

SUMMARY

In this disclosure, systems and methods are provided which may bring improvements to the arts of constructing and operating well completion systems. One example is described below in which a variable flow restricting device is configured to receive fluid which flows through a well screen. Another example is described below in which an optical waveguide is positioned external to a completion string, and one or more pressure sensors sense pressure internal and/or external to the completion string.

According to a first aspect of the present invention, there is provided a method of operating a completion string in a subterranean well, the method comprising: coupling a production string to the completion string, wherein a first control line is carried on the production string and a second control line is carried on the completion string; wherein a wet connection is made between the first control line and the second control line; closing a first flow control device and a second flow control device connected in the completion string, the completion string including a first well screen and a second well screen which filter fluid flowing between the completion string and respective ones of a first earth formation zone and a second earth formation zone, wherein a hydraulic control device controls operation of the first flow control device and the second flow control device to variably restrict flow of the fluid through respective ones of the first well screen and the second well screen, wherein the hydraulic control device is disposed within the completion string and wherein the hydraulic control device controls operation of the first flow control device and the second flow control device using a signal transmitted to the hydraulic control device via the

first control line and the second control line, and wherein
multiple pressure sensors sense pressure of the fluid which
flows through respective ones of the first well screen and
the second well screen; at least partially opening the first
5 flow control device using the hydraulic control device while
the second flow control device remains closed; measuring a
first change in the pressure of the fluid as a result of the
opening of the first flow control device; and detecting
properties of a fluid flowing between the first earth
10 formation zone and the completion string through the first
well screen.

According to a second aspect of the present invention,
there is provided a method of operating a completion string
15 in a subterranean well, the method comprising: coupling a
production string to the completion string, wherein a first
control line is carried on the production string and a
second control line is carried on the completion string;
wherein a wet connection is made between the first control
20 line and the second control line; closing a first flow
control device and a second flow control device connected in
the completion string, the completion string including a
first well screen and a second well screen which filter
fluid flowing between the completion string and respective
25 ones of a first earth formation zone and a second earth
formation zone, wherein the first flow control device and
the second flow control device variably restrict flow of the
fluid through respective ones of the first well screen and
the second well screen, wherein a hydraulic control device
30 controls operation of the first flow control device and the
second flow control device to variably restrict flow of the
fluid through respective ones of the first well screen and

the second well screen, wherein the hydraulic control device is disposed within the completion string and wherein the hydraulic control device controls operation of the first flow control device and the second flow control device using a signal transmitted to the hydraulic control device via the first control line and the second control line, and wherein multiple pressure sensors sense pressure of the fluid which flows through respective ones of the first well screen and the second well screen; at least partially opening the first flow control device while the second flow control device remains closed; measuring a first change in the pressure of the fluid as a result of the opening of the first flow control device, and selectively permitting and preventing substantially unrestricted fluid flow through at least one of the first well screen and the second well screen using a third flow control device, wherein the third flow control device is a mechanically actuated valve.

~~According to a first aspect of the present invention,~~
~~There is provided also disclosed~~ a system for use with a subterranean well having multiple earth formation zones, the system including multiple well screens which filter fluid flowing between a completion string in the well and respective ones of the multiple zones, at least one optical waveguide which senses at least one property of the fluid as it flows between the completion string and at least one of the zones, multiple flow control devices which variably restrict flow of the fluid through respective ones of the multiple well screens, and multiple pressure sensors which sense pressure of the fluid which flows through respective ones of the multiple well screens.

~~According to a second aspect of the present invention,~~
| ~~There is provided also disclosed~~ a completion string for
use in a subterranean well, the completion string
comprising: at least one well screen; at least one first
5 flow control device; and at least one second flow control
device, the second flow control device being remotely
operable, wherein the first flow control device selectively
prevents and permits substantially unrestricted flow through
the well screen, and the second flow control device variably
10 restricts flow through the well screen.

