

SINGLE TRIP MULTI-ZONE COMPLETION SYSTEMS AND METHODS**BACKGROUND**

[0001] The present invention relates to the treatment of subterranean production intervals and, more particularly, to gravel packing, fracturing, and production of multiple production intervals with a single trip multi-zone completion system.

[0002] In the production of oil and gas, recently drilled deep wells reach as much as 31,000 feet or more below the ground or subsea surface. Offshore wells may be drilled in water exhibiting depths of as much as 10,000 feet or more. The total depth from an offshore drilling vessel to the bottom of a drilled wellbore can be in excess of six miles. Such extraordinary distances in modern well construction cause significant challenges in equipment, drilling, and servicing operations.

[0003] For example, tubular strings are introduced into a well in a variety of different ways. It may take many days for a wellbore service string to make a "trip" into a wellbore, which may be due in part to the time consuming practice of making and breaking pipe joints to reach the desired depth. Moreover, the time required to assemble and deploy any service tool assembly downhole for such a long distance is very time consuming and costly. Since the cost per hour to operate a drilling or production rig is very expensive, saving time and steps can be hugely beneficial in terms of cost-savings in well service operations. Each trip into the wellbore adds expense and increases the possibility that tools may become lost in the wellbore, thereby requiring still further operations for their retrieval. Moreover, each additional trip into the wellbore oftentimes has the effect of reducing the inner diameter of the wellbore, which restricts the size of tools that are able to be introduced into the wellbore past such points.

[0004] To enable the fracturing and/or gravel packing of multiple hydrocarbon-producing zones in reduced timelines, some oil service providers have developed "single trip" multi-zone systems. The single trip multi-zone completion technology enables operators to perforate a large wellbore interval at one time, then make a clean-out trip and run all of the screens and packers at one time, thereby minimizing the number of trips into the wellbore and rig days required to complete conventional fracture and gravel packing operations in

multiple pay zones. It is estimated that such technology can save in the realm of \$20 million per well in deepwater completions. Since rig costs are so high in the deepwater environment, more efficient and economical means of carrying out single trip multi-zone completion operations is an ongoing effort.

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SUMMARY OF THE INVENTION

[0005] The present invention relates to the treatment of subterranean production intervals and, more particularly, to gravel packing, fracturing, and production of multiple production intervals with a single trip multi-zone completion system.

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[0006] In some embodiments, a single trip multi-zone completion system is disclosed. The system may include an outer completion string having at least one sand screen arranged thereabout and an interval control valve coupled to the at least one sand screen, a production tubing communicably coupled to the outer completion string at a crossover coupling, a control line extending external to the production tubing and being communicably coupled to the crossover coupling, and a surveillance line extending from the crossover coupling external to the outer completion string and interposing the at least one formation zone and the at least one sand screen, the surveillance line being communicably coupled to the interval control valve.

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[0007] In other embodiments, a method of producing from one or more formation zones is disclosed. The method may include arranging an outer completion string within a wellbore adjacent the one or more formation zones, the outer completion string having at least one sand screen arranged thereabout and an interval control valve coupled to the at least one sand screen, communicably coupling a production tubing to the completion string at a crossover coupling having one or more control lines extending thereto, communicably coupling a surveillance line to the one or more control lines at the crossover coupling, the surveillance line extending from the crossover coupling external to the outer completion string and interposing the one or more formation zones and the at least one sand screen, and actuating the at least one interval control valve to initiate production into the outer completion string, the at least one interval control valve being communicably coupled to the surveillance line.

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[0008] In yet other embodiments, a method of deploying a single trip multi-zone completion system is disclosed. The method may include locating an

inner service tool within an outer completion string arranged within a wellbore that penetrates one or more formation zones, the outer completion string having at least one sand screen arranged thereabout and an interval control valve coupled to the at least one sand screen, treating the one or more formation zones with the inner service tool, wherein a surveillance line extends external to the outer completion string and interposes the one or more formation zones and the at least one sand screen, retrieving the inner service tool from within the outer completion string, communicably coupling a production tubing to the completion string at a crossover coupling having one or more control lines extending thereto, communicably coupling the surveillance line to the one or more control lines at the crossover coupling, and actuating the at least one interval control valve to initiate production into the outer completion string, the at least one interval control valve being communicably coupled to the surveillance line.

[0009] The features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of the preferred embodiments that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The following figures are included to illustrate certain aspects of the present invention, and should not be viewed as exclusive embodiments. The subject matter disclosed is capable of considerable modifications, alterations, combinations, and equivalents in form and function, as will occur to those skilled in the art and having the benefit of this disclosure.

[0011] FIG. 1 is an exemplary single trip multi-zone completion system, according to one or more embodiments.

[0012] FIG. 2 illustrates a partial cross-sectional view of the single trip multi-zone completion system of FIG. 1 with an exemplary production tubing associated therewith, according to one or more embodiments.

DETAILED DESCRIPTION

[0013] The present invention relates to the treatment of subterranean production intervals and, more particularly, to gravel packing, fracturing, and production of multiple production intervals with a single trip multi-zone completion system.

