(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 August 2006 (03.08.2006)

PCT

(10) International Publication Number
WO 2006/081342 A1

(51) **International Patent Classification:**
E21B 10/60 (2006.01)

(21) **International Application Number:**
PCT/US2006/002735

(22) **International Filing Date:** 25 January 2006 (25.01.2006)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
60/646,963 25 January 2005 (25.01.2005) US
Not furnished 19 January 2006 (19.01.2006) US

(71) **Applicant** *(for all designated States except US)*: **BAKER HUGHES INCORPORATED** [US/US]; 3900 Essex Lane, Suite 1200, Houston, Texas 77027 (US).

(72) **Inventors: WELLS, Michael, R.**; 14479 W. Center Drive, Lakewood, Colorado 80228 (US). **BEUERSHAUSEN, Chaud, J.**; 163 S. Queenscliff Circle, The Woodlands, Texas 77382 (US).

(74) **Agents: WELBORN, Brian, S.** et al.; Baker Hughes Incorporated, 3900 Essex Lane, Suite 1200, Houston, Texas 77027 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

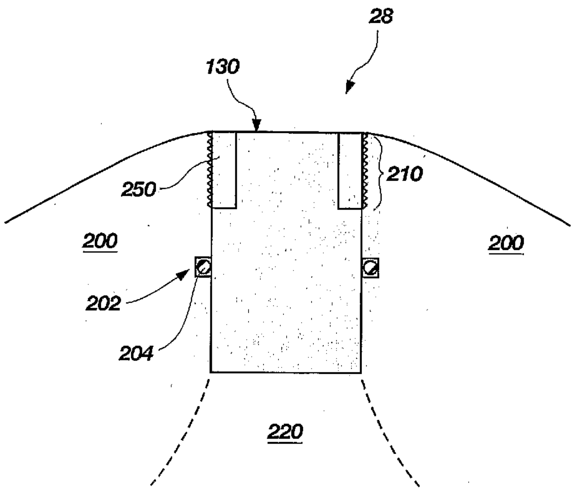
(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

[Continued on next page]

(54) Title: CONVERGING DIVERGING NOZZLE FOR EARTH-BORING DRILL BITS, METHOD OF SUBSTANTIALLY BIFURCATING A DRILLING FLUID FLOWING THERETHROUGH, AND DRILL BITS SO EQUIPPED



(57) Abstract: A nozzle (28) for substantially bifurcating a drilling fluid passing therethrough and for use upon a rotary drill bit is disclosed. Such a nozzle may include a nozzle body having at least one passage therethrough, wherein the at least one passage may comprise a converging region (120) , a diverging region (122) , a throat (124) and an exit aperture (130) , wherein at least a portion of the diverging region is substancially bifurcated. Further, a method of communication drilling fluid through a nozzle for use on a rotary drill bit is disclosed. Particularly, a drilling fluid may be introduced into a passageway of a nozzle of the present invention, caused to pass through a converging region and diverging region thereof, and substantially bifurcated within at least a portion of the diverging region. A further aspect of the present invention contemplates a rotary drill bit (10) including a nozzle of the present invention.

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CONVERGING DIVERGING NOZZLE FOR EARTH-BORING DRILL BITS, METHOD OF SUBSTANTIALLY BIFURCATING A DRILLING FLUID FLOWING THERETHROUGH, AND DRILL BITS SO EQUIPPED

TECHNICAL FIELD

The present invention relates to nozzles for use in subterranean earth-boring drill bits and drill bits so equipped and, more particularly, to nozzles exhibiting a converging diverging geometry and having a substantially bifurcated of adjustment to direct drilling fluid to different locations on and around the drilling apparatus.

BACKGROUND

Subterranean drilling operations generally employ a rotary drill bit that is rotated while being advanced through rock formations. Cutting elements or structures affixed to the rotary drill bit cut the rock while drilling fluid removes formation debris and carries it back to the surface. The drilling fluid is pumped from the surface through the drill string and out through one or more (usually a plurality of) nozzles located on the drill bit. The nozzles direct jets or streams of the drilling fluid to clean and cool cutting surfaces of the drill bit and for the aforementioned debris removal.

Because of the importance of the cooling and cleaning functions of the drilling fluid, others in the field have attempted to optimize these benefits by specifically orienting the nozzle exit to direct the drilling fluid to a predetermined location on a cutting surface of the bit. For example, U.S. Patent No. 4,776,412 to Thompson describes a nozzle assembly designed to resist rotational forces while directing drilling fluid to a predetermined rotational position. The nozzle's internal chamber is preformed to direct the fluid at a specific angle. Likewise, in U.S. Patent No. 4,794,995 to Matson, et al., a nozzle is disclosed that changes the direction of fluid flow by angling the exit of the nozzle chamber. Again, the angle of exit is predetermined and may only be rotated about its longitudinal axis. U.S. Patent No. 4,533,005 to Morris is another example of an attempt to provide a nozzle that may be reoriented to provide fluid flow in a specific direction.

Other examples of nozzles for delivering drilling fluids include: U.S. Patent No. 5,380,068 to Raghaven; U.S. Patent Nos. 5,494,124, 5,632,349, and 5,653,298 to Dove et al., and U.S. Patent No. 6,311,793 to Larsen et al. Further, U.S. Patent Application No. 2004/0155125 A1 to Kramer et al. discloses a nozzle having a somewhat oval opening. U.S. Patent Application No.2004/0069540 A1 to Kriesels discloses high pressure fluid jet nozzles having, in one embodiment, a slotted opening.

The limited ability to control drilling fluid emanating from a nozzle in a desired fashion necessarily limits the potential efficiency of the cleaning and cooling functions of the drilling fluid. Further, since conventional nozzles direct flow of drilling fluid along a single direction or path at a relatively high velocity, impingement of the drilling fluid emanating from a conventional nozzle upon a portion of the drill bit (i.e., a blade or other portion of the body thereof) may cause excessive erosion or wear to occur. Particularly, in the case where a nozzle is designed for providing a single flow stream of drilling fluid toward multiple paths (e.g., two junk slots), excessive erosion and wear may occur on the leading end of the structure(s) (e.g., blade) separating the single flow stream into the multiple paths.

Thus, it would be advantageous to provide a nozzle for use in subterranean earth-boring drill bits which provides suitable cuttings removal impetus, but which reduces undesirable erosion of the drill bit within which installed during use. It would also be advantageous to provide a nozzle design that distributes the drilling fluid emanating therefrom more evenly than conventional nozzle designs.

DISCLOSURE OF THE INVENTION

In accordance with the present invention, a nozzle for substantially bifurcating a drilling fluid passing therethrough and for use upon a rotary drill bit (inclusive of other earth-boring tools as known in the art, as defined hereinbelow) to enable selective and efficient cleaning and cooling of the rotary drill bit and its cutting structure by drilling fluid passing through the nozzle during subterranean earth-boring operations.

According to the invention, a nozzle is structured to substantially bifurcate a drilling fluid passing therethrough. The nozzle may be configured for securement into a nozzle orifice formed within a drill bit. More specifically, the nozzle comprises a nozzle body and a housing that secures the nozzle body within the nozzle orifice. The nozzle may be formed of any suitable material with adequate abrasion and erosion resistance, such as tungsten carbide, or ceramics. Alternatively, the nozzle passage may be lined with an abrasion and erosion resistant material. The nozzle may be preferably removably secured within the nozzle orifice by suitable mechanical means known in the art including threaded sleeves or retainers or permanently secured therein by brazing, adhesive bonding, or welding.

