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(54) **DOWNHOLE GAS COMPRESSION SEPARATOR ASSEMBLY**

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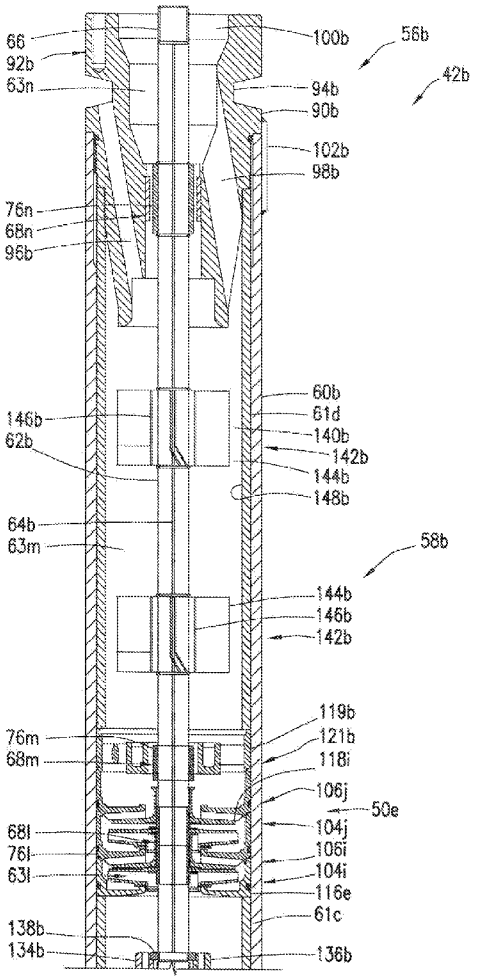
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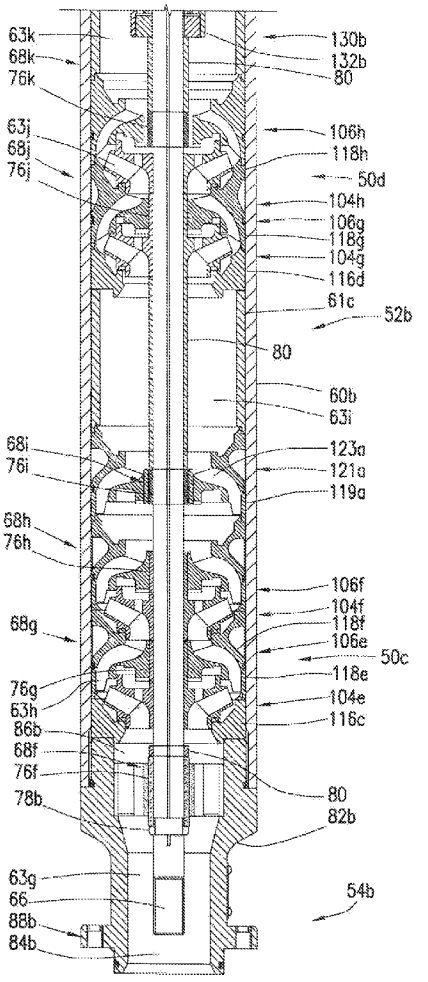
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(57) **ABSTRACT**

Downhole Electric Submersible Pumps (ESP) in a production string often experience gas lock caused by free gas present in the production liquids which reduces intake pressure below the operating parameters of the ESP. A gas compression separator assembly, having a series of compressors and separation chambers, entrains or dissolves the free gas component of the production fluid and separates free gas for downhole disposal. The production fluid fed to the ESP intake has an increased fluid pressure, a reduced volumetric fluid flow, and a lower free gas content, and is less likely to induce gas lock of the ESP.