[0014] The exemplary single trip multi-zone systems and methods disclosed herein allow multiple zones of a wellbore to be gravel packed and

fractured in the same run-in trip into the wellbore. An exemplary production tubing may be extended into an outer completion string configured to regulate and monitor production from each production interval. A control line extends along the sand face pack and allows operators to monitor production operations, including measuring fluid and well environment parameters at each point within the system. The control line also allows the operator to manipulate one or more flow control devices, thereby serving to regulate the production flow rate through associated sand screens. As a result, hydrocarbons present in each production interval may be intelligently produced. The flow control devices may be arranged within a corresponding sand screen, and therefore not restrict the inner diameter of the completion string. This maximizes the flow rate potential within the completion string as coupled to the production tubing that extends from the surface.

[0015] Referring to FIG. 1, illustrated is an exemplary single trip multi-zone completion system 100, according to one or more embodiments. As illustrated, the system 100 may include an outer completion string 102 that may be coupled to a work string 104 that is extended longitudinally within a wellbore 106. The wellbore 106 may penetrate multiple formation zones 108a, 108b, and 108c, and the outer completion string 102 may be extended into the wellbore 106 until being arranged or otherwise disposed generally adjacent the formation zones 108a-c. The formation zones 108a-c may be portions of a common subterranean formation or hydrocarbon-bearing reservoir. Alternatively, one or more of the formation zones 108a-c may be portion(s) of separate subterranean formations or hydrocarbon-bearing reservoirs. Although only three formation zones 108a-c are depicted in FIG. 1, it will be appreciated that any number of formation zones 108a-c (including one) may be treated or otherwise serviced using the system 100, without departing from the scope of the disclosure. Moreover, the term "zone" as used herein, is not limited to one type of rock formation or type, but may include several types, without departing from the scope of the disclosure.

[0016] As is depicted in FIG. 1, the wellbore 106 may be lined with a string of casing 110 and properly cemented therein, as known in the art. In at least one embodiment, a cement plug 112 may be formed at the bottom of the casing 110. In other embodiments, however, the system 100 may be deployed or otherwise operated in an open-hole section of the wellbore 106, without

departing from the scope of the disclosure. As will be discussed in greater detail below, the completion string 102 may be deployed or otherwise set within the wellbore 106 in a single trip and used to hydraulically fracture ("frack") and gravel pack the various production intervals or formation zones 108a-c, and subsequently intelligently regulate hydrocarbon production from each production interval.

[0017] Prior to deploying the system 100 in the wellbore 106, however, a sump packer 114 may be lowered into the wellbore 106 and set by wire line at a predetermined location below the various formation zones 108a-c. One or more perforations 116 may be then be formed in the casing 110 at each formation zone 108a-c. The perforations 116 may provide fluid communication between each respective formation zone 108a-c and the annulus formed between the outer completion string 102 and the casing 110. Particularly, a first annulus 118a may be generally defined between the first formation zone 108c and the outer completion string 102. Second and third annuli 118b and 118c may similarly be defined between the second and third formation zones 108b and 108c, respectively, and the outer completion string 102.

[0018] The outer completion string 102 may have a top packer 120 including slips (not shown) configured to support the outer completion string 102 within the casing 110 when properly deployed adjacent the production intervals. In some embodiments, the top packer 120 may be a VERSA-TRIEVE® hangar packer commercially available from Halliburton Energy Services of Houston, Texas, USA. Disposed below the top packer 120 may be one or more isolation packers 122 (two shown), one or more circulating sleeves 124 (three shown in dashed), and one or more sand screens 126 (three shown).

[0019] Specifically, arranged below the top packer 120 may be a first circulating sleeve 124a (shown in dashed) and a first sand screen 126a. A first isolation packer 122a may be disposed below the first sand screen 126a, and a second circulating sleeve 124b (shown in dashed) and a second sand screen 126b may be disposed below the first isolation packer 122a. A second isolation packer 122b may be disposed below the second sand screen 126b, and a third circulating sleeve 124c (shown in dashed) and a third sand screen 126c may be disposed below the second isolation packer 122b. Those skilled in the art will readily recognize that more isolation packers 122, circulating sleeves 124, and

sand screens 126 may be employed, without departing from the disclosure, and depending on the length and number of production intervals desired.

[0020] Each circulating sleeve 124a-c may be movably arranged within the completion string 102 and configured to axially translate between open and closed positions. Although described herein as movable sleeves, those skilled in the art will readily recognize that each circulating sleeve 124a-c may be any type of flow control device, without departing from the scope of the disclosure. First, second, and third ports 128a, 128b, and 128c may be defined in the outer completion string 102 at the first, second, and third circulating sleeves 124a-c, respectively. When the circulating sleeves 124a-c are moved into their respective open positions, the ports 128a-c are opened or otherwise incrementally exposed and may thereafter provide fluid communication between the interior of the completion string 102 and the corresponding annuli 118a-c.

[0021] Each sand screen 126a-c may include a corresponding flow control device 130a, 130b, and 130c (shown in dashed) movably arranged therein and also configured to axially translate between open and closed positions. In some embodiments, each flow control device 130a-c may be characterized as a sleeve, such as a sliding sleeve that is axially translatable within its associated sand screen 126a-c. As will be discussed in greater detail below, each flow control device 130a-c may be moved or otherwise manipulated in order to facilitate fluid communication between the formation zones 108a-c and the outer completion string 102 via the corresponding sand screens 126a-c. As a result, the flow control devices 130a-c may be characterized as or otherwise form part of an associated interval control valve.

