

LOW-SIDE INTAKES FOR DOWNHOLE PUMPS, AND RELATED APPARATUSES AND METHODS

TECHNICAL FIELD

[0001] This document relates to multistage intakes for downhole pumps, and related apparatuses and methods. The present disclosure relates generally to management of solids-laden fluids within the cavity between an impeller and an inlet coupler of downhole rotary pumps, and in particular application to gas avoiding multistage intakes with a rotating shaft extending therethrough.

BACKGROUND

[0002] The following paragraphs are not an admission that anything discussed in them is prior art or part of the knowledge of persons skilled in the art.

[0003] Hydrocarbons, such as oil and gas, are produced or obtained from subterranean reservoir formations that may be located onshore or offshore through wells.

[0004] Pump systems, for example, electrical submersible pump (ESP) systems and progressive cavity pump (PCP), may be used when reservoir pressure alone is insufficient to produce hydrocarbons from a well. Typically, wellbore fluids contain solid particles which have a density higher than the wellbore fluids and a hardness greater than the diffusers, inlet couplers, or housings of a pump stage or an intake stage. This presents a challenge because there is a cavity formed between the upstream face of the impeller towards the outer diameter and the adjacent diffuser or inlet coupler into which some fluid leaks past the outer diameter seal of the impeller. Due to the spinning motion of the impeller, the fluid within the cavity swirls, and the solids are thrown towards the outer diameter due to centrifugal effect, where they cause erosion of the diffuser or inlet coupler. In typical ESP stages, the tight tolerance radial seal of the impeller shroud is at the radial inside of a large cavity and is downstream of the cavity in terms of the leakage fluid flow direction. This is problematic because solids retained within the cavity are unable to move towards the radial inside of the cavity where they might be discharged through the seals. Erosion within the cavity is typically managed using “sand dams” or baffles, which interfere with the swirling of the solids-laden fluid. A cavity between an upstream face of an impeller shroud and a downstream face of a diffuser is typically not present, although it may exist in some embodiments; this smaller cavity is more analogous to the cavity of the present disclosure. According to the present disclosure, some embodiments of stage designs for multistage intakes, such as those patents described within the patent family that includes CA3,177,821 / US 17/962,323 and CA3,158,008 and CA2024/050198, a cavity is formed between an upstream face of an impeller shroud and a downstream face of an inlet coupler outer ring and the seal is at the radial outside of the cavity and is upstream of the cavity. This configuration allows a unique solution for erosion mitigation to be used, wherein a substantially radial passageway allows

discharge of solids from the cavity. A more effective method to mitigate erosion in the cavity is proposed in the present disclosure.

SUMMARY

[0005] A multi-stage intake of a downhole rotary pump with two or more intake stages arranged in parallel to define an inner common flowpath, with one or more of the intake stages having: an outer housing defining one or more outer inlet openings; an inlet coupler defining one or more inner inlet openings; and one or more impellers connected to the inlet coupler, with a cavity defined at a junction between the inlet coupler and the impeller; wherein the inlet coupler defines one or more radial passageways within the cavity.

[0006] A method is disclosed comprising: rotating an impeller of a multi-stage intake to draw wellbore fluids through an inlet coupler, through the impeller, and into a downhole rotary pump, in which: a cavity is defined at a junction between the inlet coupler and the impeller; and the inlet coupler defines one or more radial passageways within the cavity.

[0007] In various embodiments, there may be included any one or more of the following features: the inlet coupler comprises an outer ring and a shroud; the outer ring is located radially outward of the shroud; and the one or more inlet openings form an array of axial passageways between the outer ring and the shroud. The shroud defines the inner common flowpath. The outer ring defines a peripheral diffuser-mounting shoulder at an impeller end of the inlet coupler. The one or more radial passageways comprise one or more radial apertures through the outer ring of the inlet coupler. The one or more radial apertures extend through the outer ring of the inlet coupler between the impeller end and the peripheral diffuser-mounting shoulder. The one or more radial passageways comprise one or more radial slots or grooves in the outer ring of the inlet coupler. The one or more radial passageways intersect a downstream face of the outer ring at the impeller end of the intake coupler. The outer ring forms an array of teeth that are spaced apart from one another at the impeller end to define an array of the radial passageways therebetween. The one or more radial passageways are tapered with varying axial depth from the downstream face of the outer ring. The one or more radial passageways are tapered with varying axial depth from the downstream face about a circumferential path. The one or more radial passageways are tapered with varying axial depth from the downstream face about a radial path. The inlet coupler is located in a downhole direction of the impeller. The inlet coupler is located in an uphole direction of the impeller. An eccentrically weighted component that is configured to rotate within the wellbore to align a low side inlet opening defined by the eccentrically weighted component toward a low-side of the wellbore. The cavity has an average axial depth of 0.001" to 0.5". The one or more radial passageways have an average axial depth of 0.01" to 0.5". The one or more radial passageways have a cumulative circumferential length of between 0.1% and 95% of a circumference of the inlet coupler. Between 1 and

