid flow control device **400**, as illustrated, or may result in an incomplete seal creating only an increased restriction to flow without completely preventing flow.

[0059] Actuator **426** is formed from a material that expands when it comes in contact with an activating agent. In an autonomous implementation of fluid flow control device **400**, undesired fluid **440** serves as the activating agent. As best seen in FIG. **5**B, once actuator **426** is exposed to the activating agent, actuator **426** swells to longitudinally shift plunger **428**. Once this operation is complete, actuator **426** retains the activating fluid therein. As a result, after actuator **426** has transformed from its unswelled state (FIG. **5**A) to its swelled state (FIG. **5**B), actuator **426** retains its expanded size. If required, full access through fluid flow control device **400** can be reestablished via removal of plug **442**. Alternatively, in certain embodiments, actuator **426** may be deactivated upon removal of the activating agent from contact with actuator **426**. Alternatively or additionally, an outer skin may be applied to actuator **426** prior to installation that protects actuator **426** from premature actuation.

[0060] Depended upon the specific composition of the actuator, the swelling of the actuator may be related to the proportion of the undesired fluid in the production fluid stream. For example, using certain embodiments of the fluid flow control device of the present invention enables the progressive restriction of flow through the fluid flow control device as the proportion of water production increases. While the water cut is small, the material of the actuator may only swell a little such that the increase in the restriction to flow is only slight. As the water cut increase, the material of the actuator may increasingly swell, thereby creating a greater restriction to flow. Once the water proportion reaches a predetermined level, the material of actuator **426** swells to longitudinally shift plunger **428** such that it comes in contact with a seat in support member **424**, as described above.

[0061] Referring next to FIGS. **6**A-**6**B, therein is depicted a fluid flow control device according to the present invention that is representatively illustrated and generally designated **500**. Fluid flow control device **500** includes a sand control screen section **502** and a flow restrictor section **504**. Sand control screen section **502** includes a suitable sand control screen element or filter medium. In the illustrated embodiment, a protective outer shroud **506** having a plurality of perforations **508** is positioned around the exterior of the filter medium.

[0062] Flow restrictor section **504** is configured in series with sand control screen section **502** such that fluid must pass through sand control screen section **502** prior to entering flow restrictor section **504**. Flow restrictor section **504** includes an outer housing **510**. Outer housing **510** defines an annular chamber **512**, an annular chamber **514** and an annular chamber **516** with base pipe **518**. Disposed between annular chamber **512** and annular chamber **514** is a valve assembly **520**. Valve assembly **520** includes a support member **524** and an actuator **526**. Disposed between annular chamber **514** and annular chamber **516** is a tubular fluid passageway **522** and a support member **528**.

[0063] As best seen in FIG. **6**A, tubular fluid passageway **522** serves as a flow restrictor to control fluid flow through fluid flow control device **500** when a desired fluid **534** is being produced. As illustrated, once desired fluid **534** enters flow restrictor section **504**, desired fluid **534** passes through annular chamber **512**, valve assembly **520** and annular chamber **514** then encounters tubular fluid passageway **522** which restricts the flow of desired fluid **534**. After passing through tubular fluid passageway **522**, desired fluid **534** enters annular chamber **516** before passing into base pipe **518** via openings **536** for transport to the surface.

[0064] As best seen in FIG. **6**B, when an undesired fluid **540** is produced, valve assembly **520** is actuated to its closed or choking position. In the illustrated embodiment, this actuation is achieved by radial expansion of actuator **526** which reduces the area of the flow path through valve assembly **520**. Depending upon the extent of the radial expansion of actuator **526**, this may result in a complete shut off of flow through fluid flow control device **500**. In some instances a complete closedown of production is not wanted. In the illustrated embodiment, a relative small passageway exists within valve assembly **520**. In this manner, the actuation of actuator **526** creates an increased restriction to flow, without completely preventing flow. Thus, some of unwanted fluid **540** is permitted to flow through valve assembly **520**, annular chamber **514**, tubular fluid passageway **522**, annular chamber **516** and openings **536** into base pipe **518**.