[0022] In order to deploy the outer completion string 102 within the wellbore 106, it may first be assembled at the surface starting from the bottom up until it is completely assembled and suspended in the wellbore 106 up to a packer or slips arranged at the surface. The completion string 102 may then be lowered into the wellbore 102 on the work string 104, which is generally made up to the top packer 120. In some embodiments, the outer completion string 102 is lowered into the wellbore 106 until engaging the sump packer 114. In other embodiments, the outer completion string 102 may be lowered into the wellbore 106 and stung into the sump packer 114. In yet other embodiments, the sump packer 114 is omitted from the system 100 and the completion string 102 may instead be blanked off at its bottom end so that there is no inadvertent

production directly into the outer completion string 102 without first passing through at least the third sand screen 126c.

[0023] Upon aligning the sand screens 126a-c with the corresponding production zones 108a-c, the top packer 120 may be set and serves to suspend the outer completion string 102 within the wellbore 106. The isolation packers 122a,b may also be set at this time, thereby axially defining each annulus 118a-c and further defining the individual production intervals corresponding to the various formation zones 108a-c.

[0024] At this point, an inner service tool (not shown), also known as a gravel pack service tool, may be assembled and lowered into the outer completion string 102 on a work string (not shown) made up of drill pipe or tubing. The inner service tool is positioned in the first zone to be treated, *e.g.*, the third production interval or formation zone 108c. The inner service tool may include one or more shifting tools (not shown) used to open and/or close the circulating sleeves 124a-c and the flow control devices 130a-c. In some embodiments, for example, the inner service tool has two shifting tools arranged thereon or otherwise associated therewith; one shifting tool configured to open the circulating sleeves 124a-c and the flow control devices 130a-c, and a second shifting tool configured to close the circulating sleeves 124a-c and flow control devices 130a-c. In other embodiments, more or less than two shifting tools may be used, without departing from the scope of the disclosure. In yet other embodiments, the shifting tools may be omitted entirely from the inner service tool and instead the circulating sleeves 124a-c and flow control devices 130a-c may be remotely actuated, such as by using actuators, solenoids, pistons, and the like.

[0025] Before producing hydrocarbons from the various formation zones 108a-c penetrated by the outer completion string 102, each formation zone 108a-c may be hydraulically fractured in order to enhance hydrocarbon production, and each annulus 118a-c may also be gravel packed to ensure limited sand production into the completion string 102 during production. The fracturing and gravel packing processes for the outer completion string 102 may be accomplished sequentially or otherwise in step-wise fashion for each individual formation zone 108a-c, starting from the bottom of the completion string 102 and proceeding in an uphole direction (*i.e.*, toward the surface of the well).

[0026] In one embodiment, for example, the third production interval or formation zone 108c may be fractured and the third annulus 118c may be gravel packed prior to proceeding sequentially to the second and first formation zones 108b and 108a. The third annulus 118c may be defined generally in the axial direction between the sump packer 114 and the second isolation packer 122b. The one or more shifting tools associated with the inner service tool may be used to open the third circulating sleeve 124c and the third flow control device 130c disposed within the third sand screen 126c. In other embodiments, the third circulating sleeve 124c and/or flow control device 130c may be remotely actuated (*i.e.*, hydraulically, electromechanically, etc.) using actuators, solenoids, pistons, or the like, without departing from the scope of the disclosure.

[0027] A fracturing fluid may then be pumped down the work string and into the inner service tool. In some embodiments, the fracturing fluid may include a base fluid, a viscosifying agent, proppant particulates (including a gravel slurry), and one or more additives, as generally known in the art. The incoming fracturing fluid may be directed out of the outer completion string 102 and into the third annulus 118c via the third port 128c. Continued pumping of the fracturing fluid forces the fracturing fluid into the third formation zone 108c through the perforations 116 in the casing string 110, thereby creating, enhancing and extending a fracture network therein while the accompanying proppant serves to support the fracture network in an open configuration. The incoming gravel slurry builds in the annulus 118c between the sump packer 114 and the second isolation packer 122b and begins to form what is referred to as a "sand face" pack. The sand face pack, in conjunction with the third sand screen 126c, serves to prevent the influx of sand or other particulates from the third formation zone 108c into the outer completion string 102 during production operations.

[0028] Once a desired net pressure is built up in the third formation zone 108c, the fracturing fluid injection rate is stopped. The inner service tool is then axially moved to position in the reverse position and a return flow of fracturing fluid flows through the work string 104 in order to reverse out any excess proppant that may remain in the work string 104. When the proppant is successfully reversed, the third circulating sleeve 124c and the third flow control device 130c are closed using, for example, the one or more shifting tools, and

the third annulus 118c is then pressure tested to verify that the corresponding circulating sleeve 124c and flow control device 130c are properly closed. At this point, the third formation zone 108c has been successfully fractured and the third annulus 118c has been gravel packed.

