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**WELL SCREENS WITH EROSION RESISTANT SHUNT FLOW
PATHS**

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TECHNICAL FIELD

This disclosure relates generally to equipment utilized and operations performed in conjunction with subterranean wells and, in one example described below, more particularly provides well screens with erosion resistant shunt flow paths.

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BACKGROUND

Shunt tubes are sometimes used to provide alternate paths for slurry flow in an annulus between a tubular string (such as, a completion string) and a wellbore. In this manner, the slurry can bypass blockages or restrictions (such as, sand bridging) in the annulus.

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However, slurries (such as, proppant or gravel slurries) can be erosive to well screen components. Therefore, it will be appreciated that improvements are continually needed in the arts of constructing and utilizing screens for use in wells.

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BRIEF DESCRIPTION OF THE DRAWINGS

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

FIGS. 2 & 3 are elevational and partially cross-sectional views of a well screen which may be used in the system and method.

FIG. 4 is an elevational view of a shunt tube assembly which may be used in the well screen.

FIGS. 5 & 6 are representative cross-sectional views of examples of nozzles which may be used with the shunt tube assembly.

FIGS. 7 & 8 are representative cross-sectional views of examples of sections of the shunt tube assembly.

DETAILED DESCRIPTION

Representatively illustrated in FIG. 1 is a system 10 for use with a well, and an associated method, which system and method can embody principles of this disclosure. However, it should be clearly understood that the system 10 and method are merely one example of an application of the principles of this disclosure in practice, and a wide variety of other examples are possible. Therefore, the scope of this disclosure is not limited at all to the details of the system 10 and method described herein and/or depicted in the drawings.

In the FIG. 1 example, a tubular string 12 is positioned in a wellbore 14 lined with casing 16 and cement

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18. An annulus 20 is formed radially between the tubular string 12 and the wellbore 14.

In other examples, the wellbore 14 could be uncased or open hole, the wellbore could be generally horizontal or inclined, etc. The annulus 20 is not necessarily concentric, since the tubular string 12 could be to one side or another of the wellbore 14, etc.

It is desired in the FIG. 1 example to fill the annulus 20 with "gravel" about well screens 24 connected in the tubular string 12. For this purpose, a slurry 22 is flowed into the annulus 20, for example, from a surface location.

The slurry 22 in this example is erosive and may comprise a particulate portion (e.g., sand, gravel, proppant, etc.) and a liquid portion. The liquid portion may flow inwardly through the well screens 24 into the tubular string 12, and/or out into a formation 26 surrounding the wellbore 14 (e.g., via perforations, not shown, formed through the casing 16 and cement 18), leaving the particulate portion in the annulus 20 about the well screens 24.

If a fracturing operation is performed, the particulate portion (e.g., proppant, etc.) can flow into fractures formed in the formation 26. Such gravel packing, fracturing, etc., operations are well known to those skilled in the art and so are not described further herein. The scope of this disclosure is not limited to any particular gravel packing or fracturing operation being performed in the wellbore 14.

Part of the slurry 22 is also permitted to flow through shunt tube assemblies 28 extending through the screens 24. The shunt tube assemblies 28 provide multiple alternate paths for the slurry 22 flow, in order to prevent voids in

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the particulate portion which accumulates about the tubular string 12.

In the FIG. 1 example, each of the shunt tube assemblies 28 provides fluid communication between sections
5 of the annulus 20 on opposite ends of a corresponding screen 24. In addition, as described more fully below, each of the shunt tube assemblies 28 includes nozzles (not visible in FIG. 1) which direct flow of the slurry 22 outward into the annulus 20 along the screen 24, so that a more even
10 distribution of the slurry in the annulus is achieved.

Referring additionally now to FIGS. 2 & 3, an example of a well screen 24 is representatively illustrated in elevational and partially cross-sectional views. The screen 24 may be used in the system 10 and method of FIG. 1, or the
15 screen may be used in other systems and methods.

In FIG. 2, a perforated outer shroud 30 of the screen 24 is removed, so that two shunt tube assemblies 28 are visible. The outer shroud 30 is shown in FIG. 3.

Note that the shunt tube assemblies 28 are positioned
20 in a non-concentric annular space between the outer shroud 30 and a filter 32 which encircles a perforated base pipe 34 of the screen 24. The filter 32 could comprise a mesh, wire wrap, sintered, woven or other type of filter material.