As mentioned above, the present invention contemplates a nozzle for use on a rotary drill bit for forming a subterranean borehole. For example, a nozzle according to the present invention may include a nozzle body having at least one passage therethrough for directing a flow of drilling fluid from a fluid outlet opening on a face of the drill bit. Further, the nozzle element may be configured for positive securement within the rotary drill bit. Also, the at least one passage may comprise a converging region having an entrance and extending to a throat and a diverging region extending from the throat to an exit aperture, wherein at least a portion of the diverging region is substantially bifurcated.

In another aspect of the present invention, a method of communicating drilling fluid through a nozzle for use on a rotary drill bit for forming a subterranean borehole is encompassed. Particularly, a drilling fluid may be introduced into a passageway for directing a flow of drilling fluid from a fluid outlet opening on a face of the drill bit. Also, the drilling fluid may be caused to pass through a converging region of the passageway and then through a diverging region of the passageway. Additionally, the drilling fluid may be substantially bifurcated within at least a portion of the diverging region of the passageway.

A further aspect of the present invention contemplates a rotary drill bit for forming a borehole within a subterranean drilling. More specifically, the rotary drill bit may include a bit body having a face and at least one cutting element mounted on the face of the bit body. Also, at least one nozzle may be installed within the bit body and configured for communicating drilling fluid from an interior thereof to the face of the bit body. Particularly, the at least one nozzle may comprise a passageway including a converging region having an entrance and extending to a throat and a diverging region extending from the throat to an exit aperture, wherein at least a portion of the diverging region is substantially bifurcated.

Features from any of the above-mentioned embodiments may be used in combination with one another in accordance with the present invention. In addition, other features and advantages of the present invention will become apparent to those of ordinary skill in the art through consideration of the ensuing description, the accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows a partially sectioned side view of a rotary drill bit according to the present invention;

FIG. 1B shows a side cross-sectional view of a rotary drill bit similar to that of FIG. 1A, but with an asymmetrical fluid passage;

FIG. 1C shows a roller cone type rotary drill bit including a nozzle of the present invention;

FIG. 2A shows a perspective view of a nozzle according to the present invention;

FIG. 2A-A is a simplified cross-sectional view of a nozzle of the present invention positioned within a drill bit body;

FIG. 2A-B is a simplified cross-sectional view of a nozzle of the present invention positioned within a drill bit body;

FIG. 2B shows a perspective view of the passageway of the nozzle shown in FIG. 2A;

FIG. 2C shows a front view of the passageway shown in FIG. 2B, as if the viewer were looking into the exit aperture thereof;

FIGS. 3A-3D show schematic front views of different embodiments of an exit aperture of a passageway as shown in FIGS. 2B and 2C;

FIG. 4A-1 shows a side view of the passageway shown in FIG. 2B, wherein separation features extend within a portion of the diverging region thereof;

FIG. 4A-2 shows a side view of the passageway shown in FIG. 2B, wherein separation features extend within the diverging region and at least a portion of the converging region thereof;

FIGS. 4B-4D show side views of different embodiments of a passageway as shown in FIGS. 2B and 2C;

FIGS. 5A and 5B are partial conceptual views showing different geometries of a portion of a converging region and an exit aperture of a passageway according to the present invention;

FIG. 6A shows a side view of a passageway of the present invention, showing a spread angle between anticipated, bifurcated flow streams; and

FIG. 6B shows a top elevation view of a rotary drill bit including nozzles of the present invention.

BEST MODE(S) FOR CARRYING OUT THE INVENTION

Referring to FIG. 1A, an exemplary drag-type rotary drill bit 10 is shown in a partial side and partial side cross-sectional view although the present invention possesses equal utility and applicability in the context of a tricone or roller cone rotary drill bit 31 (see FIG. 1C) or other subterranean drilling tools as known in the art which employ nozzles for delivering fluids to a cutting structure during use. Accordingly, as used herein, the term "rotary drill bit" includes and encompasses core bits, roller-cone bits, fixed-cutter bits, impregnated bits, eccentric bits, bicenter bits, reamers, reamer wings, or other earth-boring tools utilizing at least one nozzle for delivery of a drilling fluid as known in the art.

As shown in FIG. 1A, rotary drill bit 10 may generally comprise a bit body 23 including a plurality of longitudinally extending blades 14 defining junk slots 16 therebetween. Each of blades 14 may define a leading or cutting face 19 that extends radially along the bit face around the distal end 15 of the rotary drill bit 10, and may include a plurality of cutting elements 18 affixed thereto for cutting a subterranean formation upon rotation of the rotary drill bit 10. Furthermore, each of blades 14 may include a longitudinally extending gage portion 22 that corresponds to an outermost radial surface of each of blades 14, sized according to approximately the largest-diameter-portion of the rotary drill bit 10 and thus may be typically only slightly smaller, if at all, than the diameter of the borehole intended to be drilled by rotary drag bit 10.

The upper longitudinal end 17 of the rotary drill bit 10, as shown in FIG. 1A, includes a threaded pin 25 including threads 27 for threadedly attaching the rotary drill bit 10 to a drill collar or downhole motor, as is known in the art. In addition, the plenum 26 or bore longitudinally extends within rotary drag bit 10 for communicating drilling fluid therewithin through nozzles 28 disposed on the face of the rotary drag bit 10. Nozzles 28 may comprise nozzles according to the present invention, as discussed in further detail hereinbelow. Threaded pin 25 may be machined directly into the upper longitudinal end 17 of the bit body 23 (i.e., typically a so-called "shank," as known in the art) as may bit breaker surface 21 for loosening and tightening the tapered threaded portion 25 of the rotary drill bit 10 when installed into the drill string.

A plurality of cutting elements 18 is secured to the blades 14 of the rotary drill bit 10 for cutting a subterranean formation as the rotary drill bit 10 is rotated into a subterranean formation. Although FIG. 1A shows two nozzles 28, it should be understood that, more generally, at least one nozzle 28 according to the present invention may be mounted within a drill bit 10 for directing drilling fluid toward at least one desired location at the bottom of the subterranean borehole being cut. For instance, the at least one nozzle 28 may be threadedly secured at an outer surface thereof within a nozzle recess 30 formed in the bit body 23 (having complementarily formed cast or machined threads) and may include fluid passageway (not shown) through which the drilling fluid is discharged, as described in further detail hereinbelow. Additionally, an annular channel (not shown) in a periphery of nozzle 28 may be adapted to receive or position a sealing element such as, for example, an O-ring between the nozzle recess 30 and the nozzle 28 for sealing therebetween. Thus, during use, a drilling fluid may be communicated through nozzles 28 through plenum 26 in the rotary drill bit 10.

For further clarity, FIG. 1B shows a side cross-sectional view of a rotary drill bit 10 about its longitudinal axis 33. More particularly, FIG. 1B illustrates one embodiment of a nozzle recess 30 within rotary drill bit body 23. A nozzle 28 may be preferably removably secured within the nozzle recess 30 by a suitable mechanical affixation mechanism (e.g., threads, pins, retaining rings, etc.) as known in the art. For example, threaded surfaces, sleeves, or retainers may be utilized for affixing nozzle 28 within nozzle recess 30. Alternatively, permanent securement of nozzle 28 within nozzle recess 30 may be effected by way of at least one of brazing, adhesive bonding, or welding.

Generally, drilling fluid is intended for cleaning and cooling the cutting elements 18 and carries formation cuttings to the top of the borehole via the annular space between the drill string and the borehole wall. It will be understood by those of ordinary skill in the art that a bladed-type rotary drill bit 10 may be configured to incorporate the at least one nozzle 28 within one or more blades 14 extending from the bit body 23.