5 **[0029]** The inner service tool (*i.e.*, the gravel pack service tool) may then be axially moved within the outer completion string 102 to locate the second formation zone 108b and the first formation zone 108a, successively, where the foregoing process is repeated in order to fracture the first and second formation zones 108a,b and gravel pack the first and second annuli 118a,b. The
10 second annulus 118b may be generally defined in the axial direction between the first and second isolation packers 122a,b. Upon locating the second production interval or formation zone 108b, the one or more shifting tools (or remotely actuated actuators, pistons, solenoids, etc.) may be used to open the second circulating sleeve 124b and flow control device 130b. Fracturing fluid may then
15 be pumped into the inner service tool and directed into the second annulus 118b via the second port 128b. The injected fracturing fluid generates and extends a fracture network into the second formation zone 108b via the perforations 116 in the casing string 110, and the gravel slurry adds to the sand face pack in the second annulus 118b between the first and second isolation packers 122a,b.

20 **[0030]** Once the second annulus 118b is pressure tested, the inner service tool (*i.e.*, the gravel pack service tool) may then be axially moved to locate the first formation zone 108a and again repeat the foregoing process. The first annulus 118a may be generally defined in the axial direction between the top packer 120 and the first isolation packer 122a. Upon locating the first
25 production interval or formation zone 108a, the one or more shifting tools (or remotely actuated actuators, pistons, solenoids, etc.) may be used to open the first circulating sleeve 124a and flow control device 130a, and fracturing fluid is subsequently pumped into the inner service tool and directed into the first annulus 118a via the first port 128a. The injected fracturing fluid generates and
30 extends a fracture network into the first formation zone 108a via the perforations 116 in the casing string 110, and the gravel slurry adds gravel pack to the sand face pack in the first annulus 118a. Once the first annulus 118a is pressure tested, the inner service tool may be removed from the outer completion string 102 and the well altogether, with the circulation sleeves 124a-
35 c and flow control devices 130a-c being closed and providing isolation during

installation of the remainder of the completion, as discussed below. At this time, the work string 104 may be detached from the completion string 102 at the top packer 120 and also retrieved to the surface.

5 **[0031]** Still referring to FIG. 1, the system 100 may further include a surveillance line 132 extending externally along the outer completion string 102 and within the gravel pack of each annulus 118a-c in each formation zone 108a-c. As will be described in greater detail below, the surveillance line 132 may include one or more control lines that extend from a crossover coupling (not shown in FIG. 1) arranged within the completion string 102. The isolation
10 packers 122a,b may include or otherwise be configured for control line bypass which allows the surveillance line 132 to pass therethrough external to the outer completion string 102.

[0032] The surveillance line 132 may be representative of or otherwise include one or more electrical, hydraulic, and/or fiber optic control lines
15 communicably coupled to various sensors, gauges, and/or devices arranged along the sand face pack and within each gravel packed annulus 118a-c. The surveillance line 132 may include, for example, a fiber optic line and one or more accompanying fiber optic gauges or sensors (not shown). The fiber optic line may be deployed along the sand face pack and the associated gauges/sensors
20 may be configured to measure and report various fluid properties and well environment parameters within each gravel packed annulus 118a-c. For instance, the fiber optic line may be configured to measure pressure, temperature, fluid density, vibration, seismic waves (e.g., flow-induced vibrations), water cut, flow rate, combinations thereof, and the like within the
25 sand face pack. In some embodiments, the fiber optic line may be configured to measure temperature along the entire axial length of each sand screen 126a-c, such as through the use of various fiber optic distributed temperature sensors or single point sensors arranged along the sand face pack, and otherwise measure fluid pressure in discrete or predetermined locations within the sand face pack.

30 **[0033]** The surveillance line 132 may further include an electrical line coupled to one or more electric pressure and temperature gauges/sensors situated along the outside of the completion string 102. Such gauges/sensors may be arranged adjacent to each sand screen 126a-c, for example, in discrete locations on one or more gauge mandrels (not shown). In operation, the
35 electrical line may be configured to measure fluid properties and well

environment parameters within each gravel packed annulus 118a-c. Such fluid properties and well environment parameters include, but are not limited to, pressure, temperature, fluid density, vibration, seismic waves (e.g., flow-induced vibrations), radioactivity, water cut, flow rate, combinations thereof, and the like. In some embodiments, the electronic gauges/sensors can be ported to the inner diameter of each sand screen 126a-c.

[0034] Accordingly, the fiber optic and electrical lines of the surveillance line 132 may provide an operator with two sets of monitoring data for the same or similar location within the sand face pack or production intervals. In operation, the electric and fiber optical gauges may be redundant until one technology fails or otherwise malfunctions. As will be appreciated by those skilled in the art, using both types of instrumenting methods provides a more robust monitoring system against failures. Moreover, this redundancy may aid in accurately diagnosing formation problems or issues with the wellbore equipment, such as the flow control devices 130a-c.