[0065] Actuator **526** is formed from a material that expands when it comes in contact with an activating agent. In an autonomous implementation of fluid flow control device **500**, undesired fluid **540** serves as the activating agent. As best seen in FIG. **6**B, once actuator **526** is exposed to the activating agent, actuator **526** swells to create a flow restriction. Once this operation is complete, actuator **526** retains the activating fluid therein. As a result, after actuator **526** has transformed from its unswelled state (FIG. **6**A) to its swelled state (FIG. **6**B), actuator **526** retains its expanded size. If required, full access through fluid flow control device **500** can be reestablished via removal of plug **542**. Alternatively, in certain embodiments, actuator **526** may be deactivated upon removal of the activating agent from contact with actuator **526**. Alternatively or additionally, an outer skin may be applied to actuator **526** prior to installation that protects actuator **526** from premature actuation.

[0066] As noted above, the fluid flow control devices of the present invention may have more that one valve assembly positioned in the flow restrictor section thereof. In the illustrated embodiment of FIGS. **6**A-**6**B, it is particularly desirable to have multiple valve assemblies **520** as the valve assemblies can operate as fluid discriminators. Specifically, in certain flow conditions wherein the fluid being produced includes both the desired fluid and undesired fluid and wherein these component are stratified within fluid flow control device **500**, valve assemblies **520** can operate independently of one another to preferentially reduce the production of the undesired fluid relative to the desired fluid. In the case

of a production fluid containing both oil and water, stratification of this production fluid may result in the oil component being above the water component within annular chamber **512**. As the water component is the activating agent to actuate valve members **520**, only the valve members being exposed to the water, those to the bottom of fluid flow control device **500**, will be actuated. This results in a preferential production of oil through the unactuated valve assemblies **520**. Likewise, in the case of a production fluid containing both oil and gas, stratification of this production fluid results in the gas component being above the oil component within annular chamber **512**. If the gas component is the activating agent to actuate valve members **520**, only the valve members being exposed to the gas, those to the top of fluid flow control device **500**, will be actuated. This results in a preferential production of oil through the unactuated valve assemblies **520**.

[0067] Referring next to FIGS. **7**A-**7**B, therein is depicted a fluid flow control device according to the present invention that is representatively illustrated and generally designated **600**. Fluid flow control device **600** includes a sand control screen section **602** and a flow restrictor section **604**. Sand control screen section **602** includes a suitable sand control screen element or filter medium. In the illustrated embodiment, a protective outer shroud **606** having a plurality of perforations **608** is positioned around the exterior of the filter medium.

[0068] Flow restrictor section **604** is configured in series with sand control screen section **602** such that fluid must pass through sand control screen section **602** prior to entering flow restrictor section **604**. Flow restrictor section **604** includes an outer housing **610**. Outer housing **610** defines an annular chamber **612** and an annular chamber **614** with base pipe **618**. Disposed between annular chamber **612** and annular chamber **614** is a valve assembly **620**. Valve assembly **620** includes a tubular fluid passageway **622**, a support member **624** and an actuator **626**.

[0069] As best seen in FIG. **7**A, tubular fluid passageway **622** serves as a flow restrictor to control fluid flow through fluid flow control device **600** when a desired fluid **634** is being produced. As illustrated, once desired fluid **634** enters flow restrictor section **604**, desired fluid **634** passes through tubular fluid passageway **622** which restricts the flow of desired fluid **634**. After passing through tubular fluid passageway **622**, desired fluid **634** enters annular chamber **614** before passing into base pipe **618** via openings **636** for transport to the surface.

[0070] As best seen in FIG. **7**B, when an undesired fluid **640** is produced, valve assembly **620** is actuated to its closed or choking position. In the illustrated embodiment, this actuation is achieved by radial expansion of actuator **626** which radially compresses tubular fluid passageway **622** and reduces the area of the flow path through tubular fluid passageway **622**. Depending upon the extent of the radial expansion of actuator **626**, this may result in a complete shut off of flow through fluid flow control device **600**. In some instances a complete closedown of production is not wanted. In the illustrated embodiment a relatively small passageway exists through tubular fluid passageway **622**. In this manner, the actuation of actuator **626** creates an increased restriction to flow, without completely preventing flow. Thus, some of unwanted fluid **640** is permitted to flow through tubular fluid passageway **622** into annular chamber **614** through openings **636** into base pipe **618**.

