US009731238B2

(12) **United States Patent**
Maier et al.

(10) **Patent No.: US 9,731,238 B2**
(45) **Date of Patent: *Aug. 15, 2017**

(54) **BLADED DRUM FOR ROTARY SEPARATOR SYSTEM**

(71) Applicant: **DRESSER-RAND COMPANY**, Olean, NY (US)

(72) Inventors: **William C. Maier**, Almond, NY (US); **Gocha Chochua**, Sugar Land, TX (US)

(73) Assignee: **Dresser-Rand Company**, Olean, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/392,456**

(22) Filed: **Dec. 28, 2016**

(65) **Prior Publication Data**

US 2017/0106319 A1 Apr. 20, 2017

Related U.S. Application Data

(63) Continuation of application No. 14/617,044, filed on Feb. 9, 2015, now Pat. No. 9,550,140, which is a continuation of application No. 13/038,941, filed on Mar. 2, 2011, now Pat. No. 8,960,447.

(60) Provisional application No. 61/312,067, filed on Mar. 9, 2010.

(51) **Int. Cl.**

B01D 45/14	(2006.01)
F22B 37/32	(2006.01)
B01D 17/02	(2006.01)
B01D 19/00	(2006.01)
B04B 7/12	(2006.01)
B04B 1/04	(2006.01)
B01D 53/24	(2006.01)

(Continued)

(52) **U.S. Cl.**
CPC ***B01D 45/14*** (2013.01); ***B01D 17/0217*** (2013.01); ***B01D 19/0057*** (2013.01); ***B01D 46/0056*** (2013.01); ***B01D 53/24*** (2013.01); ***B04B 1/04*** (2013.01); ***B04B 7/08*** (2013.01); ***B04B 7/12*** (2013.01); ***F22B 37/32*** (2013.01)

(58) **Field of Classification Search**
CPC B01D 45/14; B01D 53/24; B01D 46/0056; B01D 17/0217; B01D 19/0057; B01D 45/12; F22B 37/32; F22B 37/325; B04B 7/08; B04B 7/12; B04B 1/04; B04B 5/005; B04B 5/12
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,661,076 A *	12/1953	Walker	B01D 45/06	55/317
3,720,045 A *	3/1973	Murphy	B01D 45/14	415/115
4,832,709 A *	5/1989	Nagyszalanczy	B01D 45/14	55/398

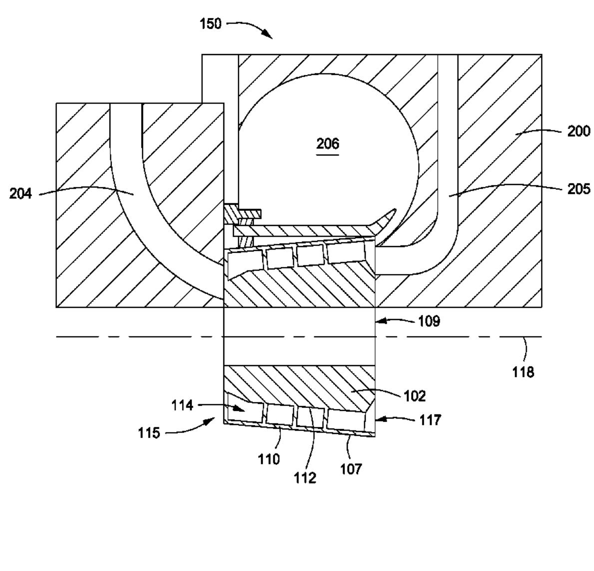
* cited by examiner

Primary Examiner — David C Mellon

(57) **ABSTRACT**

A separator method and apparatus that includes a rotatable drum defining an annular passageway therein, a plurality of blades coupled to the rotatable drum and located in the annular passageway, each of the plurality of blades including a leading section, a trailing section, a concave surface, and a convex surface, the concave and convex surfaces extending from the leading section to the trailing section, each of the plurality of blades disposed circumferentially adjacent to at least another one of the plurality of blades so as to define blade flowpaths therebetween, and a housing at least partially surrounding the rotatable drum and defining a fluid collection chamber fluidly communicating with the annular passageway.

20 Claims, 10 Drawing Sheets



(51) **Int. Cl.**

B01D 46/00	(2006.01)
B04B 7/08	(2006.01)

