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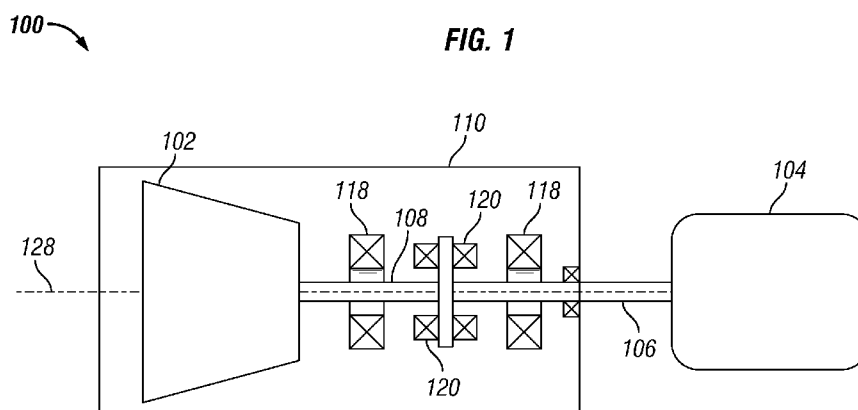
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(54) **Title:** IMPELLER WITH OFFSET SPLITTER BLADES



(57) **Abstract:** An impeller includes a hub mountable to a rotary shaft and configured to rotate about a center axis. The impeller may include a plurality of main blades and splitter blades arranged equidistantly and circumferentially about the center axis. A splitter blade having a leading edge and a trailing edge may be positioned between first and second adjacent main blades and canted such that the leading edge is displaced from a blade position equidistant the first and second adjacent main blades a first percentage amount of one half an angular distance between the first and second adjacent main blades. The trailing edge may be displaced from the blade position equidistant the first and second adjacent main blades a second percentage amount of one half the angular distance between the first and second adjacent main blades. The second percentage amount may be greater or less than the first percentage amount.

Impeller with Offset Splitter Blades

[0001] This invention was made with government support under Government Contract No. DOE-DE-FE0000493 awarded by the U.S. Department of Energy. The government has certain rights in the invention.

[0002] This application claims the benefit of U.S. Provisional Patent Application having Serial No. 62/139,032, which was filed March 27, 2015 and U.S. Utility Patent Application having Serial No. 15/075,321, which was filed March 21, 2016. The aforementioned patent applications are hereby incorporated by reference in their entirety into the present application to the extent consistent with the present application.

[0003] Compressors and systems including compressors have been developed and are utilized in a myriad of industrial processes (e.g., petroleum refineries, offshore oil production platforms, and subsea process control systems) to compress gas, typically by applying mechanical energy to the gas in a low pressure environment and transporting the gas and compressing the gas to a higher pressure environment. The compressed gas may be utilized to perform work or as an element in the operation of one or more downstream process components. As conventional compressors are increasingly used in offshore oil production facilities and other environments facing space constraints, there is an ever-increasing demand for smaller, lighter, and more compact compressors. In addition to the foregoing, it is desirable for commercial purposes that the compact compressors achieve higher compression ratios (e.g., 10:1 or greater) while optimizing efficiency and maintaining a compact arrangement.

[0004] In view of the foregoing, skilled artisans have proposed approaches to improve the efficiency of the compact compressors, many of which in the case of compact centrifugal compressors relate to the blading of one or more impellers operating therein. One such approach has included the use of splitter blades mounted to the impeller, such that each splitter blade is disposed equidistantly between adjacent full blades mounted to and extending from the hub of the impeller; however, such an approach has been determined to result in unequal mass flow in channels formed between the splitter blades and the adjacent full blades, thus resulting in efficiency losses.

[0005] What is needed, therefore, is an efficient compression system that provides increased compression ratios in a compact arrangement that is economically and commercially viable.

[0006] Embodiments of the disclosure may provide an impeller for a compressor. The impeller may include a hub mountable to a rotary shaft of the compressor and configured to rotate about a center axis. The hub may include a first meridional end portion and a second meridional end portion. The impeller may also include a plurality of main blades mounted to or integral with the hub. The plurality of main blades may be arranged equidistantly and circumferentially about the center axis.

The impeller may further include a plurality of splitter blades mounted to or integral with the hub. The plurality of splitter blades may be arranged equidistantly and circumferentially about the center axis. Each splitter blade may include a leading edge meridionally spaced from the first meridional end portion and a trailing edge proximal the second meridional end portion. A splitter blade may be positioned between a first adjacent main blade and a second adjacent main blade and canted such that the leading edge of the splitter blade is displaced from a blade position equidistant the first adjacent main blade and the second adjacent main blade a first percentage amount of one half an angular distance between the first adjacent main blade and the second adjacent main blade. The trailing edge of the splitter blade may be displaced from the blade position equidistant the first adjacent main blade and the second adjacent main blade a second percentage amount of one half the angular distance between the first adjacent main blade and the second adjacent main blade. The second percentage amount may be greater or less than the first percentage amount.

[0007] Embodiments of the disclosure may further provide a compressor. The compressor may include a housing and an inlet coupled to or integral with the housing and defining an inlet passageway configured to receive and flow a process fluid. The compressor may also include a rotary shaft configured to be driven by a driver, and a centrifugal impeller coupled with the rotary shaft and fluidly coupled to the inlet passageway. The centrifugal impeller may be configured to rotate about a center axis and impart energy to the process fluid received via the inlet passageway. The centrifugal impeller may include a hub defining a borehole through which a coupling member or the rotary shaft of the supersonic compressor extends. The hub may include a first meridional end portion having an annular portion and a second meridional end portion forming a disc-shaped portion. The centrifugal impeller may also include a plurality of blades mounted to or integral with the hub. The plurality of blades may be arranged equidistantly and circumferentially about the center axis and include a splitter blade positioned between a first adjacent main blade and a second adjacent main blade and canted with respect to the first adjacent main blade and the second adjacent main blade. The compressor may further include a static diffuser circumferentially disposed about the centrifugal impeller and configured to receive the process fluid from the centrifugal impeller and convert the energy imparted to pressure energy. The compressor may also include a collector fluidly coupled to and configured to collect the process fluid exiting the static diffuser, such that the compressor is configured to provide a compression ratio of at least about 8:1.

[0008] Embodiments of the disclosure may further provide a compression system. The compression system may include a driver including a drive shaft. The driver may be configured to provide the drive shaft with rotational energy. The compression system may also include a supersonic compressor operatively coupled to the driver via a rotary shaft integral with or coupled with the drive shaft and configured to rotate about a center axis. The supersonic compressor may

include a compressor chassis and an inlet defining an inlet passageway configured to flow a process fluid therethrough. The process fluid may have a first velocity and a first pressure energy. The supersonic compressor may further include a centrifugal impeller coupled with the rotary shaft and fluidly coupled to the inlet passageway. The centrifugal impeller may have a tip and may be configured to increase the first velocity and the first pressure energy of the process fluid received via the inlet passageway and discharge the process fluid from the tip in at least a partially radial direction having a second velocity and a second pressure energy. The second velocity may be a supersonic velocity having an absolute Mach number of about one or greater. The centrifugal impeller may include a hub defining a borehole through which a coupling member or the rotary shaft of the supersonic compressor extends. The hub may include a first meridional end portion having an annular portion and a second meridional end portion forming the tip. The centrifugal impeller may also include a plurality of blades mounted to or integral with the hub. The plurality of blades may be arranged equidistantly and circumferentially about the center axis and include a splitter blade positioned between a first adjacent main blade and a second adjacent main blade and canted with respect to the first adjacent main blade and the second adjacent main blade. The supersonic compressor may also include a static diffuser circumferentially disposed about the tip of the centrifugal impeller and defining an annular diffuser passageway configured to receive and reduce the second velocity of the process fluid to a third velocity and increase the second pressure energy to a third pressure energy, the third velocity being a subsonic velocity. The supersonic compressor may further include a discharge volute fluidly coupled to the annular diffuser passageway and configured to receive the process fluid flowing therefrom, such that the supersonic compressor is configured to provide a compression ratio of at least about 8:1.

[0009] The present disclosure is best understood from the following detailed description when read with the accompanying Figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0010] Figure 1 illustrates a schematic view of an exemplary compression system, according to one or more embodiments.

[0011] Figure 2 illustrates a cross-sectional view of an exemplary compressor, which may be included in the compression system of Figure 1, according to one or more embodiments.

[0012] Figure 3A illustrates a perspective view of an exemplary impeller, which may be included in the compressor of Figure 2, according to one or more embodiments.

[0013] Figure 3B illustrates a front view of the impeller of Figure 3A, according to one or more embodiments.