A flow passage 36 which extends longitudinally through
25 the base pipe 34 also extends longitudinally in the tubular string 12 when the screen 24 is used in the system 10 and method of FIG. 1. Thus, the liquid portion of the slurry 22 can flow inwardly through the outer shroud 30, the filter 32 and the base pipe 34, and into the flow passage 36. In other
30 examples, if fracturing of the formation 26 is desired, flow of the liquid portion into the passage 36 may be restricted or prevented, until after the fracturing operation.

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Referring additionally now to FIG. 4, an example of one of the shunt tube assemblies 28 is representatively illustrated, apart from the screen 24. In this view, it may be seen that the assembly 28 includes generally parallel
5 tubes 38, 40.

The slurry 22 can flow completely through the tube 38 (e.g., from one screen 24 to another), but a lower end 42 of the tube 40 may be closed off, so that the slurry 22 is directed outward from the tube 40 via nozzles 44. In some
10 examples, the slurry 22 can flow outwardly through the lower end 42 of the tube 40, and through the nozzles 44.

At this point it should be recognized that the shunt tube assemblies 28 described herein are merely one example of a wide variety of different ways in which a shunt flow
15 path can be provided for a slurry in a well. It is not necessary for the shunt tube assemblies 28 to be constructed as depicted in the drawings, the shunt tube assemblies are not necessarily positioned between the outer shroud 30 and the filter 32 or base pipe 34, the nozzles 44 are not
20 necessarily connected to one of two parallel tubes, the shunt flow path does not necessarily extend through tubes, etc. Thus, it will be appreciated that the scope of this disclosure is not limited to the details of the screen 24, shunt tube assemblies 28 or nozzles 44 as described herein
25 or depicted in the drawings.

Referring additionally now to FIG. 5, an enlarged scale cross-sectional view of a portion of the tube 40 and a nozzle 44 is representatively illustrated. In this view, it may be seen that the nozzle 44 directs the slurry 22 to flow
30 from an internal shunt flow path 46 to an exterior of the screen 24 (e.g., into the annulus 20).

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An erosion resistant layer 48 protects the nozzle 44 and tube 40 from erosion due to the flow of the erosive slurry 22. The erosion resistant layer 48 internally lines the tube 40 and the nozzle 44 in the FIG. 5 example.

5 Preferably, the erosion resistant layer 48 has a hardness and/or erosion resistance which is greater than that of the tube 40 and nozzle 44. In this manner, the layer 48 resists erosion due to flow of the slurry 22.

10 In some examples, the layer 48 may comprise tungsten carbide or another relatively hard and erosion resistant material. The tube 40 and nozzle 44 may be made of a softer, more ductile material which is also more susceptible to erosion (such as, mild steel, etc.). For example, the nozzle 44 may include a body 50 which is made of steel.

15 In this manner, the tube 40 and nozzle 44 can be relatively inexpensive to manufacture, but with the layer 48 therein, the assembly 28 is more capable of resisting erosion due to the slurry 22 flow. However, the scope of this disclosure is not limited to any particular material
20 used for the tube 40, nozzle 44 and/or layer 48.

 The erosion resistant material may be applied to the interior of the tube 40 and nozzle 44 using various techniques, such as, coating, spraying, explosive forming, molding, etc. The erosion resistant layer 48 may be formed
25 by flame spray, including high-velocity oxy-fuel (HVOF) thermal spray. The scope of this disclosure is not limited to any particular technique for providing the layer 48 in the tube 40 or nozzle 44.

30 In the FIG. 6 example, the entire tube 40 is not lined with the erosion resistant layer 48. Instead, a section including the nozzle 44 is separately constructed with the layer 48 therein, and this section is incorporated into the

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tube 40 (e.g., by welding, threading, slip fitting, etc.). In this manner, the area most susceptible to erosion (the nozzle 44 and adjacent section of the tube 40) is provided with the erosion resistant layer 48, and the remainder of the tube 40 is more economical to manufacture.

Referring additionally now to FIG. 6, an enlarged scale cross-sectional view of an intersection of the tubes 38, 40 is representatively illustrated. In this view, it may be seen that the slurry 22 can flow from the tube 38 to the tube 40, which directs the slurry 22 to flow from an internal shunt flow path 46 to an exterior of the screen 24 (e.g., into the annulus 20).

The flow path 46 has a smaller cross-sectional area in the tube 40, and so a velocity of the slurry 22 in the tube 40 can increase. Such increased velocity can cause increased erosion near the intersection of the tubes 38, 40.

An erosion resistant layer 48 protects the intersection of the tubes 38, 40 from erosion due to the flow of the erosive slurry 22. The erosion resistant layer 48 internally lines the intersection of the tubes 38, 40 in the FIG. 5 example.