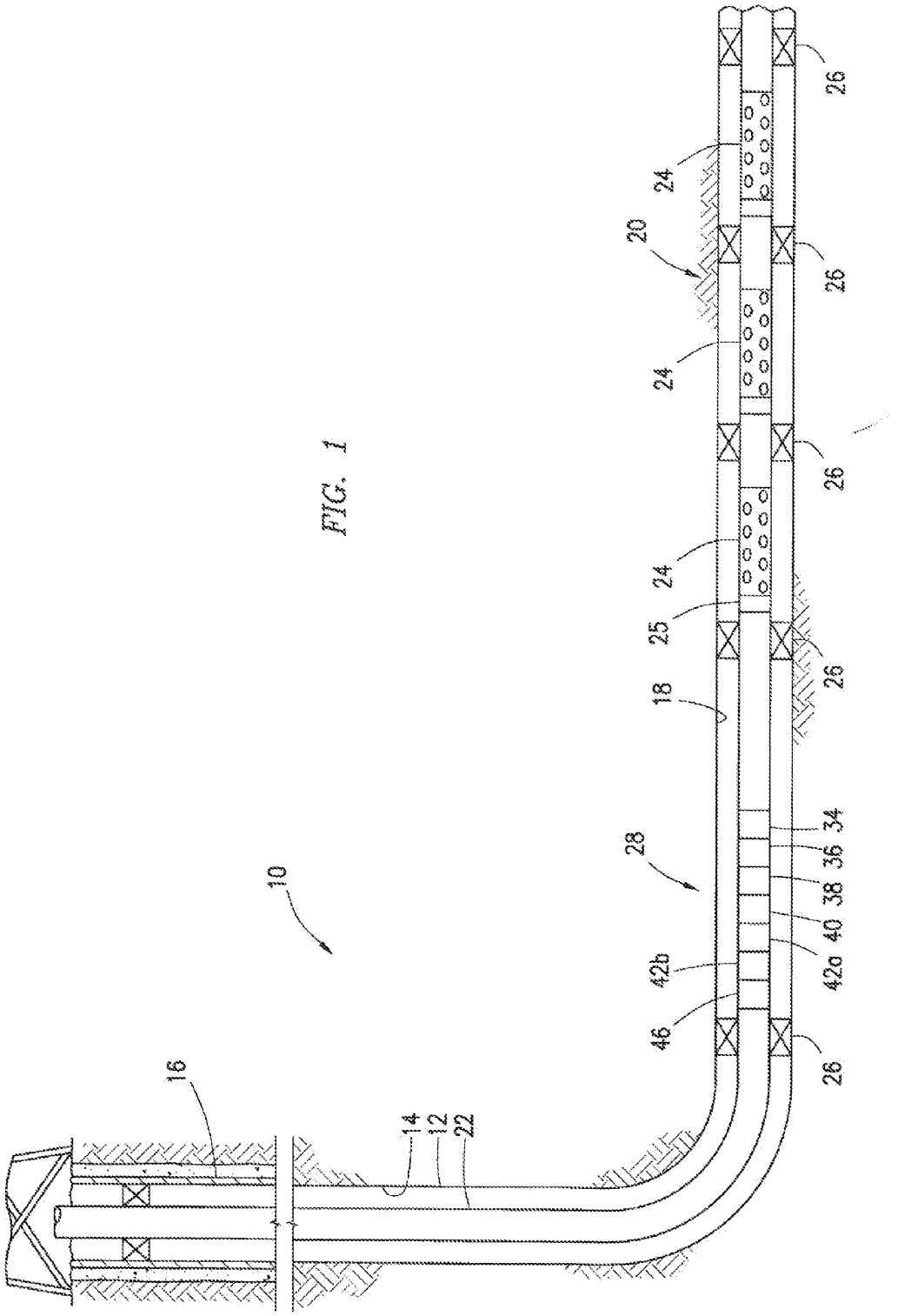


FIG. 1

FIG. 2

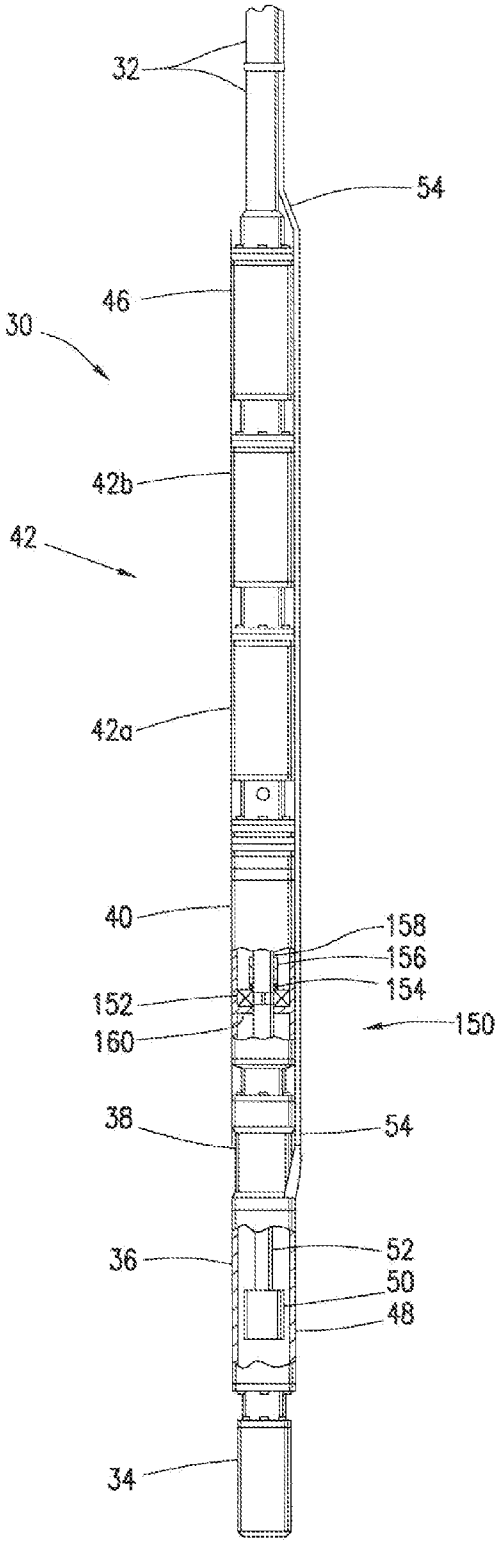

32
54
46
30
42b
42
42a
40
158
156
154
152
150
160
38
54
36
52
50
48
34

FIG. 3A

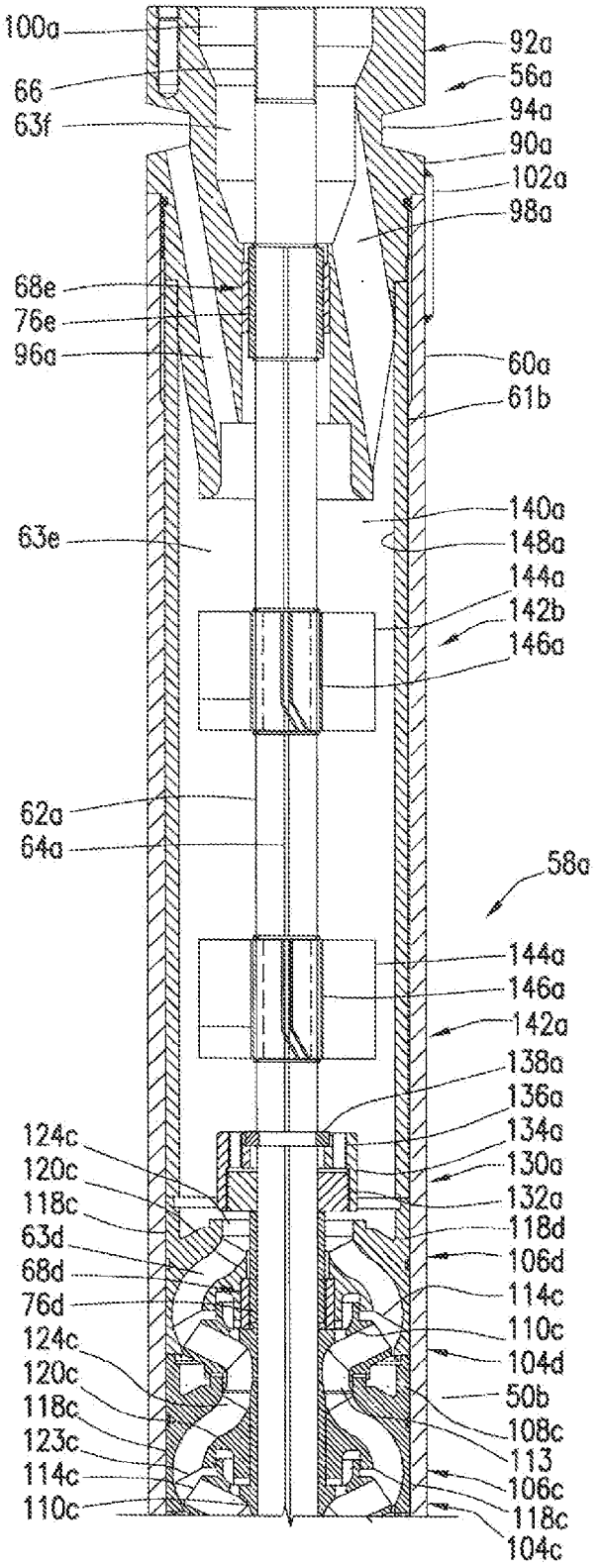

100a
66
63f
68e
76e
96a
63e
62a
64a
124c
120c
118c
63d
68d
76d
124c
120c
118c
123c
114c
110c
92a
56a
94a
90a
102a
98a
60a
61b
140a
148a
144a
142b
146a
58a
144a
146a
142a
138a
136a
134a
130a
132a
118d
106d
114c
110c
104d
50b
108c
113
106c
118c
104c

FIG. 3B

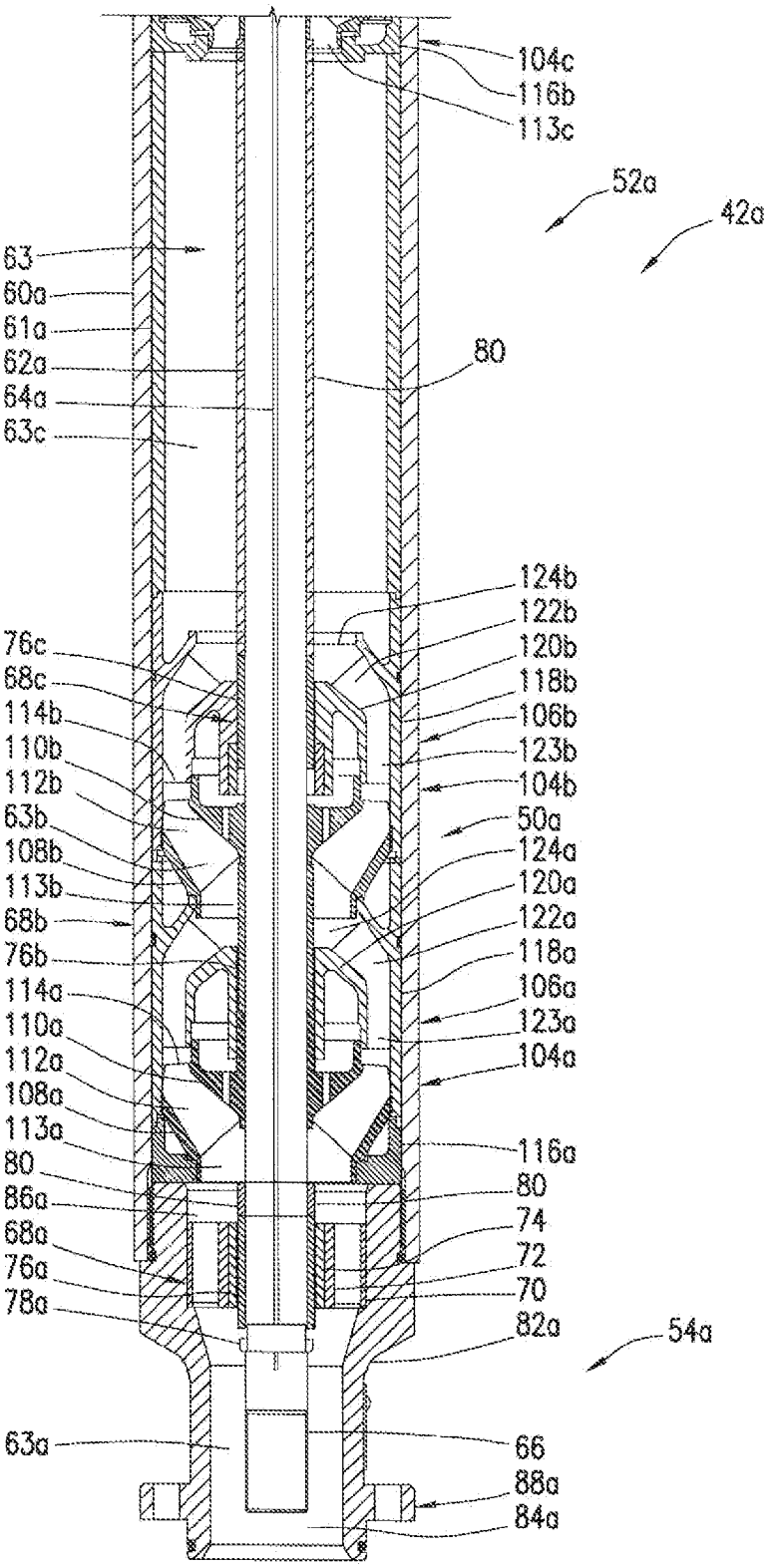

104c
116b
113c
52a
42a
63
60a
61a
62a
64a
63c
80
124b
122b
120b
118b
106b
123b
104b
50a
124a
120a
122a
118a
106a
123a
104a
116a
80
74
72
70
82a
54a
66
88a
84a
76c
68c
114b
110b
112b
63b
108b
113b
68b
76b
114a
110a
112a
108a
113a
80
86a
68a
76a
78a
63a

FIG. 4A

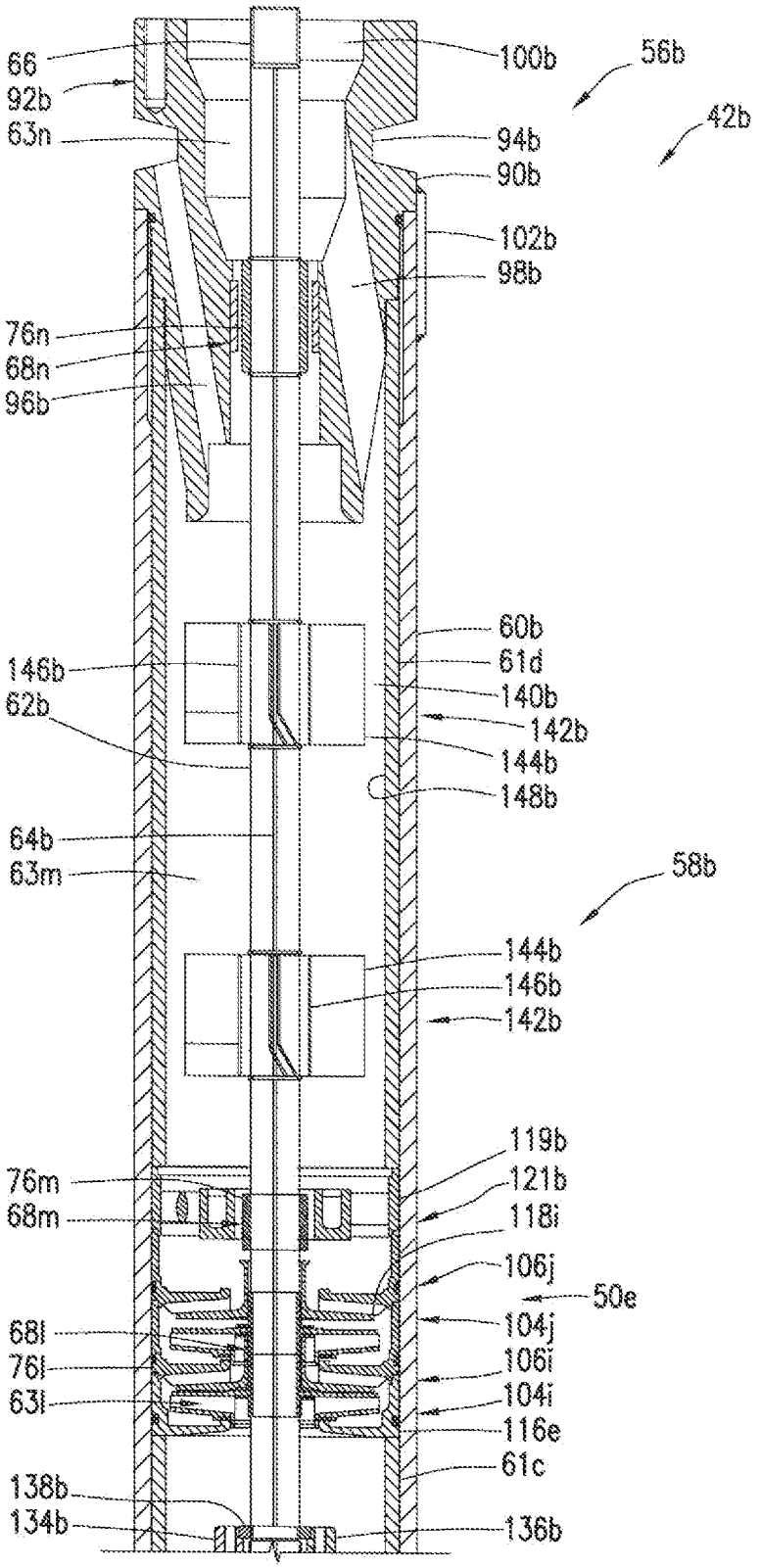

66
92b
63n
100b
56b
42b
94b
90b
102b
98b
76n
68n
96b
60b
61d
140b
142b
144b
148b
146b
62b
64b
63m
58b
144b
146b
142b
119b
121b
118i
106j
50e
104j
106i
104i
116e
61c
136b
76m
68m
68l
76l
63l
138b
134b