[0014] It is to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure; however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the Figures provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the various Figures. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact. Finally, the exemplary embodiments presented below may be combined in any combination of ways, *i.e.*, any element from one exemplary embodiment may be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0015] Additionally, certain terms are used throughout the following description and claims to refer to particular components. As one skilled in the art will appreciate, various entities may refer to the same component by different names, and as such, the naming convention for the elements described herein is not intended to limit the scope of the invention, unless otherwise specifically defined herein. Further, the naming convention used herein is not intended to distinguish between components that differ in name but not function. Additionally, in the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to." All numerical values in this disclosure may be exact or approximate values unless otherwise specifically stated. Accordingly, various embodiments of the disclosure may deviate from the numbers, values, and ranges disclosed herein without departing from the intended scope. Furthermore, as it is used in the claims or specification, the term "or" is intended to encompass both exclusive and inclusive cases, *i.e.*, "A or B" is intended to be synonymous with "at least one of A and B," unless otherwise expressly specified herein.

[0016] Figure 1 illustrates a schematic view of an exemplary compression system 100, according to one or more embodiments. The compression system 100 may include one or more compressors 102 (one is shown) configured to pressurize a process fluid. In an exemplary embodiment, the compression system 100 may have a compression ratio of at least about 6:1 or greater. For example, the compression system 100 may compress the process fluid to a compression ratio of about 6:1, about 6.1:1, about 6.2:1, about 6.3:1, about 6.4:1, about 6.5:1, about 6.6:1, about 6.7:1, about 6.8:1, about 6.9:1, about 7:1, about 7.1:1, about 7.2:1, about 7.3:1, about 7.4:1, about 7.5:1,

about 7.6:1, about 7.7:1, about 7.8:1, about 7.9:1, about 8:1, about 8.1:1, about 8.2:1, about 8.3:1, about 8.4:1, about 8.5:1, about 8.6:1, about 8.7:1, about 8.8:1, about 8.9:1, about 9:1, about 9.1:1, about 9.2:1, about 9.3:1, about 9.4:1, about 9.5:1, about 9.6:1, about 9.7:1, about 9.8:1, about 9.9:1, about 10:1, about 10.1:1, about 10.2:1, about 10.3:1, about 10.4:1, about 10.5:1, about 10.6:1, about 10.7:1, about 10.8:1, about 10.9:1, about 11:1, about 11.1:1, about 11.2:1, about 11.3:1, about 11.4:1, about 11.5:1, about 11.6:1, about 11.7:1, about 11.8:1, about 11.9:1, about 12:1, about 12.1:1, about 12.2:1, about 12.3:1, about 12.4:1, about 12.5:1, about 12.6:1, about 12.7:1, about 12.8:1, about 12.9:1, about 13:1, about 13.1:1, about 13.2:1, about 13.3:1, about 13.4:1, about 13.5:1, about 13.6:1, about 13.7:1, about 13.8:1, about 13.9:1, about 14:1, or greater.

[0017] The compression system 100 may also include, amongst other components, a driver 104 operatively coupled to the compressor 102 via a drive shaft 106. The driver 104 may be configured to provide the drive shaft 106 with rotational energy. In an exemplary embodiment, the drive shaft 106 may be integral with or coupled with a rotary shaft 108 of the compressor 102, such that the rotational energy of the drive shaft 106 is imparted to the rotary shaft 108. The drive shaft 106 may be coupled with the rotary shaft 108 via a gearbox (not shown) including a plurality of gears configured to transmit the rotational energy of the drive shaft 106 to the rotary shaft 108 of the compressor 102, such that the drive shaft 106 and the rotary shaft 108 may spin at the same speed, substantially similar speeds, or differing speeds and rotational directions.

[0018] The driver 104 may be a motor and more specifically may be an electric motor, such as a permanent magnet motor, and may include a stator (not shown) and a rotor (not shown). It will be appreciated, however, that other embodiments may employ other types of electric motors including, but not limited to, synchronous motors, induction motors, and brushed DC motors. The driver 104 may also be a hydraulic motor, an internal combustion engine, a steam turbine, a gas turbine, or any other device capable of driving the rotary shaft 108 of the compressor 102 either directly or through a power train.

[0019] In an exemplary embodiment, the compressor 102 may be a direct-inlet centrifugal compressor. In other embodiments, the compressor 102 may be a back-to-back compressor. The direct-inlet centrifugal compressor may be, for example, a version of a Dresser-Rand Pipeline Direct Inlet (PDI) centrifugal compressor manufactured by the Dresser-Rand Company of Olean, New York. The compressor 102 may have a center-hung rotor configuration or an overhung rotor configuration, as illustrated in Figure 1. In an exemplary embodiment, the compressor 102 may be an axial-inlet centrifugal compressor. In another embodiment, the compressor 102 may be a radial-inlet centrifugal compressor. As previously discussed, the compression system 100 may include one or more compressors 102. For example, the compression system 100 may include a plurality of compressors (not shown). In another example, illustrated in Figure 1, the compression system 100

may include a single compressor 102. The compressor 102 may be a supersonic compressor or a subsonic compressor. In at least one embodiment, the compression system 100 may include a plurality of compressors (not shown), and at least one compressor of the plurality of compressors is a subsonic compressor. In another embodiment, illustrated in Figure 1, the compression system 100 includes a single compressor 102, and the single compressor 102 is a supersonic compressor.

[0020] The compressor 102 may include one or more stages (not shown). In at least one embodiment, the compressor 102 may be a single-stage compressor. In another embodiment, the compressor 102 may be a multi-stage centrifugal compressor. Each stage (not shown) of the compressor 102 may be a subsonic compressor stage or a supersonic compressor stage. In an exemplary embodiment, the compressor 102 may include a single supersonic compressor stage. In another embodiment, the compressor 102 may include a plurality of subsonic compressor stages. In yet another embodiment, the compressor 102 may include a subsonic compressor stage and a supersonic compressor stage. Any one or more stages of the compressor 102 may have a compression ratio greater than about 1:1. For example, any one or more stages of the compressor 102 may have a compression ratio of about 1.1:1, about 1.2:1, about 1.3:1, about 1.4:1, about 1.5:1, about 1.6:1, about 1.7:1, about 1.8:1, about 1.9:1, about 2:1, about 2.1:1, about 2.2:1, about 2.3:1, about 2.4:1, about 2.5:1, about 2.6:1, about 2.7:1, about 2.8:1, about 2.9:1, about 3:1, about 3.1:1, about 3.2:1, about 3.3:1, about 3.4:1, about 3.5:1, about 3.6:1, about 3.7:1, about 3.8:1, about 3.9:1, about 4:1, about 4.1:1, about 4.2:1, about 4.3:1, about 4.4:1, about 4.5:1, about 4.6:1, about 4.7:1, about 4.8:1, about 4.9:1, about 5:1, about 5.1:1, about 5.2:1, about 5.3:1, about 5.4:1, about 5.5:1, about 5.6:1, about 5.7:1, about 5.8:1, about 5.9:1, about 6:1, about 6.1:1, about 6.2:1, about 6.3:1, about 6.4:1, about 6.5:1, about 6.6:1, about 6.7:1, about 6.8:1, about 6.9:1, about 7:1, about 7.1:1, about 7.2:1, about 7.3:1, about 7.4:1, about 7.5:1, about 7.6:1, about 7.7:1, about 7.8:1, about 7.9:1, about 8.0:1, about 8.1:1, about 8.2:1, about 8.3:1, about 8.4:1, about 8.5:1, about 8.6:1, about 8.7:1, about 8.8:1, about 8.9:1, about 9:1, about 9.1:1, about 9.2:1, about 9.3:1, about 9.4:1, about 9.5:1, about 9.6:1, about 9.7:1, about 9.8:1, about 9.9:1, about 10:1, about 10.1:1, about 10.2:1, about 10.3:1, about 10.4:1, about 10.5:1, about 10.6:1, about 10.7:1, about 10.8:1, about 10.9:1, about 11:1, about 11.1:1, about 11.2:1, about 11.3:1, about 11.4:1, about 11.5:1, about 11.6:1, about 11.7:1, about 11.8:1, about 11.9:1, about 12:1, about 12.1:1, about 12.2:1, about 12.3:1, about 12.4:1, about 12.5:1, about 12.6:1, about 12.7:1, about 12.8:1, about 12.9:1, about 13:1, about 13.1:1, about 13.2:1, about 13.3:1, about 13.4:1, about 13.5:1, about 13.6:1, about 13.7:1, about 13.8:1, about 13.9:1, about 14:1, or greater. In an exemplary embodiment, the compressor 102 may include a plurality of compressor stages, where a first stage (not shown) of the plurality of compressor stages may have a compression ratio of about 1.75:1 and a second stage (not shown) of the plurality of compressor stages may have a compression ratio of about 6.0:1.