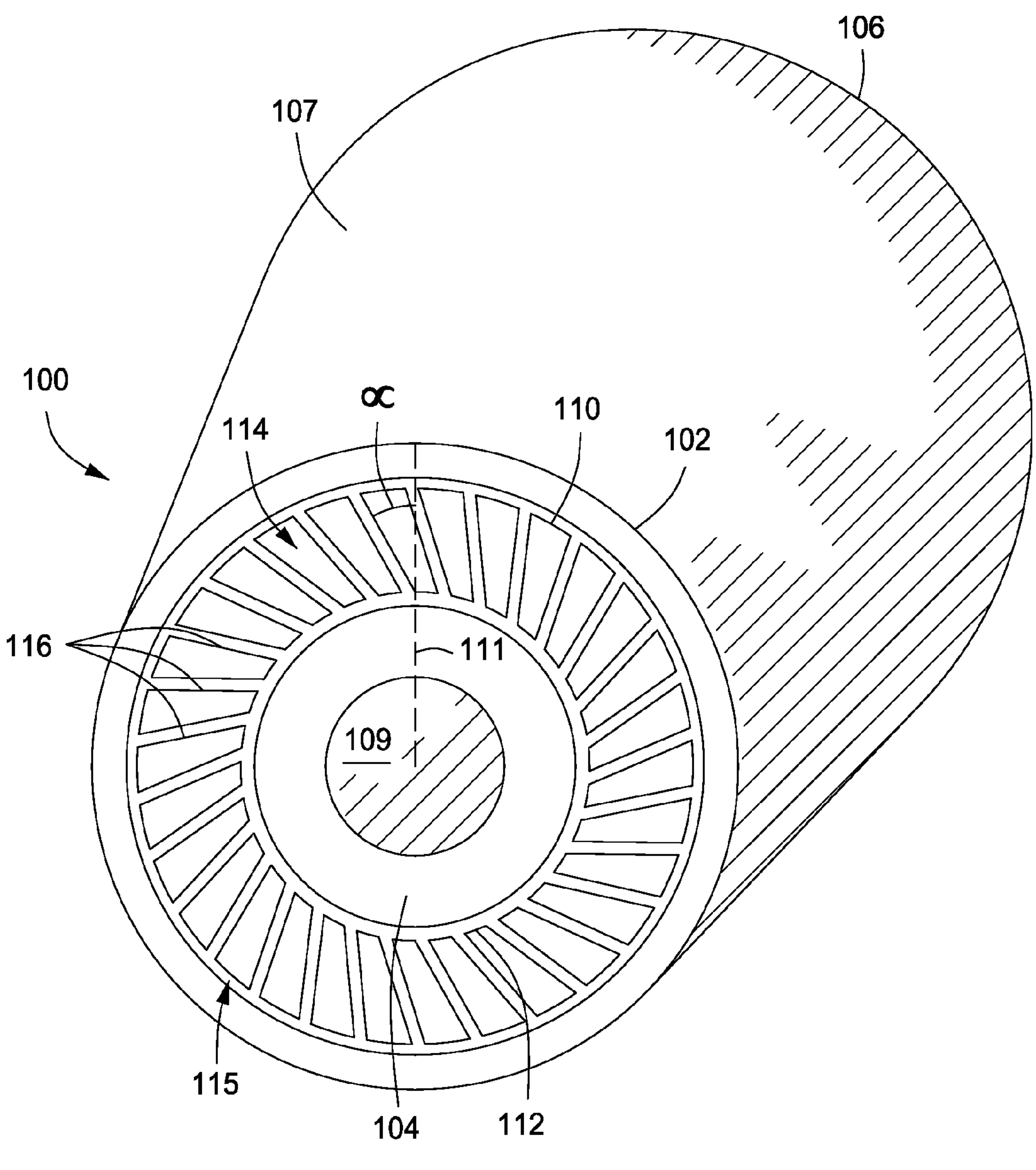


FIG. 1

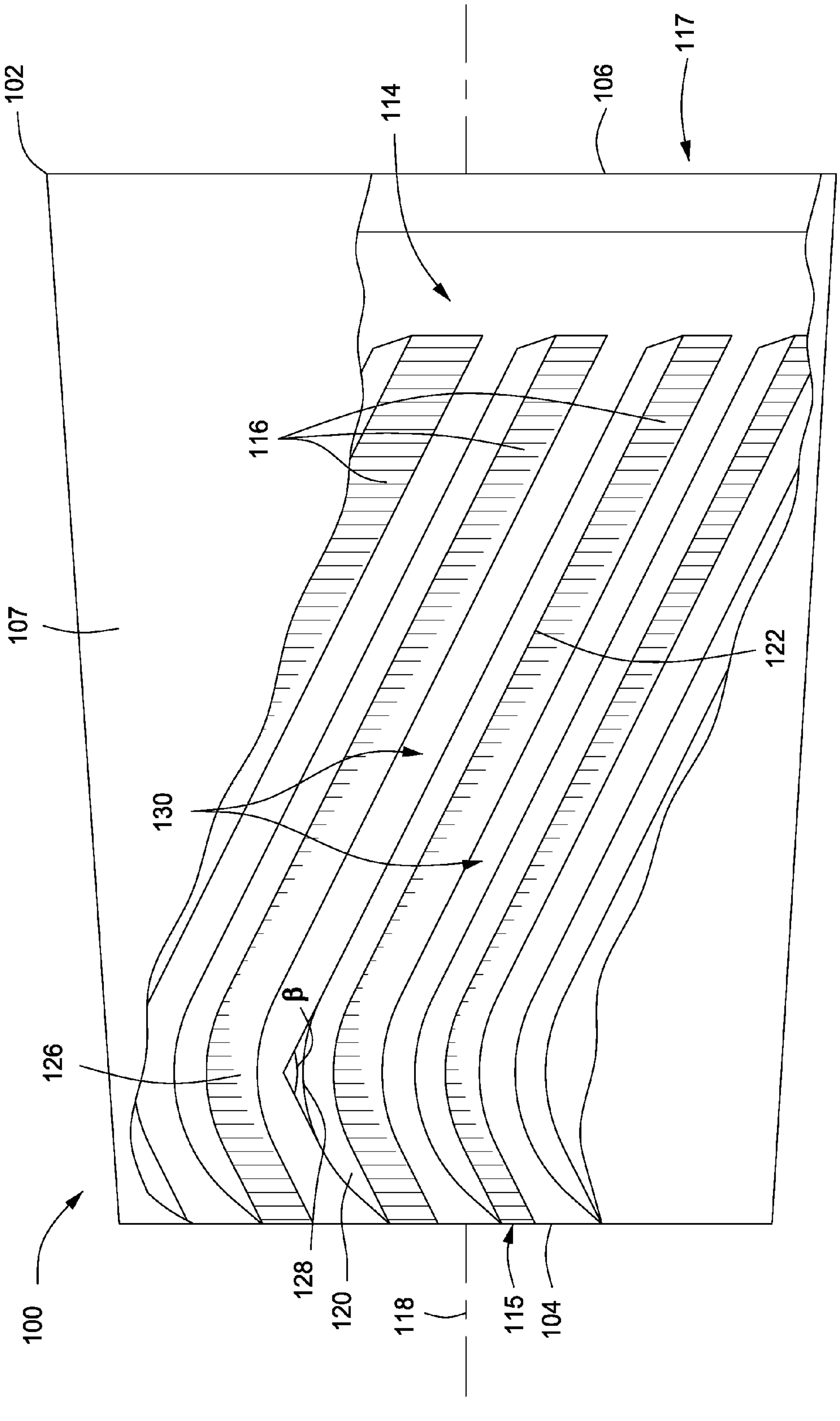


FIG. 2

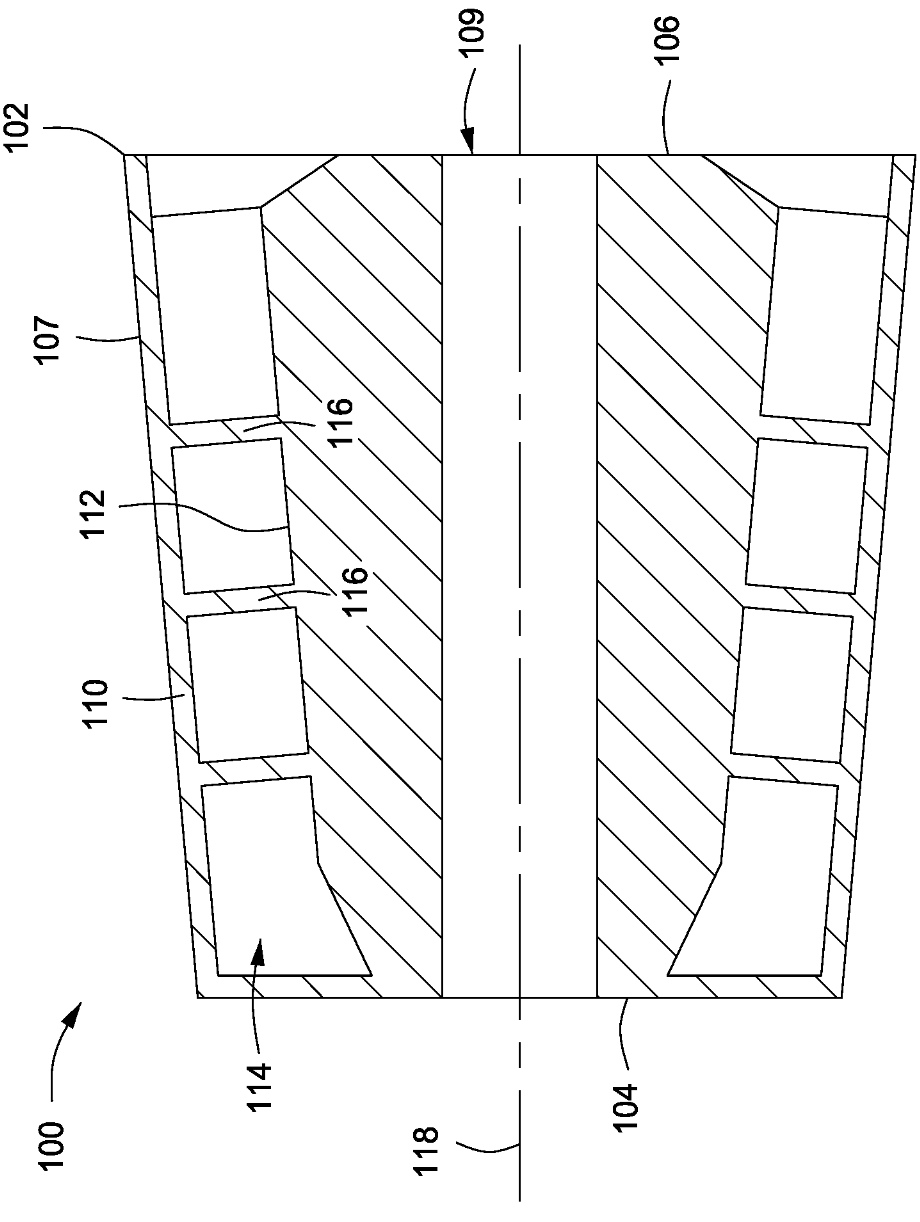


FIG. 3

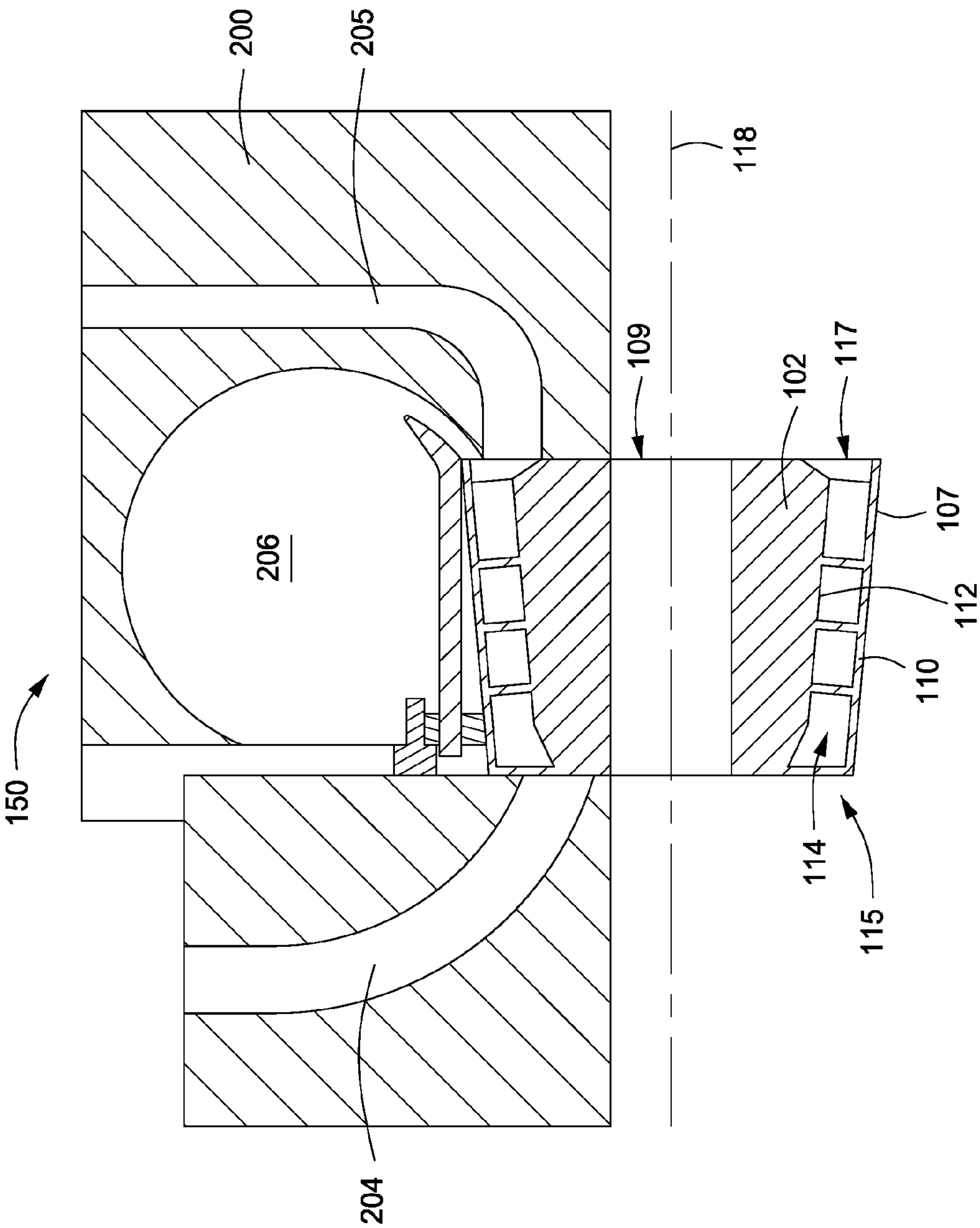