100 radial passageways. Each impeller comprises an intermediate shroud that divides an outer flowpath from an inner flowpath; the inner flowpath connects to the inner common flowpath; an inner cavity is formed at a junction between the intermediate shroud with the inlet coupler shroud; and the inlet coupler comprises one or more radial passageways that connect the inner common flowpath with the inner cavity. A downhole apparatus comprising: a tubing string; a downhole rotary pump; and the multi-stage intake. A method comprising operating the downhole rotary pump of the downhole apparatus to pump wellbore fluids through the multi-stage intake, through the downhole rotary pump, and up to surface.

[0008] The foregoing summary is not intended to summarize each potential embodiment or every aspect of the subject matter of the present disclosure. These and other aspects of the device and method are set out in the claims.

BRIEF DESCRIPTION OF THE FIGURES

[0009] Embodiments will now be described with reference to the figures, in which like reference characters denote like elements, by way of example, and in which:

[0010] Fig. 1A is a side elevation view of a rotary pump disposed on the end of a production tubing string in a wellbore that penetrates an underground formation incorporating an intake device.

[0011] Fig. 1B is a schematic cross-section view of an embodiment of a portion of a stage of a multistage intake device.

[0012] Fig. 2 is a perspective cross-section view of an embodiment of a portion of a stage of a multistage intake device with a radial passageway comprising a slot.

[0013] Fig. 3 is a perspective cross-section view of an embodiment of an inlet coupler of a portion of a stage of a multistage intake device with a radial passageway comprising multiple slots.

[0014] Fig. 4A is a perspective view of the inlet coupler of Fig. 3 with a series of six radial passageways as slots.

[0015] Fig. 4B is a perspective view of an alternate embodiment of an inlet coupler with a series of six tapered radial passageways as slots.

[0016] Fig. 4C is a perspective view of an alternate embodiment of an inlet coupler with a series of sixteen radial passageways as slots.

[0017] Fig. 4D is a perspective view of an alternate embodiment of an inlet coupler with a series of radial passageways as apertures.

[0018] Fig. 4E is a perspective view of an alternate embodiment of an inlet coupler with a series of radial passageways as apertures in a frustoconical shroud.

[0019] Fig. 4F is a perspective view of an alternate embodiment of an inlet coupler with two series of radial passageways as slots applied to inner and outer cavities.

DETAILED DESCRIPTION

[0020] Immaterial modifications may be made to the embodiments described here without departing from what is covered by the claims.

[0021] In the claims, the word “comprising” is used in its inclusive sense and does not exclude other elements being present. The indefinite articles “a” and “an” before a claim feature do not exclude more than one of the feature being present. Each one of the individual features described here may be used in one or more embodiments and is not, by virtue only of being described here, to be construed as essential to all embodiments as defined by the claims.

[0022] Features and their benefits are only discussed in detail for the first figure for which they are shown. In general, the complexity of embodiments increases sequentially through the Figs. and for the sake of clarity and brevity. In order to understand the configuration and benefits of features shown in certain figures, it may be necessary to read the entire description to that point and applying the understanding of features, configurations, and benefits from previous Figs. into the reading of subsequent figures.

[0023] The terms “couple” or “couples,” as used herein are intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection such as a shaft, flange or weld connection, or through an indirect electrical connection or a shaft coupling via other devices and connections.

[0024] The term “fluid” is used to refer to generally liquids or gasses or mixtures thereof.

[0025] The term “liquid” refers to a fluid which is primarily, or primarily intended, to be composed of liquid and typically includes the presence of some solid particles and gas which may be dissolved or entrained in the liquid as bubbles.

[0026] The term “gas” refers to a fluid which is primarily, or primarily intended, to be composed of gas and typically includes the presence of some liquid which may be carried with the gas as mist, droplets, a film, or even as slugs or waves. Gas may be wet, and for thermal operations may be primarily composed of water vapor (steam) or solvent vapor.

[0027] The term “uphole” is used to refer to the downstream location relative to fluid flow within the pump, corresponding to the direction that fluids are pumped up and out of the wellbore. Correspondingly “downhole” refers to the upstream location relative to fluid flow within the pump, regardless of the horizontal or vertical orientation of the device or wellbore.