[0021] Figure 2 illustrates a cross-sectional view of an embodiment of the compressor 102, which may be included in the compression system 100 of Figure 1. As shown in Figure 2, the compressor 102 includes a housing 110 forming or having an axial inlet 112 defining an inlet passageway 114, a static diffuser 116 fluidly coupled to the inlet passageway 114, and a collector 117 fluidly coupled to the static diffuser 116. Although illustrated as an axial inlet in Figure 2, in one or more other embodiments, the inlet 112 may be a radial inlet. The driver 104 may be disposed outside of (as shown in Figure 1) or within the housing 110, such that the housing 110 may have a first end, or compressor end, and a second end (not shown), or driver end. The housing 110 may be configured to hermetically seal the driver 104 and the compressor 102 within, thereby providing both support and protection to each component of the compression system 100. The housing 110 may also be configured to contain the process fluid flowing through one or more portions or components of the compressor 102.

[0022] The drive shaft 106 of the driver 104 and the rotary shaft 108 of the compressor 102 may be supported, respectively, by one or more radial bearings 118, as shown in Figure 1 in an overhung configuration. The radial bearings 118 may be directly or indirectly supported by the housing 110, and in turn provide support to the drive shaft 106 and the rotary shaft 108, which carry the compressor 102 and the driver 104 during operation of the compression system 100. In one embodiment, the radial bearings 118 may be magnetic bearings, such as active or passive magnetic bearings. In other embodiments, however, other types of bearings (e.g., oil film bearings) may be used. In addition, at least one axial thrust bearing 120 may be provided to manage movement of the rotary shaft 108 in the axial direction. In an embodiment in which the driver 104 and the compressor 102 are hermetically-sealed within the housing 110, the axial thrust bearing 120 may be provided at or near the end of the rotary shaft 108 adjacent the compressor end of the housing 110. The axial thrust bearing 120 may be a magnetic bearing and may be configured to bear axial thrusts generated by the compressor 102.

[0023] As shown in Figure 2, the axial inlet 112 defining the inlet passageway 114 of the compressor 102 may include one or more inlet guide vanes 122 of an inlet guide vane assembly configured to condition a process fluid flowing therethrough to achieve predetermined or desired fluid properties and/or fluid flow attributes. Such fluid properties may include flow pattern (e.g., swirl distribution), velocity, mass flow rate, pressure, temperature, and/or any suitable fluid property and fluid flow attribute to enable the compressor 102 to function as described herein. The inlet guide vanes 122 may be disposed within the inlet passageway 114 and may be static or moveable, *i.e.*, adjustable. In an exemplary embodiment, a plurality of inlet guide vanes 122 may be arranged about a circumferential inner surface 124 of the axial inlet 112 in a spaced apart orientation, each extending into the inlet passageway 114. The spacing of the inlet guide vanes 122 may be

equidistant or may vary depending on the predetermined process fluid property and/or fluid flow attribute desired. With reference to shape, the inlet guide vanes 122 may be airfoil shaped, streamline shaped, or otherwise shaped and configured to at least partially impart the one or more fluid properties and/or fluid flow attributes on the process fluid flowing through the inlet passageway 114.

[0024] In one or more embodiments, the inlet guide vanes 122 may be moveably coupled to the housing 110 and disposed within the inlet passageway 114 as disclosed in U.S. 8,632,302, the subject matter of which is incorporated by reference herein to the extent consistent with the present disclosure. The inlet guide vanes 122 may be further coupled to an annular inlet guide vane actuation member (not shown), such that upon actuation of the annular inlet vane actuation member, each of the inlet guide vanes 122 coupled to the annular inlet guide vane actuation member may pivot about the respective coupling to the housing 110, thereby adjusting the flow incident on components of the compressor 102. As configured, the inlet guide vanes 122 may be adjusted without disassembling the housing 110 in order to adjust the performance of the compressor 102. Doing so without disassembly of the compressor 102 saves time and effort in optimizing the compressor 102 for a particular operating condition. Furthermore, the impact of alternate vane angles on overall flow range and/or peak efficiency may be assessed and optimized for increased performance, and a matrix of inlet guide vane angles may be produced on a relatively short cycle time relative to conventional compressors such that the data may be analyzed to determine the best combination of inlet guide vane angles for any given application.

[0025] The compressor 102 may include a centrifugal impeller 126 configured to rotate about a center axis 128 within the housing 110. In an exemplary embodiment, the centrifugal impeller 126 includes a hub 130 and is open or “unshrouded.” In another embodiment, the centrifugal impeller 126 may be a shrouded impeller. The hub 130 may include a first meridional end portion 132, generally referred to as the eye of the centrifugal impeller 126, and a second meridional end portion 134 having a disc shape, the outer perimeter of the second meridional end portion 134 generally referred to as the tip 136 of the centrifugal impeller 126. The disc-shaped, second meridional end portion 134 may taper inwardly to the first meridional end portion 132 having an annular shape. The hub 130 may define a bore 138 configured to receive a coupling member 140, such as a tiebolt, to couple the centrifugal impeller 126 to the rotary shaft 108. In another embodiment, the bore 138 may be configured to receive the rotary shaft 108 extending therethrough.

[0026] As shown in Figure 2, the compressor 102 may include a balance piston 142 configured to balance an axial thrust generated by the centrifugal impeller 126 during operation. In an exemplary embodiment, the balance piston 142 may be integral with the centrifugal impeller 126, such that the balance piston 142 and the centrifugal impeller 126 are formed from a single or unitary piece. In

another embodiment, the balance piston 142 and the centrifugal impeller 126 may be separate components. For example, the balance piston 142 and the centrifugal impeller 126 may be separate annular components coupled with one another. One or more seals, e.g., labyrinth seals, may be implemented to isolate the balance piston 142 from external contaminants or lubricants.

[0027] The centrifugal impeller 126 may be operatively coupled to the rotary shaft 108 such that the rotary shaft 108, when acted upon by the driver 104 via the drive shaft 106, rotates, thereby causing the centrifugal impeller 126 to rotate such that process fluid flowing into the inlet passageway 114 is drawn into the centrifugal impeller 126 and accelerated to the tip 136, or periphery, of the centrifugal impeller 126, thereby increasing the velocity of the process fluid. In one or more embodiments, the process fluid at the tip 136 of the centrifugal impeller 126 may be subsonic and have an absolute Mach number less than one. For example, the process fluid at the tip 136 of the centrifugal impeller 126 may have an exit absolute Mach number less than one, less than 0.9, less than 0.8, less than 0.7, less than 0.6, or less than 0.5. Accordingly, in such embodiments, the compressor 102 discussed herein may be "subsonic," as the centrifugal impeller 126 may be configured to rotate about the center axis 128 at a speed sufficient to provide the process fluid at the tip 136 thereof with an exit absolute Mach number of less than one.

[0028] In one or more embodiments, the process fluid at the tip 136 of the centrifugal impeller 126 may be supersonic and have an exit absolute Mach number of one or greater. For example, the process fluid at the tip 136 of the centrifugal impeller 126 may have an exit absolute Mach number of at least one, at least 1.1, at least 1.2, at least 1.3, at least 1.4, or at least 1.5. Accordingly, in such embodiments, the compressor 102 discussed herein may be "supersonic," as the centrifugal impeller 126 may be configured to rotate about the center axis 128 at a speed sufficient to provide the process fluid at the tip 136 thereof with an exit absolute Mach number of one or greater or with a fluid velocity greater than the speed of sound. In a supersonic compressor or a stage thereof, the rotational or tip speed of the centrifugal impeller 126 may be about 500 meters per second (m/s) or greater. For example, the tip speed of the centrifugal impeller 126 may be about 510 m/s, about 520 m/s, about 530 m/s, about 540 m/s, about 550 m/s, about 560 m/s, or greater.

[0029] Referring now to Figures 3A and 3B, with continued reference to Figure 2, Figures 3A and 3B illustrate a perspective view and a front view, respectively, of the centrifugal impeller 126 that may be included in the compressor 102, according to one or more embodiments. As shown in Figure 2 and more clearly in Figures 3A and 3B, the centrifugal impeller 126 may include a plurality of aerodynamic surfaces or blades 144a,b coupled or integral with the hub 130 and configured to increase the velocity and energy of the process fluid. As illustrated in Figures 3A and 3B, the blades 144a,b of the centrifugal impeller 126 may be curved, such that the process fluid may be urged in a tangential and radial direction by the centrifugal force through a plurality of flow passages

146, 148 formed by the blades 144a,b and discharged from the blade tips of the centrifugal impeller 126 (cumulatively, the tip 136 of the centrifugal impeller 126) in at least partially radial directions that extend 360 degrees around the centrifugal impeller 126. It will be appreciated that the contour or amount of curvature of the blades 144a,b is not limited to the shaping illustrated in Figures 3A and 3B and may be determined based, at least in part, on desired operating parameters.