Further, as mentioned above, it should be noted that the present invention exhibits equal utility with all configurations of rotary drilling bits, reamers, or other subterranean drilling tools, without limitation, having blades or otherwise configured, while demonstrating particular utility with rotary drill bits wherein controlled fluid flow is beneficial to the hydraulic performance thereof.

Generally, the present invention contemplates that a nozzle passageway of a nozzle may be configured for substantially bifurcating a flow of drilling fluid passing therethrough. As used herein "substantially bifurcating" a drilling fluid flow means that two substantially distinct drilling fluid flows are formed from an incoming drilling fluid flow, wherein each of the two substantially distinct drilling fluid flows include at least about 25% of the incoming drilling fluid flow. Such a configuration may more evenly distribute (spatially) drilling fluid passing through a nozzle according to the present invention in comparison to a conventional nozzle. As another advantage, substantially bifurcating a flow of drilling fluid through a nozzle may also reduce erosion of a portion of a bit body or a portion of a bit blade along the nozzle axis (i.e., in the direction of exiting fluid flow) which may otherwise occur in response to drilling fluid impingement from a conventionally configured nozzle.

A nozzle of the present invention will now be described. Particularly, FIG. 2A shows a perspective view of a nozzle 28 according to the present invention. As shown in FIG. 2A, a nozzle 28 of the present invention may comprise a nozzle body 110 having at least a portion thereof configured for securing the nozzle body 110 within a nozzle recess (e.g., nozzle recesses 30 as shown in FIGS. 1A and 1B) of a rotary drill bit. In general, nozzle 28 includes a passageway 114 defined by an interior of nozzle body 110 that extends between an inlet 126 and an exit aperture 130. Thus, as may be appreciated, in a drilling fluid environment, a pressure differential (i.e., higher to lower) between a fluid proximate inlet 126 and a fluid proximate exit aperture 130 may cause fluid to flow through passageway 114 from inlet 126 toward exit aperture 130.

More particularly, nozzle 28 is defined by a nozzle body 110, an interior of which defines passageway 114 extending between an inlet 126 and an exit aperture 130. Passageway 114 may be generally configured for communicating a drilling fluid that passes into inlet 126 through passageway 114 and exits nozzle body 110 at exit aperture 130. Further, nozzle body 110 may be configured for resisting erosion due to drilling fluid passing through passageway 114. For example, nozzle body 110 may comprise a ceramic, a cermet, or another relatively hard, erosion resistant material as known in the art. In one embodiment, nozzle body 110 may comprise a cobalt-cemented tungsten carbide. Such a configuration may be resistant to the abrasive and erosive effects of drilling fluid during a drilling operation. In another embodiment, nozzle body 110 may be formed of, for example, steel which is lined with an abrasion and erosion-resistant material such as tungsten carbide, diamond, ceramics, hardfacing, or polyurethanes.

Furthermore, nozzle body 110 may be configured for securement within a rotary drill bit. For instance, nozzle body 110 may include a threaded surface for engaging a complimentarily shaped threaded surface that is formed within a drill bit (not shown). Further, nozzle body 110 may include an annular channel (not shown) in a periphery thereof that is adapted for receiving a sealing element such as, for example, an O-ring for sealing between a nozzle recess (e.g., nozzle recess 30 as shown in FIGS. 1A and 1B) formed in a rotary drill bit and the nozzle body 110. In further detail, FIGS. 2A-A and FIG. 2A-B, show two embodiments for attaching nozzle body 110 to a drill bit body 112. Particularly, FIG. 2A-A shows a simplified cross-sectional view of a nozzle 28 installed within a bit body 200, wherein a retaining ring 250 is attached to the bit body 200 along an attachment region 210. Retaining ring 250 may be attached to the bit body 200 by way of a threaded surface, a braze, welding, pins, or as otherwise known in the art. Similarly, FIG. 2A-B shows a simplified cross-sectional view of a nozzle 28 installed within a bit body 200, wherein the nozzle 28 is one-piece and includes an attachment region 220 for attachment to the bit body 200. As shown in FIGS. 2A-A and 2A-B, a cavity 202 may be formed in the bit body 200 for accepting a sealing element (e.g., an O-ring) for sealing between the bit body 200 and the nozzle 28. Also, a conduit 220 formed in the bit body may be configured for conducting drilling fluid to the nozzle 28.

It may be further appreciated, that the orientation of a nozzle according to the present invention may be important since a substantially bifurcated flow therefrom may be directed according to the orientation of the nozzle. Therefore, the present invention contemplates that the nozzle may be configured for attachment to a drill bit at a selected orientation. In an embodiment wherein the nozzle includes a threaded surface for attachment to a drill bit body, accuracies of at least about $\pm 2°$ (e.g., orientation of an axis such as horizontal axis 103 as shown in FIG. 5A, with respect to a desired or selected orientation) may be achieved. Further, at least one mark or indicium formed on the nozzle may indicate an orientation of the nozzle. For instance, at least one mark or indicium may indicate an axis about which a flow through the nozzle is bifurcated. Such a configuration may allow for selective orientation of a flow through a nozzle of the present invention, which may be desirable when a nozzle of the present invention is installed within a drill bit, as discussed in further detail hereinbelow.

In further detail, fluid passage 114 formed within the nozzle body 110, as shown in FIG. 2B, may be generally described as including a diverging-converging geometry wherein at least a portion of the diverging geometry is configured for substantially bifurcating or dividing drilling fluid passing therethrough. FIG. 2B shows a perspective view of passageway 114 including inlet region 118, converging region 120 extending to throat 124, and diverging region 122 extending from throat 124 to exit aperture 130. As known in the art, converging-diverging nozzle geometries may also be known as "venturi" nozzle geometries. As shown in FIG. 2B, inlet 126 may have a substantially constant or unchanging shape within inlet region 118. For example, inlet 126 as well as inlet region 118 may be substantially circular, substantially elliptical, substantially rectangular, substantially triangular, or cross-sectionally shaped as otherwise desired or known in the art.

Within converging region 120, the area of passageway 114 may generally decrease in the direction of flow therethrough to throat 124. Optionally, the shape of inlet region 118, at entrance 119 of converging region 120, may be substantially retained in a direction toward throat 124, if desired. Throat 124 is a portion of passageway 114 substantially transverse to the flow of fluid therethrough defining a minimum area thereof. In one embodiment, throat 124 may comprise an oblong shape derived from two 11/32 diameter circles that at least partially overlap with one another. More generally, throat 124 may comprise an oblong shape derived from two circles having a diameter between about 0.635 cm and 1.270 cm that may at least partially overlap with one another. In addition, throat 124 may contain circles having a diameter between about 0.635 cm and 1.270 cm that may be separated by an arbitrary finite distance. Of course, the size and shape of the throat 124 may exhibit various shapes (oval, elliptical, rectangular, triangular, etc.) and sizes as desired. In turn, the configuration of a nozzle body 110 may be adjusted in relation to the throat structure and the size and shape of a cavity within a drill bit for positioning a nozzle of the present invention therein may correspondingly be adjusted in relation to the nozzle body 110.

Further, as shown in FIG. 2B, diverging region 122 may extend from throat 124 toward exit aperture and may include at least one flow separation feature 140 extending generally from throat 124 to exit aperture 130. Flow separation feature 140 may be configured for at least partially separating a flow of drilling fluid through passageway 114 into two distinct flows. In addition, it should be noted that while the embodiments shown herein generally include two flow separation features 140, the present invention contemplates that at least one flow separation feature 140 may be configured for at least partially separating a flow of drilling fluid through passageway 114 into two distinct flows, without limitation. Thus, as shown in FIG. 2B, diverging region 122 may comprise enlarged conduits 132A and 132B communicative with one another by a narrow conduit 133. Such a configuration may substantially bifurcate or divide a flow of drilling fluid passing through diverging region 122 of passageway 114.

