A multi-zone screened frac system combines screens with integrated check valves, frac valves, and optional shunt tubes for slurry dehydration. The system can also include fiber optic technology. In particular, the system uses sliding sleeves and flow devices for each section. The sliding sleeves open with dropped balls or a service tool, and the flow devices have screens and act as check valves. Dehydration tubes can also be used. The system does not require a crossover tool, and in some implementations, the system does not even require a complete service tool.
MULTI-ZONE SCREENED FRAC SYSTEM
CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This is a non-provisional of U.S. Provisional Appl. 61/506,897, filed 12 Jul. 2011, which is incorporated herein by reference and to which priority is claimed.

BACKGROUND

[0002] Many wells are fractured with a propant (e.g., sand or the like) to treat a formation and improve production. In many cases, multiple frac operations are performed in a single wellbore to treat various zones of interest in the formation. Systems exist in the art that allow operators to frac multiple zones in a single trip in the wellbore. Some systems even use a wellscreen to prevent propant flowback during operations.

[0003] Unfortunately, current systems that include a wellscreen use a service crossover tool for operation. The crossover tool crosses over the fluid flow path from a workstring to the annulus outside the wellscreen and vice versa. However, using the crossover tool has a number of disadvantages.

[0004] The subject matter of the present disclosure is directed to overcoming, or at least reducing the effects of, one or more of the problems set forth above.

SUMMARY OF THE DISCLOSURE

[0005] A multi-zone frac assembly for a borehole has a tubular structure disposed in the borehole and defining a through-bore. A plurality of sections disposed on the tubular structure each has an isolation element, a flow valve, a screen, and a check valve. The isolation element, which can be a swellable packer, a hydraulically-set packer, or a mechanically-set packer, isolates a borehole annulus around the section from the other sections along the borehole. If desired, a flow tube can be disposed in the borehole annulus and can communicate through the isolation elements between one or more of the sections.

[0006] The flow valve is selectively operable between opened and closed conditions. Thus, the flow valve in the opened condition permits fluid communication between the through-bore and the borehole annulus, but the flow valve in the closed condition prevents fluid communication between the through-bore and the borehole annulus.

[0007] The screen disposed on the tubular structure communicates with the borehole annulus, and the check valve is in fluid communication between the screen and the through-bore. The check valve permits fluid communication from the screen into the through-bore, but prevents fluid communication from the through-bore to the screen.

[0008] In one arrangement, at least a portion of the tubular structure for a given one of the sections includes a basepipe having the through-bore and defining at least one pipe port communicating the through-bore outside the basepipe. Positioned on the basepipe, the check valve permits fluid communication from the screen to the at least one pipe port and prevents fluid communication from the at least one pipe port to the screen.

[0009] In particular, the check valve can have a housing disposed on the basepipe, and the screen can have one end in fluid communication with the housing. The housing has at least one internal flow passage and has at least one check ball. The at least one internal flow passage communicates the screen with the at least one pipe port. To control flow, the at least one check ball is movable relative to the at least one internal flow passage. In one condition, the at least one check ball permits fluid communication through the at least one internal flow passage, while in another condition, the at least one check ball prevents fluid communication through the at least one internal flow passage.

[0010] In one arrangement, the flow valve is a sliding sleeve having a housing and in insert movable therein. The housing has a flow port communicating the through-bore outside the housing, and the insert is movable in the housing between the closed condition preventing fluid communication through the flow port and the opened condition permitting fluid communication through the flow port.

[0011] To move the seal, the insert has a seat disposed therein that seats a plug deployed in the tubular structure thereon and moves the insert from the closed condition to the opened condition in response to application of fluid pressure against the seated plug.

[0012] In other arrangements, the insert can be moved by a shifting tool. In particular, the assembly can have a workstring disposed in the through-bore of the tubular structure. The workstring has an actuating tool and defines a fluid passageway therethrough. An outlet port communicates the fluid passageway outside the workstring. In the assembly, the workstring is operable to open and close the flow valve of each section with the actuating tool. The workstring is operable to seal inside the assembly and place the outlet port in sealed fluid communication with the borehole annulus when the flow valve has the opened condition.

[0013] If desired, the assembly can have a bypass tube for at least one of the sections. The bypass tube communicates a first portion of the through-bore on one side of a location of the workstring sealed inside the assembly to another side of the location.

[0014] In a multi-zone frac method for a borehole, an assembly disposed in the borehole, and an annulus of the borehole around the assembly is isolated into a plurality of isolated zones. To isolate the annulus, for example, the method can involve engaging packing elements on the assembly against the borehole.

[0015] Fluid communication from the annulus of the isolated zones is screened into a through-bore of the assembly with screens on the assembly, and fluid communication is prevented from the through-bore to the annulus of the isolated zones through the screens. For example, screening the fluid can involve allowing fluid communication from the screens through perforations in the assembly communicating with the through-bore, and prevent fluid communication from the through-bore to the annulus in case disposing a check valve in fluid communication between the screens and the perforations.

[0016] In the method, treating each of the isolated zones with a treatment fluid is achieved by: selectively opening a port in the assembly at the each isolated zone, and flowing the treatment fluid down the through-bore to the each isolated zone through the opened port. For example, selectively opening the port in the assembly at each isolated zone involves opening the port in the assembly by moving an insert in the assembly away from the port. Further, selectively closing the opened ports in the assembly can be achieved at each of the isolated zones.