~~According to a third aspect of the present invention,~~
| ~~There is provided also disclosed~~ a method of operating a
completion string in a subterranean well, the method
comprising: a) closing all of multiple flow control devices
5 connected in the completion string, the completion string
including multiple well screens which filter fluid flowing
between the completion string and respective ones of
multiple earth formation zones, at least one optical
waveguide which senses at least one property of the fluid as
10 it flows between the completion string and at least one of
the zones, the multiple flow control devices which variably
restrict flow of the fluid through respective ones of the
multiple well screens, and multiple pressure sensors which
sense pressure of the fluid which flows through respective
15 ones of the multiple well screens; b) at least partially
opening a selected one of the flow control devices; and c)
measuring a change in the property sensed by the optical
waveguide and a first change in the pressure of the fluid as
a result of the opening of the first selected one of the
20 flow control devices.

These and other features, advantages and benefits will
become apparent to one of ordinary skill in the art upon
careful consideration of the detailed description of
representative embodiments of the disclosure hereinbelow and
25 the accompanying drawings, in which similar elements are
indicated in the various figures using the same reference
numbers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a representative partially cross-sectional
30 view of a well system and associated method which can embody
principles of this disclosure.

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WHAT IS CLAIMED IS:

1. A system for use with a subterranean well having multiple earth formation zones, the system comprising:

5 multiple well screens which filter fluid flowing between a completion string in the well and respective ones of the multiple zones;

at least one optical waveguide which senses at least one property of the fluid as it flows between the completion
10 string and at least one of the zones;

multiple flow control devices which variably restrict flow of the fluid through respective ones of the multiple well screens; and

multiple pressure sensors which sense pressure of the
15 fluid which flows through respective ones of the multiple well screens.

2. The system of claim 1, wherein the multiple well screens, the optical waveguide, the multiple flow control
20 devices, and the multiple pressure sensors are installed in the well in a single trip into the well.

3. The system of claim 1, further comprising multiple hydraulic control devices which control application of
25 hydraulic actuation pressure to respective ones of the multiple flow control devices.

4. The system of claim 3, wherein a single one of the hydraulic control devices controls application of hydraulic

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actuation pressure to multiple ones of the flow control devices.

5 5. The system of claim 1, wherein the pressure sensors sense pressure of the fluid external to the completion string.

10 6. The system of claim 1, wherein the pressure sensors sense pressure of the fluid internal to the completion string.

15 7. The system of claim 1, wherein the flow control devices comprise remotely hydraulically actuated variable chokes.

 8. The system of claim 1, wherein the flow control devices comprise autonomous variable flow restrictors.

20 9. The system of claim 1, wherein the flow control devices receive the fluid from the respective ones of the multiple well screens.

25 10. The system of claim 1, further comprising a combined hydraulic, electrical and optical wet connection.

 11. The system of claim 1, further comprising an expansion joint with hydraulic, electrical and optical lines traversing the expansion joint.

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12. The system of claim 1, wherein the optical waveguide is positioned external to the well screens.

13. The system of claim 1, wherein the optical
5 waveguide is positioned between the well screens and the zones.

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14. A completion string for use in a subterranean well, the completion string comprising:

at least one well screen;

at least one first flow control device; and

5 at least one second flow control device, the second flow control device being remotely operable,

wherein the first flow control device selectively prevents and permits substantially unrestricted flow through the well screen, and the second flow control device variably
10 restricts flow through the well screen.

15 15. The completion string of claim 14, further comprising a hydraulic control device which controls application of hydraulic actuation pressure to the second flow control device.

20 16. The completion string of claim 15, wherein the at least one second flow control device comprises multiple second flow control devices, and wherein the hydraulic control device controls application of hydraulic actuation pressure to the multiple second flow control devices.

25 17. The completion string of claim 14, further comprising at least one optical waveguide which is operative to sense at least one property of a fluid which flows through the well screen.

18. The completion string of claim 17, wherein the optical waveguide is positioned external to the well screen.

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19. The completion string of claim 17, wherein the optical waveguide is positioned between the well screen and an earth formation.