[0030] The plurality of blades 144a,b may include main blades 144a spaced equidistantly apart and circumferentially about the center axis 128. Each main blade 144a may extend from a leading edge 150 disposed adjacent the first meridional end portion 132 of the centrifugal impeller 126 to a trailing edge 152 disposed adjacent the second meridional end portion 134 of the centrifugal impeller 126. Further, based on rotation of the centrifugal impeller 126, each main blade 144a may define a pressure surface on one side 154 of the main blade 144a and a suction surface on the opposing side 156 of the main blade 1144a. As shown in Figures 3A and 3B, the centrifugal impeller 126 may include thirteen main blades 144a; however, other embodiments including more than or less than thirteen main blades 144a are contemplated herein. The number of main blades 144a may be determined based, at least in part, on desired operating parameters.

[0031] The plurality of blades 144a,b may also include one or more splitter blades 144b configured to reduce aerodynamic choking conditions that may occur in the compressor 102 depending on the number of blades 144a,b employed with respect to the centrifugal impeller 126. The splitter blades 144b may be spaced equidistantly apart and circumferentially about the center axis 128. Each splitter blade 144b may extend from a leading edge 158, meridionally spaced and downstream from the first meridional end portion 132, to a trailing edge 160 disposed adjacent the second meridional end portion 134 of the centrifugal impeller 126. The leading edge 158 of each splitter blade 144b may be disposed meridionally outward from the leading edges 150 of the main blades 144a such that the respective leading edges 150, 158 of the main blades 144a and splitter blades 144b are staggered and not coplanar. Further, based on rotation of the centrifugal impeller 126, each splitter blade 144b may define a pressure surface on one side 162 of the splitter blade 144b and a suction surface on the opposing side 164 of the splitter blade 144b.

[0032] As most clearly illustrated in Figures 2 and 3A, each of the main blades 144a and the splitter blades 144b extends meridionally from the second meridional end portion 134 of the centrifugal impeller 126 toward the first meridional end portion 132 thereof. The configuration of the respective meridional extents of the main blades 144a and the splitter blades 144b may be substantially similar proximal the respective trailing edges 152, 160 of the main blades 144a and the splitter blades 144b. The configuration of the respective meridional extents of the main blades 144a and the splitter blades 144b may differ from the second meridional end portion 134 to the respective leading edges 150, 158 of the main blades 144a and the splitter blades 144b. In an exemplary

embodiment, the meridional extent of each of the main blades 144a may be greater than the meridional extent of each of the splitter blades 144b, such that the respective leading edges 158 of the splitter blades 144b may be disposed meridionally offset toward the second meridional end portion 134 of the centrifugal impeller 126 from the respective leading edges 150 of the main blades 144a.

[0033] The splitter blades 144b and main blades 144a may be arranged circumferentially about the center axis 128 in a pattern such that a splitter blade 144b is disposed between adjacent main blades 144a. As arranged, each splitter blade 144b may be disposed between the pressure surface side 154 of an adjacent main blade 144a and the suction surface side 156 of the other adjacent main blade 144a. Further, the splitter blades 144b may be “clocked” with respect to the main blades 144a, such that each splitter blade 144b is circumferentially offset or not equidistant from the respective adjacent main blades 144a and thus is not circumferentially centered between the adjacent main blades 144a. By clocking the splitter blades 144b, e.g., displacing the splitter blades 144b from a position equidistant from the adjacent main blades 144a, the operating characteristics of the centrifugal impeller 126 may be improved.

[0034] In one or more embodiments, the splitter blades 144b and main blades 144a may be arranged circumferentially about the center axis 128 in a pattern such that a plurality of splitter blades 144b may be disposed between adjacent main blades 144a. Accordingly, in one embodiment, at least two splitter blades 144b are disposed between adjacent main blades 144a. The leading edges 158 of the respective splitter blades 144b may be offset meridionally from one another such that the respective leading edges 158 of the splitter blades 144b are staggered and not coplanar.

[0035] As positioned between the adjacent main blades 144a, each splitter blade 144b may be oriented such that the splitter blade 144b is canted, such that the leading edge 158 of the splitter blade 144b is circumferentially offset from a position equidistant from the adjacent main blades 144a a different percentage amount than the trailing edge 160 of the splitter blade 144b. Accordingly, in an exemplary embodiment, the leading edge 158 of the splitter blade 144b may be displaced from a position equidistant from the adjacent main blades 144a by a distance of a first percentage amount of one half the angular distance θ between the adjacent main blades 144a. The trailing edge 160 of the splitter blade 144b may be displaced from the position equidistant the adjacent main blades 144a by a distance of a second percentage amount of one half the angular distance θ between the adjacent main blades 144a.

[0036] In an exemplary embodiment, the first percentage amount may be greater than the second percentage amount. In another embodiment, the first percentage amount may be less than the second percentage amount. For example, the difference in displacement between the leading edge

158 and the trailing edge 160 from the position equidistant the adjacent main blades 144a may be a percentage amount of at least about one percent, about two percent, about three percent, about four percent, about five percent, about ten percent, about fifteen percent, or about twenty percent. In another example, the difference in displacement between the leading edge 158 and the trailing edge 160 from the position equidistant the adjacent main blades 144a may be a percentage amount of between about one percent and about two percent, about three percent and about five percent, about five percent and about ten percent, or about ten percent and about twenty percent. The differences in distance related to the percentage amounts, e.g., the amount the splitter blade 144b is canted, may be determined based, at least in part, on desired operating parameters.

[0037] As shown in Figures 3A and 3B, a plurality of flow passages 146, 148 may be formed between the splitter blades 144b and the adjacent main blades 144a as arranged about the center axis 128. In an exemplary embodiment, the plurality of flow passages 146, 148 may include a first flow passage 146 formed between the pressure surface side 162 of the splitter blade 144b and the suction surface side 156 of one of the adjacent main blades 144a and a second flow passage 148 between the suction surface side 164 of the splitter blade 144b and the pressure surface side 154 of the other adjacent main blade 144a. The mass flow of the process fluid through the first and second flow passages 146, 148 may be determined based on the displacement of the splitter blade 144b in relation to the adjacent main blades 144a. For example, it has been determined that disposing the splitter blade 144b equidistantly between the adjacent main blades 144a may not result in equal mass flow through the first flow passage 146 and the second flow passage 148. Accordingly, in an exemplary embodiment, the splitter blade 144b may be circumferentially offset from a position centered between adjacent main blades 144a, such that the suction surface side 164 of the splitter blade 144b is disposed in a direction closer to the pressure surface side 154 of one of the adjacent main blades 144a and further from the suction surface side 156 of the other adjacent main blade 144a, thereby substantially equalizing the mass flow through the respective flow passages 146, 148.

[0038] As will be appreciated by those of skill in the art, the desired displacement of the splitter blades 144b may depend on various factors, such as the shape of the blades 144a,b, the angle of incidence of the blades 144a,b, the size of the blades 144a,b and of the centrifugal impeller 126, the operating speed range, etc. However, the displacement necessary to equalize the mass flow through the first flow passage 146 and the second flow passage 148 may be determined for a given design of the centrifugal impeller 126 and corresponding blades 144a,b by measurement of the mass flow, such as by use of a mass flow meter.

[0039] As shown in Figure 2, the compressor 102 may include a shroud 170 coupled to the housing 110 and disposed adjacent the plurality of blades 144a,b of the centrifugal impeller 126. In particular, a surface 172 of the shroud 170 may include an abradable material and may be

contoured to substantially align with the silhouette of the plurality of blades 144a,b, thus substantially reducing leakage flow of the process fluid in a gap defined therebetween. The abradable material is arranged on the surface 172 of the shroud 170 and configured to be deformed and/or removed therefrom during incidental contact of the rotating centrifugal impeller 126 with the abradable material of the stationary shroud 170 during axial movement of the rotary shaft 108, thereby preventing damage to the blades 144a,b and resulting in a loss of a sacrificial amount of the abradable material.

[0040] In an embodiment, illustrated most clearly in Figure 2, the compressor 102 may include the static diffuser 116 fluidly coupled to the axial inlet 112 and configured to receive the radial process fluid flow exiting the tip 136 of the centrifugal impeller 126. As shown in Figure 2, the static diffuser 116 may be a vaneless diffuser. The static diffuser 116 may be configured to convert kinetic energy of the process fluid from the centrifugal impeller 126 into increased static pressure. In an exemplary embodiment, the static diffuser 116 may be located downstream of the centrifugal impeller 126 and may be statically disposed circumferentially about the periphery, or tip 136, of the centrifugal impeller 126.

[0041] The static diffuser 116 may be coupled with or integral with the housing 110 of the compressor 102 and may form an annular diffuser passageway 174 having an inlet end adjacent the tip 136 of the centrifugal impeller 126 and a radially outer outlet end. In an exemplary embodiment, the annular diffuser passageway 174 may be formed, at least in part, by portions of the housing 110, namely a shroud wall 180 and a hub wall 182, forming the confining sidewalls of the static diffuser 116. The shroud wall 180 and the hub wall 182 may each be a straight wall or a contoured wall, such that the annular diffuser passageway 174 may be formed from straight walls, contoured walls, or a combination thereof. In addition, the annular diffuser passageway 174 may have a reduced width as the shroud wall 180 and the hub wall 182 extend radially outward. Such a "pinched" diffuser may provide for lower choke and surge limits and, thus, improve the efficiency of the centrifugal impeller 126.