That is, drilling fluid flowing through passageway 114 may pass through inlet region 118, into converging region 120 (which may accelerate such drilling fluid), further into throat 124, and through diverging region 122 wherein two substantially distinct flows or streams may be developed within enlarged conduits 132A, 132B. Of course, drilling fluid may flow within narrow conduit 133 and may be communicated between enlarged conduits 132A, 132B therethrough.

As may be appreciated, many variations of the geometry shown in FIG. 2B are encompassed by the present invention. For instance, FIG. 2C shows a front view of passageway 114 as if the viewer were looking into exit aperture 130. As shown in FIG. 2C exit aperture 130 may include two generally rounded areas defined by enlarged conduits 132A and 132B, respectively, and the centers of which are separated by a distance X. In one embodiment, exit aperture 130 may include substantially circular portions thereof that each exhibits a diameter D. Alternatively, portions of exit aperture 130 may be substantially elliptical, substantially oval, substantially oblong, generally arcuate, straight, or as otherwise may be desired, without limitation. Diameter D may be selected as desired, without limitation. For example, diameter D may be between about 0.318 cm and about 2.540 cm, without limitation.

Also, as shown in FIG. 2C, exit aperture 120 includes two flow separation features 140 wherein flow separation features 140 comprise smooth radiuses or fillets extending between each of enlarged conduits 132A and 132B and having a radius R. Furthermore, each of enlarged conduits 132A and 132B may be connected to one another by narrow conduit 133 defined between flow separation features 140, separated by distance T. Distance T may be selected as desired, without limitation. For example, distance T may be between about 0.000 cm and about 1.270 cm, without limitation. Alternatively, flow separation features 140 may actually, at some position within passageway 114, completely separate enlarged conduit 132A from enlarged conduit 132B.

As may be appreciated, with reference to FIG. 2B, the geometry of exit aperture 130 may be generally exhibited or maintained within diverging region 122. Of course, within diverging region 122 the geometry of exit aperture 130 may smoothly transition from a smaller substantially identical geometry proximate to or generally at throat 124 in relation to a selected diverging shape function. Accordingly, diameter D and distance X may substantially continuously decrease in a direction from exit aperture 130 toward throat 124.

Conversely, distance T may substantially continuously decrease (i.e., pinching between a drilling fluid flow between enlarged conduits 132A and 132B) in a direction from throat 124 toward exit aperture 130 or, alternatively, may exhibit an intermediate transitional or constant geometry therebetween. Such a configuration may advantageously inhibit or reduce a level of particle erosion due to drilling fluid passing through narrow conduit 133, since particle erosion may depend, at least in part, upon relatively high velocity fluid flow and impingement thereof upon a surface.

Summarizing, the geometry of exit aperture 130, notwithstanding flow separation features 140, may be substantially congruent to a geometry exhibited generally at or proximate to throat 124, wherein the diverging region 122 comprises a substantially continuous transition therebetween. Thus, it may be appreciated that enlarged conduits 132A and 132B may be related to the geometry exhibited by exit aperture 130.

Accordingly, the present invention contemplates a wide variety of geometries for exit aperture 130 (FIGS. 2B and 2C). For example, FIGS. 3A-3D illustrate exemplary embodiments of exit apertures 130A-130D. Particularly, FIG. 3A shows exit aperture 130A including rounded areas defined by enlarged conduits 132A and 132B in exhibiting a diameter D1 wherein each of the centers of the enlarged conduits 132A and 132B are separated by a distance X1. Furthermore, flow separation features 140 may form generally rounded fillets extending between enhanced conduits 132A and 132B that further define narrow conduit 133 having a thickness T1. As shown in FIG. 3A, enlarged conduits 132A and 132B as well as narrow conduit 133 may each be substantially symmetrical about vertical axis 101 and horizontal axis 103. Alternatively, at least one of enlarged conduit 132A, enlarged conduit 132B, and narrow conduit 133 may be unsymmetrical about at least one of vertical axis 101 and horizontal axis 103.

FIG. 3B shows exit aperture 130B including rounded areas defined by enlarged conduits 132A and 132B in exhibiting a diameter D2 wherein each of the centers of the enlarged conduits 132A and 132B are separated by a distance X2. Also, as shown in FIG. 3B, narrow conduit 133 may be asymmetrical about horizontal axis 103. In addition, narrow conduit 133 may exhibit a thickness T2 which provides a relatively ample (compared to thickness T, as shown in FIG. 3A) communication between enhanced conduits 132A and 132B. Selecting characteristics of the flow separation features 140 may provide the ability to adjust or tailor at least one of the respective fluid jets which flow from exit aperture 130B during use of the nozzle associated therewith. It may be further noted that exit aperture 130B, as shown in FIG. 3B, is substantially symmetric about vertical axis 101.

In another embodiment, FIG. 3C shows exit aperture 130C including rounded areas defined by enlarged conduits 132A and 132B in exhibiting diameters D3A and D3B, respectively, wherein each of the centers of the enlarged conduits 132A and 132B are separated by a distance X3. Also, as shown in FIG. 3C, narrow conduit 133 may be positioned asymmetrically with respect to vertical axis 101 (i.e., not centered between the centers of enlarged conduits 132A and 132B). Accordingly, FIG. 3C shows exit aperture 130C including enlarged conduits 132A and 132B, wherein enlarged conduits 132A and 132B are unsymmetrical with respect to vertical axis 101. Such a configuration may allow for a greater flow rate of drilling fluid through enlarged conduit 132B in relation to a flow rate of drilling fluid through enlarged conduit 132A. Of course, it may be appreciated that selecting characteristics of the enlarged conduits 132A and 132B may provide the ability to adjust or tailor at least one of the respective fluid jets which flow from exit aperture 130C during use of the nozzle associated therewith.

In yet another embodiment of exit aperture 130, FIG. 3D shows exit aperture 130D including rounded areas defined by enlarged conduits 132A and 132B each exhibiting a diameter D4 wherein each of the centers of the enlarged conduits 132A and 132B are separated by a distance X4. More particularly, FIG. 3D shows enlarged conduits 132A and 132B wherein each exhibits a substantially circular shape. In addition, as shown in FIG. 3D, narrow conduit 133, exhibits a thickness T4 and is formed by the intersection of substantially circular enlarged conduits 132A and 132B.

It should be understood that although the above embodiments depict enlarged conduits 132A and 132B as having generally rounded features, the present invention is not so limited. Rather, the present invention contemplates that the geometry of enlarged conduits 132A and 132B may be substantially circular, substantially elliptical, substantially oval, substantially oblong, substantially rectangular, substantially triangular, or as otherwise desired or known in the art. Accordingly, as may be appreciated with respect to the above discussion, many alternative configurations are encompassed by the present invention.

Similarly, the present invention contemplates numerous embodiments of passageway 114. In one consideration, substantial bifurcation may occur solely within a portion of a diverging region 122 of passageway 114, or within at least a portion of converging region 120 as well. For example, in one embodiment of passageway 114A, as shown in FIG. 4A-1, flow separation features 140 may extend from exit aperture 130 generally toward throat 124 and within at least a portion of diverging region 122. Of course, the size, shape, and configuration of flow separation features 140 may be selected for influencing a characteristic of drilling fluid passing through passageway 114A. In another embodiment, optionally, as shown in FIG. 4A-2, passageway 114B may include flow separation features 140 extending at least partially within converging region 120.