[0017] In moving the insert in the assembly away from the port, the method in one arrangement involves engaging a plug
on the insert; and moving the insert away from the port with application of fluid pressure against the engaged plug. Then, to flow the treatment fluid down the through-bore to the each isolated zone through the opened port, the treatment fluid can flow through the opened port when the insert is moved away from the port. In this way, treating each of the isolated zones with the treatment fluid involves successively treating the isolated zones uphe by the assembly by successively engaging plugs and moving inserts against the assembly for successive ones of the isolated zones. Once treatment is completed, the engaged plug can be removed, and the insert can be selectively closed over the opened port in the assembly.

[0018] In another arrangement to move the insert in the assembly away from the port, the insert can be engaged with a workstring disposed in the through-bore of the assembly, and the insert can be moved away from the port with movement of the engaged workstring. In this arrangement, flowing the treatment fluid down the through-bore to the each isolated zone through the opened port involves flowing the treatment fluid through an outlet in the workstring and through the opened port when the insert is moved away from the port. In this way, treating each of the isolated zones with the treatment fluid involves successively closing a given one of the insert with the workstring after treatment, and successively opening another one of the inserts with the workstring before treatment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 illustrates a multi-zone screened frac system according to the present disclosure disposed in a cased borehole and having sections with frac valves and flow devices, which include well screens and check valve devices.

[0020] FIG. 2A illustrates the multi-zone screened frac system of FIG. 1 having a dehydration tube.

[0021] FIG. 2B illustrates the multi-zone screened frac system of FIG. 1 having an expandable liner.

[0022] FIG. 3 illustrates a multi-zone screened frac system according to the present disclosure disposed in an open borehole and having sections with frac valves and flow devices, which include wellscreens and check valve devices.

[0023] FIG. 4 illustrates a multi-zone screened frac system according to the present disclosure disposed in a cased borehole and using a workstring in conjunction with frac valves and flow devices, which include wellscreens and check valve devices.

[0024] FIG. 5 illustrates the multi-zone screened frac system of FIG. 4 having flow tubes.

[0025] FIG. 6A illustrates a partial cross-section of a flow device for the disclosed multi-zone screened frac system.

[0026] FIG. 6B illustrates a detailed view of an inflow control device for the flow device of FIG. 6A.

[0027] FIG. 6C illustrates an isolated, partial cross-sectional view of the inflow flow control device of FIG. 6A.

[0028] FIGS. 7A-7B illustrate partial cross-sections of a multi-select sliding sleeve for the disclosed multi-zone screen frac system in closed and opened states.

[0029] FIGS. 8A-8B illustrate shifting tools for use on a workstring for the disclosed system of FIGS. 4-5.

DETAILED DESCRIPTION

[0030] Various embodiments of a multi-zone screened frac system are disclosed. The system does not require a crossover tool as required in the prior art. In some implementations, the system does not even require a complete service tool. To perform a frac operation on multiple zones in a cased or open borehole, the system combines: (1) wellscreens with integrated check valves, (2) frac valves, and (3) optional shunt tubes for slurry dehydration. The system can also include fiber optic technology.

[0031] In a first embodiment according to the present disclosure, FIG. 1 illustrates a multi-zone screened frac system 10 disposed in a cased borehole and having sections with frac valves and flow devices, which include wellscreens and check valve devices. The system 10 includes an upper completion or workstring 14 disposed in casing 12. This string 12 is engaged in an upright end 24 of a production string 22 of a frac assembly 20 and can engage the casing 12 with an optional packer 16.

[0032] Internally, the production string 22 of the frac assembly 20 has a through-bore 25 communicating along the length of the string 22 and communicating with the completion string 14. Externally, the frac assembly 20 has isolation devices 18, such as but not limited to a hydraulic, a mechanical, or a swellable packer, to seal the production string 22 in the casing 12. One of the isolation devices 18 is disposed at the string 22's upright end 24, while other isolation devices 18 are disposed along the length of the production string 22. Separated by the isolation devices 18, the frac assembly 20 has various sections 28 disposed at various intervals or zones of interest in the surrounding formation. At its downhole end 26, the frac assembly 20 has a bottom seat 50 for engaging a setting ball 54 during frac operations.

[0033] Each section 28 has a selective frac valve 30 and a flow device 40. Each of the selective frac valves 30 and flow devices 40 in a given section 28 is separated from other sections 28 by isolation elements 18, which isolate the borehole annulus 15 for the respective sections 28. As shown, the selective frac valves 30 are disposed upright of the flow devices 40 in the various sections 28. As an alternative, the selective frac valves 30 can be disposed downhole of the flow devices 40 in each section 28.

[0034] The selective frac valves 30 have one or more ports 32 that can be selectively opened and closed during operation. In this arrangement and as discussed in more detail below, for example, each of the selective frac valves 30 can be open to communicate their ports 32 with the surrounding annulus 15 by using frac plugs or balls 34 deployed downhole during frac operations. As treatment is performed in the well, these dropped plugs or balls 34 selectively open the frac valves 30 and isolate lower sections 28 so the selective frac valves 30 can successively divert frac treatment to adjacent zones of interest up the frac assembly 20.