[0042] In another embodiment, the static diffuser 116 may be a vaned diffuser. Accordingly, the static diffuser 116 may have a plurality of diffuser vanes (not shown) arranged in a plurality of concentric rings (not shown) about the center axis 128 and extending from the shroud wall 180 and/or the hub wall 182 of the static diffuser 116. In an exemplary embodiment, the diffuser vanes are arranged in tandem, such that a first ring of diffuser vanes is disposed radially inward from a second ring of diffuser vanes. Respective leading edges of the diffuser vanes of the second ring may be displaced radially outward from trailing edges of the diffuser vanes of the first ring. The diffuser vanes of the first ring may have a lower solidity, or chord to pitch ratio, than the diffuser vanes of the second ring. In another embodiment, the static diffuser may include a third ring of

diffuser vanes, wherein the diffuser vanes of the third ring may have a lower solidity than the diffuser vanes of the second ring. Each of the diffuser vanes may be airfoils or shaped substantially similar thereto.

[0043] A vaneless space (not shown) may be provided between the tip 136 of the centrifugal impeller 126 and the diameter formed by leading edges of the diffuser vanes of the first ring. Similarly, a vaneless space (not shown) may be provided between the diameter formed by the trailing edges of the diffuser vanes of the first ring and the leading edges of the diffuser vanes of the second ring. In one or more embodiments, the incidence of the diffuser vanes of the first ring may be determined for controlling the Mach number and reducing supersonic flow introduced at the inlet end of the static diffuser 116 to a subsonic flow at the trailing edges of the first ring. As configured, shock waves created by the leading edges of the first ring do not propagate to the diffuser vanes of the second ring; however, the leading edges of the first ring provide for a communication path from the downstream portion of the static diffuser 116 toward an upstream portion of the centrifugal impeller 126 to back pressure the centrifugal impeller 126, thereby obtaining a wider range. The incidence of the diffuser vanes of the second ring may be determined by placing the second ring in the "shadow" or flow path of the first ring. Accordingly, the diffuser vanes may be arranged such that two diffuser vanes of the second ring are provided in the wake of each diffuser vane of the first ring and are provided to alter the direction of the process fluid flow.

[0044] As discussed above, in one or more embodiments, the compressor 102 provided herein may be referred to as "supersonic" because the centrifugal impeller 126 may be designed to rotate about the center axis 128 at high speeds such that a moving process fluid encountering the inlet end 176 of the static diffuser 116 is said to have a fluid velocity which is above the speed of sound of the process fluid being compressed. Thus, in an exemplary embodiment, the moving process fluid encountering the inlet end 176 of the static diffuser 116 may have an exit absolute Mach number of about one or greater. However, to increase total energy of the fluid system, the moving process fluid encountering the inlet end 176 of the static diffuser 116 may have an exit absolute Mach number of at least about 1.1, at least about 1.2, at least about 1.3, at least about 1.4, or at least about 1.5. In another example, the process fluid at the tip 136 of the centrifugal impeller 126 may have an exit absolute Mach number from about 1.1 to about 1.5, or about 1.2 to about 1.4.

[0045] The process fluid flow leaving the outlet end of the static diffuser 116 may flow into the collector 117, as most clearly seen in Figure 2. The collector 117 may be configured to gather the process fluid flow from the static diffuser 116 and to deliver the process fluid flow to a downstream pipe and/or process component (not shown). In an exemplary embodiment, the collector 117 may be a discharge volute or specifically, a scroll-type discharge volute. In another embodiment, the collector 117 may be a plenum. The collector 117 may be further configured to increase the static

pressure of the process fluid flow by converting the kinetic energy of the process fluid to static pressure. The collector 117 may have a round tongue (not shown). In another embodiment, the collector may have a sharp tongue (not shown). It will be appreciated that the tongue of the collector 117 may form other shapes known to those of ordinary skill in the art without varying from the scope of this disclosure.

[0046] One or more exemplary operational aspects of the compression system 100 will now be discussed with continued reference to Figures 1-3B. A process fluid may be provided from an external source (not shown), having a low pressure environment, to the compression system 100. The compression system 100 may include, amongst other components, the compressor 102 having the centrifugal impeller 126 coupled with the rotary shaft 108 and the static diffuser 116 disposed circumferentially about the rotating centrifugal impeller 126. The process fluid may be drawn into the axial inlet 112 of the compressor 102 with a velocity ranging, for example, from about Mach 0.05 to about Mach 0.40. The process fluid may flow through the inlet passageway 114 defined by the axial inlet 112 and across the inlet guide vanes 122 extending into the inlet passageway 114. The process fluid flowing across the inlet guide vanes 122 may be provided with an increased velocity and imparted with at least one fluid property (e.g., swirl) prior to being drawn into the rotating centrifugal impeller 126. The inlet guide vanes 122 may be adjusted in order to vary the one or more fluid properties imparted to the process fluid.

[0047] The process fluid may be drawn into the rotating centrifugal impeller 126 and may contact the curved centrifugal impeller blades 144a,b, such that the process fluid may be accelerated in a tangential and radial direction by centrifugal force through the first flow passages 146 and the second flow passages 148 and may be discharged from the blade tips of the centrifugal impeller 126 (cumulatively, the tip 136 of the centrifugal impeller 126) in at least partially radial directions that extend 360 degrees around the rotating centrifugal impeller 126. The rotating centrifugal impeller 126 increases the velocity and static pressure of the process fluid, such that the velocity of the process fluid discharged from the blade tips (cumulatively, the tip 136 of the centrifugal impeller 126) may be supersonic in some embodiments and have an exit absolute Mach number of at least about one, at least about 1.1, at least about 1.2, at least about 1.3, at least about 1.4, or at least about 1.5.

[0048] The static diffuser 116 may be disposed circumferentially about the periphery, or tip 136, of the centrifugal impeller 126 and may be coupled with or integral with the housing 110 of the compressor 102. The radial process fluid flow discharged from the rotating centrifugal impeller 126 may be received by the static diffuser 116 such that the velocity of the flow of process fluid discharged from the tip 136 of the rotating centrifugal impeller 126 is substantially similar to the velocity of the process fluid entering the inlet end of the static diffuser 116. Accordingly, the process

fluid may enter the inlet end of the static diffuser 116 with a supersonic velocity having, for example, an exit absolute Mach number of at least one, and correspondingly, may be referred to as supersonic process fluid.

[0049] The velocity of the supersonic process fluid flowing into the inlet end of the static diffuser 116 decreases with increasing radius of the annular diffuser passageway 174 as the process fluid flows from the inlet end to the radially outer outlet end of the static diffuser 116 as the velocity head is converted to static pressure. In some embodiments, the tangential velocity of the supersonic process fluid may decelerate from supersonic to subsonic velocities across the diffuser vanes of the first ring without shock losses. Accordingly, the static diffuser 116 may reduce the velocity and increase the pressure energy of the process fluid.

[0050] The process fluid exiting the static diffuser 116 may have a subsonic velocity and may be fed into the collector 117 or discharge volute. The collector 117 may increase the static pressure of the process fluid by converting the remaining kinetic energy of the process fluid to static pressure. The process fluid may then be routed to perform work or for operation of one or more downstream processes or components (not shown).

[0051] The process fluid pressurized, circulated, contained, or otherwise utilized in the compression system 100 may be a fluid in a liquid phase, a gas phase, a supercritical state, a subcritical state, or any combination thereof. The process fluid may be a mixture, or process fluid mixture. The process fluid may include one or more high molecular weight process fluids, one or more low molecular weight process fluids, or any mixture or combination thereof. As used herein, the term "high molecular weight process fluids" refers to process fluids having a molecular weight of about 30 grams per mole (g/mol) or greater. Illustrative high molecular weight process fluids may include, but are not limited to, hydrocarbons, such as ethane, propane, butanes, pentanes, and hexanes. Illustrative high molecular weight process fluids may also include, but are not limited to, carbon dioxide (CO₂) or process fluid mixtures containing carbon dioxide. As used herein, the term "low molecular weight process fluids" refers to process fluids having a molecular weight less than about 30 g/mol. Illustrative low molecular weight process fluids may include, but are not limited to, air, hydrogen, methane, or any combination or mixtures thereof.

[0052] In an exemplary embodiment, the process fluid or the process fluid mixture may be or include carbon dioxide. The amount of carbon dioxide in the process fluid or the process fluid mixture may be at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least about 99%, or greater by volume. Utilizing carbon dioxide as the process fluid or as a component or part of the process fluid mixture in the compression system 100 may provide one or more advantages. For example, the high density and high heat capacity or volumetric heat capacity of carbon dioxide with respect to other process

fluids may make carbon dioxide more "energy dense." Accordingly, a relative size of the compression system 100 and/or the components thereof may be reduced without reducing the performance of the compression system 100.