The present invention also contemplates various configurations related to the size, shape, and position of a converging region 120 and a diverging region 122 of passageway 114. For instance, FIGS. 4A-1 and 4A-2 show side schematic views of passageway 114 wherein throat 124 is positioned substantially centrally between entrance 119 of converging region 120, depicted by reference line B-B, and exit aperture 130. Selecting a position of throat 124 (depicted by reference line A-A) may be advantageous for influencing at least one characteristic of at least one or both of the bifurcated (i.e., substantially distinct) drilling fluid jets or flows exiting the exit aperture 130 of the passageway 114. In an alternative embodiment, FIG. 4B shows passageway 114C wherein throat 124 is located proximate to entrance 119 of converging region 120. Alternatively, in yet a further alternative embodiment, FIG. 4C shows passageway 114D wherein throat 124 is positioned proximate exit aperture 130.

More generally, the present invention contemplates that a configuration (i.e., size, orientation, position, shape, etc.) of the converging region, the throat, the diverging region, and the flow separation features may be selected for influencing a characteristic of drilling fluid exiting a nozzle of the present invention. For example, the present invention contemplates that the geometry of any of the converging region, the throat, and the diverging region may be substantially circular, substantially elliptical, substantially oval, substantially oblong, substantially rectangular, substantially triangular, or as otherwise desired or known in the art. Accordingly, the present invention encompasses many alternative configurations.

In yet a further aspect of the present invention, different shapes and orientations of converging region 120 may be employed. For example, FIG. 5A shows a substantially elliptical converging region 150A (shown proximate throat 124), wherein the major axis of the elliptical converging region 150A is oriented generally parallel to horizontal axis 103. Alternatively, a major axis of an elliptically shaped converging region 150 may be oriented at any selected angle with respect to horizontal axis 103. Such a configuration may provide desirable flow streams or jets emanating from a nozzle 28 according to the present invention. In another embodiment, as shown in FIG. 5B, converging region 150B proximate to throat 124 may comprise a substantially circular shape. Similarly, such a configuration may provide different (with respect to the converging region 150A shown in FIG. 5A), yet desirable flow streams or jets emanating from a nozzle 28 according to the present invention.

As a further consideration, a so-called spread angle may be affected by the geometry of the passageway 114. As shown in FIG. 6A, spread angle represents the angular separation exhibited between exiting drilling fluid jets from a nozzle of the present invention. Such an angular separation may be advantageous for distributing drilling fluid within junk slots of a rotary drill bit.

For example, FIG. 6B shows a top elevation view of rotary drill bit 10B, (i.e., similar to rotary drill bit 10 as shown in FIGS. 1A and 1B) including a plurality of longitudinally extending blades 14 defining junk slots 16 therebetween. Each blade 14 may carry a plurality of cutting elements 18 thereon for cutting a subterranean formation upon rotation of the rotary drill bit 10. More particularly, nozzles 38 of the present invention are shown in three positions upon the face of the rotary drill bit 10B. Further, arrows from each of nozzles 38 represent two drilling fluid streams emanating therefrom, respectively. As may be appreciated, an angular separation (e.g., a spread angle , as shown in FIG. 6A) between each of the arrows from each of the nozzles 38, respectively, may be different and may be selected for providing drilling fluid to individual, circumferentially adjacent junk slots 16 without excessive erosion of the blade 14 circumferentially therebetween. In yet a further application of a nozzle of the present invention, FIG. 6C shows a rotary drill bit 10 generally as shown in FIG. 1B, wherein a nozzle 38 is affixed within a nozzle recess and spread angle is configured for encompassing a plurality of the cutting elements 18 positioned on blade 14. Such a configuration may be advantageous for cleaning of cuttings of a subterranean formation during use of the rotary drill bit 10.

In addition, the inventors herein have simulated different parameters regarding the geometry of a passageway and drilling fluid flow therethrough. Particularly, a so-called parametric design study has been performed with the aid of computational fluid dynamics. Thus, general observations regarding the relationship between a converging region, diverging region, and a throat of a passageway have been explored. Generally, the present invention contemplates that a position of throat 124 may be between about 10% to 50% of the overall distance between the entrance 119 of the converging region to the exit aperture 130. More specifically, positioning the throat from the exit aperture 130 toward the entrance 119 by a distance of about 20% of the overall distance between the entrance 119 of the converging region to the exit aperture 130 was found to consistently produce a maximum spread angle and maximum relative jet strength.

More specifically, jet strength may be quantified practically as a (normalized) measure of a maximum jet velocity generated by a fluid flow exiting a nozzle in relation to a velocity of a fluid flow at the axis of the nozzle, at a given distance along the axis of the nozzle. Such a quantification may be useful for comparison of nozzle effectiveness. For a given nozzle, a normalized jet velocity (at the axis of the nozzle) may be designated to have a magnitude of 1; therefore, the jet strength may be determined by dividing the maximum velocity of a jet by the jet velocity at the axis of the nozzle. A jet strength near 4 may imply a relatively robust jet spread with very low velocity between the two bifurcating jets or at the nozzle axis. Accordingly, a higher jet strength may imply a lower erosion for a blade positioned along the nozzle axis and in-between the bifurcated jets (*see* Fig. 6B).

In another geometric aspect of the present invention, orienting a major axis (elliptical, oval, oblong, or otherwise elongated) of a converging region of a passageway substantially parallel to a horizontal axis of an exit aperture may produce a greater spread angle . On the other hand, orienting a major axis (elliptical, oval, oblong, or otherwise elongated) of a converging region of a passageway substantially perpendicular to a horizontal axis of an exit aperture may produce a more powerful or efficient drilling fluid distribution. Further, for example, the size of enlarged conduits (at the exit aperture 130) may be about 0.635 cm to about 1.270 cm. Of course, a size of the exit aperture may be selected with respect to associated equipment for operating a rotary drill bit (e.g., pumps, mud-type, etc.). As a further consideration, a size of an area of the throat (taken substantially transverse to the flow of drilling fluid) may be between about 50% to 80% of a size of an area of the inlet (taken substantially transverse to the flow of drilling fluid). Such a configuration may provide desirable flow characteristics of drilling fluid passing through a nozzle having a passageway exhibiting at least one above-described attribute. It may be further noted that the jet spread is decreased with respect to an increasing throat area. Also, a larger throat area having an oblong shape with the minor axis (narrow) of the throat oriented perpendicular to the horizontal nozzle exit axis (labeled 103 in FIG. 5A) exhibits greater jet spread for a given throat area. Jet spread is highly related to the radial distance from the nozzle axis to the edge of the throat in the direction of the horizontal nozzle exit axis (labeled 103 in FIG. 5A).

Thus, the present invention contemplates that the direction, size, and configuration of substantially bifurcated jets, flows, or flow regimes exiting a nozzle of the present invention may be preferentially tailored for delivering drilling fluid for cleaning, cooling, or both cleaning and cooling cutting elements upon a rotary drill bit.

While certain representative embodiments and details have been shown for purposes of illustrating the invention, it will be apparent to those skilled in the art that various changes in the methods and apparatus disclosed herein may be made without departing form the scope of the invention, which is defined in the appended claims. For example, other nozzle body and passage sizes and cross-sectional shapes may be employed; and various alternative structures may be employed for attaching the nozzle body to a rotary drill bit.

CLAIMS

What is claimed is:

1. An apparatus for forming a subterranean borehole, the apparatus including a nozzle comprising:

a nozzle body configured to be secured within a drill bit; and

at least one fluid passageway extending through the nozzle body from an inlet to an exit aperture, the at least one fluid passageway comprising:

a converging region extending from a converging region entrance to a throat, the cross-sectional area of the at least one fluid passageway being a minimum at the throat; and

a diverging region extending from the throat to an exit aperture, at least a portion of the diverging region of the fluid passageway being substantially bifurcated.