FIG. 4

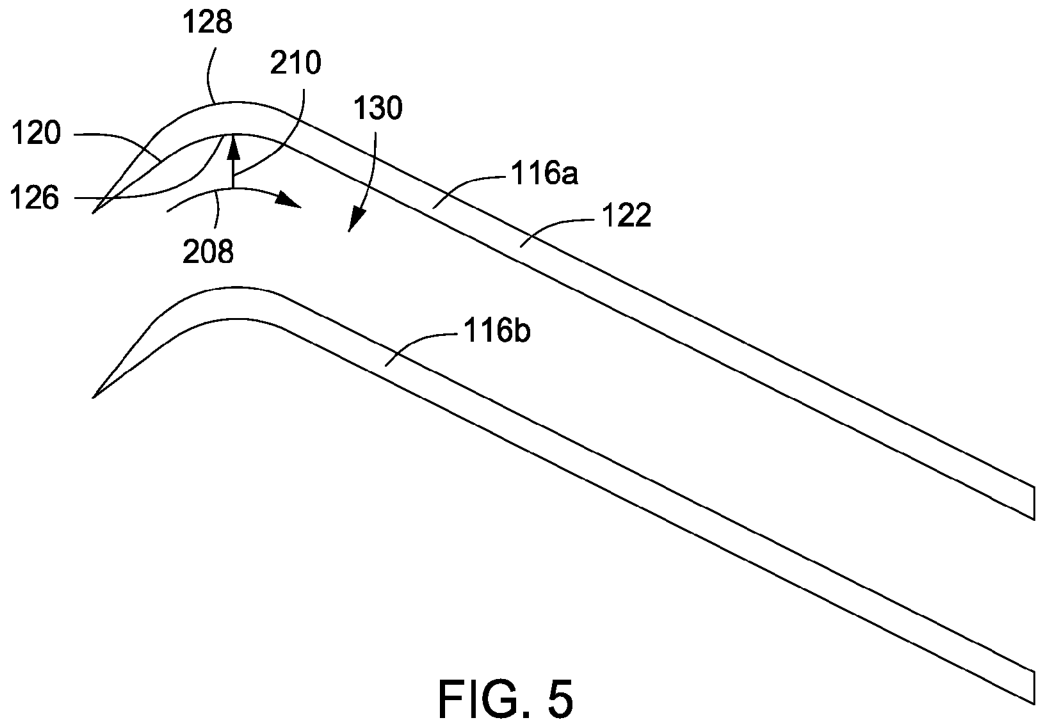

128
210
130
120
126
116a
122
208
116b

FIG. 5

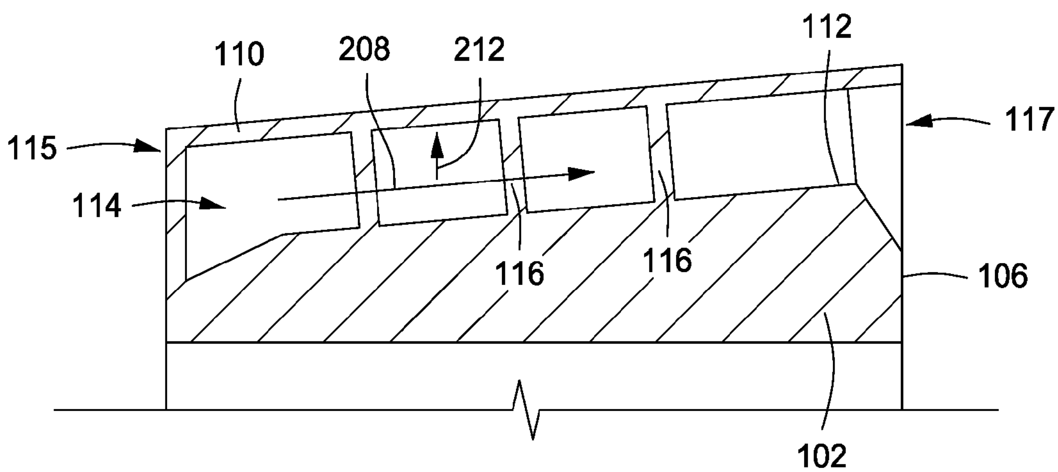
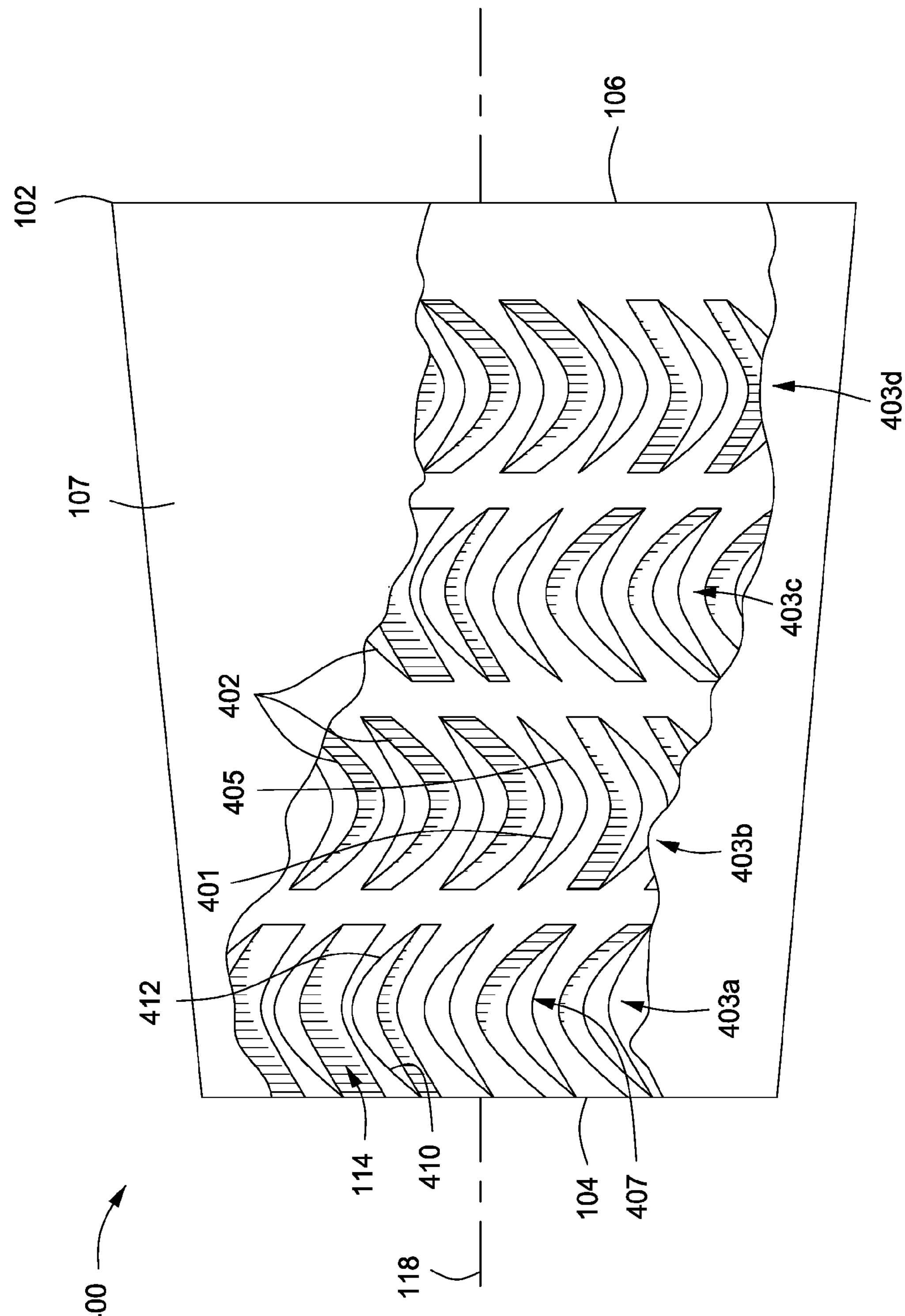