[0035] The surveillance line 132 may further include one or more hydraulic lines. In some embodiments, one hydraulic line may be configured to provide a conduit for deploying additional fiber optic fibers or additional electrical lines into the sand face pack. In other embodiments, a hydraulic line may be configured to convey hydraulic pressure to one or more one or more mechanical actuators (not shown) arranged adjacent or otherwise within each sand screen 126a-c and communicably coupled to the flow control devices 130a-c. Such mechanical actuators may include any hydraulically-actuated actuators, pistons, solenoids, etc. known to those skilled in the art. In exemplary operation, the hydraulic line may be configured to power the mechanical actuator in order to facilitate the incremental movement of the flow control devices 130a-c between the open and closed positions, thereby choking or otherwise regulating the fluid flow through the associated sand screens 126a-c.

[0036] In one or more embodiments, an electrical line may replace the hydraulic line used to power the flow control devices 130a-c. Specifically, an electrical line may provide electrical power to one or more electromechanical devices or motors communicably coupled to the flow control devices 130a-c. Actuation of such electromechanical devices may equally facilitate the incremental movement of the flow control devices 130a-c between the open and

closed positions, thereby choking or otherwise regulating the fluid flow through the associated sand screens 126a-c.

[0037] Referring now to FIG. 2, with continued reference to FIG. 1, illustrated is a partial cross-sectional view of the single trip multi-zone completion system 100 with an exemplary production tubing 202 extended to or otherwise arranged at least partially within the outer completion string 102, according to one or more embodiments. As illustrated, the outer completion string 102 may include a fluid loss valve 204 arranged therein above the first formation zone 108a and generally below the top packer 120. In operation, the fluid loss valve 204 may be configured to open and close in order to isolate the formation zones 108a-c from the surface and thereby prevent fluid loss from the production intervals prior to production operations being commenced. In at least one embodiment, the fluid loss valve 204 may be closed as the inner service tool (discussed above with reference to FIG. 1) is retrieved to the surface. In some embodiments, the fluid loss valve 204 may be an FS2 fluid loss isolation barrier valve commercially available through Halliburton Energy Services of Houston, Texas, USA. In other embodiments, the fluid loss valve 204 may be any other suitable check or isolation valve known to those skilled in the art, and may be remotely actuated via either wired or wireless communication.

[0038] The production tubing 202 may include a safety valve 206 arranged in or otherwise forming part of the production tubing 202. In some embodiments, the safety valve 206 may be a surface-controlled subsurface safety valve, or the like. In other embodiments, the safety valve 206 may be a tubing-retrievable safety valve, such as the DEPTHSTAR® safety valve commercially-available from Halliburton Energy Services of Houston, TX, USA. The safety valve 206 may be controlled using a first control line 208 that extends to the safety valve 206 from a remote location, such as the Earth's surface or another location within the wellbore 106. In at least one embodiment, the control line 208 may be a surface-controlled subsurface safety valve control line configured to control the actuation or operation of the safety valve 206.

[0039] The production tubing 202 may also include a travel joint 210 arranged in or otherwise forming part of the production tubing 202. In operation, the travel joint 210 may be configured to expand and/or contract

axially, thereby effectively lengthening and/or contracting the axial length of the production tubing 202 such that a well head tubing hanger may be accurately attached at the top of the production tubing string and landed inside of the wellhead. The travel joint 210 may be actuated or powered either electrically,
5 hydraulically, or with tubing compression, as known in the art.

[0040] The production tubing 202 may be run into the wellbore 106 and at least partially extended into the completion string 102. As illustrated, the production tubing 202 may be stung into or otherwise communicably coupled to the completion string 102 at a crossover coupling 212. In some embodiments,
10 the crossover coupling 212 may be an electro-hydraulic wet connect that provides an electrical wet mate connection between opposing male and female connectors. In other embodiments, the crossover coupling 212 may be an inductive coupler providing an electromagnetic coupling or connection with no contact between the crossover coupling 212 and the internal tubing. Exemplary
15 crossover couplings 212 that may be used in the disclosed system 100 are described in U.S. Pat. Nos. 8,082,998 and 8,079,419, 4,806,928 and in U.S. Pat. App. Ser. No. 13/405,269, each of which is hereby incorporated by reference in their entirety.

[0041] A second control line 214 may extend to the crossover coupling
20 212 external to the production tubing 202 from a remote location (e.g., the surface of the well or another location within the wellbore 106). Although only one control line 214 is shown in FIG. 2, it will be appreciated that any number of control lines 214 may be used in the system 100, without departing from the scope of the disclosure. In some embodiments, for example, the second control
25 line 214 may be a flatpack control umbilical, or the like, and may be representative of or otherwise include one or more hydraulic lines, one or more electrical lines, and/or one or more fiber optic lines. The hydraulic and electrical lines may be configured to provide hydraulic and electrical power to various downhole equipment. In some embodiments, the electrical lines may also be
30 configured to receive and convey command signals and otherwise transmit data to and from the surface of the well. The fiber optic and/or electrical lines may be communicably coupled to various sensors and/or gauges arranged along the production tubing 202 and completion string 102 and otherwise configured to transmit one or more fluid and/or well environment parameters and data to the
35 surface of the well.