[0035] The flow device 40 for each section 28 is disposed adjacent or near perforations 13 in the casing 12. In this and other assemblies disclosed herein, the flow devices 40 use wellscreens 42 with integrated check valves 44 to control the flow of fluid through the devices 44. In particular, each flow device 40 exclusively screens fluid communication through a first flow path (i.e., flow from the borehole annulus 15 to the through-bore 25 of the assembly 20 through the flow device 40). At the same time, the flow device 40 exclusively prevents fluid communication from the through-bore 25 of the assembly 20 to the borehole annulus 15 along this first flow path. Thus, the wellscreens 42 screens fluid flow along the first flow path from the borehole annulus 15 to the through-bore 25. However, the flow device 40 does not permit fluid flow in the
opposite direction along this same flow path, but in the opposite direction from the through-bore 25 to the borehole annulus 15.

[0036] In particular, the flow devices 40 can each include a wellscreen 42 and an inflow control device 44, such as a FloReg™ Deploy-Assist (DA) Device available from Weatherford International. Preferably, the inflow control device 44 lacks nozzles and is used in the system primarily as a check valve, but nozzles can be used in other arrangements. Further details of a suitable flow device 40 having a wellscreen 42 and an inflow control device 44, such as the FloReg™ Deploy-Assist (DA) Device, are provided below in FIGS. 6A-6C. Moreover, details of a suitable inflow control device 44 used with a wellscreen 42 are also disclosed in U.S. Pat. Nos. 6,371,210 and 7,828,067, which are incorporated herein by reference in its entirety.

[0037] In this and other assemblies disclosed herein, each selective frac valve 30 selectively permits and prevents fluid communication through a second flow path (i.e., between the through-bore 25 of the assembly 20 and the borehole annulus 15). In particular, the selective frac valves 30 can be sliding sleeves, such as a ZoneSelect™ MultiShift frac sliding sleeve available from Weatherford International. The selective frac valve 30 is designed to open when a ball 34 lands on a landing seat (not shown) disposed in the selective frac valve 30 and tubing pressure is applied to shear the selective frac valve 30 open to expose the through-bore 25 to the surrounding annulus 15. The balls 34 are dropped from the surface once the appropriate amount of proppant is pumped into each zone 28. Further details of a suitable multi-shift sliding sleeve, such as the ZoneSelect™ MultiShift frac sliding sleeve, are provided below in FIGS. 7A-7B.

[0038] In this and other assemblies 10 disclosed herein, a fracming operation uses the series of packers 18 and selective frac valves 30 to sequentially isolate the different zones or sections 28 of the downhole formation. Initially, the assembly 20 having the packers 18, selective frac valves 30, and flow devices 40 is run downhole and set up using known techniques. Eventually, a bottom plug or ball 54 is pumped downhole to close off the flow path through the assembly’s bottom end 50.

[0039] Next, operators set the packers 18 to create the multiple isolated sections 28 down the borehole annulus 15. How the packers 18 are set depends on the type of packers 18 used. For example, hydraulic pressure pumped down the assembly’s through-bore 25 can be used to set the packers 18. The closed bottom end 50, the closed frac valves 30, and the integrated check valves 44 prevent fluid pressure in the assembly 20 from escaping to the annulus 15 during the setting procedures. Use of different types of packers 18 would require other known procedures.

[0040] Once the packers 18 are set, operators apply a frac treatment successively to each of the isolated sections 28 by selectively opening the selective frac valves 30 and allowing the treatment fluid to interact with the adjacent zones of the formation through the opened ports 32. To open each frac valve 30, for example, operators drop specifically sized plugs or balls 34 into the assembly 20 and land them on corresponding seats (not shown) on the designated frac valves 30. Typically, the balls 34 increase in size up the borehole so that a smaller ball 34 can pass through all of the seats (not shown) on the upperfrac valves 30 before engaging its designated seat further downhole. For example, a range of plugs or balls 34 may allow fracturing up to 13, 19, and 21 sections in the borehole when 3/2 in., 4/2 in., and 5/2 in. frac valves 30 are used, respectively. An additional section can be added by using a toe sleeve (not shown).

[0041] Once a dropped ball 34 is seated, the ball 34 closes off the lower section 28 just treated, and built up pressure on the seated ball 34 forces the frac valve 30 open so frac fluid can interact with the adjacent zone of the formation through the open flow ports 32. Operators repeat this process up the assembly 20 to treat all of the sections 28 by successively dropping bigger balls 34 against bigger seats (not shown) in the frac valves 30. Once the frac treatment is complete, flow in the assembly 20 can float all the balls 34 to the surface, or operators can mill out the balls 34 and ball seats (not shown) from the frac valves 30. Finally, after fracting, the system 10 may need a clean-out trip in which a fluid wash is pumped down the assembly 10 to clear it of excess or residual prop and frac fluid.

[0042] The multi-zone frac system 10 of FIG. 1 can achieve higher flow rates and can improve reservoir performance while only requiring one trip upper and lower completions, using standard packers, not requiring a crossover tool, and offering less risk. The system 10 can also have any suitable length and spacing between sections 28. A wet connector is not required for using fiber optics, and the system 10 allows for monitoring while fracting using a fiber optic based sensor system.

[0043] In a second embodiment according to the present disclosure, the multi-zone screened frac system 10 of FIG. 2A is similar to that of FIG. 1 so that similar components are shown with the same reference numerals. In contrast to the previous arrangement, however, this system 10 has a dehydration tube (i.e., slurry or flow tube) 60 disposed along the assembly 20 running from the optional packer 16 at the uphole end 24 to the lower most packer 18 near the downhole end 26. Although the de-hydration tube 60 may be a barrier issue, this can be mitigated by running a production packer (not shown) uphole in the casing 12.