FIG. 4B

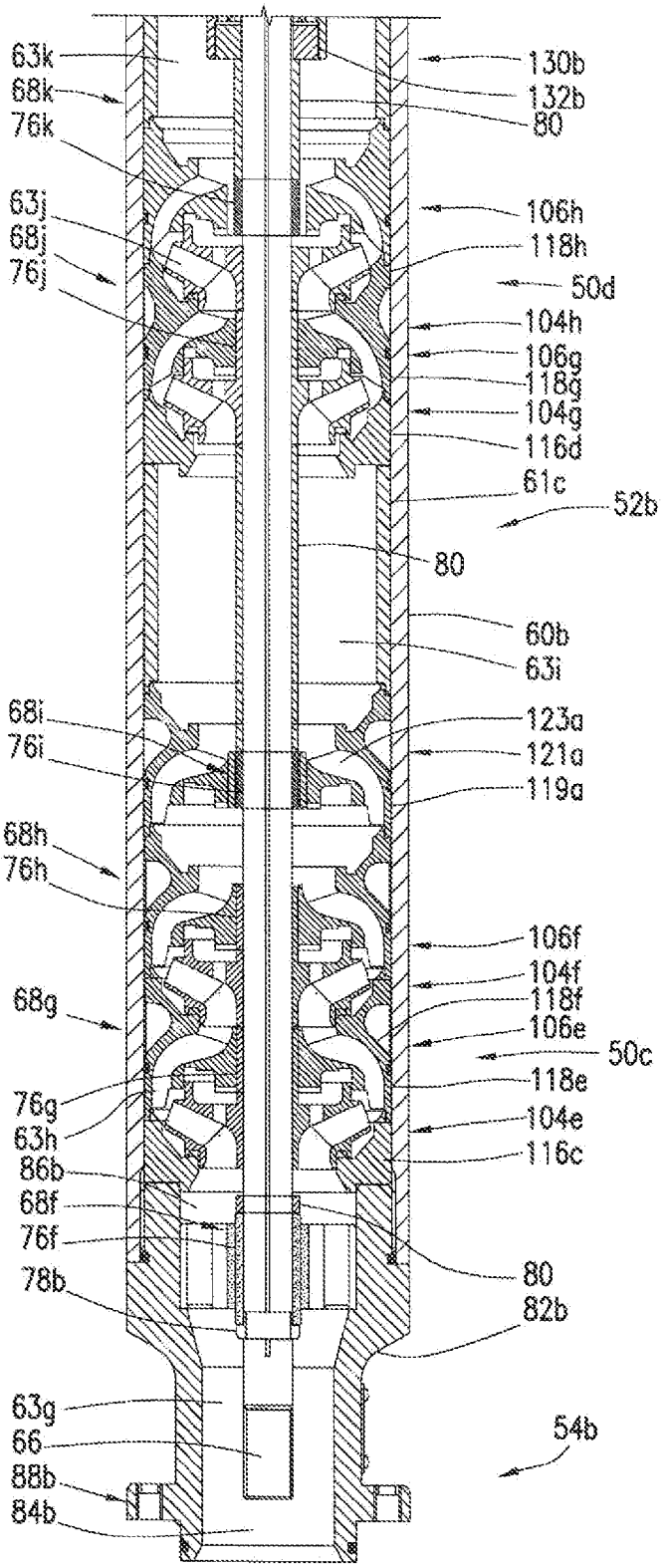

63k
68k
76k
63j
68j
76j
68i
76i
68h
76h
68g
76g
63h
86b
68f
76f
78b
63g
66
88b
84b
130b
132b
80
106h
118h
50d
104h
106g
118g
104g
116d
61c
52b
80
60b
63i
123a
121a
119a
106f
104f
118f
106e
50c
118e
104e
116c
80
82b
54b

FIG. 5A

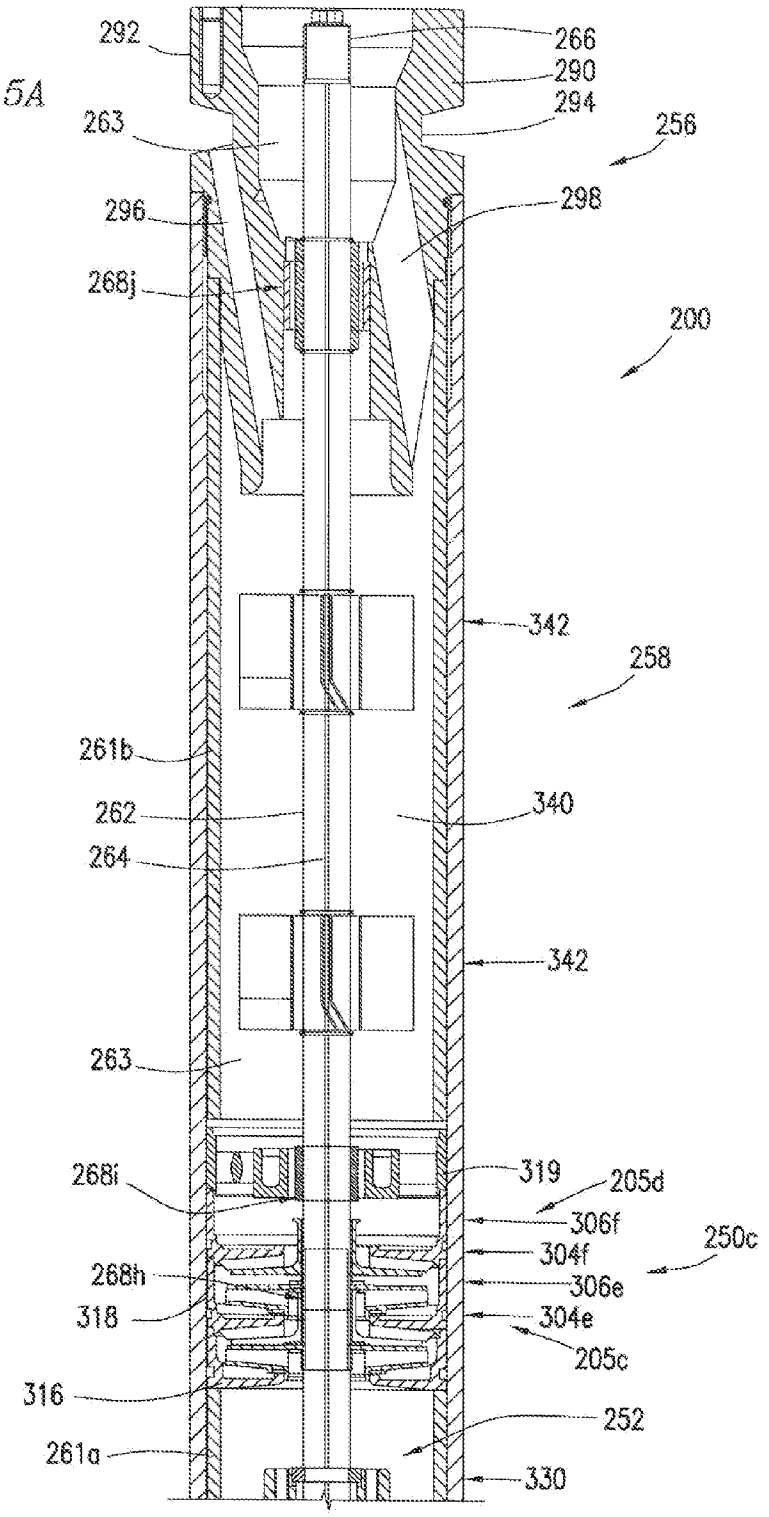
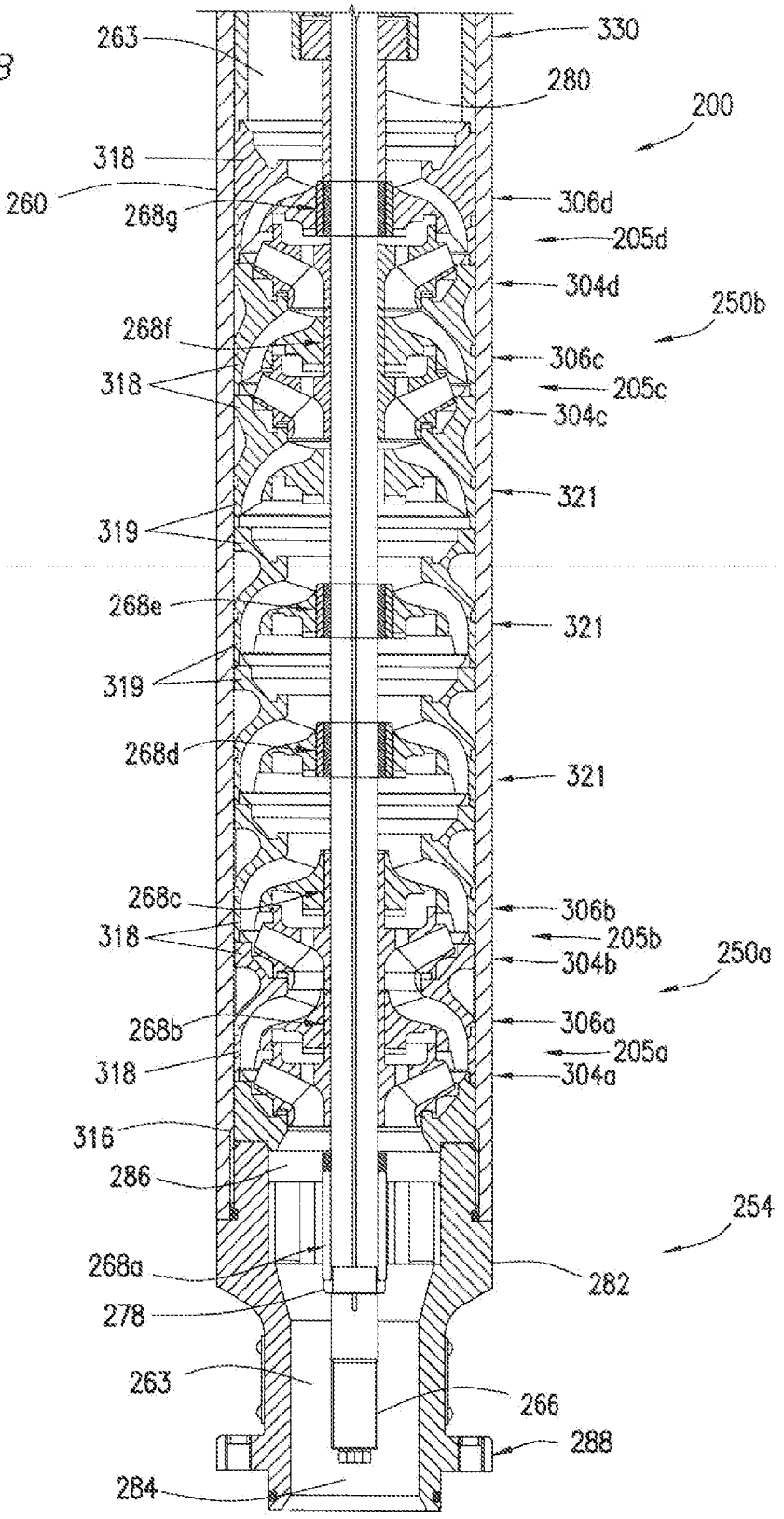

292
266
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263
256
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298
268j
200
342
258
261b
262
340
264
342
263
268i
319
205d
306f
304f
250c
306e
268h
318
304e
205c
316
252
261a
330

FIG. 5B


263
330
280
200
318
260
268g
306d
205d
304d
250b
268f
306c
318
205c
304c
321
319
268e
321
319
268d
321
268c
306b
318
205b
304b
250a
268b
306a
205a
318
304a
316
286
254
268a
282
278
263
266
288
284

DOWNHOLE GAS COMPRESSION SEPARATOR ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] None.