[0028] The term “impeller” may be used broadly to refer to rotating components with vanes in this disclosure. Impellers are typically coupled to the shaft via keys or splines, which transmits rotation and torque from the motor to each impeller, although the detail of such keyway or spline is not typically visible in the present drawings. The thrust loads generated by impellers are typically supported axially by the adjacent diffusers or inlet couplers in a ‘floater’ design or transmitted through sleeves on the shaft in a ‘compression’ design. Impeller flowpath designs (meridional shape and vane structure) may range from axial-flow designs where the diameter and cross-section are constant, helicoaxial flow design where the diameter increases between the fluid entry flowpath and the fluid exit flowpath, or radial flow design where the flowpath turns in a radial outward direction. Impellers, particularly those of multistage intakes, may have two flowpaths separated by a wall – an inward and an outward flowpath. The inward and outward flowpaths may have a similar or different flowpath designs which may include the designs listed above, and any other design. The present embodiments may be applicable primarily to shrouded impellers which have a substantially flat face at their upstream end towards the outer diameter, but may also be applicable to unshrouded impellers if the unshrouded impeller creates a cavity at the junction with the inlet coupler (some unshrouded impeller designs may not create a cavity). Certain embodiments of such configuration options are shown as illustrative embodiments throughout this disclosure, but do not cover the full range of options in order to keep the number of figures to a reasonable amount. In locations where a single impeller is located, multiple impellers may be located acting in series, without departing from the spirit of this disclosure. If multiple impellers are used within a stage, they would typically be arranged in series with a diffuser between adjacent impellers.

[0029] The term “inlet coupler” may be used broadly to refer to non-rotating components having “inner inlet openings” as discussed in related patent documents, throughout this disclosure. It may or may not include diffuser vanes in the inner common flowpath, and may or may not include a bushing for shaft support. Certain embodiments of these configuration options are shown as illustrative embodiments throughout this disclosure, but do not cover the full range of options in order to keep the number of figures to a reasonable amount. Inlet couplers may or may not include inserts for impeller seals, impeller supports, coatings, shaft seals and shaft supports such as bearings (bushings), and some of the illustrative embodiments throughout this disclosure have been simplified to not show these components as separate pieces, even though they would be present in a typical functional assembly. Inlet couplers may be sealed and supported within the housing in a resilient manner, such as O-rings, or by axial compression. There may be interlocking features that guarantee that the inlet coupler will not spin. Inlet couplers may be located uphole or downhole of an impeller of a stage of a multistage intake. Additionally, thrust bushings, seals and other features functioning to support the shaft and the impellers may be used but are not necessarily shown.

[0030] Impellers and inlet couplers may be manufactured by a suitable technique in mass production such as by casting but may also be manufactured with other techniques including machining or 3D printing.

[0031] The present disclosure relates generally to the mitigation of inlet coupler erosion of a downhole rotary pump and more particularly to a multistage intake.

[0032] Long intakes and multi-stage intakes with impellers arranged between stages are proposed in PCT application No. CA2022050335 and U.S. Pat. Application No. 17/962,323 and C.A. Pat. No. 3,177,821. Another disclosure by the present author included gas avoider and low-side configurations in PCT application No. CA2023050806. Another disclosure by the present author included axial-flow low-side within a gas separation chamber configuration in PCT application No. CA2024050198.

[0033] Various erosion mitigations for the cavity of a diffuser are disclosed in U.S. Pat. No: 9,200,642, Russia Pat. No: 2514469, U.S. Pat. No: 10,738,794, U.S. Pat. No: 11,629,733, U.S. Pat. No: 8,556,580, U.S. Pat. No: 4,872,808, U.S. Pat. No: 5,160,240. These disclosures are categorized by various baffle structures which primarily function to disrupt swirl within the cavity. Some of them are directed to an inner cavity, which is towards the inner diameter from the flowpath of the stage, and therefore have a different arrangement of the cavity and seal and leak direction. Generally, they are for a typical ESP stage where there is a large cavity radially outwards from the seal, which is different than the present disclosure regarding a relatively small cavity inwards from the seal. Other solutions have been proposed, such as ported impellers – see U.S. Pat. No: 9,638,207, and U.S. Pat. No: 2,066,505 as examples of this. None of the prior art contemplates erosion mitigation of an inlet coupler of a multistage intake, nor the use of radial passageways in the manner proposed.

[0034] Referring to Fig. 1A, a downhole apparatus may be positioned within a wellbore 1 in use. The apparatus may comprise a tubing string (production tubing 2), a downhole rotary pump 9, and a multi-stage intake apparatus 10. The wellbore 1 may be configured to receive fluids through openings between wellbore and reservoir 3 (for example perforations, screens, ports or other lower completions assembly devices). Fluid flowing in wellbore toward a downhole pump 4 may flow past a downhole rotary motor 6 (which may be electric, hydraulic or other). While a downhole motor 6 is shown, rotation and power may also be provided to the pump of the present disclosure via sucker or continuous rods from a surface drive head or pump jack. Fluids may be taken in from the wellbore to the downhole rotary pump 9, through intake apparatus 10 of the present disclosure. The downhole rotary pump 9 may be used to pump wellbore fluids through a multi-stage intake apparatus 10, through the downhole rotary pump 9, and up to surface. Gas that bypasses the pump intake and any gas that may be exhausted from an active gas separator may flow to surface within the wellbore 1, typically in an annulus 5 formed between the wellbore 1 and the production tubing 2. Liquids within the pump 9 have their pressure boosted