[0044] The dehydration tube 60 communicates with the borehole annulus 15 of each of the sections 28 using flow ports (not shown) or the like. Additionally, the tube 60 passes through the packers 18 isolating the sections 28. Use of the tube 60 is beneficial when frac pack operations are performed, which involve fracting a zone of interest and then gravel packing the borehole annulus 15 around the well screen 42. In this way, use of the tube 60 in the system 10 allows dehydration of the annular gravel pack when performed.

[0045] After fracting operations, the system 10 in FIG. 2A may need a clean-out trip and may require 3-4 MM in lower tertiary. The multi-zone frac system 10 of FIG. 2A can provide higher rates and improve reservoir performance without requiring a crossover tool and offering less risk. The system 10 can be any length and spacing, may eliminate the need for a wet-connector for fiber optic, and allows for monitoring while fracting.

[0046] As noted above in FIGS. 1 and 2A, the system 10 can be used in ease borehole having casing 12 with perforations 13. Other completion arrangements can be used. For example, instead of the borehole having perforated casing 12, the borehole can have an expandable pre-slotted or pre-perforated liner 17a as in FIG. 2B. As is customary, such an expandable liner 17a can be suspended from a liner hanger and packer assembly 17b disposed in casing 12. Below the liner hanger and packer assembly 17b, the expandable liner 17a extends into an open borehole section. The expandable
liner 17a can have slots or perforations (not shown) in those zones of the formation to be produced. Although not shown, the expandable liner 17a can be constructed to suit the zones of the formation using modular components, including expandable liner or sand screen sections, blank pipe sections, and expandable zonal isolation joints, such as are available in Weatherford’s Expandable Reservoir Completion systems.  

[0047] How the liner hanger and packer assembly 17b and the expandable liner 17a are installed in the borehole will be appreciated by one skilled in the art with the benefit of the present disclosure so that particular details are not provided here. Briefly though, the liner hanger and packer assembly 17b and expandable liner 17a are disposed downhole, and the hanger and packer assembly 17b is set by dropping a ball and applying pressure. Expansion of the liner 17a is then performed using liner expansion tools. Once the liner is set, frac operations can be performed by deploying the frac assembly 20 as described previously.

[0048] Other than a cased or lined borehole as noted above, the multi-zone screened frac system 10 can also be used for open hole completions. In a third embodiment according to the present disclosure, for example, the multi-zone screened frac system 10 of FIG. 3 is used for an open hole completion and has many of the same components as described previously so that like reference numeral are used for similar components. In contrast to the cased or lined hole arrangements of FIGS. 1 and 2A-2B, open hole packers 19 are used for this system 10 in FIG. 3. These packers 19 can be swellable and/or hydraulic set packers for open holes.

[0049] After fracing operations, the system 10 may need a clean-out operation. As before, the frac valves 30 are disposed upheole of the flow devices 40, but they could be disposed downhole of the flow devices 40 in each section 28. As another alternative, slurry de-hydration tubes (not shown) could also be used along the assembly 10.

[0050] The multi-zone frac system 10 of FIG. 3 provides the highest rates and improved reservoir performance. The system 10 can be of any length and any spacing. The system 10 does not require perforating to be performed and offers the option to step down one casing size in its implementation, which can give significant savings potential. Finally, the system 10 does not need wet-connectors for using fiber optics, and the system 10 allows for monitoring while fracking.

[0051] In a fourth embodiment according to the present disclosure, the multi-zone screened frac system 10 of FIG. 4 is also used for openhole completions as with the embodiment of FIG. 3. In contrast to previous arrangements, this system 10 has a workstring 70 that disposes in the frac assembly 20 to open the various frac valves 30 and treat portions of the formation. As shown, the workstring 70 has external seals 76 disposed near outlet ports 72 and a dropped ball 74 can seat in an distal seat of the workstring 70 to divert fluid flow down the workstring 70, out the outlet ports 72, and to the open ports 32 in the frac valve 30 to treat the surrounding formation.

[0052] The frac operation for the system 10 of FIG. 4 involves running the assembly 20 downhole and setting the packers 19 to create the multiple isolated sections 28 down the borehole annulus 15. Once the packers 19 are set, operators apply a frac treatment successively to each of the isolated sections 28 by selectively opening the selective frac valves 30 with a shifting tool 78 on the workstring 70 since dropped balls are not used.

[0053] Details about opening the frac valves 30 are provided below with reference to FIGS. 7A-7B and 8A-8B. In general, the shifting tool 78 can be a “B” shifting tool for shifting an inner sleeve in the frac valve 30 relative to the valve’s ports 32. Thus, opening a given frac valve 30 involves engaging the shifting tool 78 in an appropriate profile of the valve’s inner sleeve and moving the inner sleeve with the workstring 70 to an opened condition so that the assembly’s through-bore 25 communicates with the borehole annulus 15 via the now opened ports 32.

[0054] Once a given frac valve 30 is opened, the seals 76 on the workstring 70 can engage and seal against inner seats 36, surfaces, seals, or the like in the frac valve 30 or elsewhere in the assembly 20 on both the upheole and downhole sides of the opened ports 32. The seals 76 can use elastomeric or other types of seals disposed on the inner workstring 70, and the seals 36 can be polished seats or surfaces inside the frac valve 30 or other part of the assembly 30 to engage the seals 76. Although shown with this configuration, the reverse arrangement can be used with seals on the inside of the frac valve 30 or assembly 20 and with seats on the workstring 70.