FIELD OF INVENTION

[0002] The disclosure generally relates to production of hydrocarbon-bearing fluids from a wellbore extending through a subterranean reservoir. More particularly, the disclosure addresses apparatus and methods for reducing free gas in production fluid by separating free gas from production liquid and by compressing the production fluid to dissolve or entrain free gas.

BACKGROUND OF INVENTION

[0003] In the production of hydrocarbons from a wellbore extending through a hydrocarbon-bearing zone in a reservoir, a production string or tubing is often positioned in the wellbore. A production string can include multiple downhole tools, pipe sections and joints, sand screens, flow and inflow control devices, etc. To pump production fluid to the surface, an electrical submersible pump (ESP), powered by an electric motor through a drive shaft, is positioned downhole in the wellbore. Electrical power is typically provided from a surface source by power cable extending to the downhole electric motor. Additional tools are used in conjunction with an ESP and electric motor, including one or multiple seal subassemblies, protectors, sensor assemblies, gas separators, additional pumps, standing valves, etc. The electric motor typically is used to power the pumps, gas separators, etc., via a drive shaft connected to the rotary elements of these devices.

[0004] A submersible pump can see dozens of shut-offs each year for various reasons. Unwanted and nuisance shut-offs include those caused by gas lock, a condition in pumping and processing equipment caused by induction of free gas. The presence of compressible gas, or free gas, interferes with operation of the pump, preventing intake of production fluid. Natural gas, and other naturally occurring gases, is often found entrained or dissolved in the production fluid. Where the gas is in a gaseous phase, mixed with production liquids, the free gas can exist in situ in the reservoir or can evolve during production as pressure drops below the bubble point.

[0005] Further, it is often undesirable to produce natural gas from wells having both gas and oil, for example. Consequently, downhole gas separators are used to separate the gaseous fluid from the liquid fluid of the production fluid at a downhole location, with the gaseous fluid vented back into the wellbore. The produced fluid at the surface is then composed of a larger percentage of the preferred liquid fluid. Free gas at the surface can still occur, for example, as the production fluid reaches the bubble point during pumping to the surface, however, a smaller amount of gaseous phase fluid occurs with the use of downhole separators.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

[0007] FIG. **1** is a schematic view of an exemplary well system utilizing an embodiment of a gas compression separator assembly disclosed herein;

[0008] FIG. **2** is a schematic partial view of an exemplary tubing string having various downhole tools thereon, including an electrical submersible pump and electrical motor for use in conjunction with a gas compression separator assembly according to the disclosure;

[0009] FIGS. **3**A-B are cross-sectional views of a lower section of an exemplary gas compression separator assembly according to an aspect of the disclosure;

[0010] FIGS. **4**A-B are cross-sectional views of an upper section of the gas compression separator assembly according to an aspect of the disclosure; and

[0011] FIGS. **5**A-B are cross-sectional views of another exemplary embodiment of a gas compression separator according to an aspect of the disclosure.

[0012] It should be understood by those skilled in the art that the use of directional terms such as above, below, upper, lower, upward, downward and the like are used in relation to the illustrative embodiments as they are depicted in the figures, the upward direction being toward the top of the corresponding figure and the downward direction being toward the bottom of the corresponding figure. Where this is not the case and a term is being used to indicate a required orientation, the Specification will state or make such clear.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0013] While the making and using of various embodiments of the present disclosure are discussed below, a practitioner of the art will appreciate that the disclosure provides concepts which can be applied in a variety of specific embodiments and contexts. The specific embodiments discussed herein are illustrative of specific ways to make and use the disclosed apparatus and methods and do not limit the scope of the claimed invention.

[0014] As used herein, the words "comprise," "have," "include," and all grammatical variations thereof are each intended to have an open, non-limiting meaning that does not exclude additional elements or steps. It should be understood that, as used herein, "first," "second," "third," etc., are arbitrarily assigned, merely differentiate between two or more items, and do not indicate sequence. Furthermore, the use of the term "first" does not require a "second," etc.

[0015] The terms "uphole" and "downhole," "upward" and "downward," and the like, refer to movement or direction with respect to the wellhead, regardless of borehole orientation. The terms "upstream" and "downstream" refer to the relative position or direction in relation to fluid flow, irrespective of the borehole orientation. Although the description may focus on particular means for positioning tools in the wellbore, such as a tubing string, coiled tubing, or wireline, those of skill in the art will recognize where alternate means can be utilized. Directional terms, such as "above" and "below" may also be used with respect to the Figures as shown and so do not limit to the orientation of the assembly or tool in use.

[0016] FIG. **1** is a schematic illustration of a well system, indicated generally **10**, having a compressor and gas separator assembly according to an embodiment of the disclosure. A wellbore **12** extends through various earth strata, including at least one production zone. Exemplary wellbore **12** has a substantially vertical section **14** and a substantially deviated section **18**, shown as horizontal, which extends through a hydro-

carbon-bearing subterranean zone **20**. As illustrated, the wellbore is cased with a casing **16** along an upper length. The wellbore is open-hole along a lower length. The disclosed apparatus and methods will work in various wellbore orientations and in open or cased bores.

[0017] Positioned within wellbore **12** and extending from the surface is a production tubing string **22**. Typically the production tubing string is hung from or attached to the casing or wellhead. The production tubing string **22** provides a conduit for production fluids to travel from the formation zone **20** up to the surface. Positioned within the string **22** in various production intervals adjacent to the zone **20** are a plurality of production tubing sections **24**. Annular isolation devices **26**, such as packers, provide annular seals to fluid flow and differential pressure in the annulus defined between the production tubing string **22** and the casing **16**. The areas between adjacent isolation devices **26** define production intervals.

[0018] In FIG. **1**, the production tubing sections **24** include sand control capability such as sand control screen elements to allow production fluid to flow therethrough but filter particulate matter of sufficient size. Other tools and mechanisms can be used in conjunction with the production string along the production zone, such as flow control devices, autonomous flow control devices, check valves, protective shrouds, sliding sleeve valves, etc. Such elements are well known in the industry.

[0019] The production string allows production fluid to enter the string. The production fluid can have multiple components, such as oil, water, natural gas and other gases, in varying proportions. Further, the composition of the production fluid can vary between production intervals. The term "natural gas" as used herein means a mixture of hydrocarbons and varying quantities of non-hydrocarbons that exist in a gaseous phase at room temperature and pressure. The term does not indicate that the natural gas is in a gaseous phase at the downhole location of the inventive systems. Where it is intended to refer to a substance in a gaseous phase, the terms "free gas," "gaseous phase," or similar, is used. It is to be understood that at formation pressure and temperature, natural gas may exist dissolved in a liquid or mixed with a liquid. Such natural gas can evolve to a gaseous phase, for example, in the production string under lower pressures or temperatures. The disclosed apparatus and methods are useful to entrain or dissolve evolved free gas into the liquid components of the production fluid.

[0020] The production tubing string seen in FIG. **1** also includes an exemplary and schematic tool stack **28** or series of tools for managing production fluid downhole and pumping production fluid to the surface. The tools presented are exemplary, non-limiting, and are discussed with further respect to FIG. **2**, including gas compression separator assembly **42**.

[0021] FIG. **2** is a schematic view in elevation of an exemplary tubing string having various downhole tools thereon, including an electrical submersible pump and electric motor for use in conjunction with a compressor and gas separator assembly according to the disclosure.

[0022] The tubing string **30** includes multiple connected downhole tools positioned below a string of tubulars **32** extending to the surface. The exemplary tubing string **30** includes a sensor assembly **34**, an electric motor assembly **36**, a seal subassembly **38**, a protector assembly **40**, a gas compression separator assembly **42***a-b*, and an electrical submersible pump assembly **46**. The gas compression separator assembly **42** is divided into a lower section **42***a* and an upper section **42***b*. The protector **40** is seen in partial tear-away to show an exemplary thrust bearing assembly **150**. The thrust bearing is discussed in greater detail below herein. Additional tools can be employed, including multiple pumps, separators, and protectors. The tools are connected to one another using threaded connections or other connection mechanisms. Attached to and extending below the illustrated string is a production string extending through one or more production zones of the reservoir and typically having sand screens, flow control devices, inflow control devices, valves, and the like, and into which production fluid from the reservoir flows. The combined tubing and production strings can be referred to as a production string for ease of reference. The ESP assembly pumps the production fluid to the surface via tubulars **32**.

[0023] FIGS. **3**A-B and **4**A-B are cross-sectional views of an exemplary gas compression separator assembly **42** according to an aspect of the disclosure. FIGS. **3**A-B provide a cross-sectional view of the lower section **42***a* of the gas compression separator assembly **42**, and FIGS. **4**A-B provide a cross-sectional view of the upper section **42***b* of the gas compression separator assembly **42**. The Figures are discussed in sequence, however, like parts on the sections are indicated by like numbers, typically with a distinguishing suffix.

[0024] The gas compression separator **42** is designed to treat, at a downhole location, production fluid having both a free gas component and a liquid component. Generally, the exemplary gas separator assembly **42** is seen split into a lower section **42***a* and upper section **42***b*. The division into sections is largely for ease of manufacture, assembly, and transport. As shown, the lower section **42***a* includes a first compression stage **50***a* and a second compressor stage **50***b*, arranged in series, with each stage having two impellers and diffusers. Similarly, the upper section **42***b* has a third compressor stage **50***c* and a fourth compressor stage **50***d*, also in series, and each having two impellers and diffusers. Each compressor stage acts on the production fluid to incrementally increase fluid pressure (typically measured in psi), decrease fluid volume, and reduce volumetric fluid flow rate (often measured in barrels per day, bpd). The stage capacities are carefully selected such that, at each stage, the production fluid is within the operating pressure range and flow rate range for that compressor stage. Similarly, each compressor stage provides compressed production fluid to the next compressor stage in the series at a pressure and flow rate within the operating range of the next stage.

[0025] Generally, the compression stages receive production fluid and, via centrifugal forces, compress it to reduce free gas in the fluid. The compression stages raise fluid pressure prior to discharge. The centrifugal force entrains free gas into a gas-liquid mix and dissolves gas into the production liquid. The compressor is preferably powered by the electric motor via a drive shaft although alternative power sources can be applied. Production fluid entering the compressor proceeds through multiple compression stages, with fluid pressure increased at each stage. Stages are arranged in series to produce, for each stage and for a combined total, a target fluid pressure, a target production volume (e.g., in bpd), a target flow rate, etc.

[0026] Further, the compressors provide increased fluid pressure without restricting fluid flow; that is, the compressor does not utilizing a restrictor plate, orifice plate, back-pressure device, or other mechanism to restrict fluid flow. Where such mechanisms are used, the restriction becomes a high-wear point and is susceptible to failure due to erosion, espe-

cially when the production fluid a high sand content. Erosion can result in cutting of the tool in two, with a resultant loss of the lower portion of the tool and any tools connected below. A fishing trip to retrieve the dropped string is expensive and time consuming. Further, such restrictions tend to plug with debris. The compression stages herein better handle debris, eliminate high-erosion points, reduce likelihood of erosive failure, and prolong useful life of the tool. The compressor design does not restrict or limit fluid flow, or hydrocarbon production, to increase fluid pressure.