Preferably, the erosion resistant layer 48 has a hardness and/or erosion resistance which is greater than that of the tubes 38, 40. In this manner, the layer 48 resists erosion due to flow of the slurry 22.

In some examples, the layer 48 may comprise tungsten carbide or another composite or relatively hard and erosion resistant material. The tubes 38, 40 may be made of a softer, more ductile material which is also more susceptible to erosion (such as, mild steel, etc.). For example, the tube 40 may include a body 50 which is made of steel.

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In this manner, the tubes 38, 40 can be relatively inexpensive to manufacture, but with the layer 48 therein, the assembly 28 is more capable of resisting erosion due to the slurry 22 flow. However, the scope of this disclosure is not limited to any particular material used for the tubes 38, 40, and/or layer 48.

The erosion resistant material may be applied to the interior of the tubes 38, 40 using various techniques, such as, cladding, coating, spraying, explosive forming, molding, etc. The scope of this disclosure is not limited to any particular technique for providing the layer 48 in the tubes 38, 40.

In the FIG. 7 example, a section of the tube 40 in which the slurry 22 is induced to change direction is lined with the erosion resistant layer 48. In this manner, erosive effects due to the change in direction of the slurry 22 flow are mitigated.

Note that it is not necessary that all of either of the tubes 38, 40 be entirely lined with the erosion resistant layer 48. Instead, any separate section of the tube(s) 38 and/or 40 can be separately constructed with the layer 48 therein, and this section incorporated into the tube(s) 38, 40 (e.g., by welding, threading, slip fitting, etc.). Alternatively (or in addition), the layer 48 can be applied to any or all sections of the tube(s) 38, 40. In this manner, the areas most susceptible to erosion (e.g., areas experiencing relatively high velocity slurry 22 flow, areas where the slurry flow experiences a change in direction, etc.) can be provided with the erosion resistant layer 48, and the remainder of the tube(s) 38, 40 can be more economical to manufacture.

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It may now be fully appreciated that the above disclosure provides significant advancements to the art of constructing well screens. In examples described above, the screen 24 is provided with shunt tube assemblies 28 in which
5 nozzles 44 thereof have an erosion resistant layer 48 therein.

A well screen 24 is provided to the art by the above disclosure. In one example, the screen 24 can include a shunt flow path 46, and an erosion resistant layer 48
10 between the shunt flow path 46 and a body 50, the erosion resistant layer 48 having a greater erosion resistance as compared to the body 50.

The erosion resistant layer 48 may internally line the shunt flow path 46. The erosion resistant layer 48 may be
15 positioned in a section of the shunt flow path 46 having a reduced cross-sectional area, and/or in a section of the shunt flow path 46 having a change in direction, and/or in a section of the shunt flow path 46 comprising an intersection between shunt tubes 38, 40.

20 The shunt flow path 46 may provide fluid communication between opposite ends of the well screen 24, and/or between an interior and an exterior of the well screen 24.

The body 50 can comprise a steel material. The erosion resistant layer 48 can comprise a tungsten carbide material.

25 The erosion resistant layer 48 may comprise a coating applied to an interior of a shunt tube 38, 40.

A method of constructing a well screen 24 is also described above. In one example, the method can comprise: constructing a shunt flow path 46 to direct an erosive
30 slurry 22 to an exterior of the well screen 24, the shunt flow path 46 having an erosion resistant layer 48 therein,

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and positioning the shunt flow path 46 with the well screen 24, whereby the shunt flow path 46 can convey the erosive slurry 22 between opposite ends of the well screen 24.

5 The constructing step can include positioning the erosion resistant layer 48 between the shunt flow path 46 and a body 50, the erosion resistant layer 48 having a greater erosion resistance as compared to the body 50.

10 A steel body 50 may surround the shunt flow path 46, the steel body 50 having the erosion resistant layer 48 therein, whereby the erosion resistant layer 48 protects the steel body 50 from the erosive slurry 22.

15 A system 10 for use with a well is also described above. In one example, the system 10 can include a well screen 24 including a shunt flow path 46 through which an erosive slurry 22 flows between sections of an annulus 20 external to the well screen 24, and an internal erosion resistant layer 48 in the shunt flow path 46.

20 Another well screen 24 is provided to the art by the disclosure above. In one example, the screen 24 can include a shunt flow path 46 and a nozzle 44 which provides fluid communication between the shunt flow path 46 and an exterior of the well screen 24. The nozzle 44 has an erosion resistant layer 48 therein.