[0055] Once the workstring 70 is seated, treatment fluid is flowed down the through-bore 75 of the workstring 70 to the sealed and opened ports 32 in the frac valve 30. The treatment fluid flows through the outlet ports 72 in the workstring 70 and through the opened ports 32 to the surrounding borehole annulus 15, which allows the treatment fluid to interact with the adjacent zone of the formation.

[0056] Once treatment is completed for the given zone, operators manipulate the workstring 70 to engage the shifting tool 78 in the frac valve 30 to close the ports 32. For example, the shifting tool 78 can engage another suitable profile on an inner sleeve of the frac valve 30 to move the sleeve and close the ports 32. At this point, the workstring 70 can be moved in the assembly 20 to open another one of the frac valves 30 to perform treatment. Operators repeat this process up the assembly 20 to treat all of the sections 28. Once the frac treatment is complete, the system 10 may not need a clean-out trip.

[0057] The multi-zone frac system 10 of FIG. 4 can have higher rates compared to a conventional single trip multi-zone system and can improve reservoir performance. The system 10 can have any suitable length and spacing, allows the option to step down one casing size, does not require perforating, and does not require a clean-out trip. Consideration should be given to potential sticking the workstring 70 during operation and to annulus packing that can occur for a particular implementation.

[0058] In a fifth embodiment of the multi-zone screened frac system 10 of FIG. 5 also has a workstring 70, as with the previous embodiment of FIG. 4. In addition to all of the same components, this system 10 has slurry dehydration tubes 80 disposed along the various sections 28.

[0059] During a frac operation similar to that discussed above, the tubes 80 help dehydrate slurry intended to gravel pack the borehole annulus 15 of the sections 28 during a frac pack type of operation. In addition, the tubes 80 can act as a bypass for fluid returns during the operation. As treatment fluid flows from the workstring 70 seated in a frac valve 30, through the opened ports 32, and into the borehole annulus 15, the well screen 42 screens fluid returns from the annulus 15, and the fluid returns can flow into the assembly 20 downhole of the engagement of the workstring 70 in the assembly 20. The tubes 80 can, therefore, allow these fluid returns to
flow from the downhole section of the assembly 20 to the micro-annulus between the workstring 70 and the inside of the assembly 20. Uplift of the sealed engagement of the workstring 70 with the ports 32. From this point, the fluid returns can then flow to the surface.

[0060] The multi-zone frac system 10 of FIG. 5 can have higher rates compared to a conventional single trip multi-zone system 10 and can improve reservoir performance. Furthermore, the system 10 can have any length and spacing, offers the option to step down one casing size, does not require perforating, does not require a clean-out trip, and can give good annulus packing. Consideration should be given to potential sticking of the workstring 70 for a particular implementation.

[0061] As noted above, the various embodiments of the multi-zone frac system 10 in FIGS. 1-5 use flow devices 40 disposed on the frac assembly 20, and the flow devices 40 includes wellscreens 42 and check valves 44. Turning now to FIGS. 6A-6B, a flow device 150 that can be used for the disclosed system 10 is shown in a partial cross-sectional view and a detailed view, respectively. The flow device 150 is a screen joint having a screen jacket 160 (i.e., wellscreen) and an inflow control device 170 (i.e., check valve) disposed on a basepipe 152. (FIG. 6C shows the inflow control device 170 in an isolated view without the basepipe and the screen jacket.)

[0062] The flow device 150 is deployed on a completion string (22: FIGS. 1-5) with the screen jacket 160 typically mounted upstream of the inflow control device 170, although this may not be strictly necessary. The basepipe 152 defines a through-bore 155 and has a coupling crossover 156 at one end for connecting to another joint or the like. The other 154 end can connect to a crossover (not shown) of another joint on the completion string (22). Inside the through-bore 155, the basepipe 152 defines pipe ports 158 where the inflow control device 170 is disposed.

[0063] As noted above, the inflow control device 170 can be similar to a FloReg deploy-assist (DA) device available from Weatherford International. As best shown in FIG. 6B, the inflow control device 170 has an outer sleeve 172 disposed about the basepipe 152 at the location of the pipe ports 158. A first end-ring 174 seals to the basepipe 152 with a seal element 175, and a second end-ring 176 attaches to the end of the screen jacket 160. Overall, the sleeve 172 defines an annular space around the basepipe 152 communicating the pipe ports 158 with the screen jacket 160. The second end-ring 176 has flow ports 180 that separate the sleeve’s annular space into a first inner space 186 communicating with the screen 160 and a second inner space 188 communicating with the pipe ports 158.

[0064] For its part, the screen jacket 160 is disposed around the outside of the basepipe 152. As shown, the screen jacket 160 can be a wire wrapped screen having rods or ribs 164 arranged longitudinally along the base pipe 152 with windings of wire 162 wrapped thereabout to form various slots. Fluid can pass from the surrounding borehole annulus to the annular gap between the screen jacket 160 and the basepipe 152. Although shown as a wire-wrapped screen, the screen jacket 160 can use any other form of screen assembly, including metal mesh screens, pre-packed screens, protective shell screens, expandable sand screens, or screens of other construction.