sufficiently to overcome the hydrostatic head, friction pressure, and surface backpressure and flow up the production tubing 2 to a surface gathering or collection system for further processing and sale. The wellbore 1 may be substantially horizontal, or otherwise highly deviated. The present disclosure may be applied to any ESP stage or intake stage, for any wellbore configuration. The present disclosure may offer erosion mitigation performance advantages over the prior art.

[0035] Referring to Fig. 1B, one or more stages of a multistage intake apparatus 10 comprise an inlet coupler 40 and an outer housing (not shown, for example refer to Fig. 2 label 30). The figure shown illustrates a portion of the apparatus 10 on one side of a center axis 12 of the apparatus 10. The inlet coupler 40 may define one or more inner inlet openings 42, upstream of an outer passageway 62 of an impeller 60 of the multistage intake apparatus 10. One or more impellers 60 may be positioned in close proximity to the inlet coupler 40. A cavity 110 may be defined at a junction between the inlet coupler 40 and the impeller 60. The cavity 110 may be a location where erosion by sand and particulate swirling is likely to occur from the motion of the impeller. The inlet coupler may define one or more radial passageways 100 within the cavity 110. For example, the diffuser 54 may comprise a radial passageway 100 and/or 100'. The radial passageway 100 and/or 100' in the embodiment shown is formed as a slot (or gap) intersecting the cavity 110 and/or 110' between the impeller 60 and the diffuser 54. The multi-stage intake apparatus 10 may have two or more intake stages arranged in parallel to define an inner common flowpath. In use, impeller 60 or impellers of the multi-stage intake apparatus 10 may be rotated to draw wellbore fluids through the inlet coupler 40, through the impeller 60, and into the downhole rotary pump 9.

[0036] Referring to Fig. 1B, in the generic embodiment shown, the flow direction 31 within the plenum 33 between outer housing and inner housing may be in an uphole or downhole direction (uphole may be at either the left or right side of the page). The flow direction 51 in the inner common flowpath is in an uphole direction which may be aligned with the flow direction 31 in the plenum, or reversed. The inlet coupler 40 may be located in a downhole direction of the impeller 60, or the inlet coupler 40 may be located in an uphole direction of the impeller 60. The general function of multiple stages is explained in related patent documents. An optimal impeller design may include an outer passageway 62 with substantially axial flow direction which may be shrouded or not (the shrouded version is shown; present embodiments may also be used with an unshrouded outer impeller if it includes a cavity).

[0037] Referring to Fig. 1B, the impeller 60 may have a suitable structure. One or more of the impellers 60 may comprise an intermediate shroud 61 that divides an outer flowpath from an inner flowpath. The inner flowpath may connect to the inner common flowpath. An inner cavity 110' may be formed at a junction between the intermediate shroud 61 with the shroud 47 of the inlet coupler 40. The inlet coupler 40 may comprise one or more radial passageways 100' that connect the inner common

flowpath with the inner cavity 110'. The impeller may comprise vanes 63, for example the outer impeller passageway 62 may comprise vanes 63. The inner passageway 64 of impeller 60 may comprise vanes 65. The inner passageway 64 may be provided for the flow from other intake stages (not shown) of a multistage intake below the intake stage shown. The intermediate shroud 61 may divide the inner impeller passageway 64 from the outer impeller passageway 62, and defines cavity 110' where it is adjacent to inlet coupler 40. Flow through the outer portion of the impeller may be combined with flow through the inner portion of the impeller and/or flow from other stages of the multistage intake downstream of outer impeller passageway 62. Seals may be formed at generally cylindrical interfaces between the impeller 60 and the diffuser 54, for example at both the outer shroud 67 of the impeller, and the intermediate shroud 61.

[0038] Referring to Fig. 1B, the inlet coupler may have a suitable structure. The inlet coupler 40 may comprise an outer ring 46 and a shroud 47. The outer ring 46 may be located radially outward of the shroud 47. The one or more inlet openings 42 may form an array of axial passageways between the outer ring 46 and the shroud 47. The shroud 47 may define the inner common flowpath. The outer ring 46 may form an array of teeth that are spaced apart from one another at the impeller end to define an array of the radial passageways 100 therebetween. The seal between the impeller outer shroud 67 may be formed to a surface of the inlet coupler 40 (future figures will illustrate embodiments where the seal is formed to a separate diffuser).

