[0018] The invention provides a method and apparatus for use of a fluid diode in a passageway to provide a relatively high resistance to fluid flow through a passageway in one direction while providing a relatively low resistance to fluid flow in the opposite direction. It is envisioned that such relative restriction of fluid flow can be used in any operation where fluid flow is desired in one direction and undesired in the opposite direction. For example, during production of hydrocarbons from the wellbore, fluid typically flows from the wellbore, into the tubing string, and thence uphole towards the surface. However, if flow is reversed for some reason, a fluid diode, or series of diodes, will restrict flow in the reverse direction. The diodes can be used similarly in injection operations to restrict fluid flow uphole. Persons of skill in the art will recognize other uses where restriction of flow in one direction is preferable.

[0019] Figure 2 is a cross-sectional view of a fluid diode of a preferred embodiment of the invention. The fluid diode 100 is positioned in a fluid passageway 102 defined by a passageway wall 101. The passageway 102 can be positioned in a downhole tool, tubing string, as part of a larger autonomous fluid control system, in series with additional fluid diodes, or individually.

[0020] The fluid diode 100 has a high resistance entry 104 and a low resistance entry 106. The low resistance entry 104, in the preferred embodiment shown, has a substantially conical surface 108 narrowing from a large diameter end 110 to a small diameter end 112 and terminating at an orifice 114. The substantially conical surface is preferably manufactured such that it is, in fact, conical; however, the surface can instead vary from truly conical, such as made of a plurality of flat surfaces arranged to provide a

It is claimed:

1. An apparatus for autonomously controlling fluid flow in a subterranean well, the apparatus comprising:

a fluid passageway having a fluid diode positioned therein;

the fluid diode having opposing high resistance and low resistance entries;

the low resistance entry providing a relatively low resistance to fluid flowing into the diode through the low resistance entry; and

the high resistance entry providing a relatively high resistance to fluid flowing into the diode through the high resistance entry, and wherein the high resistance entry has a concave, annular surface surrounding an orifice.

2. An apparatus as in claim 1, wherein the low resistance entry has a substantially conical surface.

3. An apparatus as in claim 2, wherein the substantially conical surface narrows and ends at the orifice.

4. An apparatus as in claim 1, wherein the concave annular surface extends longitudinally beyond the plane of the orifice.

5. An apparatus as in claim 1, further comprising a downhole tool, the fluid passageway and diode positioned in the downhole tool.

6. An apparatus as in claim 5, wherein the subterranean well extends from the surface, and wherein the diode is positioned such that fluid flow towards the surface enters the low resistance entry of the diode.

7. An apparatus as in claim 5, further comprising an autonomous fluid control system having a vortex assembly and flow control assembly.

8. An apparatus as in claim 7, wherein the diode is positioned upstream from the vortex assembly.

9. An apparatus as in claim 7, wherein the diode is positioned downstream from the flow control assembly.

10. An apparatus as in claim 4, the concave surface for creating eddies in fluid flowing into the diode through the high-resistance entry.

11. A method of servicing a wellbore extending through a hydrocarbon-bearing subterranean formation, the method comprising the steps of:

providing a fluid diode in fluid communication with the wellbore;

flowing fluid through a low resistance entry of the diode; and

flowing fluid through a high resistance entry of the diode, thereby restricting fluid flow through the diode.

12. A method as in claim 11, wherein the low resistance entry has a conical surface.

13. A method as in claim 11, wherein the high resistance entry has a concave, annular surface surrounding an orifice.

14. A method as in claim 11, further comprising flowing fluid through an autonomous fluid control system having a flow control assembly and a vortex assembly.

15. A method as in claim 14, further comprising flowing production fluid from the wellbore into the autonomous fluid control system.

16. A method as in claim 11, further comprising flowing fluid into the wellbore.

17. A method as in claim 14, wherein the step of flowing fluid through an autonomous fluid control system occurs prior to the step of flowing fluid through the low resistance entry of the diode.

18. A method as in claim 13, further comprising the step of creating eddies in the fluid flow during the step of flowing fluid through the high resistance entry of the diode.

19. A method as in claim 18, wherein the eddies are created adjacent the concave, annular surface of the high resistance entry.

20. A method as in claim 13, wherein the concave, annular surface extends longitudinally beyond a plane defined by the orifice.