[0071] Actuator **626** is formed from a material that expands when it comes in contact with an activating agent. In an autonomous implementation of fluid flow control device **600**, undesired fluid **640** serves as the activating agent. As best seen in FIG. **7**B, once actuator **626** is exposed to the activating agent, actuator **626** swells to increase the flow restriction of tubular fluid passageway **622**. Once this operation is complete, actuator **626** retains the activating fluid therein. As a result, after actuator **626** has transformed from its unswelled state (FIG. **7**A) to its swelled state (FIG. **7**B), actuator **626** retains its expanded size. If required, full access through fluid flow control device **600** can be reestablished via removal of plug **642**. Alternatively, in certain embodiments, actuator **626** may be deactivated upon removal of the activating agent from contact with actuator **626**. Alternatively or additionally, an outer skin may be applied to actuator **626** prior to installation that protects actuator **626** from premature actuation.

[0072] Referring next to FIGS. **8**A-**8**B, therein is depicted a fluid flow control device according to the present invention that is representatively illustrated and generally designated **700**. Fluid flow control device **700** includes a sand control screen section **702** and a flow restrictor section **704**. Sand control screen section **702** includes a suitable sand control screen element or filter medium. In the illustrated embodiment, a protective outer shroud **706** having a plurality of perforations **708** is positioned around the exterior of the filter medium.

[0073] Flow restrictor section **704** is configured in series with sand control screen section **702** such that fluid must pass through sand control screen section **702** prior to entering flow restrictor section **704**. Flow restrictor section **704** includes an outer housing **710**. Outer housing **710** defines an annular chamber **712** and an annular chamber **714** with base pipe **718**. Disposed at least partially within annular chamber **714** is a valve assembly **720**. Valve assembly **720** includes a tubular fluid passageway **722**, a support member **724**, a sliding sleeve **728** and a support member **730**. Valve assembly **720** also includes an actuation system including actuator **726** and biasing member **732**.

[0074] As best seen in FIG. **8**A, tubular fluid passageway **722** serves as a flow restrictor to control fluid flow through fluid flow control device **700** when a desired fluid **734** is being produced. As illustrated, once desired fluid **734** enters flow restrictor section **704**, desired fluid **734** passes through annular chamber **712** and encounters tubular fluid passageway **722** which restricts the flow of desired fluid **734**. After passing through tubular fluid passageway **722**, desired fluid **734** enters the interior of sliding sleeve **728**, passes through openings **736** into annular chamber **714** before passing into base pipe **718** via openings **738** for transport to the surface.

[0075] As best seen in FIG. **8**B, when an undesired fluid **740** is produced, valve assembly **720** is actuated to its closed or choking position. In the illustrated embodiment, this actuation is achieved by longitudinally shifting sliding sleeve **728** such that openings **736** are blocked by the outer surface of the tubular including tubular fluid passageway **722**. Depending upon the sealing therebetween, this may result in a complete shut off of flow through fluid flow control device **700**. In some instances a complete closedown of production is not wanted. In the illustrated embodiment an incomplete seal is created between sliding sleeve **728** and tubular fluid passageway **722**. In this manner, the actuation of actuator **726** creates an increased restriction to flow, without completely preventing

flow. Thus, some of unwanted fluid **740** is permitted to flow through openings **738** into base pipe **718**.

[0076] Actuator **726** is formed from a composite material that includes a plurality of pellets of a material that expands when it comes in contact with an activating agent in an epoxy matrix. In an autonomous implementation of fluid flow control device **700**, undesired fluid **740** serves as the activating agent. As best seen in FIG. **8**B, once actuator **726** is exposed to the activating agent, the swellable pellets of actuator **726** swell and break the epoxy matrix which allows the biasing force of biasing member **732** to longitudinally shift sliding sleeve **728**. Once this operation is complete, full access through fluid flow control device **700** can be reestablished via removal of plug **742**.

[0077] While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

1. A sand control screen positionable within a wellbore, the sand control screen comprising:
- a base pipe having at least one opening that allows fluid flow between an exterior of the base pipe and an interior flow path of the base pipe;
- a filter medium positioned exteriorly of the base pipe, the filter medium selectively allowing fluid flow therethrough and preventing particulate flow of a predetermined size therethrough; and
- a flow restricting device operably positioned in a fluid flow path between the filter medium and the at least one opening, the flow restricting device including a valve and an actuator, the actuator including a material that swells in response to contact with an undesired fluid such that the flow restricting device is operable to autonomously reduce the fluid flow through the screen in response to contact between the material and the undesired fluid.

2. The sand control screen as recited in claim **1** wherein the fluid flow through the screen is increasingly restricted in response to contact between the material and the undesired fluid.

3. The sand control screen as recited in claim **1** wherein the fluid flow through the screen is substantially completely restricted in response to contact between the material and the undesired fluid.