[0027] The system relies on a series of multiple compression stages, but the number, size, and capacity of stages is selected based on the application, formation pressure, formation depth, production rate, free gas to liquid mix, etc. Consequently, alternative embodiments can employ fewer or greater compression stages, with varying stage specifications, and fewer or more compression stages per section. The number of compression stages, impellers, diffusers, staging sections, and the specifications for each, provided herein are therefore exemplary and not limiting.

[0028] Turning to FIG. **3**A-B, the lower section **42***a* is seen having compressors arranged as stages **50***a-b*, a fluid chamber **52***a*, a base assembly **54***a*, a head assembly **56***a*, and a gas separation assembly **58***a*. A generally cylindrical housing **60***a* encloses the compression stages **50***a-b*, fluid chamber **52***a*, separation assembly **58***a*, and portions of the base **54***a* and head **56***a* assemblies. Further, a compression tube **61** is formed along much of the length of the tool section, with compression tube sections **61***a-b* combining with diffuser bodies **118***a-d*, and compressor bases **116***a-b* to form the compression tube. The section elements define an interior passageway **63** extending the length of the section **42***a*, through which production fluid flows.

[0029] Drive shaft **62***a* extends longitudinally through the assembly **42***a*, having a keyway **64***a* for attachment of rotary elements to the shaft, upper and lower spline sections **66** for connecting the shaft to similar shafts above and below the tool. The shaft is powered, typically, by an electric motor having a rotary drive shaft and positioned downhole from the gas compression separator assembly **42***a*. An exemplary shaft, for example, has an 11/16 inch (1.746 cm) diameter and is made of a high strength metal such as Inconel 718 (trade name). A preferable shaft design is rated for a maximum of 500 horsepower. The shaft can be specialized for high-torque systems and is preferably of corrosion-resistant material. The shaft can be monolithic or formed of several shaft components.

[0030] The shaft is supported radially by a plurality of bearing assemblies **68***a-e* spaced along the shaft length. Bearing assemblies are known in the art and can preferably include associated sleeves, bushings, snap rings, pins, screws, or other attachment mechanisms. The bearings provide stability to the drive shaft during rotation. More or fewer bearings can be used depending on construction, materials, expected operating conditions, etc. Preferably the bearings are made of hardened materials, such as tungsten for example.

[0031] Base bearing **68***a* has a tubular body **70**, bearing sleeve **72**, and bushing **74**. Preferably sleeves **76***a-e* oppose the bearings **68***a-e* or associated bushings, respectively. The sleeves **76** are preferably hardened, such as of hardened carbide, etc., as is known in the art. Spacing and attachment mechanisms, such as two-piece ring **78***a*, spacer **80**, shims, etc., can be used as those of skill in the art will recognize. Additional bearings can be of alternate construction, or provided in whole or in part by another tool element, such as the impeller, diffuser and cross-over assemblies, for example.

[0032] Base assembly **54***a* has a base body **82***a* threadedly or otherwise attached to the section housing **60***a*. The base defines an interior passageway **63***a* which forms a portion of passageway **63**. The base has a fluid intake **84***a* for receiving fluid from a tool or tubing positioned below and a fluid outlet **86***a* for delivering fluid to a tool or tubing positioned above. In this instance, the outlet delivers fluid to the upper section **42***b*. The base **82***a* houses bearing **68***a* and the lower end of the shaft **62***a*, and has a coupling **88***a* for attachment to an adjacent tool or tubing.

[0033] The head assembly **56***a* is of similar construction, having a head body **90***a* defining an interior passageway **63***f* which forms a portion of passageway **63**. The head houses bearing **68***e*, sleeve **76***e*, and the upper end of the shaft **62***a*, and provides a tool coupling **92***a*. The head also defines a fishing neck **94***a*, as is known in the art. The head assembly **56***a* is a cross-over tool, providing for fluid, in this case separated free gas, to cross from the interior chamber **140***a* to the exterior of the lower tool **42***a*. Most or all of the separated free gas is vented, through a plurality of vents **96***a*, preferably to the wellbore or casing annulus defined between the tool section **42***a* and the wellbore or casing. The production liquid (and any remaining gas) flows through a plurality of interior ports **98***a* defined in the head body **90***a* and thence through head outlet **100***a*. The head assembly is threadedly or otherwise attached to the section housing **60***a* and by lock plate **102***a*.

[0034] Fluid chamber **52***a* is defined between the first and second compression stages **50***a* and **50***b* and interior to compression tube **61***a*. Shaft **62***a* extends through the fluid chamber. The chamber receives compressed fluid from the outlet of the first compressor assembly **50***a* and delivers fluid to the inlet of second compressor assembly **50***b*. Fluid pressure, fluid volume, and fluid flow rate are static across the fluid chamber **52***a*.

[0035] The lower section **42***a* is seen having a plurality of compressor assemblies, namely, **50***a-b*. Similarly, the upper section **42***b* has a plurality of compressor assemblies **50***c-e*. The first compressor assembly **50***a* is discussed in detail, with the remaining compressor assemblies **50***b-e* only briefly described as they have many of the same features and construction. Compressor assemblies are generally known in the field, as those of skill in the art will recognize. Exemplary first compressor assembly **50***a* is comprised of, in order of fluid flow, impeller assembly **104***a*, diffuser assembly **106***a*, impeller assembly **104***b*, and diffuser assembly **106***b*.

[0036] Impeller assembly **104***a* is discussed in detail, the description applying to the remaining impeller assemblies where like parts have like numbers with distinguishing suffixes in the figures. Impeller assembly **104***a* has an impeller body **108***a*, a hub **110***a* which attaches to the shaft **62***a*, and defines a plurality of radially and longitudinally extending impeller passageways **112***a* which are separated by a plurality of vanes. Impeller inlet **113***a* intakes fluid from the base outlet **86***a*. Impeller outlets **114***a* emit production fluid to diffuser inlets **123***a*. A compressor base **116***a* provides for mounting and stability of the impeller and diffuser assemblies. The remaining impeller assemblies **104***b-d* of the lower section **42***a* are of similar construction and function. Impeller outlets **114***b* of impeller assembly **104***c* emit fluid into the fluid chamber **52***a*. Preferably the impellers and diffusers are made of corrosion-resistant material, such as tungsten alloy, nickel

alloy, Ni-Resist, 9-chrome 1-molly, and the like, as are known in the art. Impeller design and use is known in the art to those of ordinary skill and will not be discussed in greater detail herein.

[0037] Diffuser assembly **106***a* is discussed in detail, the description applying to the remaining diffuser assemblies where like parts have like numbers with distinguishing suffixes. Diffuser assembly **106***a* has a diffuser body **118***a*, a hub **120***a* which also provides a bearing surface for the shaft **62***a* or the sleeve **76***b*, and defines a plurality of radially and longitudinally extending diffuser passageways **122***a* which are separated by a plurality of vanes. Diffuser outlet **124***a* emits production fluid to the inlet **113***b* of impeller **104***b*. The diffuser inlets **123***a* accept fluid from the outlets **114***a* of the impeller **104***a*. Preferably the diffusers are made of corrosion-resistant materials, such as tungsten alloy, carbide, nickel alloy, and the like. Diffuser design and use is known in the art to those of ordinary skill and will not be discussed in greater detail herein.

[0038] A compression nut assembly **130***a* is mounted to the shaft **62***a* above the compressor assembly **50***b*. The exemplary compression nut assembly has a compression nut **132***a*, compression sleeve **134***a*, set screw **136***a*, and two-piece ring **138***a*. The compression nut assembly acts as a mounting or retainer for the compressor and bearing elements below the compression nut assembly. In a preferred embodiment, the compression nut assembly is fixedly attached to the shaft and provides a load-bearing face for mounting the below elements in compression. The compression nut assembly and two-piece ring **78***b* work to "sandwich" the intervening elements, maintaining them in compression. Compression nut assemblies and equivalents are known in the art. Further, a deflector or protective sleeve can be used to protect the compression nut assembly from direct impingement by sand-laden production fluid.

[0039] The gas separation assembly **58***a* includes a plurality of vortex generators **142***a* mounted to the shaft **62***a* and positioned in a gas separation chamber **140***a*. A pair of vortex generators is mounted to the shaft **62***a* to rotate with the shaft. The vortex generators have radially extending, vertical paddles **144***a* on a hub **146***a* supported by the shaft **62***a*. The paddles stir passing production fluid in the chamber **140***a*, creating a vortex, wherein the heavier liquid components are forced radially outward against the chamber wall **148***a* while free gas components gather near the vortex axis near the center of the chamber. The length of the chamber **140***a* is selected to provide sufficient dwell time to allow for adequate separation of free gas and liquids. The length of the chamber can, in part, be determined by the formation and production characteristics, such as the amount of produced gas and production pressure. Free gas is separated from the production liquid component and exits the chamber and the tool section through the cross-over head vents **96***a*. The remaining production fluid is drawn through interior ports **98** and continues upward through the assembly. Other vortex generators are known in the art and can be used alone or in combination with the generators **142***a* shown.

[0040] Turning to FIG. **4**A-B, the upper section **42***b* is seen having compressors arranged as stages **50***c-e*, a fluid chamber **52***b*, a base assembly **54***b*, a head assembly **56***b*, and a gas separation assembly **58***b*. A generally cylindrical housing **60***b* encloses the compression stages **50***c-e*, fluid chamber **52***b*, separation assembly **58***b*, and portions of the base **54***b* and head **56***b* assemblies. Further, a compression tube **61** is formed along much of the length of the tool section, with compression tube sections **61***c-d* combining with diffuser bodies **118***e-i*, compressor bases **116***c-d*, and diffuser bearing housings **119***a-b*, to form the compression tube. The section elements, as those of the lower section, continue to define interior passageway **63** extending the length of the section **42***a*, for production fluid flow.

[0041] Drive shaft **62***b* extends longitudinally through the assembly **42***b*, having a keyway **64***b* for attachment of rotary elements to the shaft, upper and lower spline sections **66** for connecting the shaft to similar shafts above and below the tool. The shaft is powered, typically, by an electric motor having a rotary drive shaft and positioned downhole from the gas compression separator assembly **42***b*. An exemplary shaft, for example, has an 1 1/16 inch (1.746 cm) diameter and is made of a high strength metal such as Inconel 718 (trade name). A preferable shaft design is rated for a maximum of 200 horsepower (202.8 hp(M)). The shaft can be specialized for high-torque systems and is preferably of corrosion-resistant material. The shaft can be monolithic or formed of several connected shaft components.

[0042] The shaft is supported radially by a plurality of bearing assemblies **68***f-k* spaced along the shaft length. Bearing assemblies are known in the art and can preferably include associated sleeves, bushings, snap rings, pins, screws, or other attachment mechanisms. The bearings provide stability to the drive shaft during rotation. More or fewer bearings can be used depending on construction, materials, expected operating conditions, etc.

[0043] Base bearing **68***f* is of similar construction to base bearing **68***a* described above herein and will not be discussed in detail. Preferably treated sleeves **76***f-k* oppose bearings **68***f-k* or their bushings, respectively. The sleeves are preferably made of hardened material, such as iron carbide, etc. Spacing, stabilizing, and attachment mechanisms, such as two-piece ring **78***b*, spacers **80**, shims, etc., can be used as those of skill in the art will recognize. Additional bearings can be of alternate construction, or provided in whole or in part by other tool elements, such as a diffuser body, diffuser bearing housing, cross-over body, etc.