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20. The completion string of claim 14, wherein the second flow control device comprises a hydraulically actuated variable choke.

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21. The completion string of claim 14, further comprising a pressure sensor which senses pressure external to the completion string.

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22. The completion string of claim 14, further comprising a pressure sensor which senses pressure internal to the completion string.

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23. A method of operating a completion string in a subterranean well, the method comprising:

closing all of multiple flow control devices connected in the completion string, the completion string including
5 multiple well screens which filter fluid flowing between the completion string and respective ones of multiple earth formation zones, at least one optical waveguide which senses at least one property of the fluid as it flows between the completion string and at least one of the zones, the
10 multiple flow control devices which variably restrict flow of the fluid through respective ones of the multiple well screens, and multiple pressure sensors which sense pressure of the fluid which flows through respective ones of the multiple well screens;

15 at least partially opening a first selected one of the flow control devices; and

measuring a first change in the property sensed by the optical waveguide and a first change in the pressure of the fluid as a result of the opening of the first selected one
20 of the flow control devices.

24. The method of claim 23, further comprising:

closing all of the multiple flow control devices after the step of at least partially opening the first selected
25 one of the flow control devices;

at least partially opening a second selected one of the flow control devices; and

measuring a second change in the property sensed by the optical waveguide and a second change in the pressure of the
30 fluid as a result of the opening of the second selected one of the flow control devices.

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25. The method of claim 23, further comprising installing the multiple well screens, the optical waveguide, the multiple flow control devices, and the multiple pressure
5 sensors in the well in a single trip into the well.

26. The method of claim 23, wherein the completion string further comprises multiple hydraulic control devices which control application of hydraulic actuation pressure to
10 respective ones of the multiple flow control devices.

27. The method of claim 26, wherein a single one of the hydraulic control devices controls application of hydraulic actuation pressure to multiple ones of the flow
15 control devices.

28. The method of claim 23, wherein the pressure sensors sense pressure of the fluid external to the completion string.
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29. The method of claim 23, wherein the pressure sensors sense pressure of the fluid internal to the completion string.

25 30. The method of claim 23, wherein the flow control devices comprise remotely hydraulically actuated variable chokes.

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31. The method of claim 23, wherein the flow control devices comprise autonomous variable flow restrictors.

32. The method of claim 23, wherein the flow control
5 devices receive the fluid from the respective ones of the multiple well screens.

33. The method of claim 23, wherein the completion string further comprises a combined hydraulic, electrical
10 and optical wet connection.

34. The method of claim 23, wherein the completion string further comprises an expansion joint with hydraulic, electrical and optical lines traversing the expansion joint.
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35. The method of claim 23, wherein the optical waveguide is positioned external to the well screens.

36. The method of claim 23, wherein the optical
20 waveguide is positioned between the well screens and the zones.

37. The method of claim 23, wherein further comprising closing all of the flow control devices, thereby preventing
25 inadvertent flow of the fluid into the completion string.

38. The method of claim 23, wherein further comprising closing all of the flow control devices, thereby preventing inadvertent flow of the fluid out of the completion string.

Claims

1. A method of operating a completion string in a subterranean well, the method comprising:

coupling a production string to the completion string,

5 wherein a first control line is carried on the production string and a second control line is carried on the completion string;

wherein a wet connection is made between the first control line and the second control line;

10 closing a first flow control device and a second flow control device connected in the completion string,

the completion string including a first well screen and a second well screen which filter fluid flowing between the completion string and respective ones of a first earth

15 formation zone and a second earth formation zone,

wherein a hydraulic control device controls operation of the first flow control device and the second flow control device to variably restrict flow of the fluid through respective ones of the first well screen and the second well

20 screen,

wherein the hydraulic control device is disposed within the completion string and wherein the hydraulic control device controls operation of the first flow control device and the second flow control device using a signal transmitted to the

25 hydraulic control device via the first control line and the second control line, and

wherein multiple pressure sensors sense pressure of the fluid which flows through respective ones of the first well screen and the second well screen;

30 at least partially opening the first flow control device using the hydraulic control device while the second flow control device remains closed;

measuring a first change in the pressure of the fluid as a result of the opening of the first flow control device; and

detecting properties of a fluid flowing between the first earth formation zone and the completion string through the first well screen.