4. The sand control screen as recited in claim **1** wherein the undesired fluid is water.

5. The sand control screen as recited in claim **1** wherein the undesired fluid is gas.

6. The sand control screen as recited in claim **1** wherein the valve further comprises a sliding sleeve.

7. The sand control screen as recited in claim **1** wherein the valve further comprises a longitudinally shiftable valve element.

8. The sand control screen as recited in claim **1** wherein the valve further comprises a valve element having a fluid flow passageway with a cross sectional area that is reduced in response to contact between the material and the undesired fluid.

9. The sand control screen as recited in claim **1** wherein the actuator further comprises a biasing member that biases a valve element in a first direction and wherein the material prevents movement of the valve element in the first direction until the material is contacted by the undesired fluid.

10. The sand control screen as recited in claim **1** wherein the material remains in a swelled state as long as the material stays in contact with the undesired fluid and returns to an unswelled state when contact with the undesired fluid ceases.

11. A flow control apparatus for controlling the inflow of production fluids from a subterranean well, the flow control apparatus comprising:
- a tubular member having at least one opening that allows fluid flow between an exterior of the tubular member and an interior flow path of the tubular member; and
- a flow restricting device operably positioned in a fluid flow path between a fluid source and the at least one opening, the flow restricting device including a valve and an actuator, the actuator including a material that swells in response to contact with an undesired fluid such that the flow restricting device is operable to autonomously reduce the fluid flow through the flow control apparatus in response to contact between the material and the undesired fluid.

12. The flow control apparatus as recited in claim **11** wherein the fluid flow through the flow control apparatus is increasingly restricted in response to contact between the material and the undesired fluid.

13. The flow control apparatus as recited in claim **11** wherein the fluid flow through the flow control apparatus is substantially completely restricted in response to contact between the material and the undesired fluid.

14. The flow control apparatus as recited in claim **11** wherein the undesired fluid is water.

15. The flow control apparatus as recited in claim **11** wherein the undesired fluid is gas.

16. The flow control apparatus as recited in claim **11** wherein the valve further comprises a sliding sleeve.

17. The flow control apparatus as recited in claim **11** wherein the valve further comprises a longitudinally shiftable valve element.

18. The flow control apparatus as recited in claim **11** wherein the valve further comprises a valve element having a fluid flow passageway with a cross sectional area that is reduced in response to contact between the material and the undesired fluid.

19. The flow control apparatus as recited in claim **11** wherein the actuator further comprises a biasing member that biases a valve element in a first direction and wherein the material prevents movement of the valve element in the first direction until the material is contacted by the undesired fluid.

20. The flow control apparatus as recited in claim **11** wherein the material remains in a swelled state as long as the material stays in contact with the undesired fluid and returns to an unswelled state if contact with the undesired fluid ceases.

21. A sand control completion for installation in a wellbore, the completion comprising:
- first and second seal assemblies that define a production zone in the wellbore; and
- a sand control screen operably positioned between the first and second seal assemblies, the sand control screen comprising a base pipe having at least one opening that

allows fluid flow between an exterior of the base pipe and an interior flow path of the base pipe, a filter medium positioned exteriorly of the base pipe, the filter medium selectively allowing fluid flow therethrough and preventing particulate flow of a predetermined size therethrough and a flow restricting device operably positioned in a fluid flow path between the filter medium and the at least one opening, the flow restricting device including a valve and an actuator, the actuator including a material that swells in response to contact with an undesired fluid such that the flow restricting device is operable to autonomously reduce the fluid flow through from the production zone in response to contact between the material and the undesired fluid.

22. A multizone sand control completion for installation in a wellbore, the completion comprising:

at least two sets of first and second seal assemblies that define at least two production zones in the wellbore; and

a sand control screen positioned between each of the first and second seal assemblies, each of the sand control screens comprising a base pipe having at least one opening that allows fluid flow between an exterior of the base pipe and an interior flow path of the base pipe, a filter medium positioned exteriorly of the base pipe, the filter medium selectively allowing fluid flow therethrough and preventing particulate flow of a predetermined size therethrough and a flow restricting device operably positioned in a fluid flow path between the filter medium and the at least one opening, the flow restricting device including a valve and an actuator, the actuator including a material that swells in response to contact with an undesired fluid such that each of the flow restricting devices is operable to autonomously reduce the fluid flow from a respective production zone in response to contact between the material and the undesired fluid.

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