[0044] Base assembly **54***b* has a base body **82***b* threadedly or otherwise attached to the section housing **60***b*. The base defines an interior passageway **63***g* which forms a portion of passageway **63**. The base has a fluid intake **84***b* for receiving fluid from a tool or tubing positioned below and a fluid outlet **86***b* for delivering fluid to a tool or tubing positioned above. In this instance, the outlet **86***b* delivers fluid to the inlet of compressor assembly **104***e*. The base **82***b* houses bearing **68***f* and the lower end of the shaft **62***b*, and has a coupling **88***b* for attachment to an adjacent tool or tubing.

[0045] The head assembly **56***b* is of similar construction, having a head body **90***b* defining an interior passageway **63***n* which forms a portion of passageway **63**. The head houses bearing **68***n*, sleeve **76***n*, and the upper end of the shaft **62***b*, and provides a tool coupling **92***b*. The head also defines a fishing neck **94***b*, as is known in the art. The head assembly **56***b* is a cross-over tool, providing for fluid, in this case separated free gas, to cross from the interior chamber **140***b* to the exterior of the lower tool **42***b*. Most or all of the separated free gas is vented, through a plurality of vents **96***b*, preferably to the wellbore or casing annulus defined between the tool section **42***a* and the wellbore or casing. The production liquid (and any remaining gas) flows through a plurality of interior ports **98***b* defined in the head body **90***b* and thence through

head outlet **100***b*. The head assembly is threadedly or otherwise attached to the section housing **60***b* and by lock plate **102***b*.

[0046] Fluid chamber **52***b* is defined between the compression stages **50***c* and **50***d* and interior to compression tube **61***b*. Shaft **62***b* extends through the fluid chamber. The chamber receives compressed fluid from the outlet of the compressor assembly **50***c* and delivers fluid to the inlet of compressor assembly **50***d*. Fluid pressure, fluid volume, and fluid flow rate are static across the fluid chamber **52***b*.

[0047] The upper section **42***b* is seen having a plurality of compressor assemblies, namely, **50***c-d*, similar in construction to those of the lower section **42***a*. Since the compressor assembly **50***a* is discussed in detail above, the compressor assemblies **50***c-d* are only briefly described. Compressor assemblies are generally known in the field, as those of skill in the art will recognize Compressor assembly **50***c* is comprised of, in order of fluid flow, impeller assembly **104***e*, diffuser assembly **106***e*, impeller assembly **104***f*, and diffuser assembly **106***f*. The assembly further preferably includes a diffuser bearing **121***a* having a housing **119***a* and fluid passageways **123***a*. The diffuser bearing **121***a* provides additional stability for the shaft **62***b* at bearing assembly **68***i* and sleeve **76***i*, similar to those described above herein. Similarly, the compressor assembly **50***e* also includes, at its upper end, a diffuser bearing **121***b* having a housing **119***b* and defining fluid passageways **123***b*. The diffuser bearing **121***b* provides additional stability for the shaft **62***b* at bearing assembly **68***m* and sleeve **76***m*, similar to those described above herein.

[0048] Impeller and diffuser assemblies **104** and **106** are discussed in detail above, with the description applying to the remaining impeller and diffuser assemblies, where like parts have like numbers with distinguishing suffixes. Impeller assemblies **104***e-j* and diffuser assemblies **106***e-j* are of similar construction and will not be discussed in further detail.

[0049] A compression nut assembly **130***b* is mounted to the shaft **62***b* above the compressor assembly **50***d*. The exemplary compression nut assembly has a compression nut **132***b*, compression sleeve **134***b*, set screw **136***b*, and two-piece ring **138***b*. The compression nut assembly is fixedly attached to the shaft and provides a load-bearing face for maintaining the elements below in compression between the compression nut assembly and two-piece ring **78***b*.

[0050] The gas separation assembly **58***b* includes a plurality of vortex generators **142***b* mounted to the shaft **62***b* and positioned in a gas separation chamber **140***b*. A pair of vortex generators is mounted to the shaft **62***b* to rotate with the shaft. The vortex generators have radially extending, vertical paddles **144***b* on a hub **146***b* supported by the shaft **62***b*. The paddles stir passing production fluid in the chamber **140***b*, creating a vortex, wherein the heavier liquid components are forced radially outward against the chamber wall **148***b* while free gas components gather near the vortex axis near the center of the chamber. Free gas is separated from the production liquid component and exits the chamber and the tool section through the cross-over head vents **96***b*. The remaining production fluid is drawn through interior ports **98***b* and continues upward through the assembly.

[0051] Generally, the assembly can be implemented either in compression or as a "floater" design in accordance with various embodiments of the present disclosure. Preferably, the assemblies are assembled in compression. In the lower section **42***a*, seen in FIG. **3**A-B, the compression nut assembly **130***a*, at the upper end, and the two-piece split ring **78***a*, at the lower end, serve to place into compression each of the impeller hubs **110***a-d*, sleeves **76***b-d*, and spacers. From the compression nut assembly **130***a* to the two-piece split ring **78***a*, a continuous series of metal parts in metal-to-metal contact is provided. Similarly, in the upper section **42***b* seen in FIG. **4**A-B, the compression nut assembly **130***b*, at the upper end, and the two-piece split ring **78***b*, at the lower end, serve to place into compression each of the impeller hubs **110***e-h*, sleeves **76***g-k*, and spacers **80**. From the compression nut assembly **130***b* to the two-piece split ring **78***b*, a continuous series of metal parts with metal-to-metal contact is provided. Similarly, in FIG. **5**A-B, compression nut assembly **330** and two-piece ring **278** act to maintain the intervening part in compression.

[0052] During assembly of the gas compression separator assembly, the compression nut assembly is used to place substantial force (e.g., 50-60 ft-lbs) on the metal part stack (impellers, sleeves, spacers) to pull the parts into contact with one another and to place them in compression.

[0053] A schematic view of a simplified, exemplary thrust bearing assembly **150** is seen in FIG. **2**. To set the configuration in compression, a thrust bearing is provided to bear the thrust of the rotating portions of the sections. The thrust bearing can be positioned at the lower end of the lower section **42***a*, or elsewhere along the drive shaft. In the exemplary embodiment, the thrust bearing assembly **150** is positioned at the lower end of the protector **40**. The thrust bearing assembly **150** includes a thrust bearing **152**, a two-piece split ring **154**, and spacer **156**, positioned about protector shaft **158**. The thrust bearing **150** is supported by a support block **160** which is an extension of or attached to the protector housing, for example.

[0054] In practice, during assembly, the shaft of the gas compression separator assembly is lifted a small amount (e.g., 0.15 to 0.030 inches), such that the impellers are not supported by the diffusers. The weight of the impellers, sleeves, and shaft are then supported by the thrust bearing below. This prevents premature wear to the impellers and diffusers due to down-thrust because the impellers do not touch, or do not place weight upon, the diffusers or diffuser thrust pads Shims are used during assembly at the bottom end of the shaft to position the shaft correctly, supported by the shaft of a below protector or other tool, such that the proper spacing is provided between the impellers and diffusers and the impeller and shaft weight and down-thrust is borne by the thrust bearing rather than the diffusers. An exemplary shim raises bottom of the shaft in the range of about 0.015 to 0.030 inch.

[0055] Returning briefly to FIG. **2**, the sensor assembly **34** can be of various types for measuring various downhole environmental or motor characteristics. Preferably the sensor assembly includes pressure and temperature sensors. Measurements are conveyed to the surface by wire or wirelessly, providing the motor operator data for use in controlling the motor. A preferred sensor assembly includes a surface transceiver module, a surface safety choke, downhole temperature and pressure sensors, and various adapters, connectors, and power sources. The sensors are connected to the ESP motor **50**. A preferred sensor assembly includes a temperature sensor for measuring fluid temperature, a motor oil temperature sensor, and motor winding temperature sensor. A pressure sensor measures fluid pressure at the sensor location. Optionally, a vibration sensor, measuring vibration on three axes, is also present. The transceiver module provides power to and

receives measurement data from the sensors. The measurements are conveyed to the surface. Preferably, the system automatically shuts down when measurements exceed a predetermined and pre-programmed maximum. Sensor systems are commercially available, such as the sensor systems sold as Global or Halliburton Artificial Lift Sensor Systems, available from Halliburton Energy Services, Inc.

[0056] The electric motor assembly **36** includes a housing **48** and an electric motor **50** having a drive shaft **52** extending therefrom. The electric motor is powered by electricity delivered along power cable **54** extending from the surface. The cable is typically disposed in a protective conduit and can run either along the interior or exterior of the string. Electric ESP motors are commercially available, for example, from Halliburton Energy Services, Inc. The motor specifications are selected based on operating and well conditions as will be understood by those of skill in the art. The ESP motor **50** is connected to the sensor system and is typically controlled by a motor operator and has selected automatic shut-offs based on sensor data. The drive shaft **52** extends from the upper end of the motor and drives the separators, compressors, and ESPs on the production string.

[0057] The seal sub **38** and protector **40**, sometimes also referred to as a seal, can serve to prevent production fluid or contaminants from entering the ESP motor **36** by equalizing interior and exterior pressure, provide a dielectric or other acceptable motor oil reservoir, conduct heat away from the motor, and compensate for pressure to absorb thermal expansion. A thrust bearing accepts fluid column load upon start-up and absorbs axial load of the ESP pump **46**. Protectors are available in varying sizes and weight specifications and varying configurations, including labyrinth, pre-filled, single, double and modular bag, or combinations arranged in series or parallel. Further, models are available for high-load thrust bearing and high-strength shaft. Protectors are commercially available from Halliburton Energy Services, Inc. One or multiple seals or protectors can be employed on an ESP production string.

[0058] The ESP assembly **46** pumps production fluid to the surface. The ESP intake receives fluid from the last sequential compressor **44** at a pressure within the operating limits of the ESP, eliminating or reducing the risk of gas lock. The ESP is preferably rotated by a drive shaft powered by the motor **36**. Alternate power sources can be employed. For centrifugal ESPs, the number of stages determines the total lift provided and determines the total power required for operation. Sensors and instrumentation can be employed to provide operating condition data to the operator or for automatic operation. For example, automatic shut-down sensors can be used to limit potential damage from unexpected well conditions. ESP specifications include a minimum fluid pressure requirement at the pump intake. The compressor **44** (or multiple compressors in series) is selected to provide production fluid to the ESP intake within its operating range.

[0059] In use, production fluid which enters the production string, typically through screen assemblies **24** positioned in the wellbore downhole from the electric motor assembly **36**. The production fluid is pulled upwards in response to the operation of the one or more ESPs. Production fluid flows past the electric motor **50** at assembly **36**, through the one or more seal subs **38** and protectors **40**, through the gas compression separator **42***a-b*, and to the intake of ESP **46**. Fluid is pumped to the surface through tubing **32**. The operation and methods of the seal subs, protectors, ESP, electric motor, and sensors are known in the art and not described in detail here. Additional tools can be employed on the production string as well.