110
208
212
112
115
117
114
116
116
106
102

FIG. 6



400
102
106
107
402
405
401
412
403d
403c
403b
403a
114
410
104
407
118

FIG. 7

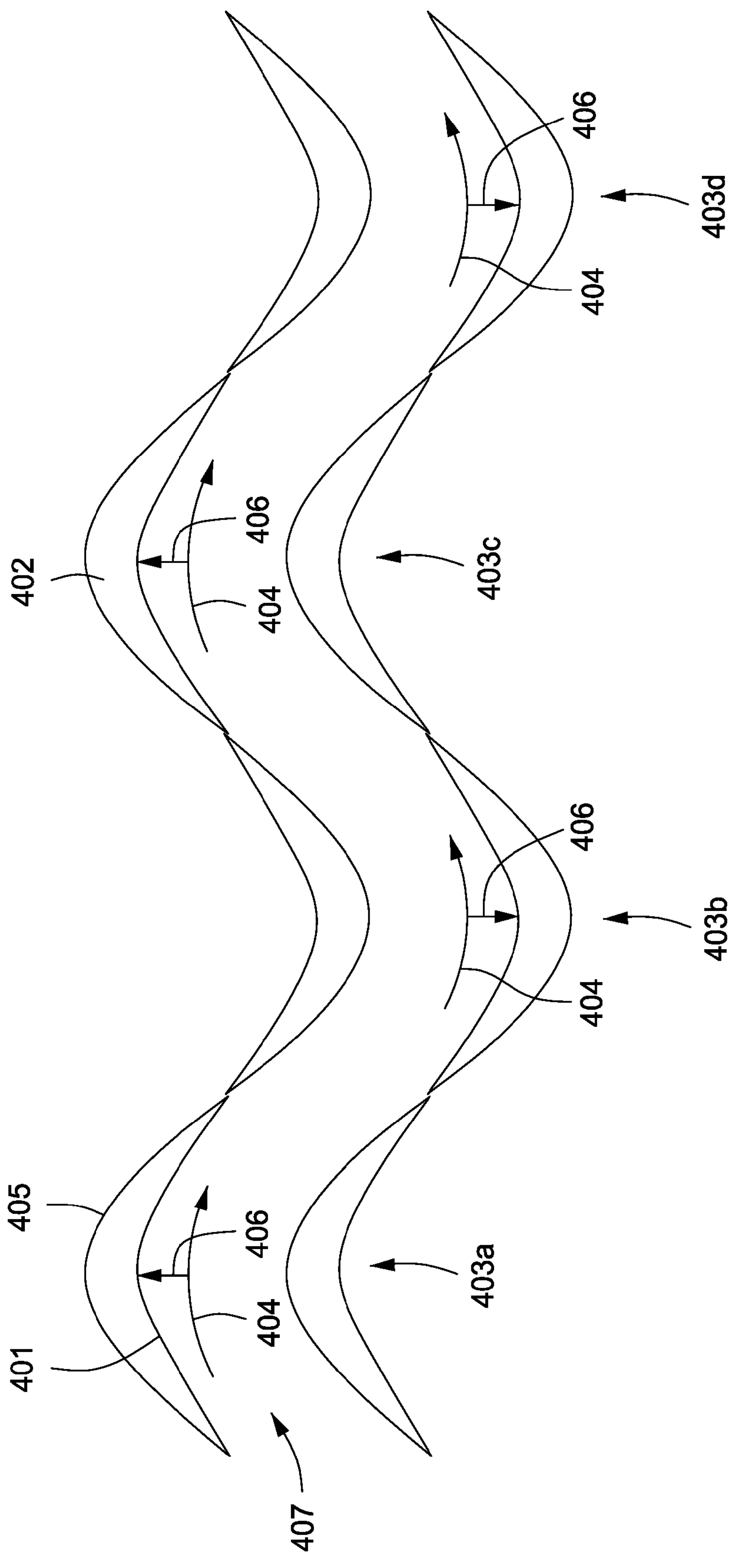

402
406
404
406
403d
404
403c
406
404
403b
405
406
401
404
403a
407

FIG. 8

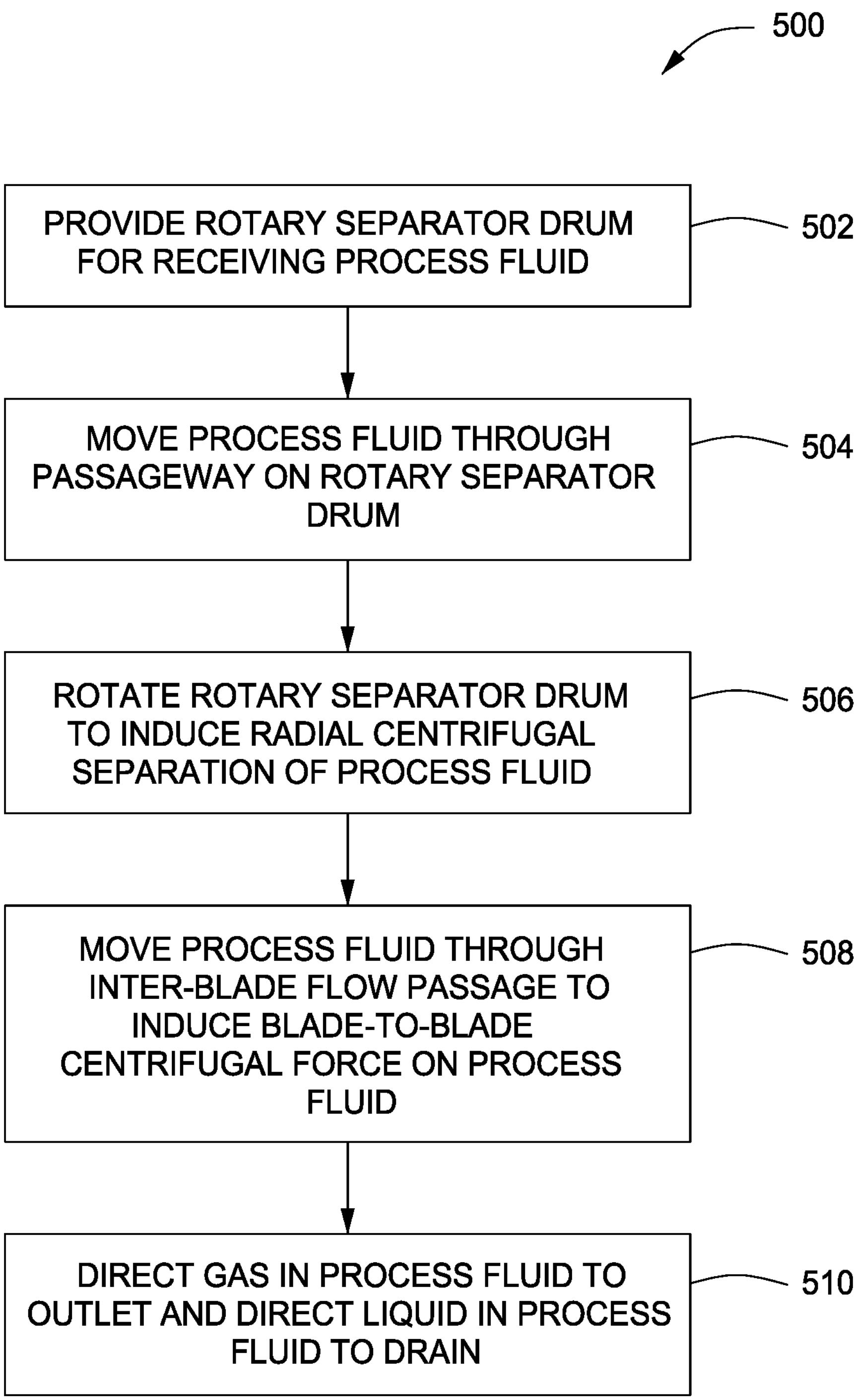

500
PROVIDE ROTARY SEPARATOR DRUM FOR RECEIVING PROCESS FLUID
502
MOVE PROCESS FLUID THROUGH PASSAGEWAY ON ROTARY SEPARATOR DRUM
504
ROTATE ROTARY SEPARATOR DRUM TO INDUCE RADIAL CENTRIFUGAL SEPARATION OF PROCESS FLUID
506
MOVE PROCESS FLUID THROUGH INTER-BLADE FLOW PASSAGE TO INDUCE BLADE-TO-BLADE CENTRIFUGAL FORCE ON PROCESS FLUID
508
DIRECT GAS IN PROCESS FLUID TO OUTLET AND DIRECT LIQUID IN PROCESS FLUID TO DRAIN
510