2. The apparatus of claim 1, wherein a cross-sectional area of the at least one fluid passageway at the throat is between about fifty percent (50%) and about (80%) of a cross-sectional area of the at least one fluid passageway at the inlet.

3. The apparatus of claim 1, wherein a distance between the converging region entrance and the throat is between about ten percent (10%) and about fifty percent (50%) of a distance between the converging region entrance and the exit aperture.

4. The apparatus of claim 3, wherein a distance between the converging region entrance and the throat is about twenty percent (20%) of a distance between the converging region entrance and the exit aperture.

5. The apparatus of claim 1, further comprising an inlet region extending between the inlet and the converging region entrance, a portion of the at least one fluid passageway extending through the inlet region between the inlet and the converging region entrance.

6. The apparatus of claim 1, wherein at least a portion of the converging region is substantially bifurcated.

7. The apparatus of claim 1, wherein the cross-sectional area of the at least one fluid passageway at the throat has an oblong shape.

8. The apparatus of claim 1, wherein the substantially bifurcated portion of the diverging region of the at least one fluid passageway comprises:

a first enlarged conduit; and

a second enlarged conduit.

9. The apparatus of claim 8, wherein the first enlarged conduit and the second enlarged conduit each have a diameter that varies between the throat and the exit aperture, the diameter of the second enlarged conduit being equal to the diameter of the first enlarged conduit at all points between the throat and the exit aperture.

10. The apparatus of claim 8, further comprising a narrow conduit providing fluid communication between the first enlarged conduit and the second enlarged conduit.

11. The apparatus of claim 8, wherein the first enlarged conduit is configured to direct a fluid flowing therethrough out from the exit aperture in a first general direction, and wherein the second enlarged conduit is configured to direct a fluid flowing therethrough out from the exit aperture in a second general direction that is oriented at an angle relative to the first general direction.

12. The apparatus of claim 1, further comprising:
a bit body having a face; and
at least one cutting element mounted on the face of the bit body;
wherein the at least one nozzle is installed within the bit body and configured for communicating drilling fluid from an interior thereof to the face of the bit body.

13. The apparatus of claim 12, wherein the bit body comprises a plurality of longitudinally extending blades defining junk slots therebetween, and wherein the at least one cutting element mounted on the face of the bit body comprises a plurality of cutting elements, each longitudinally extending blade having a plurality of cutting elements thereon.

14. The apparatus of claim 13, wherein the at least one nozzle is configured to direct a first stream of fluid in a first general direction towards a first junk slot and to direct a second stream of fluid in a second general direction towards a second junk slot.

15. The apparatus of claim 13, wherein the at least one nozzle is configured to direct a stream of fluid out from the exit aperture in a spread angle, the spread angle encompassing a plurality of cutting elements on a longitudinally extending blade.

16. The apparatus of claim 12, further comprising an orientation feature on at least one of the bit body and the at least one nozzle, the orientation feature configured to indicate an orientation of the at least one nozzle with respect to the bit body.

17. A method of communicating drilling fluid to a face of a rotary drill bit for forming a subterranean borehole, comprising:

introducing a drilling fluid into a fluid passageway extending between an inlet disposed within an interior region of a drill bit and an exit aperture disposed at a face of the drill bit;

causing the drilling fluid to flow through a converging region of the fluid passageway from the inlet to a throat region;

causing the drilling fluid to flow through a diverging region of the fluid passageway from the throat region to the exit aperture; and

substantially bifurcating the drilling fluid at least within a portion of the diverging region of the fluid passageway.

18. The method of claim 17, wherein substantially bifurcating the drilling fluid comprises:

substantially separating the drilling fluid into a first fluid stream and a second fluid stream;

directing the first fluid stream in a direction towards a first junk slot defined between two longitudinally extending blades of the drill bit; and

directing the second fluid stream in a direction towards a second junk slot defined between two longitudinally extending blades of the drill bit.

19. The method of claim 17, wherein substantially bifurcating the drilling fluid comprises:

spreading the drilling fluid across an angle; and

directing the drilling fluid towards a plurality of cutting elements mounted on the face of the drill bit.

20. The method of claim 17, wherein causing the drilling fluid to flow through a converging region comprises causing the drilling fluid to flow through a converging region of the fluid passageway from the inlet to a throat region, the fluid passageway having a cross-sectional area at the throat region that is between about fifty percent (50%) and about eighty percent (80%) of a cross-sectional area of the fluid passageway at the inlet.