[0060] The electric motor **50**, powered by an electric cable **54** from the surface, rotates a drive shaft **52**. The drive shaft **52** is connected to and powers the shafts of the gas compression separator **42** and the ESP **46**. The shaft is radially supported at various locations including in the gas compression separator at bearing assemblies **68***a-e*.

[0061] Turning to the gas compression separator, production fluid having liquid and gaseous components enters the gas compression separator lower section **42***a* at base assembly intake **84**. In lower section **42***a* and upper section **42***b*, the production fluid flows through a series of compression stages **50***a-b* and **50***c-e*, respectively, although a fewer or a greater number of stages can be employed. Each compression stage takes in a relatively large volumetric flow rate of production fluid and reduces, by compression, the volumetric flow rate. Each stage builds compression, increases fluid pressure, and reduces volumetric flow rate. As fluid pressure increases, free gas in the production fluid is dissolved or entrained into the production liquid. The division of the stages into upper and lower sections allows, among other things, for use of different shaft sizes. In one example, a larger ⅞ inch diameter shaft is used in the lower section to rotate relatively larger compression stages, while a smaller 1 1/16 inch diameter shaft is used in the upper section to rotate relatively smaller compression stages.

[0062] The stages each preferably include two compressor assemblies which, in turn, have two impeller assemblies and two diffuser assemblies. The impellers are attached to the shaft and rotate as the shaft rotates. In a preferred embodiment, the electric motor rotates the impellers in the range of about 3000-5000 rpm, and more specifically between about 3500-4500 rpm. Preferably, at least the lower section is assembled in compression, eliminating stage damage from running out of the acceptable operating range of a comparable floater assembly. A thrust bearing carries the thrust forces and can be positioned at the lower end of the lower section **42***a* or in a lower tool assembly, such as the protector. Also preferably, at least some of the compression stages or compressor assemblies in the upper section **42***b* are configured in compression. With the assemblies, or portions thereof, in compression and weight and thrust carried by the thrust bearing, the system has a greater usable operation range. A floater configuration is designed for use without damage in an optimum range, for example, between 2500-3500 BPD. A similar system configured in compression can operate in a wider range, for example, between 1000-4000 BPD without mechanical damage to the impellers or diffusers.

[0063] The stage capacities are selected to gradually reduce the volumetric fluid flow and correspondingly gradually increase the fluid pressure. In an exemplary embodiment of the disclosure, the first compressor stage **50***a* utilizes two nominal 4300 BPD (normal range 3000-5400 BPD) compressor assemblies arranged in series. At the second stage **50***b*, two nominal 3000 BPD (normal range 2000-3600 BPD) compressor assemblies are utilized in series. The third stage **50***c*, in the upper section, utilizes two compressors capable of about 2200 BPD, in an exemplary embodiment. The fourth stage **50***d* utilizes two compressor assemblies with a capacity of about 1750 BPD, and the fifth stage utilizes compressor assemblies of about 850 BPD.

[0064] Other arrangements can be used. In further exemplary embodiments, the following stage capacities and char-

acteristics can be used as seen in Chart **1** in which figures are in barrels per day (BPD) and represent the capacities of the compressor assemblies in each exemplary stage in order of fluid flow.

CHART 1

	Stage				
	1	2	3	4	5
Example 1	6000/6000	4300/4300	2200/2200	2200/2200	1750/1750
Example 2	4300/4300	3000/3000	1750/1750	1250/1250	1250/1250
Example 3	4300/4300	3000/3000	850/650	850/650	850/650

[0065] Compressor capacities are listed as nominal values but are designed to safely operate within an operational flow rate range. Flow rate maximums and minimums are known for a given compressor assembly. For example, a compressor assembly listed at 650 BPD has an operational range of 415 to 867 BPD. In this example, the lower end of the standard operational range (415 BPD) is approximately 36 percent below the nominal flow rate (650 BPD). The operating ranges, however, are provided on the assumption that the compressor assemblies are mounted in floater configuration on the drive shaft. Compressors in floater configuration are not as tolerant of rate variations or extreme operational ranges as compressors assembled in compression. In the preferred embodiment, however, at least one stage of compressor assemblies are mounted in compression as explained elsewhere herein. This allows the compressor assemblies configured in compression, as in the preferred embodiment, to run in a much expanded operational range. When a 650 BPD compressor assembly is mounted in compression, for example, its lower end operational range is extended to around about 200 BPD. (Caution should be taken at these lower rates to insure adequate flow for cooling of the electric motor.) The lower end (200 BPD) of the modified operational range, in this example, is approximately 69 percent below the nominal flow rate (650 BPD).

[0066] Production fluid compressed in the first two stages flows into the chamber **140***a* and is stirred into a vortex by the rotation of the paddles **144***a* mounted to the drive shaft **62***a*. Centrifugal force pushes the heavier liquid component of the production fluid toward the compression tube wall **148***a* while the lighter gaseous component of the production fluid moves towards the vortex axis near the shaft. The free gas flows up the vortex axis and into the vents **96***a* defined in the head assembly **56***a*. The free gas is ported to the exterior of the lower section **42***a*, typically into an annulus formed between the section and the casing or wellbore. The liquid component, as well as any remaining free gas, flows upwards into and through the interior ports **98***a* defined in the head assembly. The production fluid passes out of the lower section through outlet **100***a* and into the upper section **42***b*.

[0067] Briefly, the compression and separation processes are repeated in the upper section **42***b*. Production fluid, compressed and with lowered gas content, from the lower section **42***a* is received into inlet **84***b* of the base assembly **54***b* and passes into the third compressor stage **50***c*. The impellers **104***e-f* compress the production fluid resulting in higher fluid pressure, dissolving and entraining of free gas, and a reduction in volumetric fluid flow rate. Exemplary compressor sizes are provided above in Chart **1**. Production fluid leaving the third stage passes through fluid passageways **123***a* of diffuser bearing **121***a*. Fluid flows through chamber **52***b* and into the fourth stage **50***d* and its two compressor assemblies with impellers **104***g-h*. Fluid exits the fourth stage into chamber **63***k* and enters the fifth stage **50***e*, where the impellers **104***i-j* further compress the production fluid, reduce volumetric flow rate, and dissolve and entrain free gas. Fluid flows through diffuser bearing **121***b* and into the separation assembly **58***b*. The diffuser bearings **121***a-b* provide stability for the shaft **62***b*. The diffuser bearings do not restrict fluid flow or create an increase in backpressure on the fluid.

[0068] Separator stage **142***b* works similarly to separation assembly **142***a*, separating free gas and liquid via vortex, with free gas exiting the upper section **42***a* through vents **96***b* and production liquid (and any remaining free gas) passing through ports **98***b* and through outlet **100***b*. Mounted above the head assembly **56***b* is preferably at least one ESP for pumping the compressed production fluid to the surface.

[0069] The gas compression separator assembly can be used at various well depths, typically ranging from 500 feet to over 13,000 feet deep. It is anticipated that the gas compression separator assembly will be of greater use in wells producing larger volumes of free gas, where the assembly entrains or dissolves free gas into the production liquid. The system is useful to prevent or reduce gas lock conditions, repetitive time-outs, restarts, down time, and consequent lost production.

[0070] The gas compression separator assembly does not rely on flow restriction to build pressure or to regulate fluid flow rates to within a range determined by the ESP capacity. No restriction plate or flow regulator plate is positioned in the system. Instead, the gas compression separator acts to compress the production fluid including its free gas component allowing fluid flow to continue uninterrupted while reducing the volumetric flow rate. In the exemplary embodiment described herein, the volumetric flow rate is reduced by a factor of up to approximately 18. The gas compression separator assembly allows uninterrupted production fluid flow through the production string along the assembly length. This does not imply that the compressor and separator assemblies do not, respectively, compress production fluid and separate free gas from the production fluid. Rather, the fluid flow is uninterrupted by any back-pressure or restriction devices, such as restrictor plates, restriction orifices, nozzles, or ports, or other flow restriction devices (such as "diffusers" designed to restrict flow rate, for example) which restrict or regulate fluid flow in order to create back-pressure or limit flow to a rate within the operating range of an ESP, etc. The uninterrupted flow is output at the assembly outlet, preferably to an intake of an ESP positioned above the assembly. Alternately, the production fluid, now compressed and with a reduced free gas volume, can be flowed through additional tools, passageways, etc., to one or more ESPs positioned above. The ESP pumps the production fluid to the surface and, like the compressor assemblies and separator assemblies of the gas compression separator assembly, is powered by rotary shaft driven by the downhole electric motor.

[0071] FIGS. **5**A-B are cross-sectional views of another exemplary embodiment of a gas compression separator according to an aspect of the disclosure. The figures show a gas compression separator of alternate construction but having similar elements as those described in detail above with respect to FIGS. **3**-**4**. Consequently, the description regarding FIGS. **5**A-B is concise, with fewer part references and the description of parts above applying to like parts in assembly

200. The assembly seen in FIGS. **5**A-B can be used as a substitute for the upper section **42***b* or as a stand-alone unit.

[0072] The tool section **200** has a series of compressors arranged in compression stages **250***a-c*, fluid chamber **252**, base assembly **254**, head assembly **256**, and a gas separation assembly **258**, positioned in or connected to a generally cylindrical housing **260**. A compression tube **261** is formed by a combination of compressor tubes **261***a-b*, diffuser bodies **318**, and diffuser bearing housings **319**. An interior passageway **263** is defined through the tool section **200** for flow of production fluid.

[0073] Drive shaft **262** extends through the assembly **200** and has a keyway **264** for attachment of rotary elements to the shaft. Upper and lower splines **266** allow connection to similar shafts above and below.

[0074] The shaft is supported by a plurality of bearing assemblies **268***a-j*. Bearing assemblies are known in the art and preferably include associated sleeves, bushings, snap rings, pins, screws, etc. Bearing assemblies can be stand-alone and fitted into the tool, as with the bearings **268***a* in the base assembly **254** and bearing **268***j* in the head **256**, or can be part of or partially formed by compressor elements such as, for example, diffuser bodies, diffuser bearing housings, etc. The bearings are of similar design and function as those described elsewhere herein and are not described in detail.

[0075] Base assembly **254** has a body **282** attached to the housing **260**, a fluid intake **284**, and a fluid outlet **286**. The base **282** further houses bearing **268***a* and has a coupling **288** for attachment to an adjacent tool or tubing. The head assembly **256** has a body **290** defining a portion of passageway **263**. The head assembly includes bearing **268***j*, a tool coupling **292**, and a fishing neck **294**. The head assembly is a cross-over tool, providing a plurality of vents **296** for separated free gas to cross from the chamber **340** to the exterior of the tool section **200**. Production liquid (and remaining free gas) flows through ports **298** to a tool attached above.

[0076] Fluid chamber **252** is defined between the compression stages **250***b* and **250***c*. In a preferred embodiment, the compression nut assembly **330** is positioned in the chamber **252**.

[0077] The tool section **200** has a plurality of compression stages **250***a-c*. Each stage has two corresponding compressor assemblies **205** in a preferred embodiment. For example, the first compression stage **250***a* includes compressor assemblies **205***a-b*. The compressor assemblies each comprise an impeller **304** and diffuser **306**. The diffusers **306** typically include a bearing assembly **268**. As an example, compressor assembly **205***a* includes impeller **304***a*, diffuser **306***a*, bearing assembly **268***b*, diffuser bodies **318**, and a compressor base **316**. The remaining stages, compressors, etc., have similar reference numbers and will not be called out. Compressor assemblies are known in the art as those of skill will recognize.