FIG. 9

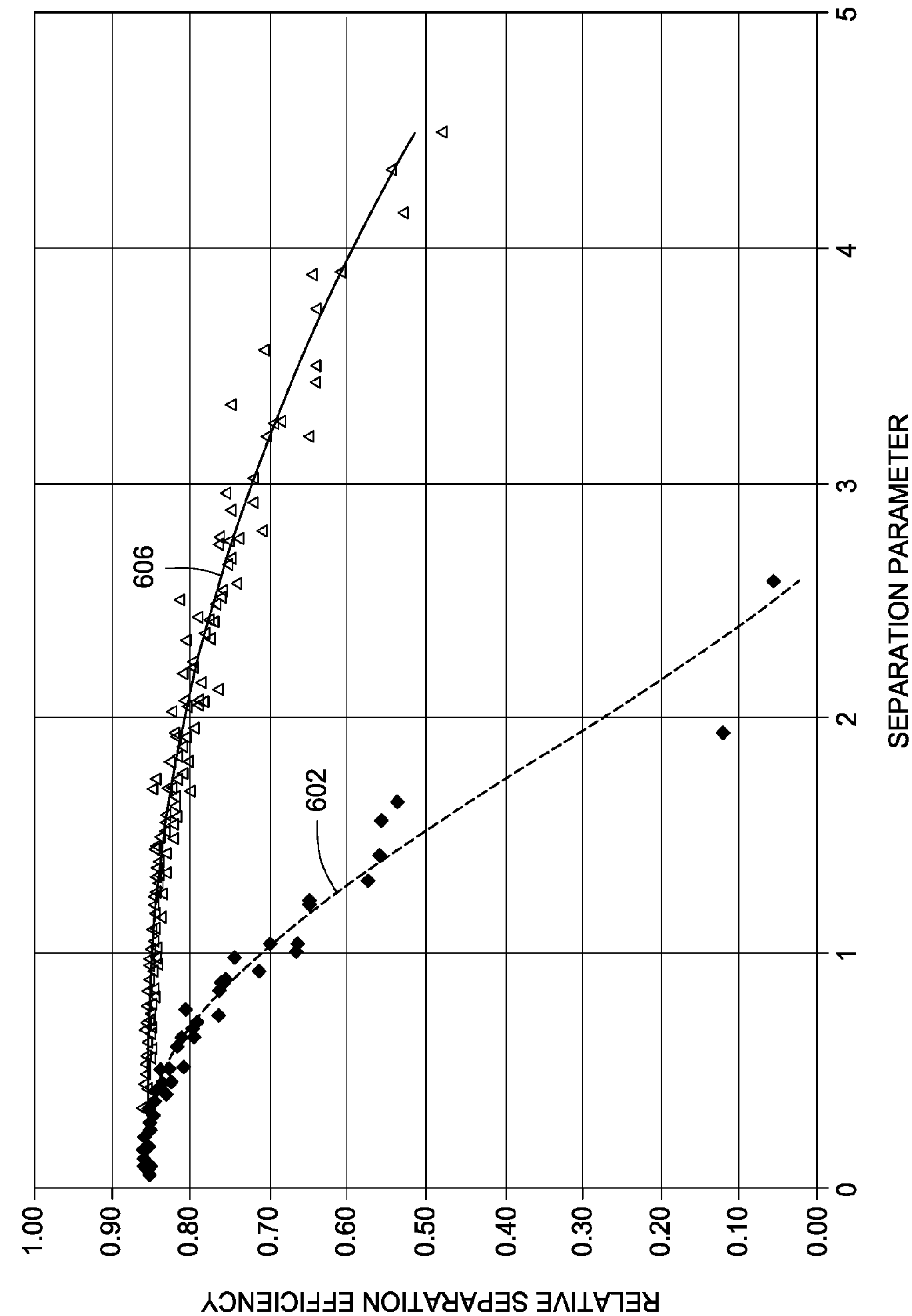

606
602
SEPARATION PARAMETER
RELATIVE SEPARATION EFFICIENCY
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1
2
3
4
5

FIG. 10

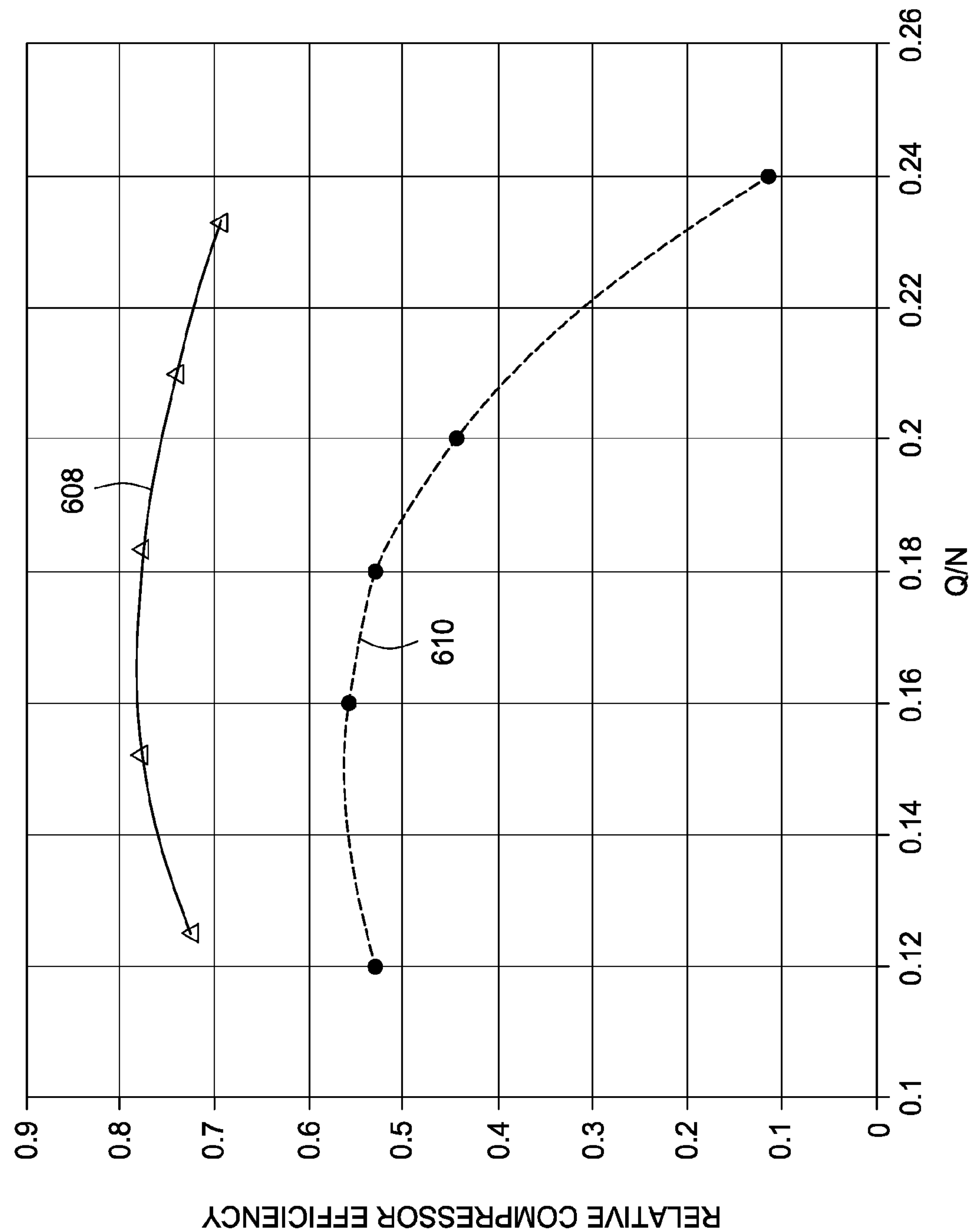

RELATIVE COMPRESSOR EFFICIENCY
Q/N
608
610
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26

FIG. 11

BLADED DRUM FOR ROTARY SEPARATOR SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation of co-pending U.S. patent application Ser. No. 14/617,044, filed Feb. 9, 2015, which is a continuation of U.S. patent application Ser. No. 13/038,941, now U.S. Pat. No. 8,960,447, filed Mar. 2, 2011, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/312,067, filed Mar. 9, 2010, the disclosures of which are incorporated herein by reference to the extent consistent with the present application.

BACKGROUND

In many industrial processes where it is desired to compress a process fluid, the process fluid includes both lower-density and higher-density components, for example, gases and liquids, respectively. Liquids, however, can potentially damage, corrode, reduce the efficiency of, and/or wear on the compression equipment; therefore, it is generally desirable to remove as much of the liquid from the process fluid as possible, prior to compression. This is balanced against avoiding significant increases in materials and operating expenses, along with retaining a sufficient throughput rate. One way to remove such liquid is to channel the process fluid through a density-based separator, such as a rotary separator, thereby separating and expelling the higher-density components from the lower-density components of the process fluid. To achieve a desired separation efficiency, the axial length of rotary separators is typically dictated by the axial velocity of the process fluid, the radial velocity of the liquid that is induced by the rotational motion of the rotary separator, and the radial distance the liquid must travel before reaching the drain. These factors limit the ability to reduce the axial length of these rotary separators and equipment in which the separators may be included. What is needed, therefore, is a rotary separator that can efficiently separate the process fluid at a high axial velocity over a shorter axial distance.

SUMMARY

Embodiments of the disclosure may provide an exemplary separator apparatus. The separator apparatus may include a rotatable drum defining an annular passageway extending axially therethrough, with the rotatable drum being configured to separate a higher-density component of a fluid from a lower-density component of the fluid. The separator apparatus may also include a plurality of blades coupled to the rotatable drum, located in the annular passageway, and being configured to rotate with the rotatable drum, each of the plurality of blades including a leading section, a trailing section, a concave surface, and a convex surface, the concave and convex surfaces extending from the leading section to the trailing section, each of the plurality of blades being disposed circumferentially adjacent to at least another one of the plurality of blades so as to define blade flowpaths therebetween. The separator apparatus may further include a housing at least partially surrounding the rotatable drum and defining a fluid collection chamber fluidly communicating with the annular passageway.