[0039] Referring to Fig. 1B, the apparatus may be structured to permit seal leakage to reduce wear and allow rotation without friction. The apparatus may be structured such that leakage through one or both sets of seals is into the inner inlet openings 42 (note that the intake's outer inlet openings are in an outer housing, which is not shown). The seal leakage direction in the outer cavity 110 adjacent to the outer shroud 67 may be in a radially inwards direction, which is contrary to the centrifugal effects acting on dense particulate spinning in the cavity, which may make this outer cavity 110 the more critical cavity to apply radial passageways 100 of the present disclosure. The seal leakage direction in the inner cavity 110' formed between the impeller intermediate shroud 61 and the shroud 47 of the inlet coupler may be in a radially outwards direction, which aligns with the centrifugal effects acting on dense particulate spinning in the cavity, which may allow dense particles to enter and pass through the seal; this may be effective for particulates of a sufficiently small size, however, typical radial clearances in the seals may be in the range of 0.002" to 0.010", so particulates that enter the cavity which are too large to pass the seals may still cause premature erosion of the diffuser 54, or premature erosion of the seals and may necessitate the use of radial passageways 100'. While most of the following figures show radial passageways 100 applied to the outer cavity 110, the reader should understand that similar embodiments of inner radial passageway 100' may be applied for the inner cavity 110' also. Moreover, in some cases the impeller may

lack an intermediate shroud, and may provide only a single flow path (not illustrated in the present disclosure but are disclosed in related family patent publications).

[0040] Referring to Fig. 2, one or more stages of a multistage intake apparatus 10 may comprise a diffuser 54 downstream the intake coupler 40, and in some cases also the impeller 60. The diffuser 54 may comprise a generally cylindrical body 56 whose impeller end 58 is structured to mount, integrally or by another connection, to a peripheral shoulder 45 of the inlet coupler 40. Inner inlet openings 42 are upstream of an outer passageway 62 of an impeller 60 of the multistage intake apparatus 10. The diffuser 54 may define at least part of the radial passageway 100, in the embodiment shown it defines the radially outer wall of the radial passageway 100. The one or more radial passageways 100 may comprise one or more radial slots or grooves in the outer ring 46 of the inlet coupler 40. The radial passageway 100 may be formed as a slot (or gap) in the cavity 110 between the impeller 60 outer shroud 67 and the inlet coupler 40. The one or more radial passageways 100 may intersect a downstream face of the outer ring 46 at the impeller end of the intake coupler 40. The impeller 60 is shown in an axial position relatively very close to inlet coupler 40 with inlet openings 42 such that the cavity 110 is relatively very small. However, in operation the impeller 60 may be positioned more towards the left of the page which would increase the axial length of cavity 110. In the configuration shown with a very short axial cavity length, there may be sufficient radial velocity of the leaked fluid to flush solids out of the cavity 110, and therefore there may be greater necessity for the radial slot in operation where the impeller 60 is spaced further from diffuser 54 creating a larger cavity 110 than is shown in Fig. 2. The axial position of the impeller 60 may be floating, or the impeller position may be constrained by a suitable method such as shaft spacer sleeves 21 for a compression type pump. The shaft 20 may be generally in tension, while the compression sleeves 21, sleeves 22, and impellers 60 may be in axial compression to transmit thrust loads from the impellers to a thrust bearing (not shown). Typically, with compression type pumps the impeller in operation is spaced to create a cavity length ranging from 0.05" and 0.25", however the cavity may range from 0.001" to 0.5". A diffuser 54 downstream of the intake impeller outer passageway may have vanes 24 that support the radial bearings, including bushing 23. This diffuser may overlap with an extension of impeller 60 to minimize the bearing's exposure to solids of the wellbore fluids. Bushing retention features and/or up-thrust washers are not shown. The inner housing may comprise a tube 50, a diffuser 54 downstream of impeller 60, and an inlet coupler 40 upstream of impeller 60 which together define an inner common flowpath; an inlet coupler 40 defines inner inlet openings 42. As above, the outer ring 46 may define a peripheral diffuser-mounting shoulder 45 at an impeller end of the inlet coupler 40. The shoulder 45 of the inlet coupler 40 may abut and mate with diffuser 54. The outer housing 30 may define one or more outer inlet openings 32. The inner housing components may be compressed within outer housing 30, which defines outer inlet openings 32. In the embodiment shown, the flow direction 31

within the plenum 33 between the outer housing and the inner housing is in a generally uphole direction, and may be the same as the flow direction 51 in the inner common flowpath.