25 The erosion resistant layer 48 can comprise a coating which internally lines both the nozzle 44 and the shunt flow path 46.

30 The shunt flow path 46 can also provide fluid communication between opposite ends of the well screen 24 (e.g., via the tube 38). The nozzle 44 can include a steel body 50 having the erosion resistant layer 48 therein,

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whereby the erosion resistant layer 48 protects the steel body 50 from an erosive slurry 22.

The erosion resistant layer 48 may comprise a tungsten carbide material. The erosion resistant layer 48 may
5 comprise a coating applied in the shunt flow path 46 and to an interior of the nozzle 44. The erosion resistant layer 48 can extend into the shunt flow path 46.

The erosion resistant layer 48 can have a greater erosion resistance and/or hardness as compared to a body 50
10 of the nozzle 44.

A method of constructing a well screen 24 is described above in which, in one example, comprises: connecting a nozzle 44 to a shunt flow path 46, whereby the nozzle 44 can direct an erosive slurry 22 to an exterior of the well
15 screen 24, the nozzle 44 and shunt flow path 46 having an erosion resistant layer 48 therein; and positioning the shunt flow path 46 with the well screen 24, whereby the shunt flow path 46 can convey the erosive slurry 22 between opposite ends of the well screen 24.

Also provided to the art by the above description is a
20 system 10 for use with a well. The system 10 can include a well screen 24 including a shunt flow path 46 through which an erosive slurry 22 flows between sections of an annulus 20 external to the well screen 24, and a nozzle 44 which
25 directs the erosive slurry 22 from the shunt flow path 46 to the annulus 20, the nozzle 44 and shunt flow path 46 having an internal erosion resistant layer 48.

Although various examples have been described above, with each example having certain features, it should be
30 understood that it is not necessary for a particular feature of one example to be used exclusively with that example. Instead, any of the features described above and/or depicted

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in the drawings can be combined with any of the examples, in addition to or in substitution for any of the other features of those examples. One example's features are not mutually exclusive to another example's features. Instead, the scope
5 of this disclosure encompasses any combination of any of the features.

Although each example described above includes a certain combination of features, it should be understood that it is not necessary for all features of an example to
10 be used. Instead, any of the features described above can be used, without any other particular feature or features also being used.

It should be understood that the various embodiments described herein may be utilized in various orientations,
15 such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of this disclosure. The embodiments are described merely as examples of useful applications of the principles of the disclosure, which is not limited to any specific
20 details of these embodiments.

In the above description of the representative examples, directional terms (such as "above," "below," "upper," "lower," etc.) are used for convenience in referring to the accompanying drawings. However, it should
25 be clearly understood that the scope of this disclosure is not limited to any particular directions described herein.

The terms "including," "includes," "comprising," "comprises," and similar terms are used in a non-limiting sense in this specification. For example, if a system,
30 method, apparatus, device, etc., is described as "including" a certain feature or element, the system, method, apparatus, device, etc., can include that feature or element, and can

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also include other features or elements. Similarly, the term "comprises" is considered to mean "comprises, but is not limited to."

Of course, a person skilled in the art would, upon a
5 careful consideration of the above description of
representative embodiments of the disclosure, readily
appreciate that many modifications, additions,
substitutions, deletions, and other changes may be made to
the specific embodiments, and such changes are contemplated
10 by the principles of this disclosure. For example,
structures disclosed as being separately formed can, in
other examples, be integrally formed and *vice versa*.
Accordingly, the foregoing detailed description is to be
clearly understood as being given by way of illustration and
15 example only, the spirit and scope of the invention being
limited solely by the appended claims and their equivalents.

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WHAT IS CLAIMED IS:

1. A well screen, comprising:

a shunt flow path; and

5 an erosion resistant layer between the shunt flow path and a body, the erosion resistant layer comprising a coating applied to an interior of the body.

2. The well screen of claim 1, wherein the erosion
10 resistant layer internally lines the shunt flow path.

3. The well screen of claim 1, wherein the erosion resistant layer is positioned in a section of the shunt flow path having a reduced cross-sectional area.

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4. The well screen of claim 1, wherein the erosion resistant layer is positioned in a section of the shunt flow path having a change in direction.

20 5. The well screen of claim 1, wherein the erosion resistant layer is positioned in a section of the shunt flow path comprising an intersection between shunt tubes.

25 6. The well screen of claim 1, wherein the shunt flow path provides fluid communication between opposite ends of the well screen.