[0042] At the crossover coupling 212 the second control line 214 may be communicably coupled to the surveillance line 132, which may penetrate and exit the completion string 102 therebelow and thereafter extend external to the completion string 102 within the gravel packed annuli 118a-c, as generally described and discussed above. Accordingly, upon properly coupling the production tubing 202 to the completion string 102 at the crossover coupling 212, the crossover coupling 212 may be configured to provide either an electro-hydraulic wet mate connection and/or an electromagnetic connection between the surveillance line 132 and the second control line 214. As a result, the second control line 214 may be communicably coupled to the surveillance line 132 such that the second control line 214 is, in effect, extended into the sand face pack of each gravel packed annulus 118a-c in the form of the surveillance line 132.

[0043] The surveillance line 132 may thus be provided with the hydraulic, electrical, and fiber optic control lines, as generally described above. Accordingly, the surveillance line 132 may facilitate real time monitoring and reporting of fluid and/or well environment parameters, such as pressure, temperature, seismic waves (e.g., flow-induced vibrations), radioactivity, compaction, water cut, flow rate, etc., and may also provide the hydraulic and/or electrical power needed to actuate the various flow control devices 130a-c. As illustrated, the second control line 214 may also extend to the travel joint 210 and provide hydraulic and/or electrical power thereto. As a result, the travel joint 210 may be able to axially expand and contract and its position or degree of expansion/contraction may be measured and reported to the surface in real time.

[0044] Once the production tubing 202 is appropriately situated within the completion string 102, and otherwise communicably coupled thereto at the crossover coupling 212, an upper packer 216 may be set within the casing string 110, thereby anchoring the production tubing 202 within the wellbore 106. In some embodiments, the upper packer 116 may be a retrievable packer, such as an HF-1 packer commercially available from Halliburton Energy Services of Houston, Texas, USA. Similar to the isolation packers 122a,b, the upper packer 216 may also include or otherwise be configured for control line bypass which allows the second control line 214 to pass therethrough external to the production tubing 202.

[0045] In exemplary operation, production of fluids from each production interval or formation zone 108a-c may be commenced by first opening the fluid loss valve 204. In some embodiments, this may be done by applying hydraulic pressure through the production tubing 202. In other
5 embodiments, the fluid loss valve 204 may be opened by actuating one or more downhole actuators, pistons, solenoids, motors, etc. (not shown), without departing from the scope of the disclosure. Once the fluid loss valve 204 is open, the flow control devices 130a-c in each individual sand screen 126a-c may be intelligently controlled using the hydraulic and/or electric power provided by
10 the surveillance line 132 to the interval control valves 218a-c.

[0046] In some embodiments, for example, the flow control devices 130a-c may incorporated into or otherwise form an integral part of an associated interval control valve 218a, 218b, and 218c, each interval control valve 218a-c being integrated into its corresponding sand screen 126a-c and communicably
15 coupled to the surveillance line 132. Each interval control valve 218a-c may be configured to incrementally manipulate the axial position of each flow control device 130a-c. For instance, in at least one embodiment, the interval control valves 218a-c may include an actuator, solenoid, piston, or similar actuating device (not shown) coupled to its associated flow control device 130a-c and
20 configured to move the flow control device 130a-c. One or more position sensors (not shown) may also be included in or otherwise associated with each interval control valve 218a-c and configured to measure and report the axial position of each flow control device 130a-c as moved within with the associated sand screens 126a-c.

[0047] Accordingly, the position of each flow control device 130a-c may be known and adjusted in real-time in order to choke or otherwise regulate the production flow rate through each corresponding sand screen 126a-c. In some
25 embodiments, for example, it may be desired to open one or more of the flow control devices 130a-c only partially (e.g., 20%, 40%, 60%, etc.) in order to
30 choke production flow from one or more associated formation zones 108a-c. In other embodiments, it may be desired to slow or entirely shut down production from a particular production interval or formation zone 108a-c and instead produce increased amounts from the remaining production intervals or formation zones 108a-c.

[0048] Each interval control valve 218a-c may further include one or more sensors or gauges (not shown) configured to measure and report real-time pressure, temperature, and flow rate data for each associated formation zone 108a-c. The data feedback and accurate flow control capability of each flow control device 130a-c as controlled by the associated interval control valves 218a-c allows an operator to optimize reservoir performance and enhance reservoir management.

[0049] In one or more embodiments, one or more of the interval control valves 218a-c may be a SCRAMS® (Surface Controlled Reservoir Analysis and Management System) device commercially available through Halliburton Energy Services of Houston, Texas, USA. At least one advantage of using the SCRAMS® technology is the incorporation of redundant electrical and hydraulic control lines that ensure uninterrupted control of the flow control device 130a-c even in the event the main electrical and/or hydraulic control lines feeding the particular interval control valve 218a-c are severed or otherwise rendered inoperable. Those skilled in the art will readily recognize, however, that the interval control valves 218a-c may be any other known downhole tool configured to regulate fluid flow through a flow control device 130a-c or similar downhole device. Accordingly, the flow control devices 130a-c may be actuated mechanically, hydraulically, electromechanically, electro-hydraulically, combinations thereof, and the like.