[0041] Referring to Fig. 2, the apparatus may have other suitable features. An eccentrically weighted component, such as an eccentrically weighted tube 34, may be configured to rotate within the wellbore to align a low side inlet opening 38 defined by the eccentrically weighted component toward a low-side of the wellbore. The eccentrically weighted tube 34 may be weighted by eccentric weights 39. The tube 34 may define one or more lowside inlet openings 38 which only allow flow from the lowside of the wellbore. The eccentrically weighted tube may be supported by sealed bearings 36 at both ends. A suitable impeller design may include a shrouded outer passageway 62 with substantially axial orientation. The outer passageway may have an inlet meridian width at least 1.5x the narrowest restriction. The outer passageway may have one or more vanes, for example three vanes 63 as shown, each with a wrap angle between 150 and 200 degrees. The inner passageway 64 of impeller 60 may be provided for flow from other intake stages (not shown) of a multistage intake below the intake stage. Flow through the inner and outer portions of the impeller may be combined within the diffuser 54 and flowed through an inner common flowpath 52 within the inner housing tube 50. Impeller inner passageway vanes 65 may be provided, and may have a suitable shape such as a substantially triangular, or other polygonal shape. Polygonal vane shapes with relatively sharp edges (or small radii), may promote flow detachment, often referred to as “stalling” at low-flow-rate conditions which may allow a more desirable performance curve where less head is generated at low flow conditions, which allows better uniformity of the inflow profile of multiple stages whilst using the same impeller design within each stage.

[0042] Referring to Fig. 3, one or more stages of an alternate intake device is illustrated that comprises similar elements as the embodiment of Fig. 2, but is configured with a flow direction reversal downstream of the outer impeller passageway 62. In this configuration the inlet coupler 40 with inner inlet openings 42 is located in an uphole direction or upstream of an outer passageway 62 of impeller 60 and is also in a downhole direction or downstream of the inner passageway 64 of the same impeller 60. The flow direction 31 within the plenum 33 between the outer housing and inner housing is in a generally downhole direction and is reversed after or within the impeller relative to the flow direction 51 in the inner common flowpath. A cavity 110 is formed between inlet coupler 40 and impeller 60, and the cavity comprises one or more radial passageways 100. The cavity 110 may have a suitable dimension, for example an average axial depth of 0.001” to 0.5”. The one or more radial passageways 100 may have suitable dimensions, such as an average axial depth of 0.01” to 0.5”. In this figure the impeller is shown spaced at a location that may be more typical of a compression type pump in operation – that is, with a greater axial length than shown in Fig. 2. The radial passageway 100 in this example may have a suitable shape such as the form of a slot. The radial passageway may have suitable cross-section shape, such as a

circular, square, rectangular, slot like, bevelled, angled, curved, or any other regular or irregular shape that allows solids-laden fluid in the cavity to escape the centrifugal effects of the swirling fluid in the cavity, and to be carried back into the main flowstream. There may be a suitable number of passageways, such as between 1 and 100 radial passageways 100. Another benefit of the radial passageway 100 directly intersecting the cavity 110, is that the variable axial lengths of the cavity 110 around its perimeter may disrupt the swirl of the fluid which reduces the velocity of solids within it, and reduces the centrifugal effects making a situation where solids more easily swept back into the main flowstream. The one or more radial passageways 100 may have a suitable cumulative circumferential length, such as a cumulative circumferential length of between 0.1% and 95% of a circumference of the inlet coupler 40.

[0043] Referring to Fig. 4A, an inlet coupler 40 comprising inlet openings 42 defines radial passageways 100 of the same design as shown in Fig. 3. The outer ring 46 may define a diffuser-mounting peripheral shoulder 45 at an impeller end 48 of the inlet coupler 40. The one or more radial passageways 100 are shown as a plurality of radial slots or grooves in the outer ring of the inlet coupler. The one or more radial passageways 100 may also intersect a downstream face 46A of the outer ring 46 at the impeller end 48 of the intake coupler 40.

[0044] Referring to Fig. 4B, the one or more radial passageways 100 may be tapered. For example, the passageways 100 may be tapered with varying axial depth from the downstream face 46A of the outer ring 46, for example about a radial path. The one or more radial passageways 100 may be tapered with varying axial depth from the downstream face 46A about a circumferential path, for example forming an arcuate portion of a full circumference. In the example shown, the radial passageways 100 are relatively long in a circumferential direction relative to the embodiment in Fig. 4A, such that the passageways comprise more than half the circumferential perimeter of the face that faces the impeller (not shown). This may make it appear that the face has “buttresses” or “teeth” instead of “passageways”, but the function of the passageways is the same regardless of the relative ratio of circumferential length of passageways to the distance between the passageways. The passageways may perform the same function regardless of whether their circumferential length comprises from 0.1% to 95% of the total circumference of the inlet coupler.