[0065] Internally, the inflow control device 170 has a number (e.g., ten) flow ports 180. Rather than providing a predetermined pressure drop along the screen jacket 160 by using multiple open or closed nozzles (not shown), the inflow control device 170 as shown in FIGS. 6A-6C may lack the typically used restrictive nozzles and closing pins for the internal flow ports 180. Instead, the flow ports 180 may be relatively unrestricted flow passages and may lack the typical nozzles, although a given implementation may use such nozzles if a pressure drop is desired from screen jacket 160 to the basepipe 152.

[0066] Internally, however, the inflow control device 170 does include port isolation balls 182, which allow the device 170 to operate as a check valve. Depending on the direction of flow or pressure differential between the inner spaces 186 and 188, the port isolation balls 182 can move to an open condition (to the right in FIG. 6B) permitting fluid communication from the screen’s inner space 186 to the pipe’s inner space 188 or to a closed condition (to the left in FIG. 6B) against a seat end 184 of the flow port 180 preventing fluid communication from the pipe’s inner space 188 to the screen’s inner space 186.

[0067] In general, the inflow control device 170 can facilitate fluid circulation during deployment and well cleanup and can be used in interventionless deployment and setting of openhole packers. In deployment, for example, the isolation balls 182 maximize fluid circulation through the completion shoe (50: FIGS. 1-5) of the frac assembly 20 to aid efficient deployment of the completion string (22) and assembly (20). When the housing components (172, 174, 175, & 176) are disposed on the basepipe 150, the isolation balls 182 are retained in-place. During initial installation and production, the isolation balls 182 can prevent formation surging, thereby reducing damage to the formation. In some arrangements, the isolation balls 182 within the device 170 can be configured to erode over a period of time, allowing access to the interval for workover activity such as stimulation.

[0068] Should a pressure drop be desired from the screen jacket 160 to the basepipe 152, the flow ports 180 can include nozzles (not shown) that restrict flow of the screen fluid (i.e., inflow) from the screen jacket 160 to the pipe’s inner space 188. For example, the inflow control device 170 can have ten nozzles, although they all may not be open. Operators can set a number of these nozzles open at the surface to configure the device 170 for use downhole in a given implementation. Depending on the number of open nozzles, the device 170 can thereby produce a configurable pressure drop along the screen jacket 160.

[0069] As noted above, the various embodiments of the multi-zone frac system 10 in FIGS. 1-5 use frac valves 30 disposed on the frac assembly 20 that can be opened and closed to communicate ports 32 with the borehole annulus 15. Turning now to FIGS. 7A-7B, a frac valve 210 for the disclosed multi-zone screen frac system 10 is shown in partial cross-section in a closed state (FIG. 7A) and an opened state (FIG. 7B). As noted above, the frac valve 210 can be a sliding sleeve similar to Weatherford’s ZoneSelect MultiShift frac sliding sleeve and can be placed between isolation packers in the multi-zone completion. The sliding sleeve 210 includes a housing 220 with upper and lower subs 222 and 224. An inner sleeve or insert 230 movable within the housing 220 opens or closes fluid flow through the housing’s flow ports 226 based on the inner sleeve 230’s position.

[0070] When initially run downhole, the inner sleeve 230 positions in the housing 220 in a closed state (FIG. 7A). In this state, a holder 234 holds the inner sleeve 230 toward the upper
sub 222, and locking dogs 238 fit into an annular slot within the housing 220. Outer seals 236 on the inner sleeve 230 engage the housing 220’s inner wall both above and below the flow ports 226 to seal them off. In addition, the flow ports 226 may be covered by a protective sheath 227 to prevent debris from entering into the sliding sleeve apparatus 210. Such a sheath 227 can be composed of a destructible material, such as a composite.

[0071] As noted previously with respect to FIGS. 1-3, the sliding sleeve 210 is designed to open when a ball 34 lands on the landing seat 232 and tubing pressure is applied to move the inner sleeve 230 open. To open the sliding sleeve 210 in a frac operation, for example, operators drop an appropriately sized ball 34 downhole and pump the ball 34 until it reaches the landing seat 232 disposed in the inner sleeve 230 as shown in FIG. 7B. The designated ball 34 for the landing seat 232 of this particular sleeve 210 is dropped from the surface once the appropriate amount of proppant has been pumped into the lower formation’s zone.

[0072] Once the ball 34 is seated, built up pressure forces against the inner sleeve 230 in the housing 220, thereby shearing any shear pins and freeing the dogs 238 from the housing’s annular slot to the inner sleeve 230 and slide downward. As it slides, the inner sleeve 230 uncovers the flow ports 226. Preferably, as the inner sleeve 230 shifts past the flow ports 226, fracturing does not occur through the inner sleeve 230, which protects it from erosion.

[0073] To mitigate potential damage to the sleeve 210 as the inner sleeve 230 moves downward, a shock absorber 240 can be connected to the inner sleeve 230’s lower end. As shown in FIG. 7A, this shock absorber 240 is initially connected in an extended position by shear pins 242 within the inner sleeve 230. As the inner sleeve 230 moves downward during opening, the absorber’s distal lip 245 engages a shoulder 225 on the housing’s lower sub 224, thereby breaking the downward energy of the moving inner sleeve 230.

[0074] After the fracturing job, the well is typically flowed clean and the ball seat 232 and remaining ball 34 is milled out. The ball seat 232 can be constructed from cast iron to facilitate milling, and the balls can be composed of aluminum or non-metallic material. Once milling is complete, the inner sleeve 230 can be closed or opened with a standard “B” shifting tool on the tool profiles 234 and 236 in the inner sleeve 230 so the sliding sleeve 210 can then function like any conventional sliding sleeve shifting with a “B” tool. The ability to selectively open and close the sliding sleeve 210 with a “B” shifting tool after milling enables operators to isolate the particular section (28: FIGS. 1-5) of the assembly (20).