[0053] The carbon dioxide may be of any particular type, source, purity, or grade. For example, industrial grade carbon dioxide may be utilized as the process fluid without departing from the scope of the disclosure. Further, as previously discussed, the process fluids may be a mixture, or process fluid mixture. The process fluid mixture may be selected for one or more desirable properties of the process fluid mixture within the compression system 100. For example, the process fluid mixture may include a mixture of a liquid absorbent and carbon dioxide (or a process fluid containing carbon dioxide) that may enable the process fluid mixture to be compressed to a relatively higher pressure with less energy input than compressing carbon dioxide (or a process fluid containing carbon dioxide) alone.

[0054] It should be appreciated that all numerical values and ranges disclosed herein are approximate values and ranges, whether "about" is used in conjunction therewith. It should also be appreciated that the term "about," as used herein, in conjunction with a numeral refers to a value that is $\pm 5\%$ (inclusive) of that numeral, $\pm 10\%$ (inclusive) of that numeral, or $\pm 15\%$ (inclusive) of that numeral. It should further be appreciated that when a numerical range is disclosed herein, any numerical value falling within the range is also specifically disclosed.

[0055] Certain embodiments and features have been described using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges including the combination of any two values, e.g., the combination of any lower value with any upper value, the combination of any two lower values, and/or the combination of any two upper values are contemplated unless otherwise indicated.

[0056] The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

We claim:

1. An impeller for a compressor, comprising:

a hub mountable to a rotary shaft of the compressor and configured to rotate about a center axis, the hub comprising a first meridional end portion and a second meridional end portion;

a plurality of main blades mounted to or integral with the hub, the plurality of main blades arranged equidistantly and circumferentially about the center axis; and

a plurality of splitter blades mounted to or integral with the hub, the plurality of splitter blades arranged equidistantly and circumferentially about the center axis, each splitter blade comprising a leading edge meridionally spaced from the first meridional end portion and a trailing edge proximal the second meridional end portion,

wherein a splitter blade is positioned between a first adjacent main blade and a second adjacent main blade and canted such that the leading edge of the splitter blade is displaced from a blade position equidistant the first adjacent main blade and the second adjacent main blade a first percentage amount of one half an angular distance between the first adjacent main blade and the second adjacent main blade, and the trailing edge of the splitter blade is displaced from the blade position equidistant the first adjacent main blade and the second adjacent main blade a second percentage amount of one half the angular distance between the first adjacent main blade and the second adjacent main blade, the second percentage amount being greater or less than the first percentage amount.

2. The impeller of claim 1, wherein the splitter blade is positioned between the first adjacent main blade and the second adjacent main blade such that the splitter blade is circumferentially offset from the blade position equidistant the first adjacent main blade and the second adjacent main blade.

3. The impeller of claim 1, wherein each main blade of the plurality of main blades comprises:
a leading edge proximal the first meridional end portion;
a trailing edge proximal the second meridional end portion;
a pressure surface side extending between the leading edge and the trailing edge; and
a suction surface side opposing the pressure surface side and extending between the leading edge and the trailing edge,

wherein the splitter blade is positioned between a pressure surface side of the first adjacent main blade and a suction surface side of the second adjacent main blade such that the splitter blade

is circumferentially offset from the blade position equidistant the first adjacent main blade and the second adjacent main blade.

4. The impeller of claim 3, wherein the splitter blade is circumferentially offset in a direction toward the pressure surface side of the first adjacent main blade.

5. The impeller of claim 3, wherein:

a first flow passage is formed between the splitter blade and the pressure surface side of the first adjacent main blade; and

a second flow passage is formed between the splitter blade and the suction surface side of the second adjacent main blade, such that the first flow passage and the second flow passage are configured to receive substantially equal mass flow therethrough.

6. The impeller of claim 5, wherein the splitter blade comprises:

a pressure surface side extending between the leading edge and the trailing edge of the splitter blade; and

a suction surface side opposing the pressure surface side and extending between the leading edge and the trailing edge of the splitter blade,

wherein the first flow passage is formed between the suction surface side of the splitter blade and the pressure surface side of the first adjacent main blade, and the second flow passage is formed between the pressure surface side of the splitter blade and the suction surface side of the second adjacent main blade.

7. The impeller of claim 1, wherein the plurality of main blades and the plurality of splitter blades are equal in number.

8. The impeller of claim 1, wherein the respective leading edges of the main blades and the respective leading edges of the splitter blades are arranged in a meridionally-staggered pattern with respect to one another.

9. The impeller of claim 1, wherein the splitter blade is positioned between the first adjacent main blade and the second adjacent main blade and canted such that the second percentage amount is greater than the first percentage amount.

10. The impeller of claim 1, wherein the splitter blade is positioned between the first adjacent main blade and the second adjacent main blade and canted such that the second percentage amount is less than the first percentage amount.

11. A compressor comprising:

a housing;

an inlet coupled to or integral with the housing and defining an inlet passageway configured to receive and flow a process fluid;

a rotary shaft configured to be driven by a driver;

a centrifugal impeller coupled with the rotary shaft and fluidly coupled to the inlet passageway, the centrifugal impeller configured to rotate about a center axis and impart energy to the process fluid received via the inlet passageway, the centrifugal impeller comprising:

a hub defining a borehole through which a coupling member or the rotary shaft of the compressor extends, the hub comprising a first meridional end portion having an annular portion and a second meridional end portion forming a disc-shaped portion; and

a plurality of blades mounted to or integral with the hub, the plurality of blades arranged equidistantly and circumferentially about the center axis and comprising a splitter blade positioned between a first adjacent main blade and a second adjacent main blade and canted with respect to the first adjacent main blade and the second adjacent main blade;

a static diffuser circumferentially disposed about the centrifugal impeller and configured to receive the process fluid from the centrifugal impeller and convert the energy imparted to pressure energy; and

a collector fluidly coupled to and configured to collect the process fluid exiting the static diffuser,

wherein the compressor is configured to provide a compression ratio of at least about 8:1.

12. The compressor of claim 11, wherein:

the splitter blade comprises a leading edge meridionally spaced from the first meridional end portion and a trailing edge proximal the second meridional end portion, and

the splitter blade is positioned between the first adjacent main blade and the second adjacent main blade and canted such that the leading edge of the splitter blade is displaced from a blade position equidistant the first adjacent main blade and the second adjacent main blade a first percentage amount of one half an angular distance between the first adjacent main blade and the second adjacent main blade, and the trailing edge of the splitter blade is displaced from the blade

position equidistant the first adjacent main blade and the second adjacent main blade a second percentage amount of one half the angular distance between the first adjacent main blade and the second adjacent main blade, the second percentage amount being greater or less than the first percentage amount.

13. The compressor of claim 11, wherein the splitter blade is positioned between the first adjacent main blade and the second adjacent main blade such that the splitter blade is circumferentially offset from the blade position equidistant the first adjacent main blade and the second adjacent main blade.

14. The compressor of claim 11, wherein each main blade of the plurality of main blades comprises:

- a leading edge proximal the first meridional end;
- a trailing edge proximal the second meridional end;
- a pressure surface side extending from the leading edge to the trailing edge; and
- a suction surface side opposing the pressure surface side and extending from the leading edge to the trailing edge,

wherein the splitter blade is positioned between a pressure surface side of the first adjacent main blade and a suction side surface of the second adjacent main blade such that the splitter blade is circumferentially offset from the blade position equidistant the first adjacent main blade and the second adjacent main blade.

15. The compressor of claim 14, wherein the splitter blade is circumferentially offset in a direction toward the pressure surface side of the first adjacent main blade.

16. The compressor of claim 14, wherein:

- a first flow passage is formed between the splitter blade and the pressure surface side of the first adjacent main blade; and

- a second flow passage is formed between the splitter blade and the suction surface side of the second adjacent main blade, such that the first flow passage and the second flow passage are configured to receive substantially equal mass flow therethrough.

17. The compressor of claim 11, wherein:

- the process fluid comprises carbon dioxide;

- the compressor is configured to provide a compression ratio of at least about 10:1; and

the second meridional end portion of the centrifugal impeller is configured to discharge the process fluid therefrom in at least a partially radial direction at an absolute Mach number of about 1.3 or greater.

18. The compressor of claim 17, wherein the centrifugal impeller is configured to rotate via the rotary shaft at a rotational speed of about 500 meters per second or greater.