Embodiments of the disclosure may also provide an exemplary method for separating a mixed process fluid. The method may include introducing the mixed process fluid to

a rotary separator drum, the mixed process fluid including a higher-density component and a lower-density component. The method may further include centrifugally separating of at least a portion of the higher-density component from the lower-density component. Centrifugally separating the portion of the higher-density component from the lower density component may include rotating the rotary separator drum with the mixed process fluid introduced therein, and directing the mixed process fluid between curved blades disposed circumferentially adjacent one another in the rotary separator drum. The method may also include directing the separated higher-density component to an outer wall of the rotary separator drum.

Embodiments of the disclosure may further provide an exemplary apparatus for separating a higher-density component from a lower-density component of a process fluid. The apparatus may include a housing defining a fluid collection chamber, a housing inlet, and a housing outlet. The apparatus may further include a drum rotatably positioned between the housing inlet and the housing outlet and including an inner wall and an outer wall that is disposed around the inner wall and radially offset therefrom to define a passageway therebetween, the passageway including an entrance located proximal the housing inlet and an exit located proximal the housing outlet, the passageway extending an axial length between the entrance and exit and communicating with the fluid collection chamber. The apparatus may also include a plurality of blades extending at least partially between the inner and outer walls of the drum and disposed around the drum and at least partially along the axial length of the passageway, each of the plurality of blades having a leading section, a trailing section, a convex surface, and a concave surface, the convex and concave surfaces extending from the leading section to the trailing section.

BRIEF DESCRIPTION OF THE DRAWINGS

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.

FIG. **1** illustrates an isometric view of an exemplary rotary separator drum, in accordance with the disclosure.

FIG. **2** illustrates a cut-away, side perspective view of the rotary separator drum, in accordance with the disclosure.

FIG. **3** illustrates a cross-sectional side view of the rotary separator drum, in accordance with the disclosure.

FIG. **4** illustrates a cross-sectional view of the rotary separator drum coupled to a housing, in accordance with the disclosure.

FIG. **5** illustrates side view of two exemplary blades of the rotary separator with a process fluid being directed therebetween, in accordance with the disclosure.

FIG. **6** illustrates a partial cross-sectional view of the rotary separator drum, showing a process fluid shown moving therein, in accordance with the disclosure.

FIG. **7** illustrates a cut-away, side perspective view of another exemplary rotary separator drum, in accordance with the disclosure.

FIG. **8** illustrates a side view of a plurality of exemplary blades of the embodiment of the rotary separator drum shown in FIG. **7**, showing a process fluid moving between the blades, in accordance with the disclosure.

FIG. **9** illustrates a flow chart illustrating an exemplary method for separating a process fluid, in accordance with the disclosure.

FIG. **10** illustrates a graph illustrating the efficiency of an experimental embodiment of the rotary separator system in comparison to conventional separators, in accordance with the disclosure.

FIG. **11** illustrates a graph illustrating the separation performance of an experimental embodiment of the rotary separator system compared to conventional separators, in accordance with the disclosure.

DETAILED DESCRIPTION

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.

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. Further, 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, 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.

FIG. **1** illustrates a rotary separator **100**, according to an exemplary embodiment. The rotary separator **100** includes a rotatable drum **102** having a front surface **104**, a rear surface **106** located axially opposite the front surface **104**, and an outer surface **107** that extends between the front surface **104** and the rear surface **106**. In an exemplary embodiment, the drum **102** may increase in diameter proceeding from the front surface **104** to the rear surface **106**, such that the drum **102** is substantially frustoconical. In another exemplary embodiment, a center region between the front and rear surfaces **104**, **106** may be enlarged in diameter (not shown) relative to both the front and rear surfaces **104**, **106**. In yet another exemplary embodiment, the drum **102** may maintain a substantially constant diameter such that the drum **102** is cylindrical. In various other exemplary embodiments, the drum **102** may include one or more of a variety of different shapes. Furthermore, it will be appreciated that the front and rear surfaces **104**, **106** may be reversed, without departing from the scope of this disclosure.

The drum **102** may define a central bore **109** extending axially therethrough, for example, from the front surface **104** to the rear surface **106**. The central bore **109** may receive a shaft (not shown), such that the drum **102** may be rotated by an external source of rotational energy, such as a turbine, motor, or the like, or may instead provide rotational energy to an external device (not shown), such as a generator or a compressor. The drum **102** may also have an outer wall **110** and an inner wall **112**, with the outer and inner walls **110**, **112** being generally concentric with respect to each other. The outer and inner walls **110**, **112** may be radially offset from each other, defining passageway **114** therebetween, with the passageway **114** having an entrance **115** proximal the front surface **104**, as shown. In an exemplary embodiment, the geometry of the passageway **114** may generally conform to the geometry of the drum **102**, such that, in an exemplary embodiment in which the drum **102** is frustoconical, the passageway **114** is also frustoconical. In various exemplary embodiments, however, the passageway **114** can be cylindrical or any other suitable shape.

The rotary separator **100** also includes a plurality of blades **116**, which may extend radially through at least a part of the passageway **114**. For example, the plurality of blades **116** may be coupled to and extend between the outer and inner walls **110**, **112**. Any number of blades **116** may be employed, and each may be spaced circumferentially apart from the others around the drum **102**. Furthermore, the blades **116** may be coupled to the outer and inner walls **110**, **112** using fasteners, welding, brazing, dovetail fitting, or the like, may be cast, cut, or otherwise formed integrally with the drum **102**, and/or may be coupled to the outer and/or inner walls **110**, **112**, by any other suitable process. Additionally, the blades **116** may have a lean angle α with respect to a radial line **111**. The blades **116** may lean clockwise or counterclockwise depending on the direction the drum **102** is configured to rotate. In various exemplary embodiments, the lean angle α may range from about 8 degrees, about 11 degrees, or about 14 degrees to about 17 degrees, about 20 degrees, or about 22 degrees. In at least one exemplary embodiment, the lean angle α may be about 15 degrees.

FIG. **2** illustrates a side perspective view of the rotary separator **100**, according to an exemplary embodiment, showing the drum **102** with the outer surface **107** partially broken away to reveal the passageway **114** extending between the front and rear surfaces **104**, **106**. An axis **118** may be defined through the middle of the drum **102**, about which the drum **102** rotates. Further, each of the plurality of blades **116** includes a leading section **120**, which may be tapered to a thin edge, as shown, and a trailing section **122**. The leading and trailing sections **120**, **122** are connected together by a curved portion, which may include concave and convex surfaces **126**, **128**. Each blade **116** may be precision-cast, milled from a solid block, or otherwise integrally-formed, or made of multiple parts that are fixed together. Each blade **116** may be arranged so that the leading section **120** is generally positioned upstream (i.e., proximal the front surface **104** and/or the entrance **115**) in the passageway **114** relative to the trailing section **122**. In at least one exemplary embodiment, the leading section **120** of each of the blades **116** is positioned adjacent the front surface **104** of drum **102**. Moreover, the concave surface **126** may be also be referred to as the pressure surface of the blade **116** and convex surface **128** may also be referred to as the suction surface of the blade **116**.

Between adjacent blades **116** there is defined an inter-blade flowpath **130**. Each inter-blade flowpath **130** may be defined by the leading and trailing sections **120**, **122** and the convex surface **128** of one blade **116**, and the leading and trailing sections **120**, **122** and the concave surface **126** of another blade **116**. The inter-blade flow path **130** may extend axially, at least partially from the entrance **115** to the exit **117** of the passageway **114**. Furthermore, the trailing section **122** may be angled relative to the leading section **120** to define an angle β. The angle β may range from about 90 degrees, about 100 degrees, or about 110 degrees to about 130 degrees, about 140 degrees, or about 150 degrees. In at least one exemplary embodiment, the angle β may be about 120 degrees.

In an exemplary embodiment, each of the plurality of blades **116** may be substantially identical; however, in various other exemplary embodiments, the shape, structure, and/or material of the blades **116** may vary. Furthermore, the trailing section **122** of the blades **116** may extend a length that is at least about twice as long as the length leading section **120**. In various exemplary embodiments, each of the blades **116** may extend along at least about 60%, at least about 70%, or at least about 80% of a length of the drum **102** from the front surface **104** to the rear surface **106**. In an exemplary embodiment, the length of the blades **116** may be substantially the same; however, in various other exemplary embodiments, the blades **116** may vary in length.

FIG. **3** illustrates a cross-section of the rotary separator **100** of FIG. **2**, according to an exemplary embodiment. It will be appreciated that the curved blades **116** each appear where they intersect the plane illustrated by the cross-section; therefore, several of the blades **116** of the illustrated embodiment are shown, with each appearing as one or two rectangles in FIG. **3**. Moreover, FIG. **3** illustrates a frustoconical embodiment of the drum **102**, with accordingly frustoconical outer and inner walls **110**, **112** and outer surface **107**. As shown, the axis **118** may be defined through the central bore **109**, such that the drum **102** can be rotated thereabout.

As also noted above with reference to FIG. **1**, the outer and inner walls **110**, **112** may be radially offset from each other, defining the passageway **114** therebetween, with the blades **116** extending at least partially through the passageway **114**. In various exemplary embodiments, the outer and inner walls **110**, **112** may be substantially parallel, as shown, or may be converging. Furthermore, the outer and inner walls **110**, **112** may increase in diameter from the front surface **104** to the rear surface **106** at an angle of from about 3 degrees to about 6 degrees proceeding from the front surface **104** to the rear surface **106**.