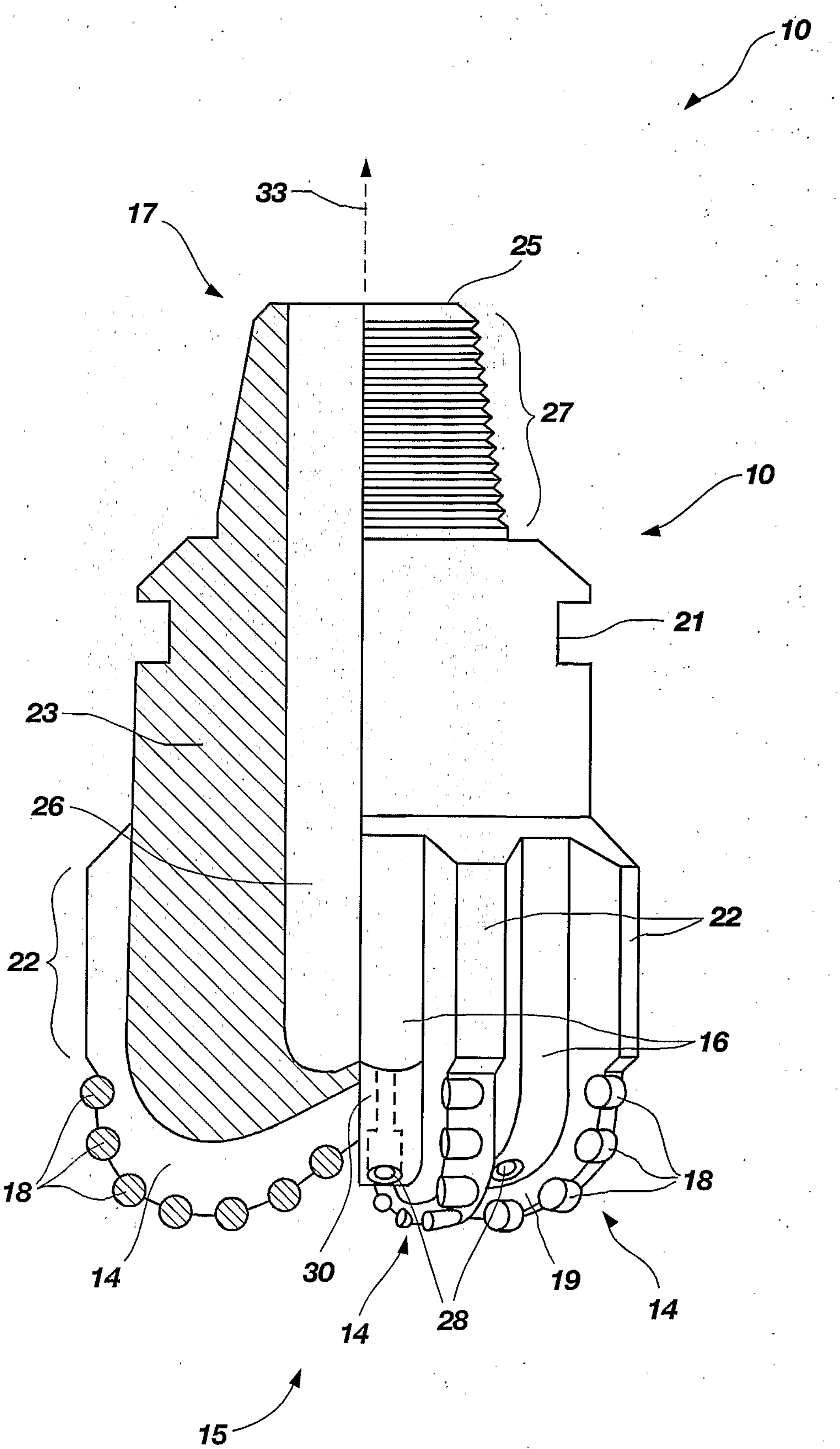

FIG. 1A

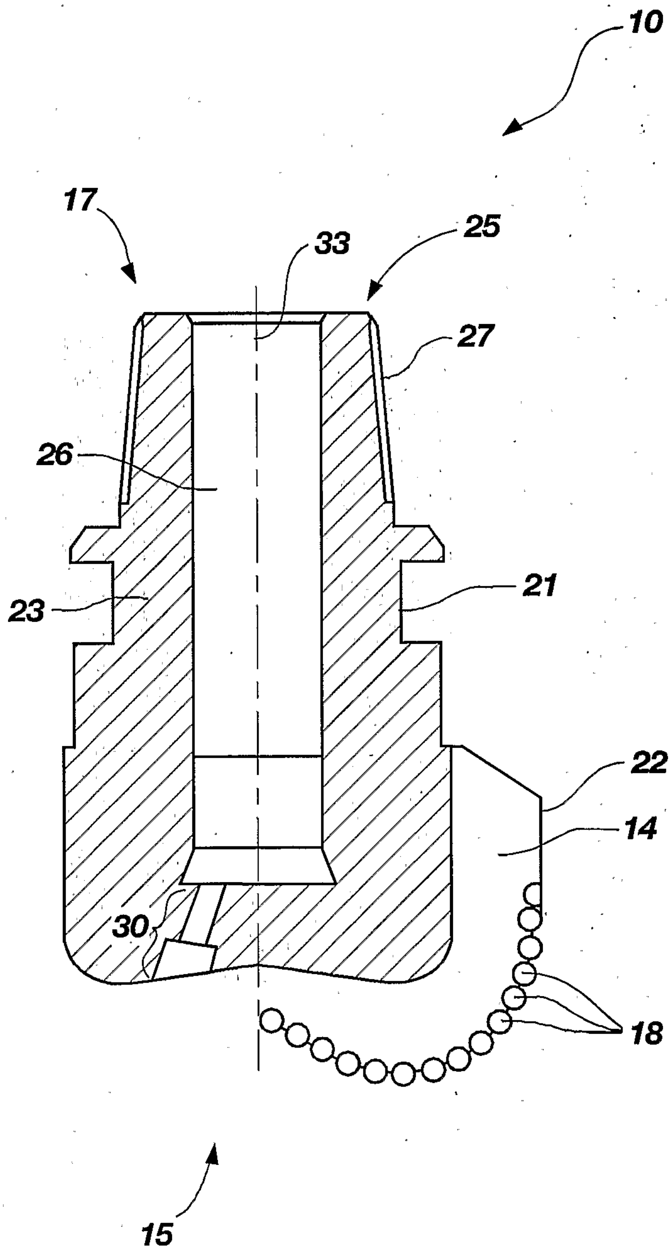

FIG. 1B

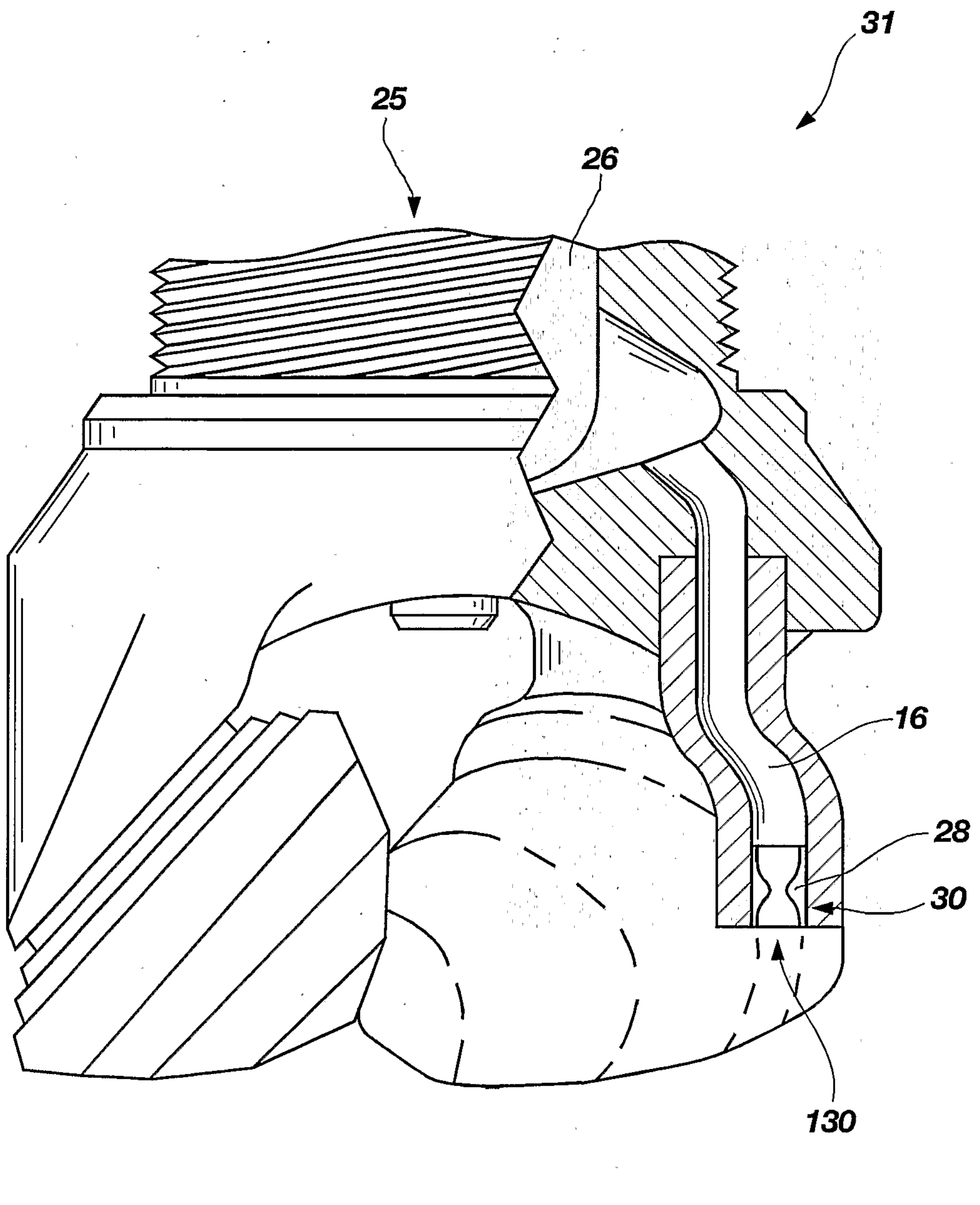

FIG. 1C