[0045] Referring to Fig. 4C, relative to the embodiments of Figs. 4A-B, the coupler defines many radial passageways 100, for example which comprise up to or greater than 75% of the total circumference of the inlet coupler. The outer ring 46 may form an array of teeth that are spaced apart from one another at the impeller end 48 to define an array of the radial passageways 100 therebetween.

[0046] Referring to Fig. 4D, an alternative inlet coupler 40 is disclosed that varies from prior figures in a number of ways. The cavity 110 may be defined as being relatively elongated to include a space that is axially spaced from the face 44 that is adjacent to the upstream end of the impeller 60 at the

impeller outer shroud 67. Buttresses 120, may fill a portion of this cavity, and may be used for centralizing the inlet coupler 40 with the diffuser 54 (not shown) downstream of the impeller 60. These buttresses 120 may also act as sand dams, and reduce the swirl velocity in the cavity and create eddy currents that disturb the swirling flow within the cavity and allow particulate to enter radial passageways 100. The one or more radial passageways 100 may comprise one or more radial apertures through the outer ring 46 of the inlet coupler 40. Radial passageways 100 may allow solids-laden fluids to be ejected from the cavity. Radial passageways 100 in this example do not intersect the end face 44 of the inlet coupler 40 in this embodiment. This embodiment may be advantageous in that the flow through the apertures and out of the cavity is completely separated from the upstream face of the impeller outer shroud, to further minimize erosion.

[0047] Referring to Fig. 4E, an inlet coupler 40 is illustrated that is similar to but different in other ways from the embodiment of Fig. 4D. Relative to Fig. 4D, in Fig. 4E the cavity 110 does not comprise buttresses 120. This may not be a preferred embodiment for the mitigation of erosion; however, it may still function adequately having radial passageways 100 to cause large particles to circulate out of the cavity 110, through radial passageways 100, and back into the inlet openings 42. The one or more radial passageways 100 may comprise one or more radial apertures through the outer ring 46 of the inlet coupler 40. The one or more radial apertures may extend through the outer ring 46 of the inlet coupler 40 between the impeller end and the peripheral diffuser-mounting shoulder 45. A cavity wall may be tapered as shown which allows the radial passageways 100 to intersect the cavity near the OD of the cavity 110, which may be beneficial to allow large particles spinning in the cavity to enter the radial passageways, and the radial passageways may also interrupt the swirling flow in the cavity. Radial passageways comprised of apertures need not be round as illustrated.

[0048] Referring to Fig. 4F, an inlet coupler 40 is illustrated that is similar to the embodiment of Fig. 4A, with an alternate embodiment of the radial passageways 100 (or slots) which intersect the face 44 of the inlet coupler 40 that is adjacent to the cavity 110. The radial passageways 100 taper such that the passageway axial length (or slot width) at the OD of the cavity 110 is very small, or may be zero. It is important to distinguish that this is not just a chamfered surface, since it is not continuous around the full perimeter and is instead divided into discrete passages or slots. The number of radial passageways 100 (or tapered slots) shown in this figure is 4, but the number may range from 1 to 100. The tapered radial passageways of Fig 4F do not need to have a flat/straight surface, they may be curved in any manner, and they may vary in depth relative to one another, or they may gradually vary in depth (similar to Fig. 4B). The one or more tapered radial passageways 100 may be each tapered with varying axial depth from the downstream face 46A about a radial path, for example respective radial paths. Radial passageways 100'

of a similar tapered design are located at the intersection of the shroud 47 of the inlet coupler 40 with the impeller intermediate shroud (not shown) where a cavity 110' is formed.

[0049] Table of Parts:

1 Wellbore	44 face of diffuser adjacent to upstream end of
2 Production Tubing	impeller at the impeller outer shroud
3 Openings between wellbore and reservoir	45 Shoulder of the inlet coupler - for mating with
4 Fluid flowing in wellbore towards pump	diffuser
5 The Annulus (between the wellbore wall and the	46 Outer ring of inlet coupler
pump or production tubing) which extends to	46A Downstream face of outer ring
surface as a distinct flowpath for gas	47 Shroud of inlet coupler
6 Downhole rotary motor	48 impeller end of inlet coupler
9 Rotary pump	50 Tube of intake inner housing
10 Multistage intake apparatus	52 inner common flowpath within inner structural
12 center axis	housing
20 Rotary shaft	51 Flow in the inner common flowpath
21 shaft spacer sleeve	54 diffuser downstream of impeller
22 shaft sleeve	56 diffuser body
23 shaft radial bearings	58 impeller end of diffuser
24 ribs or vanes supporting shaft radial bearings	60 impeller of an intake stage
30 intake outer housing	61 impeller intermediate shroud
31 Flow in the plenum	62 outer passageway of an intake impeller
32 Outer inlet openings	63 outer passageway vanes
33 Plenum between outer and inner housings	64 inner passageway of an intake impeller
34 Eccentrically weighted tube	65 inner passageway vanes
36 Bearing of an eccentrically weighted tube	67 impeller outer shroud
38 Lowside inlet opening of an eccentrically	100 radial passageway in diffuser upstream of
weighted tube	intake impeller outer passageway
39 Eccentric tapered weight of an eccentrically	100' radial passageway in the inlet coupler
weighted tube	intersecting the inner cavity
40 Inlet coupler	110 cavity of an outer seal
42 inlet openings of the diffuser upstream of the	110' cavity of an inner seal
intake impeller outer passageway	120 Buttresses (or sand dam)