[0018] The invention provides a method and apparatus for use of a fluid diode in a passageway to provide a relatively high resistance to fluid flow through a passageway in one direction while providing a relatively low resistance to fluid flow in the opposite direction. It is envisioned that such relative restriction of fluid flow can be used in any operation where fluid flow is desired in one direction and undesired in the opposite direction. For example, during production of hydrocarbons from the wellbore, fluid typically flows from the wellbore, into the tubing string, and thence uphole towards the surface. However, if flow is reversed for some reason, a fluid diode, or series of diodes, will restrict flow in the reverse direction. The diodes can be used similarly in injection operations to restrict fluid flow uphole. Persons of skill in the art will recognize other uses where restriction of flow in one direction is preferable.

[0019] Figure 2 is a cross-sectional view of a fluid diode of a preferred embodiment of the invention. The fluid diode 100 is positioned in a fluid passageway 102 defined by a passageway wall 101. The passageway 102 can be positioned in a downhole tool, tubing string, as part of a larger autonomous fluid control system, in series with additional fluid diodes, or individually.

[0020] The fluid diode 100 has a high resistance entry 106 and a low resistance entry 104. The low resistance entry 104, in the preferred embodiment shown, has a substantially conical surface 108 narrowing from a large diameter end 110 to a small diameter end 112 and terminating at an orifice 114. The substantially conical surface is preferably manufactured such that it is, in fact, conical; however, the surface can instead vary from truly conical, such as made of a plurality of flat surfaces arranged to provide a

CLAIMS

1. An apparatus for autonomously controlling fluid flow in a subterranean well, the apparatus comprising:

a fluid passageway having a fluid diode positioned therein;

the fluid diode having opposing high resistance and low resistance entries;

the low resistance entry providing a relatively low resistance to fluid flowing into the diode through the low resistance entry; and

the high resistance entry providing a relatively high resistance to fluid flowing into the diode through the high resistance entry, and wherein the high resistance entry has a concave, annular surface surrounding an orifice;

wherein the fluid passageway is one of a pair of parallel passageways that extend between a common inlet where fluid may be divided into the pair of parallel passageways and respective outlets where fluid may be recombined from the pair of parallel passageways.

2. An apparatus as in claim 1, wherein the low resistance entry has a substantially conical surface.

3. An apparatus as in claim 2, wherein the substantially conical surface narrows and ends at the orifice.

4. An apparatus as in claim 1, wherein the concave annular surface extends longitudinally beyond the plane of the orifice.

5. An apparatus as in claim 1, further comprising a downhole tool, the fluid passageway and diode positioned in the downhole tool.

6. An apparatus as in claim 5, wherein the subterranean well extends from the surface, and wherein the diode is positioned such that fluid flow towards the surface enters the low resistance entry of the diode.

7. An apparatus as in claim 5, further comprising an autonomous fluid control system having a vortex assembly and flow control assembly.

8. An apparatus as in claim 7, wherein the diode is positioned upstream from the vortex assembly.

9. An apparatus as in claim 7, wherein the diode is positioned downstream from the flow control assembly.

10. An apparatus as in claim 4, the concave surface for creating eddies in fluid flowing into the diode through the high-resistance entry.

11. A method of servicing a wellbore extending through a hydrocarbon-bearing subterranean formation, the method comprising the steps of:

providing a fluid diode positioned in a fluid passageway, wherein said fluid diode is in fluid communication with the wellbore;

flowing fluid through a low resistance entry of the diode; and

flowing fluid through a high resistance entry of the diode, thereby restricting fluid flow through the diode;

wherein the fluid passageway is one of a pair of parallel passageways that extend between a common inlet where fluid may be divided into the pair of parallel passageways and respective outlets where fluid may be recombined from the pair of parallel passageways.

12. A method as in claim 11, wherein the low resistance entry has a conical surface.

13. A method as in claim 11, wherein the high resistance entry has a concave, annular surface surrounding an orifice.

14. A method as in claim 11, further comprising flowing fluid through an autonomous fluid control system having a flow control assembly and a vortex assembly.

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18. A method as in claim 13, further comprising the step of creating eddies in the fluid flow during the step of flowing fluid through the high resistance entry of the diode.

19. A method as in claim 18, wherein the eddies are created adjacent the concave, annular surface of the high resistance entry.

20. A method as in claim 13, wherein the concave, annular surface extends longitudinally beyond a plane defined by the orifice.