[0050] As each flow control device 130a-c is moved from its closed position into an open position (either fully or partially open), a corresponding flow port 220a, 220b, and 220c defined in the outer completion string 102 is uncovered or otherwise exposed, thereby allowing the influx of fluids into the outer completion string 102 from the respective formation zone 108a-c. In some embodiments, one or more of the flow ports 220a-c may have an elongated or progressively enlarged shape in the axial direction required to move the flow control device 130a-c from closed to open positions. As the flow control device 130a-c translates to its open position, the volumetric flow rate through the corresponding flow port 220a-c may progressively increase proportional to its progressively enlarged shape. In some embodiments, for example, one or more of the flow ports 220a-c may exhibit an elongated triangular shape which progressively increases volumetric flow potential in the axial direction, thereby allowing an increased amount of fluid flow as the

corresponding flow control device 130a-c moves to its open position. In other embodiments, however, one or more of the flow ports 220a-c may exhibit a tear drop shape or the like , and achieve substantially the same fluid flow increase as the flow control device 130a-c moves axially. Accordingly, each flow control device 130a-c may be characterized as an integrated flow control choke device.

[0051] In other embodiments, however, one or more of the flow control devices 130a-c may be an autonomous variable flow restrictor. For instance, at least one of the flow control devices 130a-c may include a spring actuated movable sleeve that opens and closes autonomously, and depending at least in part on the pressure experienced within each production interval. Such an autonomous inflow control device may prove advantageous in equalizing fluid flow across multiple production intervals.

[0052] Those skilled in the art will readily appreciate the advantages the disclosed system 100 may provide. For instance, the interval control devices 218a-c and associated flow control devices 130a-c are integrated directly into the sand screens 126a-c, thereby allowing for a larger flow area in the interior of the completion string 102 as coupled to the production tubing 202. In some embodiments, slim versions of the flow control devices 130a-c may be employed, without departing from the scope of the disclosure, thereby providing for an even larger flow area in the interior of the completion string 102. As a result, the inner diameter of the completion string 102 is not restricted and flow rate is maximized. Moreover, this allows for larger tools to bypass the completion string 102, if needed, in order to extend the depth of the wellbore 106.

[0053] Another significant advantage obtained by the system 100 is the instrumentation of the sand face pack via the surveillance line 132. The measurements derived from the surveillance line and its corresponding sensors/gauges may prove highly advantageous in intelligently producing the hydrocarbons from each formation zone 108a-c. For instance, by knowing real time production rates and other environmental parameters associated with each formation zone 108a-c, an operator may be able to adjust fluid flow rates through each sand screen 126a-c by incrementally adjusting the flow control devices 130a-c. As a result, the formation zones 108a-c may be more efficiently produced, in order to maximize production and save time and costs. Moreover, by continually monitoring the environmental parameters of each formation zone

108a-c, the operator may be able to determine when a problem has resulted, such as formation collapse, water break through, or zonal depletion, thereby being able to proactively manage production.

[0054] Various alternative configurations to the single trip multi-zone completion system 100 are contemplated herein, without departing from the scope of the disclosure. For instance, in some embodiments, the flow control devices 130a-ca-c may be replaced with inflow control devices, inflow control devices that can be shut off, or adjustable inflow control devices. This may prove advantageous in applications where an injection well is desired. Such inflow control devices are known to those skilled in the art, and therefore are not described herein.

[0055] Therefore, the present invention is well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the present invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered, combined, or modified and all such variations are considered within the scope and spirit of the present invention. The invention illustratively disclosed herein suitably may be practiced in the absence of any element that is not specifically disclosed herein and/or any optional element disclosed herein. While compositions and methods are described in terms of "comprising," "containing," or "including" various components or steps, the compositions and methods can also "consist essentially of" or "consist of" the various components and steps. All numbers and ranges disclosed above may vary by some amount. Whenever a numerical range with a lower limit and an upper limit is disclosed, any number and any included range falling within the range is specifically disclosed. In particular, every range of values (of the form, "from about a to about b," or, equivalently, "from approximately a to b," or, equivalently, "from approximately a-b") disclosed herein is to be understood to set forth every number and range encompassed within the broader range of values. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee. Moreover, the indefinite articles "a" or "an," as used in the

claims, are defined herein to mean one or more than one of the element that it introduces. If there is any conflict in the usages of a word or term in this specification and one or more patent or other documents that may be incorporated herein by reference, the definitions that are consistent with this

5 specification should be adopted.

CLAIMS

The invention claimed is:

1. A single trip multi-zone completion system, comprising:
an outer completion string having at least one sand screen arranged thereabout and an interval control valve coupled to the at least one sand screen;
a production tubing communicably coupled to the outer completion string at a crossover coupling;
a control line extending external to the production tubing and being communicably coupled to the crossover coupling; and
a surveillance line extending from the crossover coupling external to the outer completion string and interposing the at least one formation zone and the at least one sand screen, the surveillance line being communicably coupled to the interval control valve.
2. The system of claim 1, further comprising a fluid loss valve arranged within the outer completion string.
3. The system of claim 1, wherein the crossover coupling is an electro-hydraulic wet connect providing an electrical wet mate connection.
4. The system of claim 1, wherein the crossover coupling is an inductive coupler providing an electromagnetic connection.
5. The system of claim 1, wherein the control line comprises one or more hydraulic lines, one or more electrical lines, and/or one or more fiber optic lines.
6. The system of claim 1, wherein the surveillance line comprises one or more hydraulic lines, one or more electrical lines, and/or one or more fiber optic lines.
7. The system of claim 1, wherein the surveillance line includes one or more associated gauges and/or sensors configured to measure and report fluid and well parameters external to the outer completion string.
8. The system of claim 7, wherein the fluid and well environment parameters comprise at least one of pressure, temperature, fluid density, seismic activity, vibration, compaction, and any combination thereof.
9. The system of claim 1, wherein the at least one interval control valve is configured to choke a fluid flow into the outer completion string.