5 2. The method of claim 1, wherein at least one of the first flow control device and the second flow control device comprises an autonomous variable flow restrictor.

10 3. The method of claim 1, wherein the completion string further comprises a combined hydraulic, electrical and optical wet connection.

15 4. The method of claim 1, wherein the completion string further comprises an expansion joint with hydraulic, electrical and optical lines traversing the expansion joint.

20 5. The method of claim 1, wherein at least one of the first flow control device and the second flow control device comprises a remotely hydraulically actuated variable choke.

25 6. The method of claim 1, wherein the completion string further comprises at least one optical waveguide which senses at least one property of the fluid as it flows between the completion string and at least one of the first earth formation zone and the second earth formation zone, the method further comprising measuring a first change in the property sensed by the optical waveguide.

30 7. The method of claim 1, further comprising:
closing the first flow control device;

at least partially opening the second flow control device using the hydraulic control device while the first flow control device remains closed;

measuring a second change in the pressure of the fluid as
5 a result of the opening of the second flow control device;

detecting properties of a fluid flowing between the second earth formation zone and the completion string through the second well screen.

10 8. A method of operating a completion string in a subterranean well, the method comprising:

coupling a production string to the completion string,

wherein a first control line is carried on the production string and a second control line is carried on the completion
15 string;

wherein a wet connection is made between the first control line and the second control line;

closing a first flow control device and a second flow control device connected in the completion string,

20 the completion string including a first well screen and a second well screen which filter fluid flowing between the completion string and respective ones of a first earth formation zone and a second earth formation zone, wherein the first flow control device and the second flow control device
25 variably restrict flow of the fluid through respective ones of the first well screen and the second well screen,

wherein a hydraulic control device controls operation of the first flow control device and the second flow control device to variably restrict flow of the fluid through
30 respective ones of the first well screen and the second well screen,

wherein the hydraulic control device is disposed within the completion string and wherein the hydraulic control device controls operation of the first flow control device and the

second flow control device using a signal transmitted to the hydraulic control device via the first control line and the second control line, and

5 wherein multiple pressure sensors sense pressure of the fluid which flows through respective ones of the first well screen and the second well screen;

at least partially opening the first flow control device while the second flow control device remains closed;

10 measuring a first change in the pressure of the fluid as a result of the opening of the first flow control device, and

selectively permitting and preventing substantially unrestricted fluid flow through at least one of the first well screen and the second well screen using a third flow control device, wherein the third flow control device is a mechanically
15 actuated valve.

9. The method of claim 8, wherein at least one of the first flow control device and the second flow control device comprises a remotely hydraulically actuated variable choke.

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10. The method of claim 8, wherein at least one of the first flow control device and the second flow control device comprises autonomous variable flow restrictors.

25 11. The method of claim 8, wherein the completion string further comprises a combined hydraulic, electrical and optical wet connection.

30 12. The method of claim 8, wherein the completion string further comprises an expansion joint with hydraulic, electrical and optical lines traversing the expansion joint.

13. The method of claim 8, wherein the completion string further comprises at least one optical waveguide which senses at least one property of the fluid as it flows between the completion string and at least one of the first earth formation zone and the second earth formation zone, the method further comprising measuring a first change in the property sensed by the optical waveguide.

14. The method of claim 8, further comprising:

10 closing the first flow control device;

 at least partially opening the second flow control device using the hydraulic control device while the first flow control device remains closed;

15 measuring a second change in the pressure of the fluid as a result of the opening of the second flow control device;

 detecting properties of a fluid flowing between the second earth formation zone and the completion string through the second well screen.