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A multi-stage intake of a downhole rotary pump, with two or more intake stages arranged in parallel to define an inner common flowpath, and with one or more of the intake stages having:
 - an outer housing defining one or more outer inlet openings;
 - an inlet coupler defining one or more inner inlet openings; and
 - one or more impellers connected to the inlet coupler, with a cavity defined at a junction between the inlet coupler and the impeller;wherein the inlet coupler defines one or more radial passageways within the cavity.
2. The multi-stage intake of claim 1 in which:
 - the inlet coupler comprises an outer ring and a shroud;
 - the outer ring is located radially outward of the shroud; and
 - the one or more inlet openings form an array of axial passageways between the outer ring and the shroud.
3. The multi-stage intake of claim 2 in which the shroud defines the inner common flowpath.
4. The multi-stage intake of any one of claim 2 – 3 in which the outer ring defines a diffuser-mounting peripheral shoulder at an impeller end of the inlet coupler.
5. The multi-stage intake of claim 4 in which the one or more radial passageways comprise one or more radial apertures through the outer ring of the inlet coupler.
6. The multi-stage intake of claim 5 in which the one or more radial apertures extend through the outer ring of the inlet coupler between the impeller end and the peripheral diffuser-mounting shoulder.
7. The multi-stage intake of any one of claim 2 - 6 in which the one or more radial passageways comprise one or more radial slots or grooves in the outer ring of the inlet coupler.
8. The multi-stage intake of any one of claim 7 in which the one or more radial passageways intersect a downstream face of the outer ring at the impeller end of the intake coupler.

9. The multi-stage intake of claim 8 in which the outer ring forms an array of teeth that are spaced apart from one another at the impeller end to define an array of the radial passageways therebetween.
10. The multi-stage intake of any one of claim 8 - 9 in which the one or more radial passageways are tapered with varying axial depth from the downstream face of the outer ring.
11. The multi-stage intake of claim 10 in which the one or more radial passageways are tapered with varying axial depth from the downstream face about a circumferential path.
12. The multi-stage intake of any one of claim 8 - 11 in which the one or more radial passageways are each tapered with varying axial depth from the downstream face about a radial path.
13. The multi-stage intake of any one of claim 1 - 12 in which the inlet coupler is located in a downhole direction of the impeller.
14. The multi-stage intake of any one of claim 1 - 13 in which the inlet coupler is located in an uphole direction of the impeller.
15. The multi-stage intake of any one of claim 1 - 14 defining an eccentrically weighted component that is configured to rotate within the wellbore to align a low side inlet opening defined by the eccentrically weighted component toward a low-side of the wellbore.
16. The multi-stage intake of any one of claim 1 - 15 in which the cavity has an average axial depth of 0.001" to 0.5".
17. The multi-stage intake of any one of claim 1 - 16 in which the one or more radial passageways have an average axial depth of 0.01" to 0.5".
18. The multi-stage intake of any one of claim 1 - 17 in which the one or more radial passageways have a cumulative circumferential length of between 0.1% and 95% of a circumference of the inlet coupler.
19. The multi-stage intake of any one of claim 1 - 18 having between 1 and 100 radial passageways.

20. The multi-stage intake of any one of claim 1 - 19 in which:
each impeller comprises an intermediate shroud that divides an outer flowpath from an inner flowpath;
the inner flowpath connects to the inner common flowpath;
an inner cavity is formed at a junction between the intermediate shroud, of the impeller, with the inlet coupler shroud; and
the inlet coupler comprises one or more radial passageways that connect the inner common flowpath with the inner cavity.
21. A downhole apparatus comprising:
a tubing string;
a downhole rotary pump; and
the multi-stage intake of any one of claim 1 - 20.
22. A method comprising operating the downhole rotary pump of the downhole apparatus of claim 21 to pump wellbore fluids through the multi-stage intake, through the downhole rotary pump, and up to surface.
23. A method comprising:
rotating an impeller of a multi-stage intake to draw wellbore fluids through an inlet coupler, through the impeller, and into a downhole rotary pump, in which:
a cavity is defined at a junction between the inlet coupler and the impeller; and
the inlet coupler defines one or more radial passageways within the cavity.