19. A compression system comprising:

a driver comprising a drive shaft, the driver configured to provide the drive shaft with rotational energy;

a supersonic compressor operatively coupled to the driver via a rotary shaft integral with or coupled with the drive shaft and configured to rotate about a center axis, the supersonic compressor comprising:

a compressor chassis;

an inlet defining an inlet passageway configured to flow a process fluid therethrough, the process fluid having a first velocity and a first pressure energy;

a centrifugal impeller coupled with the rotary shaft and fluidly coupled to the inlet passageway, the centrifugal impeller having a tip and configured to increase the first velocity and the first pressure energy of the process fluid received via the inlet passageway and discharge the process fluid from the tip in at least a partially radial direction having a second velocity and a second pressure energy, the second velocity being a supersonic velocity having an absolute Mach number of about one or greater, wherein the centrifugal impeller comprises:

a hub defining a borehole through which a coupling member or the rotary shaft of the supersonic compressor extends, the hub comprising a first meridional end portion having an annular portion and a second meridional end portion forming the tip; and

a plurality of blades mounted to or integral with the hub, the plurality of blades arranged equidistantly and circumferentially about the center axis and comprising a splitter blade positioned between a first adjacent main blade and a second adjacent main blade and canted with respect to the first adjacent main blade and the second adjacent main blade;

a static diffuser circumferentially disposed about the tip of the centrifugal impeller and defining an annular diffuser passageway configured to receive and reduce the second

velocity of the process fluid to a third velocity and increase the second pressure energy to a third pressure energy, the third velocity being a subsonic velocity; and

a discharge volute fluidly coupled to the annular diffuser passageway and configured to receive the process fluid flowing therefrom,

wherein the supersonic compressor is configured to provide a compression ratio of at least about 8:1.

20. The compression system of claim 19, wherein:

the process fluid comprises carbon dioxide;

the second velocity has an absolute Mach number of about 1.3 or greater;

the supersonic compressor is configured to provide a compression ratio of at least about 10:1; and

the splitter blade is positioned between the first adjacent main blade and the second adjacent main blade such that the splitter blade is circumferentially offset from a blade position equidistant the first adjacent main blade and the second adjacent main blade, the splitter blade being circumferentially offset in a direction toward a pressure surface side of the first adjacent main blade.