FIG. **4** illustrates a partial cross-sectional view of a rotary separator system **150**, according to an exemplary embodiment, which incorporates the drum **102** of the rotary separator **100** (FIGS. **1-3**). The rotary separator system **150** may include a housing **200**, which may be substantially symmetric about the axis **118**, and which includes an inlet **204**, an outlet **205**, and a collection chamber **206**. The drum **102** is positioned in the housing **200** such that the entrance **115** of passageway **114** is located proximal, for example, adjacent and aligned with, the inlet **204**, while the exit **117** is located proximal, for example, adjacent and aligned with, the outlet **205** of the housing **200**. In an exemplary embodiment, fluid flowing along the outer wall **110** is directed into the collection housing **206**, while fluid flowing proximal the inner wall **112** flows into the outlet **205**. In various exemplary embodiments, the outlet **205** can be, include, or be fluidly coupled to, an impeller of a centrifugal compressor. In other exemplary embodiments, the outlet **205** can be, include, or be coupled to any other device.

With additional reference to FIG. **3**, in exemplary operation, a mixed process fluid may be introduced to the rotary separator system **150** via the inlet **204**. In the inlet **204**, the mixed process fluid may include a higher-density component and a lower-density component. In an exemplary embodiment, the lower-density component may be gas and the higher-density component may be liquid; however, it will be appreciated that the higher-density component may be or include relatively dense liquids, gases, solids, or any combination thereof, while the lower-density component may be or include relatively less-dense liquids, gases, solids, or any combination thereof. For example, the rotary separator **150** may be operable to separate denser gases from less-dense gases, solids from liquids, denser liquids from less-dense liquids, or any combination thereof.

The mixed process fluid may then proceed to the entrance **115** of the passageway **114** of the drum **102**. The drum **102** may be rotated about its axis **118** via a shaft (not shown) received into the central bore **109**, with the shaft being powered by an external mechanism (not shown) such as a turbine, motor, or the like. In other exemplary embodiments, the drum **102** may be instead or additionally be rotated by the energy in the mixed process fluid flow as it engages the blades **116**. Subsequently, the mixed process fluid may continue into the passageway **114** and flow toward the exit **117**. During flow through passageway **114**, separation of the various components of the process fluid is enhanced utilizing the blades **116**, as will be described in further detail below.

FIG. **5** illustrates a pair of blades **116***a,b* with the inter-blade flow passage **130** defined therebetween, according to an exemplary embodiment. As the process fluid flows along passageway **114** (FIGS. **1-4**), the flowpath of the process fluid therein may be constrained by the blades **116***a,b*, thereby forcing the process fluid to flow through the inter-blade flow passage **130** and across blades **116***a,b*. Thus, in the inter-blade flow passage **130**, higher-density components of the process fluid will be driven to the concave side **126** of the blade **116***a*, as shown by arrow **210**, while lower-density components of the process fluid will flow adjacent the convex side **128** of the second blade **116***b*. The higher-density may thus coalesce on the concave side **126** of the blade **116***a*.

With continuing reference to FIG. **5**, FIG. **6** illustrates the process fluid traveling through the passageway **114** from the entrance **115** toward the exit **117**, as shown by the arrow **208**. As described above, at least some of the higher-density component of the process fluid coalesces on the concave surface **126**. Due to the continued rotation of the drum **102**, the coalesced higher-density component is centrifuged outward, as shown by arrow **212**. Additional amounts of the higher-density component may also be centrifuged directly out of the process fluid stream via the rotation of the drum **102**, without necessitating engagement with the blades **116**.

The separated higher-density component is thus directed to the outer wall **110** for collection.

The blades **116** may be dimensioned or otherwise angled such that substantially all of the higher-density component coalesced thereon engages the outer wall **110** before reaching the exit **117**. Thus, when the process fluid arrives at a point adjacent the rear surface **106** of the drum **102**, substantially all of the higher-density component in the process fluid may engage the outer wall **110** and substantially all of the lower-density component may remain in passageway **114** between the outer wall **110** and the inner wall **112**. However, in various exemplary embodiments, the lower-density component may engage the inner wall **112** as well. The lower-density component of the process fluid may move through the exit **117** defined by the rotary separator **100** to the outlet **205**, while the higher-density component of the process fluid may be directed into the collection chamber **206** (FIG. **4**), and ultimately to a drain (not shown) connected to the housing **200** (FIG. **4**).

FIG. **7** illustrates another rotary separator **400**, according to an exemplary embodiment, shown with a portion of the outer surface **107** broken away to reveal the passageway **114**. The rotary separator **400** may be substantially similar to the rotary separator **100**, shown in and described above with reference to FIGS. **1-6**, and may be best understood with reference thereto. However, the rotary separator **400** includes a plurality of blades **402** arranged in a plurality of blade rows **403***a*, **403***b*, **403***c* and **403***d* in the drum **102**. In an exemplary embodiment, a trailing section **412** of each blade **402** of rows **403***a-c* is proximal a leading section **410** of a blade **402** in a subsequent row **403***b-d*, as shown. Moreover, each blade **402** may include a concave surface **401** and a convex surface **405**. Further, each blade **402** may be positioned in the passageway **114** between the front surface **104** and the rear surface **106**. Additionally, each of the blades **402** may be spaced-apart from each other so as to form inter-blade flow passages **407** between adjacent blades **402**. In an exemplary embodiment, each row of blades **403***a-d* extends around the circumference of the passageway **114**; however, in various other exemplary embodiments, one or more of the rows of blades **403***a-d* may stop at a point, and/or the rows **403***a-d* may be staggered around the drum **402**. Other orientations will be readily apparent in accordance with this disclosure. Furthermore, adjacent rows **403***a-d* may face in opposing circumferential directions, as shown. For example, the concave surface **405** of the blades **402** in the first row **403***a* faces “down,” as shown from the side, corresponding to a clockwise circumferential direction, while the concave surface **405** of the blades **402** in the second row **403***b* faces “up,” as shown from the side, corresponding to a counterclockwise circumferential direction.

FIG. **8** illustrates a portion of each of the blade rows **403***a-d*, according to an exemplary embodiment, with the rows **403***a-d* arranged in alternating sequence and the inter-blade flow path **407** defined therebetween. The rows **403***a-d* are arranged such that a fluid flowing along a convex surface **405** of a blade **402** in one row **403***a-d* will be directed to the concave surface **401** of a blade **402** in an adjacent row **403***a-d*, as shown by arrow **404**. Likewise, a fluid flowing along a concave surface **405** of a blade **402** in one row **403***a-d* will be turned to the convex surface **401** of a blade **402** in an adjacent row **403***a-d*. Accordingly, a fluid flowing through the inter-blade flowpath **130** is turned toward a first circumferential direction while traversing the first row of blades **403***a*, and is turned toward an opposing second circumferential direction while traversing the second row of

blades **403***b*. This alternating turning provides a blade-to-blade acceleration and thus a resulting blade-to-blade centrifugal force. The blade-to-blade centrifugal force drives the higher-density components of the process fluid in the direction illustrated by arrows **406** against the high-pressure surface, i.e., the concave surface **401** of the blades **402**.

In one or more embodiments, each row **403***a-d* may turn the flowpath **404** about 60 degrees (e.g., +/− about 30 degrees relative to axis **118** shown in FIGS. **2-4**). By alternating the flowpath direction, separation of components within a process fluid may be further enhanced with respect to a single blade row embodiment, by forcing the higher-density components to the concave surface **401** bounding the inter-blade flow path **407**. In at least one exemplary embodiment, adjacent blade rows **403***a-d* may be staggered circumferentially around the drum **102** (FIG. **7**) in order to maximize the amount of process fluid that travels to the concave surface **401** with each turning of the process fluid.

FIG. **9**, with additional reference to FIGS. **1-8**, illustrates a method **500** for separating a higher-density component (e.g., liquid) from a lower-density component (e.g., gas) in a mixed process fluid, according to an exemplary embodiment. Such method **500** may be employed upstream from additional fluid processing equipment such as compressors, turbines, or the like. The method **500** may begin at **502**, where a rotary separator drum **102** is provided for receiving the mixed process fluid. The method **500** may then proceed to **504**, where the mixed process fluid is moved through a passageway **114** defined in the drum **102**. As described above with reference to FIG. **4**, for example, the mixed process fluid may be introduced into the drum **102** so as to move generally axially through the passageway **114**. At least a portion of the mixed process fluid may continue flowing axially along the length of passageway **114** and pass through exit **117**.

The method **500** may proceed to **506**, where, as the mixed process fluid moves through the passageway **114**, for example, the drum **102** is rotated to induce radial centrifugal separation of the mixed process fluid into at least a higher-density component and a lower-density component. The higher-density component has a greater density than the lower-density component, thus the inertial forces on the higher-density will be greater than those on the lower-density component, resulting in separation of the higher-density component from the lower-density component.

The method may then proceed to **508**, in which the mixed process fluid flowing along passageway **114** encounters blades **116** (FIGS. **1-5**) and/or **402** (FIGS. **7** and **8**) disposed therein. The process fluid may then be forced to flow in the inter-blade flow path **130** and/or **407** defined between adjacent blades **116***a,b* (FIG. **5**) or **402** so as to induce a centrifugal separation of the higher-density and lower-density components of the mixed process fluid. The higher-density component may be guided to the concave surfaces **126** of the blades **116**, where the higher-density component coalesces into a film thereon. The continued application of centrifugal forces by rotation of the drum **102** on the coalesced higher-density component causes it to flow outward along the blade **116** to the outer wall **110**.