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7. The well screen of claim 1, wherein the shunt flow path provides fluid communication between an interior and an exterior of the well screen.

5 8. The well screen of claim 1, wherein the body comprises a steel material.

9. The well screen of claim 1, wherein the erosion resistant layer comprises a tungsten carbide material.

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10. The well screen of claim 1, wherein the erosion resistant layer is applied to an interior of a shunt tube.

11. The well screen of claim 1, wherein the erosion
15 resistant layer has a greater erosion resistance as compared to the body.

12. The well screen of claim 1, further comprising a
nozzle which provides fluid communication between the shunt
20 flow path and an exterior of the well screen, and wherein the coating lines an interior of the nozzle.

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13. A method of constructing a well screen, the method comprising:

constructing a shunt flow path having an erosion resistant layer therein, the erosion resistant layer
5 comprising a coating; and
positioning the shunt flow path with the well screen.

14. The method of claim 13, wherein the constructing further comprises positioning the erosion resistant layer
10 between the shunt flow path and a body, the erosion resistant layer having a greater erosion resistance as compared to the body.

15. The method of claim 14, wherein a steel body
15 surrounds the shunt flow path, the steel body having the erosion resistant layer therein, whereby the erosion resistant layer protects the steel body from the erosive slurry.

20 16. The method of claim 13, wherein the constructing further comprises the erosion resistant layer internally lining the shunt flow path.

17. The method of claim 13, wherein the constructing
25 further comprises positioning the erosion resistant layer in a section of the shunt flow path having a reduced cross-sectional area.

18. The method of claim 13, wherein the constructing
30 further comprises positioning the erosion resistant layer in

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a section of the shunt flow path having a change in direction.

19. The method of claim 13, wherein the constructing
5 further comprises positioning the erosion resistant layer in
a section of the shunt flow path comprising an intersection
between shunt tubes.

20. The method of claim 13, wherein the erosion
10 resistant layer comprises a tungsten carbide material.

21. The method of claim 13, further comprising
connecting a nozzle to the shunt flow path, whereby the
nozzle can direct an erosive slurry to an exterior of the
15 well screen, the nozzle having the erosion resistant layer
therein.

22. The method of claim 13, wherein the shunt flow
path can convey an erosive slurry between opposite ends of
20 the well screen.

23. The method of claim 13, wherein the shunt flow
path can convey an erosive slurry between an interior and
an exterior of the well screen.

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24. A system for use with a well, the system comprising:

a well screen including a shunt flow path through which an erosive slurry flows between longitudinal sections of an annulus external to the well screen, and an internal erosion
5 resistant layer in the shunt flow path, the erosion resistant layer comprising a coating.

25. The system of claim 24, wherein the erosion
10 resistant layer is positioned between the shunt flow path and a body, the erosion resistant layer having a greater erosion resistance as compared to the body.

26. The system of claim 25, wherein the body comprises
15 a steel material.

27. The system of claim 24, wherein the erosion resistant layer internally lines the shunt flow path.

20 28. The system of claim 24, wherein the erosion resistant layer is positioned in a section of the shunt flow path having a reduced cross-sectional area.

29. The system of claim 24, wherein the erosion
25 resistant layer is positioned in a section of the shunt flow path having a change in direction.

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30. The system of claim 24, wherein the erosion resistant layer is positioned in a section of the shunt flow path comprising an intersection between shunt tubes.

5 31. The system of claim 24, wherein the shunt flow path provides fluid communication between opposite ends of the well screen.

10 32. The system of claim 24, wherein the shunt flow path provides fluid communication between an interior and an exterior of the well screen.

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33. A well screen, comprising:

a shunt flow path;

a nozzle which provides fluid communication between the shunt flow path and an exterior of the well screen; and

5 an erosion resistant layer which lines the shunt flow path and an interior of the nozzle.

34. The well screen of claim 33, wherein the shunt flow path provides fluid communication between opposite ends
10 of the well screen.

35. The well screen of claim 33, wherein the nozzle comprises a steel body having the erosion resistant layer therein, whereby the erosion resistant layer protects the
15 steel body from an erosive slurry.

36. The well screen of claim 33, wherein the erosion resistant layer comprises a tungsten carbide material.

20 37. The well screen of claim 33, wherein the erosion resistant layer comprises a coating applied in the shunt flow path and to the interior of the nozzle.

38. The well screen of claim 33, wherein the erosion
25 resistant layer has a greater erosion resistance as compared to a body of the nozzle.

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39. The well screen of claim 33, wherein the erosion resistant layer has a greater hardness as compared to a body of the nozzle.