[0075] For those embodiments of the disclosed multi-zone screen frac system 10 that do not use a ball and seat arrangement, such as in FIGS. 4-5, the sliding sleeve 210 may lack a seat 232 altogether. Instead as noted above, the workstring (70: FIGS. 4-5) has a shifting tool (78), such as a standard “B” shifting tool, that can engage on the tool profiles 234 and 236 in the inner sleeve 230 so workstring 70 can selectively move the inner sleeve 230 and open and close the ports 226.

[0076] Turning now to FIGS. 8A-8B, details of shifting tools 78 for the workstring 70 of FIGS. 4-5 are discussed. As shown in FIG. 8A, one shifting tool 78 includes upper and lower shifting tools 310 and 320 disposed on the workstring 70 with a mandrel 302 disposed between upper and lower sections of the workstring 70. Because the mandrel 302 is part of the workstring 70, it has a bore (not shown) therethrough for flow of fluid.

[0077] In the present example, the upper tool 310 is designed to be a closing tool for closing a sliding sleeves (e.g., 210: FIGS. 7A-7B) by engaging the upper profile (234), jarring up of the workstring 70, and shifting the inner sleeve (230) upward in the sliding sleeve (210). Likewise in this example, the lower tool 320 is designed to be an opening tool for opening the sliding sleeves (210) by engaging the lower profile (236), jarring down with the workstring 70, and shifting the inner sleeve (230) downward in the sliding sleeve (210). A reverse arrangement could also be used.

[0078] As detail of the closing shifting tool 310 shows a biased collet 312 that fits around the mandrel 302 and that connects at both ends to stops 314 and 316 on the mandrel 302. The collet 312 has B-profiles 318 that include an upward facing shoulder, an upper (shortened) cam, and a lower (extended) cam. As discussed above, the B-profiles 318 enable the collet 312 to engage the recessed profile (234) in the sliding sleeve (210) in the up direction and bypass the recessed profiles (234 and 236) in the sliding sleeve (210) in the down direction. This type of shifting tool is typically referred to as a B shifting tool with a B-profile.

[0079] Another arrangement of the shifting tool 78 uses a two-way shifting tool 330 as shown in FIG. 8B. Here, the two-way shifting tool 330 a biased collet 332 that fits around the mandrel 302 and that connects at both ends to stops 334 and 336 on the mandrel 302. The collet 332 has dual B-profiles 328 having a downward-facing shoulder 340, an upper cam 342, an upward-facing shoulder 345, and a lower cam 347. Depending on the configuration of the sliding sleeve (210) and its profiles (234 and 236) and the direction the workstring 70 is being moved, the shifting tool 330 can open/close the sliding sleeve (210) by jarring down/up.

[0080] The foregoing description of preferred and other embodiments is not intended to limit or restrict the scope or applicability of the inventive concepts conceived of by the Applicants. It will be appreciated with the benefit of the present disclosure that features described above in accordance with any embodiment or aspect of the disclosed subject matter can be utilized, either alone or in combination, with any other described feature, in any other embodiment or aspect of the disclosed subject matter.

[0081] In exchange for disclosing the inventive concepts contained herein, the Applicants desire all patent rights afforded by the appended claims. Therefore, it is intended that the appended claims include all modifications and alterations to the full extent that they come within the scope of the following claims or the equivalents thereof.

What is claimed is:
1. A multi-zone frac assembly for a borehole, comprising: a tubular structure disposed in the borehole and defining a through-bore; and a plurality of sections disposed on the tubular structure, each of the sections comprising: an isolation element disposed on the tubular structure and isolating a borehole annulus of the section from the other sections, a flow valve disposed on the tubular structure and selectively operable between open and closed conditions, the flow valve in the open condition permitting fluid communication between the through-bore and the borehole annulus, the flow valve in the closed
condition preventing fluid communication between the through-bore and the borehole annulus, a screen disposed on the tubular structure and communicating with the borehole annulus, and a check valve disposed on the tubular structure and in fluid communication between the screen and the through-bore, the check valve permitting fluid communication from the screen into the through-bore and preventing fluid communication from the through-bore to the screen.

2. The assembly of claim 1, wherein the isolation element comprises a swellable packer, a hydraulically-set packer, or a mechanically-set packer.

3. The assembly of claim 1, wherein at least a portion of the tubular structure for a given one of the sections comprises a basepipe having the through-bore and defining at least one pipe port communicating the through-bore outside the basepipe.

4. The assembly of claim 1, wherein the check valve is disposed on the tubular structure adjacent at least one pipe port communicating the through-bore outside the tubular structure, the check valve permitting fluid communication from the screen to the at least one pipe port and preventing fluid communication from the at least one pipe port to the screen.

5. The assembly of claim 4, wherein the check valve comprises a housing disposed on the tubular structure, the housing having at least one internal flow passage and having at least one check ball, the at least one internal flow passage communicating the screen with the at least one pipe port, the at least one check ball movable to one condition permitting fluid communication through the at least one internal flow passage and movable to another condition preventing fluid communication through the at least one internal flow passage.

6. The assembly of claim 4, wherein the screen is disposed on the tubular structure and has one end in fluid communication with the check valve.