The higher-density component, coalesced and flowing along the concave surfaces **126** of the blades **116**, may then be directed to the outer wall **110** of the drum **102** and into a collection chamber **206**. The collection chamber **206** may be disposed adjacent to the drum **102**, specifically the outer wall **110**, and positioned radially outside thereof; further, the collection chamber **206** may be configured to receive the separated higher-density component of the mixed process fluid. Meanwhile, the lower-density component may continue past collection chamber **206** (FIG. **4**) in a generally axial flow direction to the outlet **205**, as at **510**.

While the process fluid has been described as including at least one liquid and at least one gas, and the rotary separator drum has been described as being operable to separate the at least one liquid from the at least one gas, one of skill in the art will recognize that the process fluid may include two fluid components having different densities and that the rotary separator drum may be used to separate those two fluid components without departing from the scope of the present disclosure.

Example

The foregoing discussion can be further described with reference to the following non-limiting example.

FIGS. **10** and **11** illustrate experimental result data from an experimental embodiment of the rotary separator system **150** described above. The test conditions were as follows: rotational speed of the rotary separator was set at about 10,000 rpm, the pressure at about 150 psia, and the temperature at about 100° F. The process fluid consisted of a combination of nitrogen gas and EXXSOL® D60 liquid.

FIG. **10** illustrates a performance comparison between a conventional rotary separator and an embodiment of the rotary separator system **150**. Specifically, FIG. **10** shows a graph of relative separation efficiency as a function of a separation parameter. Separation efficiency is generally defined as the ratio of the amount of liquid separated by the rotary separator to the total amount of liquid entering the rotary separator. The graph shows the relative separation efficiency, illustrating the separation efficiency of the tracked results in comparison to a traditional separator system. The separator parameter is generally defined to be the measure of how difficult the separation environment is, that is, how difficult it is to separate the lower-density components from the higher-density components, e.g., the gas from the liquid in the process fluid. The higher the separation parameter, the more difficult it becomes to separate the process fluid. Further, the separation parameter is generally a function of pressure, temperature, and fluid composition, as well as the rotation speed and characteristic diameter of the rotary separator.

Line **602** tracks the relative separation efficiency of the conventional separator, while line **606** tracks the relative separation efficiency of the rotary separator system **150**. As the separation parameter increases, lines **602** and **606** diverge. Thus, the conventional rotary separator drops in efficiency relative to the traditional separator as separation conditions become more difficult. In contrast, the rotary separator system **150** maintains increased separation efficiency, even at the higher separation parameter, indicating that the rotary separator system **150** described above substantially outperforms the conventional separator system, even in difficult separation environments.

FIG. **11** illustrates a performance comparison between a compression system using a conventional separator and one using an embodiment of the rotary separator system **150**. Specifically, FIG. **11** illustrates relative compressor efficiency as a function of the ratio of the volumetric flow rate of process fluid to the rotation speed of the rotary separator (Q/N). Compressor efficiency is generally defined to mean the amount of work that is transferred to the process fluid by compressor versus the amount of energy consumed by the compression system. Further, the compressor efficiency is shown as relative compressor efficiency, illustrating the advantage of the tracked system over traditional compressor/separator systems. Line **610** tracks the compressor using the conventional rotary separator, while line **608** tracks the compressor using the rotary separator system **150**. As will be appreciated, for both lines **608** and **610**, as Q/N is increased, relative compressor efficiency decreases. However, at all points, line **608** is above line **610**, illustrating that the rotary separator system **150** enables a higher efficiency for the compressor regardless of the Q/N ratio. Further, as the Q/N increases, the relative efficiency of both systems may increase to a maximum value, before falling off. As can be appreciated from the graph, line **610** shows the relative efficiency of the compression system employing the conventional rotary separator dropping more quickly than the relative efficiency of the compression system employing the rotary separator system **150**, as shown by line **608**. Thus, the rotary separator system **150** outperforms the conventional separator, with differences being increased as the Q/N ratio increases.

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.

What is claimed is:

1. A rotary separator, comprising:

a rotatable drum comprising an inner wall and an outer wall radially offset from the inner wall, the inner wall and the outer wall defining an inlet at a front surface of the rotatable drum, an outlet at a rear surface of the rotatable drum, and a fluid passageway extending from the inlet to the outlet, wherein the rotatable drum is configured to separate a higher-density component of a fluid from a lower-density component of the fluid;

at least one row of blades circumferentially disposed in the fluid passageway, each blade of the at least one row of blades extending from the inner wall to the outer wall such that circumferentially adjacent blades of the at least one row of blades define respective blade flowpaths therebetween; and

a housing disposed adjacent the rotatable drum and defining a collection chamber in fluid communication with the fluid passageway via the outlet of the rotatable drum, wherein substantially all of the higher-density component of the fluid is directed into the collection chamber, and substantially all of the lower-density component of the fluid is directed through the outlet of the rotatable drum.

2. The rotary separator of claim **1**, wherein the inner wall and the outer wall define a radial length of the fluid passageway, and the radial length is substantially constant between the inlet and the outlet of the rotatable drum.

3. The rotary separator of claim **1**, wherein a radial length of the fluid passageway at the inlet of the rotatable drum is greater than a radial length of the fluid passageway at the outlet of the rotatable drum.

4. The rotary separator of claim **1**, wherein the fluid passageway is cylindrical.

5. The rotary separator of claim **4**, wherein the rotatable drum is cylindrical.

6. The rotary separator of claim 1, wherein the fluid passageway is frustoconical.

7. The rotary separator of claim 6, wherein the rotatable drum is frustoconical.

8. The rotary separator of claim 1, wherein each blade of the at least one row of blades comprises a concave surface and a convex surface extending between a leading section and a trailing section thereof.

9. The rotary separator of claim 8, wherein each blade of the at least one row of blades leans at an angle of from about 8 degrees to about 22 degrees relative to a radius of the rotatable drum.

10. The rotary separator of claim 9, wherein the trailing section of each blade of the at least one row of blades extends a length that is at least about twice as long as a length of the leading section.

11. The rotary separator of claim 9, wherein the trailing section of each blade of the at least one row of blades is oriented at an angle of from about 90 degrees to about 150 degrees with respect to the leading section.

12. A separator for separating a process fluid including a higher-density component and a lower-density component, comprising:

a rotatable drum comprising an inner wall and an outer wall radially offset from the inner wall, the inner wall and the outer wall defining an inlet at a front surface of the rotatable drum, an outlet at a rear surface of the rotatable drum, and a fluid passageway extending from the inlet to the outlet, wherein the inner wall and the outer wall define a radial length of the fluid passageway, and the radial length is substantially constant between the inlet and the outlet of the rotatable drum;

a plurality of blades disposed in the fluid passageway and at least partially extending between the inner wall and the outer wall of the rotatable drum; and

a housing disposed adjacent the rotatable drum and defining a collection chamber, a housing inlet, and a housing outlet,

wherein the collection chamber and the housing outlet are in fluid communication with the fluid passageway via the outlet of the rotatable drum, and

wherein substantially all of the higher-density component of the process fluid is directed into the collection chamber, and substantially all of the lower-density component of the process fluid is directed through the outlet of the rotatable drum.

13. The separator of claim 12, wherein the fluid passageway is in fluid communication with the housing inlet via the inlet of the rotatable drum.

14. The separator of claim 12, wherein each blade of the plurality of blades comprises a concave surface and a convex surface extending between a leading section and a trailing section thereof.

15. The separator of claim 14, wherein the plurality of blades comprises a first row of blades disposed in the fluid passageway and a second row of blades disposed axially adjacent the first row of blades.

16. A rotary separator, comprising:

a rotatable drum having an inner wall and an outer wall radially offset from the inner wall, the inner wall and the outer wall defining an annular passageway extending from an inlet at a front surface of the rotatable drum to an outlet at a rear surface of the rotatable drum, the rotatable drum being configured to separate a higher-density component of a fluid from a lower-density component of the fluid;

a plurality of blades disposed in the annular passageway and extending from the inner wall to the outer wall such that adjacent blades of the plurality of blades define respective blade flowpaths therebetween, each blade of the plurality of blades being substantially identical to the other blades of the plurality of blades; and

a housing disposed adjacent the rotatable drum and defining a collection chamber in fluid communication with the annular passageway via the outlet of the rotatable drum, wherein substantially all of the higher-density component of the fluid is directed into the collection chamber, and substantially all of the lower-density component of the fluid is directed through the outlet of the rotatable drum.

17. The rotary separator of claim 16, wherein each blade of the plurality of blades comprises a concave surface and a convex surface extending between a leading section and a trailing section thereof.

18. The rotary separator of claim 16, wherein the annular passageway is cylindrical.

19. The rotary separator of claim 18, wherein the inner wall and the outer wall of the rotatable drum are substantially parallel with one another.

20. The rotary separator of claim 18, wherein the housing further defines a housing inlet and a housing outlet, and the annular passageway is in fluid communication with the housing outlet and the collection chamber via the outlet of the rotatable drum.

* * * * *