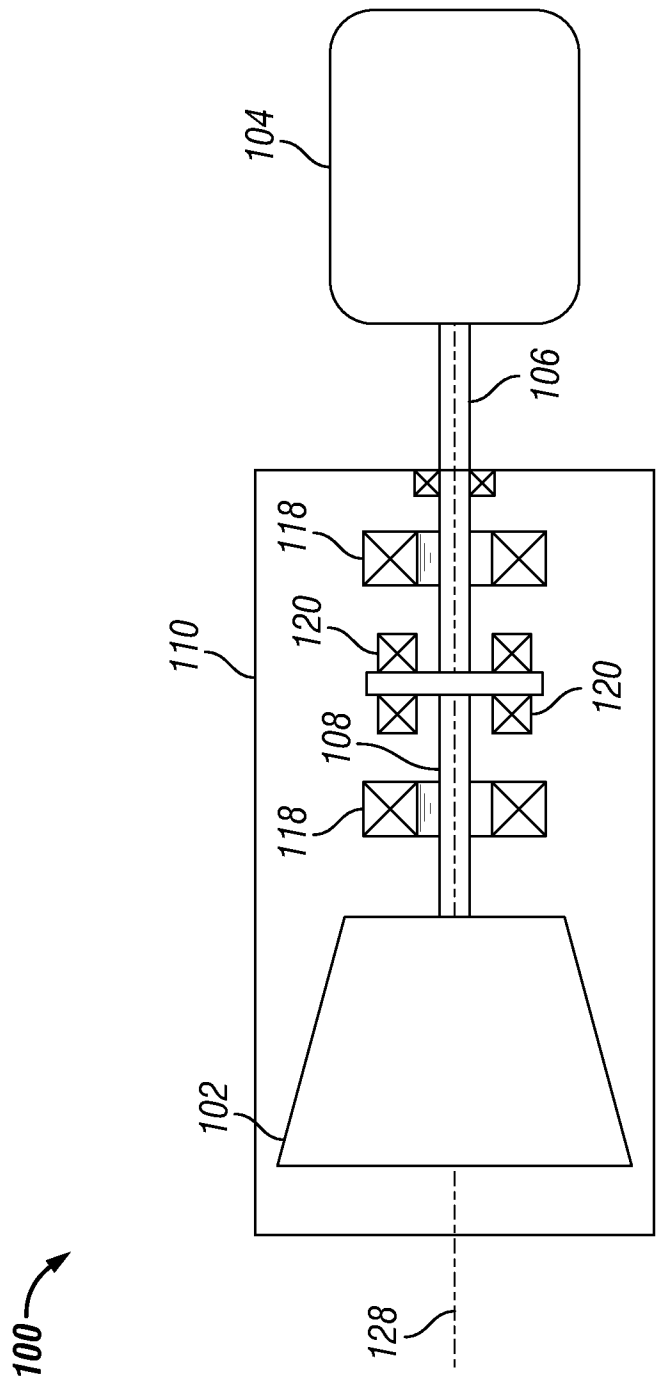


FIG. 1

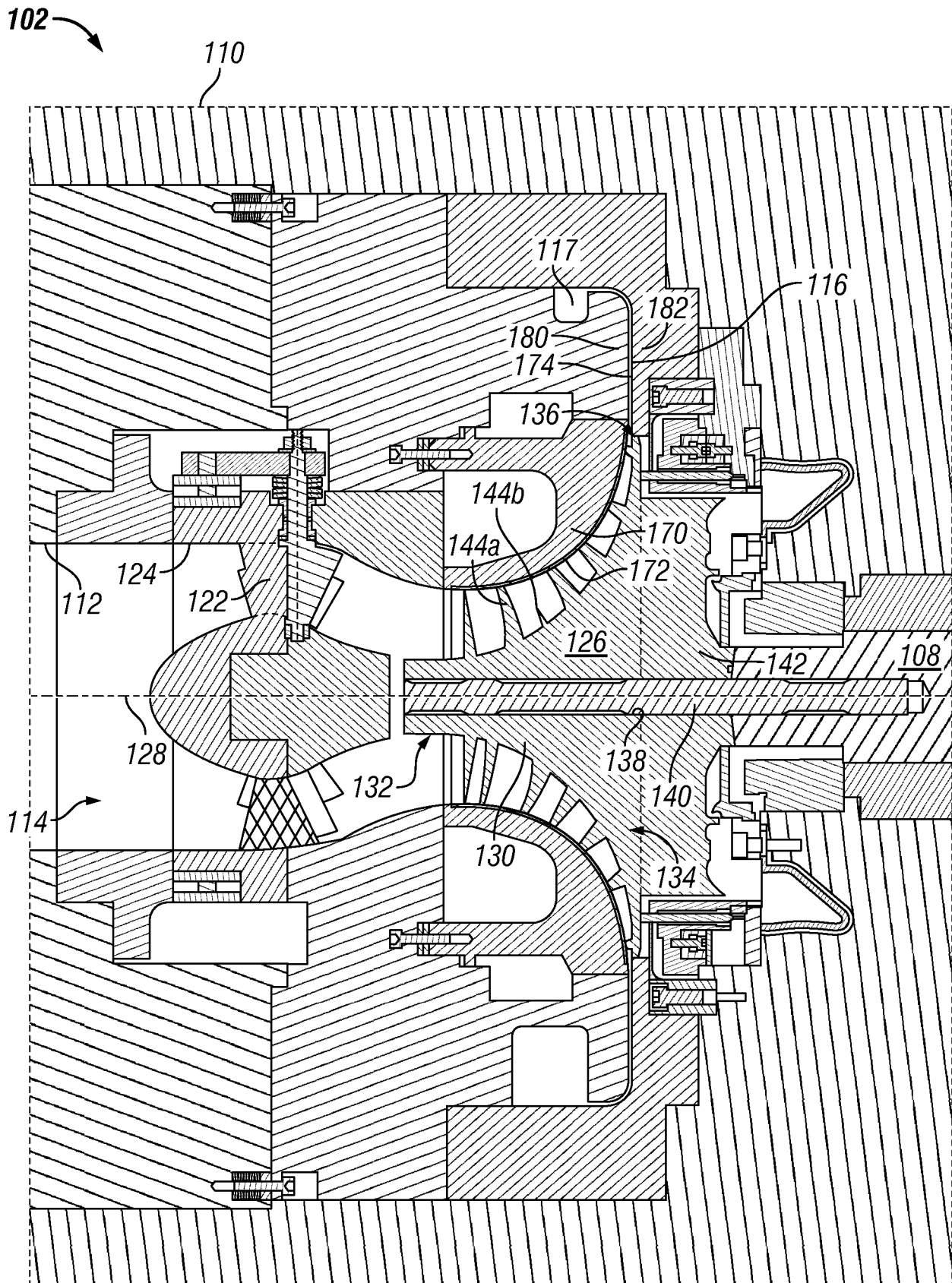


FIG. 2

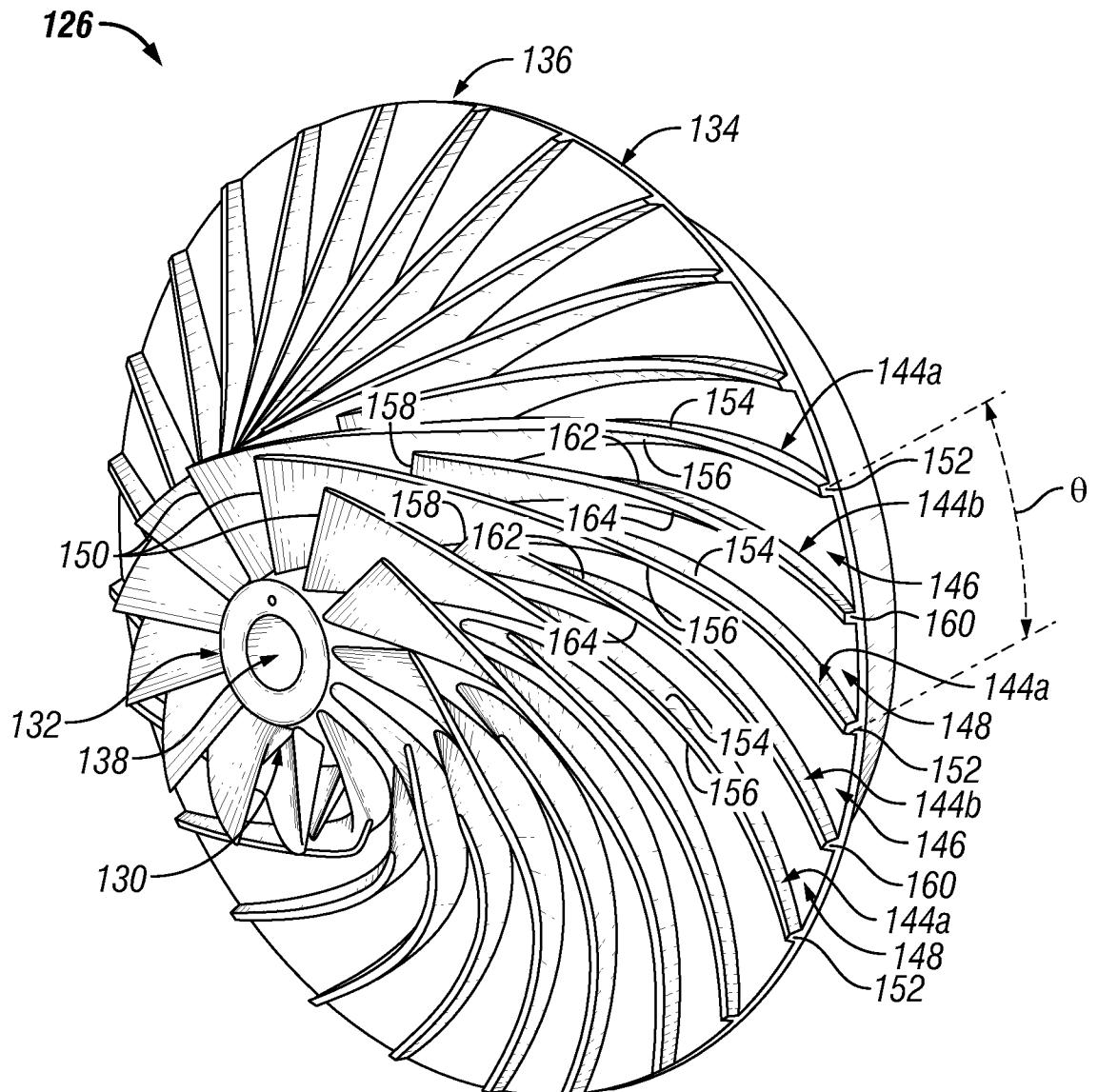
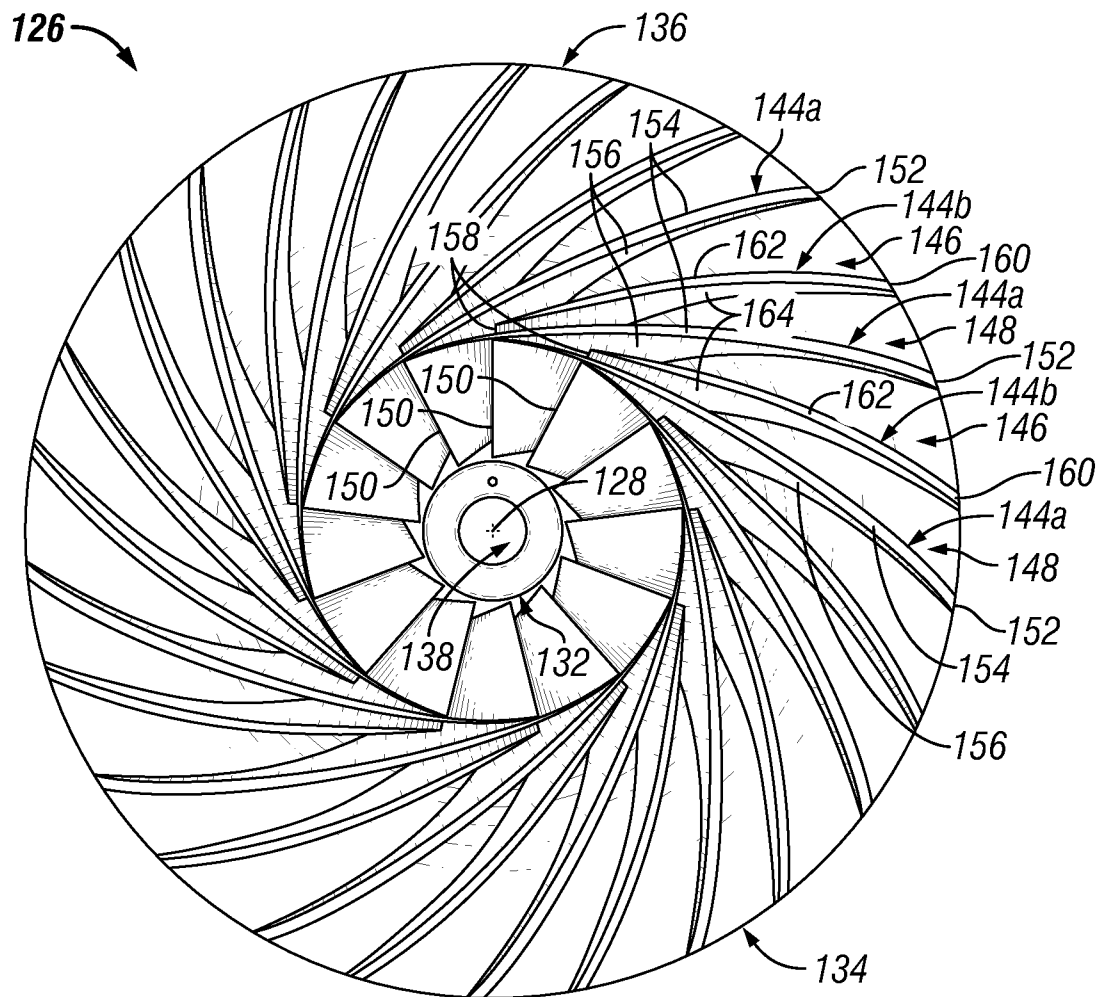


FIG. 3A

**FIG. 3B**

A. CLASSIFICATION OF SUBJECT MATTER**F04D 29/30(2006.01)i, F04D 29/26(2006.01)i, F04D 17/08(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04D 29/30; F04D 29/28; F04D 29/42; F01D 5/22; F04D 29/44; F04D 19/00; F04D 17/10; F04D 29/26; F04D 17/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: compressor, impeller, main blades, splitter blade, hub, canted, displaced, leading edge, trailing edge, angular distance

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0272861 A1 (TOMITA et al.) 17 October 2013 See abstract, paragraphs [0053]-[0056], [0078]-[0087], claim 1, and figures 1-2, 6-9.	1-10
Y		11-20
Y	US 2014-0341706 A1 (LARDY et al.) 20 November 2014 See abstract, paragraphs [0008], [0017]-[0025], [0031], [0036], [0039], and figures 1-3.	11-20
A	US 2013-0195667 A1 (HOSHI et al.) 01 August 2013 See abstract, paragraphs [0070]-[0088], and figures 1-6.	1-20
A	US 2012-0328444 A1 (SUGIMOTO et al.) 27 December 2012 See abstract, paragraphs [0067]-[0082], and figures 1-3.	1-20
A	US 2013-0115067 A1 (BRONFELD et al.) 09 May 2013 See abstract, paragraph [0037], and figure 1.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

18 July 2016 (18.07.2016)

Date of mailing of the international search report

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Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/023925

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US 2013-0115067 A1	09/05/2013	EP 2520763 A2 IL 212729 A IL 212729 B US 9033668 B2	07/11/2012 31/07/2011 31/03/2015 19/05/2015