10. The system of claim 1, further comprising a flow control device arranged within the at least one interval control valve and movable between an open position and a closed position.

11. The system of claim 10, wherein the flow control device is a sleeve, and when in the open position one or more flow ports defined in the outer completion string are exposed and allow fluid flow into the interior of the production tubing.

12. The system of claim 11, wherein, when in the closed position, the one or more flow ports are occluded by the sleeve.

13. The system of claim 10, wherein the interval control valve chokes a fluid flow into the outer completion string by incrementally moving the flow control device partially between the closed and open positions.

14. A method of producing from one or more formation zones, comprising:

- arranging an outer completion string within a wellbore adjacent the one or more formation zones, the outer completion string having at least one sand screen arranged thereabout and an interval control valve coupled to the at least one sand screen;

- communicably coupling a production tubing to the completion string at a crossover coupling having one or more control lines extending thereto;

- communicably coupling a surveillance line to the one or more control lines at the crossover coupling, the surveillance line extending from the crossover coupling external to the outer completion string and interposing the one or more formation zones and the at least one sand screen; and

- actuating the at least one interval control valve to initiate production into the outer completion string, the at least one interval control valve being communicably coupled to the surveillance line.

15. The method of claim 14, further comprising opening a fluid loss valve arranged within the outer completion string.

16. The method of claim 14, further comprising measuring one or more fluid and well environmental parameters external to the outer completion string with one or more gauges and/or sensors associated with the surveillance line.

17. The method of claim 16, wherein the fluid and well environment parameters comprise at least one of pressure, temperature, fluid density, seismic activity, vibration, compaction, and any combination thereof.

18. The method of claim 14, wherein actuating the at least one interval control valve further comprises regulating a fluid flow through the sand screen and into the outer completion string with the at least one interval control valve.

19. The method of claim 18, further comprising choking the fluid flow into the outer completion string with the at least one interval control valve.

20. The method of claim 14, wherein actuating the at least one interval control valve further comprises moving a flow control device arranged within the at least one sand screen between a closed position and an open position.

21. The method of claim 20, further comprising choking a fluid flow into the outer completion string by incrementally moving the flow control device partially between the closed and open positions with the at least one interval control valve.

22. A method of deploying a single trip multi-zone completion system, comprising:

locating an inner service tool within an outer completion string arranged within a wellbore that penetrates one or more formation zones, the outer completion string having at least one sand screen arranged thereabout and an interval control valve coupled to the at least one sand screen;

treating the one or more formation zones with the inner service tool, wherein a surveillance line extends external to the outer completion string and interposes the one or more formation zones and the at least one sand screen;

retrieving the inner service tool from within the outer completion string;

communicably coupling a production tubing to the completion string at a crossover coupling having one or more control lines extending thereto;

communicably coupling the surveillance line to the one or more control lines at the crossover coupling; and

actuating the at least one interval control valve to initiate production into the outer completion string, the at least one interval control valve being communicably coupled to the surveillance line.

23. The method of claim 22, wherein retrieving the inner service tool further comprises closing a fluid loss valve arranged within the outer completion string.

24. The method of claim 23, further comprising opening the fluid loss valve once the production tubing is communicably coupled to the completion string.

25. The method of claim 22, further comprising anchoring the outer completion string within the wellbore with a top packer.

26. The method of claim 22, further comprising separating the one or more formation zones from each other with one or more isolation packers.

27. The method of claim 22, further comprising measuring one or more fluid and well environmental parameters external to the outer completion string with one or more gauges and/or sensors associated with the surveillance line.

28. The method of claim 27, further comprising measuring compaction of a gravel pack in the one or more formation zones with one or more gauges and/or sensors.

29. The method of claim 27, further comprising monitoring the one or more formation zones for water break through or zonal depletion with the one or more gauges and/or sensors.

30. The method of claim 22, wherein actuating the at least one interval control valve further comprises regulating a fluid flow through the sand screen and into the outer completion string with the at least one interval control valve.

31. The method of claim 30, further comprising choking the fluid flow into the outer completion string with the at least one interval control valve.

32. The method of claim 22, wherein actuating the at least one interval control valve further comprises moving a flow control device arranged within the at least one sand screen between a closed position and an open position.

33. The method of claim 32, further comprising choking a fluid flow into the outer completion string by incrementally moving the flow control device partially between the closed and open positions with the at least one interval control valve.

34. The method of claim 22, wherein treating the one or more formation zones comprises hydraulically fracturing and gravel packing the one or more formation zones.

35. The method of claim 22, further comprising:

detaching the production tubing from the outer completion string;
retrieving the production tubing to a well surface while the outer completion string remains within the wellbore adjacent the one or more formation zones;
re-locating the production tubing within the outer completion string; and
communicably coupling the production tubing to the outer completion string at the crossover coupling once again.