7. The system of claim 1, wherein the flow valve comprises:
   a housing having a flow port communicating the through-bore outside the housing; and
   an insert movable in the housing between the closed condition preventing fluid communication through the flow port and the opened condition permitting fluid communication through the flow port.

8. The assembly of claim 7, wherein the insert comprises a seat disposed therein, the seat seating a plug deployed in the tubular structure thereon and moving the insert from the closed condition to the opened condition in response to application of fluid pressure against the seated plug.

9. The assembly of claim 1, further comprising a flow tube disposed in the borehole annulus and communicating through the isolation elements between one or more of the sections.

10. The assembly of claim 1, further comprising a workstring disposed in the through-bore of the tubular structure, the workstring operable to open and close the flow valve of each section and operable to seal inside the assembly and place an outlet port on the workstring in sealed communication with the borehole annulus when the flow valve has the opened condition.

11. The assembly of claim 10, wherein the workstring comprises an actuating tool operable to engage the flow valve in one direction and actuate the flow valve open and operable to engage the flow valve in another direction and actuate the flow valve closed.

12. The assembly of claim 10, wherein the assembly comprises seats disposed in the through-bore on both upheole and downhole sides of a flow port in the flow valve, and wherein the workstring comprises seats disposed on both upheole and downhole sides of the outlet port, the seats configured to seal against the seats disposed in the through-bore.

13. The assembly of claim 10, further comprising a bypass tube for at least one of the sections, the bypass tube communicating a first portion of the through-bore on one side of a location of the workstring sealed inside the assembly to another side of the location.

14. A multi-zone frac assembly for a borehole, comprising:
   a tubular structure disposed in the borehole and defining a through-bore; and
   a plurality of sections disposed on the tubular structure, each of the sections comprising:
   means for isolating a borehole annulus of the section from the other sections,
   means for selectively permitting and preventing fluid communication between the through-bore and the borehole annulus through a first flow path,
   means for exclusively screening fluid communication from the borehole annulus to the through-bore through a second flow path, and
   means for exclusively preventing fluid communication from the through-bore to the borehole annulus through the second flow path.

15. The assembly of claim 14, wherein the means for selectively permitting and preventing fluid communication between the through-bore and the borehole annulus through the first flow path comprises means for selectively opening and closing ports in the tubular structure.

16. The assembly of claim 14, wherein the means for exclusively screening fluid communication from the borehole annulus to the through-bore through the second flow path comprises means for permitting fluid communication of the screened fluid into the through-bore through the second flow path.

17. A multi-zone frac method for a borehole, the method comprising:
   disposing the assembly in the borehole;
   isolating an annulus of the borehole around the assembly into a plurality of isolated zones;
   screening fluid communication from the annulus of the isolated zones into a through-bore of the assembly with screens on the assembly;
   preventing fluid communication from the through-bore to the annulus of the isolated zones through the screens; and
   treating each of the isolated zones with a treatment fluid by:
   selectively opening a port in the assembly at the each isolated zone, and
   flowing the treatment fluid down the through-bore to the each isolated zone through the opened port.

18. The method of claim 17, wherein disposing the assembly in the borehole comprises disposing the assembly in casing having perforations, in an expanded liner having slots, or in an open hole.

19. The method of claim 18, wherein isolating the annulus of the borehole around the assembly into the isolated zones
comprises engaging packing elements on the assembly against a wall of the casing, a wall of the expanded liner, or a wall of the open hole.

20. The method of claim 17, wherein screening fluid from the annulus of the isolated zones into the through-bore of the assembly with screens on the assembly comprises allowing fluid communication from the screens through perforations in the assembly communicating with the through-bore.

21. The method of claim 20, wherein preventing fluid communication from the through-bore to the annulus of the isolated zones through the screens comprises disposing a check valve in fluid communication between the screens and the perforations.

22. The method of claim 17, wherein selectively opening the port in the assembly at the each isolated zone comprises opening the port in the assembly by moving an insert in the assembly away from the port.

23. The method of claim 22, further comprising selectively closing the opened ports in the assembly at each of the isolated zones.

24. The method of claim 22, wherein moving the insert in the assembly away from the port comprises:
engaging a plug on the insert, and
moving the insert away from the port with application of fluid pressure against the engaged plug.

25. The method of claim 24, wherein flowing the treatment fluid down the through-bore to each isolated zone through the opened port comprises flowing the treatment fluid through the opened port when the insert is moved away from the port.

26. The method of claim 24, wherein treating each of the isolated zones with the treatment fluid comprises:
successively treating the isolated zones uphole on the assembly by successively engaging plugs and moving inserts uphole on the assembly for successive ones of the isolated zones.

27. The method of claim 24, further comprising:
removing the engaged plug; and
selectively closing the insert over the opened port in the assembly.

28. The method of claim 22, wherein moving the insert in the assembly away from the port comprises:
engaging the insert with a workstring disposed in the through-bore of the assembly; and
moving the insert away from the port with movement of the engaged workstring.

29. The method of claim 28, wherein flowing the treatment fluid down the through-bore to each isolated zone through the opened port comprises flowing the treatment fluid through an outlet in the workstring and through the opened port when the insert is moved away from the port.

30. The method of claim 28, wherein treating each of the isolated zones with the treatment fluid comprises:
successively closing a given one of the inserts with the workstring after treatment; and
successively opening another one of the inserts with the workstring before treatment.

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