[0078] In an exemplary embodiment, the compression stage **250***a* utilizes two compressor assemblies with a 2200 BPD capacity, the compression stage **250***b* utilizes two compressor assemblies with 1250 BPD capacity, and the compression stage **250***c* utilizes two compressor assemblies with 650 BPD capacity. The compressor assemblies in a stage can have the same or differing capacities, more or fewer compression stages and compressor assemblies can be used, etc.

[0079] The gas compression separator assembly preferably also includes one or more diffuser bearings **321** each having a housing **319**. The diffuser bearings **321** provide additional stability for the shaft **262**.

[0080] Impeller and diffuser assemblies are discussed in detail above with descriptions applying to the impellers **304***a-f* and diffusers **306***a-f*.

[0081] A compression nut assembly **330** is mounted on the shaft **262** above compressor assembly **205***d*. The exemplary compression nut assembly has a compression nut, sleeve, set screw, and two-piece ring, as described above herein, and can be used with necessary spacers **280**. The compression nut assembly acts as a mounting or retainer for the compressor and diffuser bearing elements below. In a preferred embodiment, the compression nut assembly attaches fixedly to the shaft and provides a load-bearing face for mounting the compressor assemblies and diffuser bearings in compression. Compression nut assemblies and equivalents are known in the art.

[0082] The gas separation assembly **258** includes a plurality of vortex generators **342** mounted to the shaft **262** and positioned in a chamber **340**. The vortex generators are discussed above herein and will not be described in detail here. The vortex generators create a vortex, wherein heavier production liquid components are forced outward against the chamber wall while the lighter free gas component gathers near the vortex axis proximate the shaft. Separated free gas exits the chamber and the tool section through vents **296**. The remaining production fluid is drawn through interior ports **298**.

[0083] As described above, the assembly or portions thereof can be assembled in compression or in floater configuration. Preferably, the gas compression separator assembly is in compression, in part or in whole. Here, the elements below the compression nut assembly **330** and above the two-piece ring **278** are in compression. The compression nut assembly **330** and two-piece ring **278** act to hold the intervening impellers **304***a-f*, bearing sleeves, and spacers **280** in compression. From the compression nut assembly **330** to the two-piece split ring **278**, a continuous series of metal parts, in metal-to-metal contact, is provided. Assembly of parts in compression is described elsewhere herein. Similarly, the use and positioning of a thrust bearing is described elsewhere herein.

Method Claim Support

[0084] In preferred embodiments, various methods are disclosed. The steps listed herein infra are not exclusive, not all required in methods disclosed herein, and can be combined in various ways and orders. It is explicitly stated that the following steps can be arranged in different orders, omitted, repeated, transposed, and/or re-arranged, and additional steps can be added. Steps presented in an order XYZ, for example, can be performed in the order XZY, YXZ, YZX, etc. Persons of ordinary skill in the art, upon reading this disclosure, will be well aware of various methods including some or all of the steps disclosed herein without an exhaustive listing of every potential combination of steps, addition or omission of steps, etc. Further, a person of ordinary skill in the art will understand that and which steps can be performed, and in what various orders, without those steps being listed consecutively in a single paragraph. Steps and methods which are disclosed herein in relation to a description of one or more embodiments or elements thereof, for example, are explicitly under-

stood to be steps which can be taken in conjunction with other steps, even though the steps are not in the same sentence or paragraph. The various possible combinations and orders of various steps not only do not depart from the spirit of the inventions disclosed herein, they are explicitly taught and disclosed by this paragraph and throughout. Finally, where steps are required to be taken in particular order, must be taken consecutively with no intervening steps, etc., such will either be explicitly stated in the text or claim, or will, again, be apparent to one of ordinary skill in the art.

[0085] Method steps are presented here, numbered for ease of reference, even though a practitioner of the arts or one of ordinary skill in the art is capable of discerning these and other steps from the disclosure supra. Exemplary steps include: 1. a method of producing fluid from a subterranean well having a production string positioned downhole in a wellbore extending through a formation, the method comprising the steps of: a) flowing production fluid from the formation through an interior passageway defined in the production string, the production fluid having a free gas component and a liquid component; b) allowing uninterrupted production fluid flow through a gas compression separator assembly positioned along the production string while: compressing the production fluid in the production string; separating at least some free gas from the production liquid; and c) flowing the compressed production fluid to the intake of an ESP. Additional steps and details regarding possible steps follow. 2. The method of 1, wherein step (b) further comprises dissolving or entraining at least a portion of the free gas into the production liquid. 3. The method of 1-2, wherein step (b) further comprises venting the separated free gas to the exterior of the production string at a downhole location. 4. The method of 1-3, wherein the step of compressing further comprises incrementally compressing the production fluid using a series of compressor assemblies. 5. The method of 4, further comprising the step of sequentially reducing the volumetric fluid flow rate of the production fluid using the series of compressor assemblies. 6. The method of 4-5, wherein each compressor assembly of the series has an operating range, and further comprising compressing the production fluid using a compressor assembly to within the operating range of a subsequent compressor assembly. 7. The method of 4-6, wherein the compressor assemblies have at least one impeller and at least one diffuser. 8. The method of 4-7, wherein at least one of the compressor assemblies of the series are assembled in compression. 9. The method of 4-8, wherein the series of compressor assemblies are divided into a plurality compression stages, each compression stage having at least two compressor assemblies, and further comprising driving at least two compression stages utilizing different diameter shafts. 10. The method of 1-9, wherein the step of compressing further includes reducing volumetric flow rate of the production fluid. 11. The method of 1-10, wherein the step of compressing further includes increasing production fluid pressure. 12. The method of 1-11, wherein the step of separating free gas from production liquid further comprises creating a vortex of production fluid in a fluid chamber. 13. The method of 12, further comprising forcing lighter production free gas toward the center of the vortex and heavier production liquid toward the fluid chamber wall. 14. The method of 1-13, further comprising venting a portion of free gas through a crossover tool. 15. The method of 12, wherein creating the vortex includes the step of rotating at least one paddle in the fluid chamber. 16. The method of 1-15, further comprising the step of pumping the compressed production fluid to the surface using the ESP. 17. The method of 1-16, further comprising the step of reducing the likelihood of gas lock occurring in the ESP.

[0086] Exemplary methods of use of the invention are described, with the understanding that the invention is determined and limited only by the claims. Those of skill in the art will recognize additional steps, different order of steps, and that not all steps need be performed to practice the inventive methods described.

[0087] Persons of skill in the art will recognize various combinations and orders of the above described steps and details of the methods presented herein. While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments as well as other embodiments of the disclosed apparatus and methods will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

It is claimed:

1. A method to produce fluid from a subterranean well having a production string positioned downhole in a wellbore extending through a formation, the method comprising the steps of:

(a) flowing production fluid from the formation through an interior passageway defined in the production string, the production fluid having a free gas component and a liquid component;

(b) allowing uninterrupted production fluid flow through a gas compression separator assembly positioned along the production string while:

compressing the production fluid in the production string;

separating at least some free gas from the production liquid; and

(c) flowing the compressed production fluid to the intake of an ESP.

2. The method of claim **1**, wherein step (b) further comprises dissolving or entraining at least a portion of the free gas into the production liquid.

3. The method of claim **1**, wherein step (b) further comprises venting the separated free gas to the exterior of the production string at a downhole location.

4. The method of claim **1**, wherein the step of compressing further comprises incrementally compressing the production fluid using a series of compressor assemblies.

5. The method of claim **4**, further comprising the step of sequentially reducing the volumetric fluid flow rate of the production fluid using the series of compressor assemblies.

6. The method of claim **4**, wherein each compressor assembly of the series has an operating range, and further comprising compressing the production fluid using a compressor assembly to within the operating range of a subsequent compressor assembly.

7. The method of claim **4**, wherein the compressor assemblies have at least one impeller and at least one diffuser.

8. The method of claim **4**, wherein at least one of the compressor assemblies of the series are assembled in compression.

9. The method of claim **4**, wherein the series of compressor assemblies are divided into a plurality compression stages, each compression stage having at least two compressor

assemblies, and further comprising driving at least two compression stages utilizing different diameter shafts.

10. The method of claim **1**, wherein the step of compressing further includes reducing volumetric flow rate of the production fluid.

11. The method of claim **1**, wherein the step of compressing further includes increasing production fluid pressure.

12. The method of claim **1**, wherein the step of separating free gas from production liquid further comprises creating a vortex of production fluid in a fluid chamber.

13. The method of claim **12**, further comprising forcing lighter production free gas toward the center of the vortex and heavier production liquid toward the fluid chamber wall.

14. The method of claim **1**, further comprising venting a portion of free gas through a cross-over tool.

15. The method of claim **12**, wherein creating the vortex includes the step of rotating at least one paddle in the fluid chamber.

16. The method of claim **1**, further comprising the step of pumping the compressed production fluid to the surface using the ESP.

17. The method of claim **1**, further comprising the step of reducing the likelihood of gas lock occurring in the ESP.

18. An apparatus to prepare production fluid, having a free gas and a liquid component, to be pumped to the surface from a wellbore extending through a subterranean formation, the apparatus comprising:

(a) a gas compression separator assembly having a plurality of compression stages arranged in series and at least one gas separator assembly, the assemblies allowing uninterrupted production fluid flow therethrough;

(b) each compression stage having at least one compressor assembly having an impeller and at least one diffuser; and

(c) each separator assembly having at least one vent allowing flow of separated free gas to the exterior of the apparatus.

19. The apparatus of claim **18**, wherein at least one gas separator assembly is interposed between successive compression stages.

20. The apparatus of claim **18**, wherein at least one of the compressor assemblies is mounted in compression on a rotary shaft.

21. The apparatus of claim **20**, wherein the compressor assembly mounted in compression transmits torque through the shaft to at least one thrust bearing.

22. The apparatus of claim **20**, wherein the compressor assembly mounted in compression includes an impeller mounted to prevent axial movement along the shaft.

23. The apparatus of claim **18**, wherein the separator assemblies include a vortex inducer and wherein the at least one vent extends from proximate the axis of a produced vortex to the exterior of the apparatus.

24. The apparatus of claim **18**, wherein the compressor assemblies include an impeller made of a corrosion-resistant material.

25. The apparatus of claim **18**, wherein the plurality of compression stages comprises at least a first, second, and third compression stage, arranged in series with at least one separator assembly positioned between two compression stages.

26. The apparatus of claim **25**, wherein the first compression stage has at least one compressor assembly with a nominal operating range between about 4300 and 6000 BPD.

27. The apparatus of claim **25**, wherein the second compression stage has at least one compressor assembly with a nominal operating range of between about 3000 and 4300 BPD.

28. The apparatus of claim **25**, wherein the third compression stage has at least one compressor assembly with a nominal operating range of between about 650 and 2200 BPD.

29. The apparatus of claim **18**, further comprising at least one ESP in fluid communication with the gas compression separator assembly.

30. The apparatus of claim **18**, further comprising an electric motor having a drive shaft for powering the compressor assemblies and at least one gas separator assembly.

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