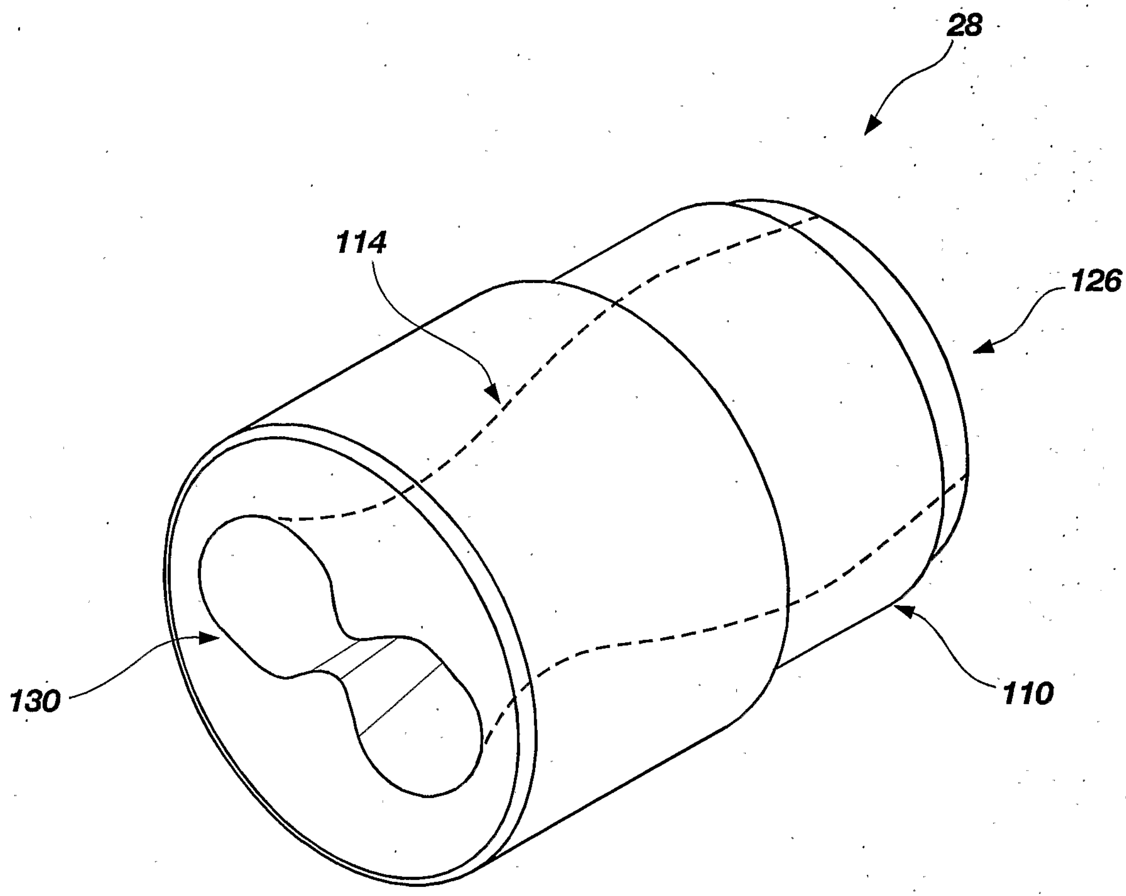

FIG. 2A

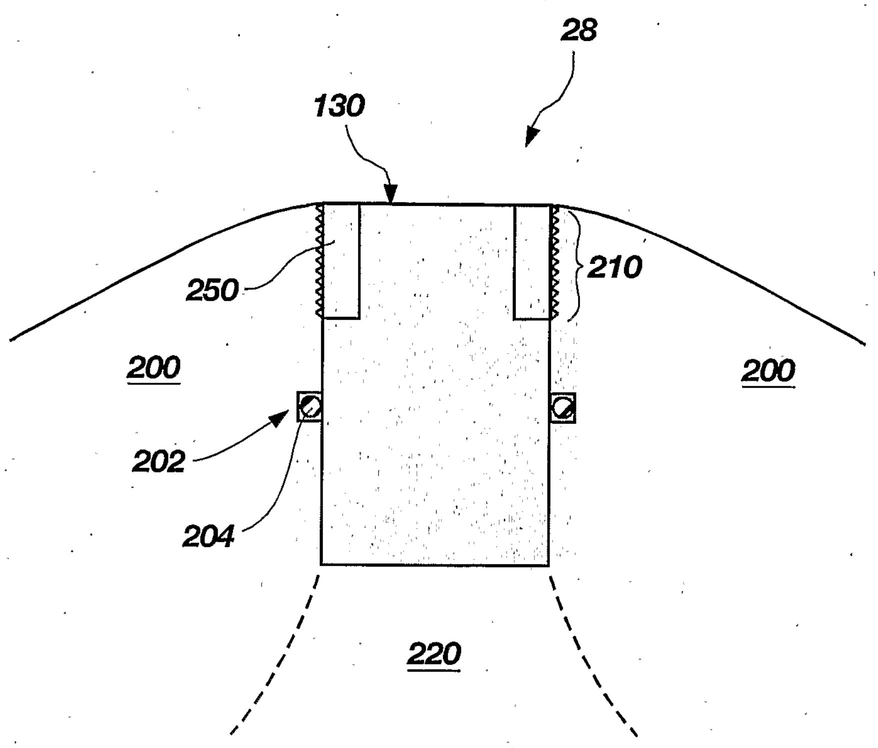

FIG. 2A-A

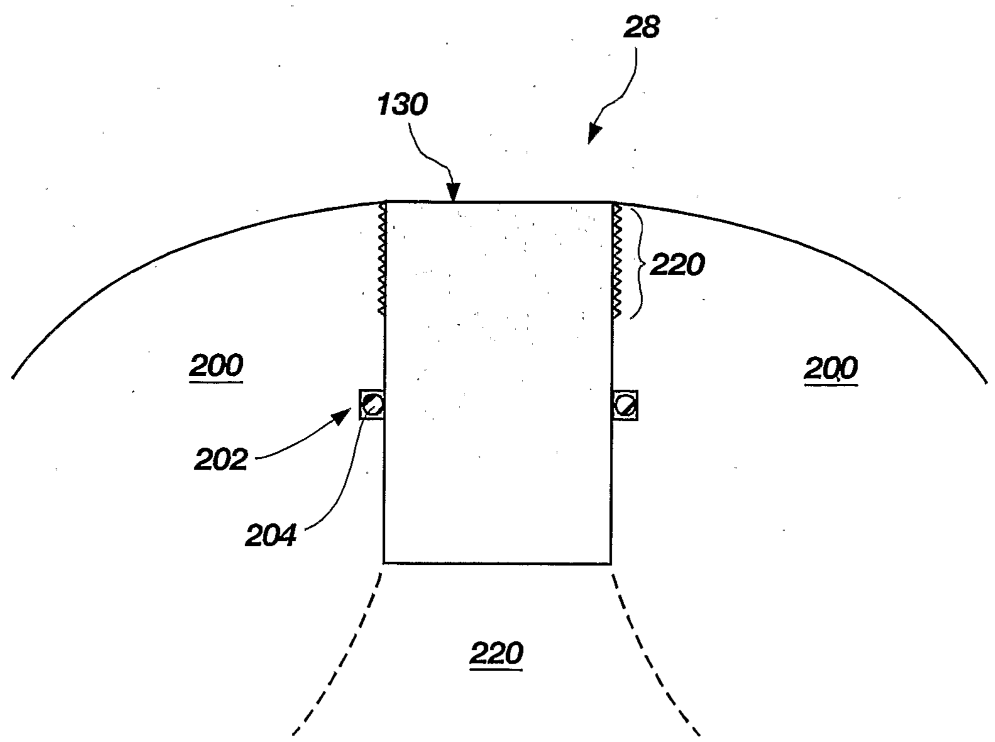

FIG. 2A-B

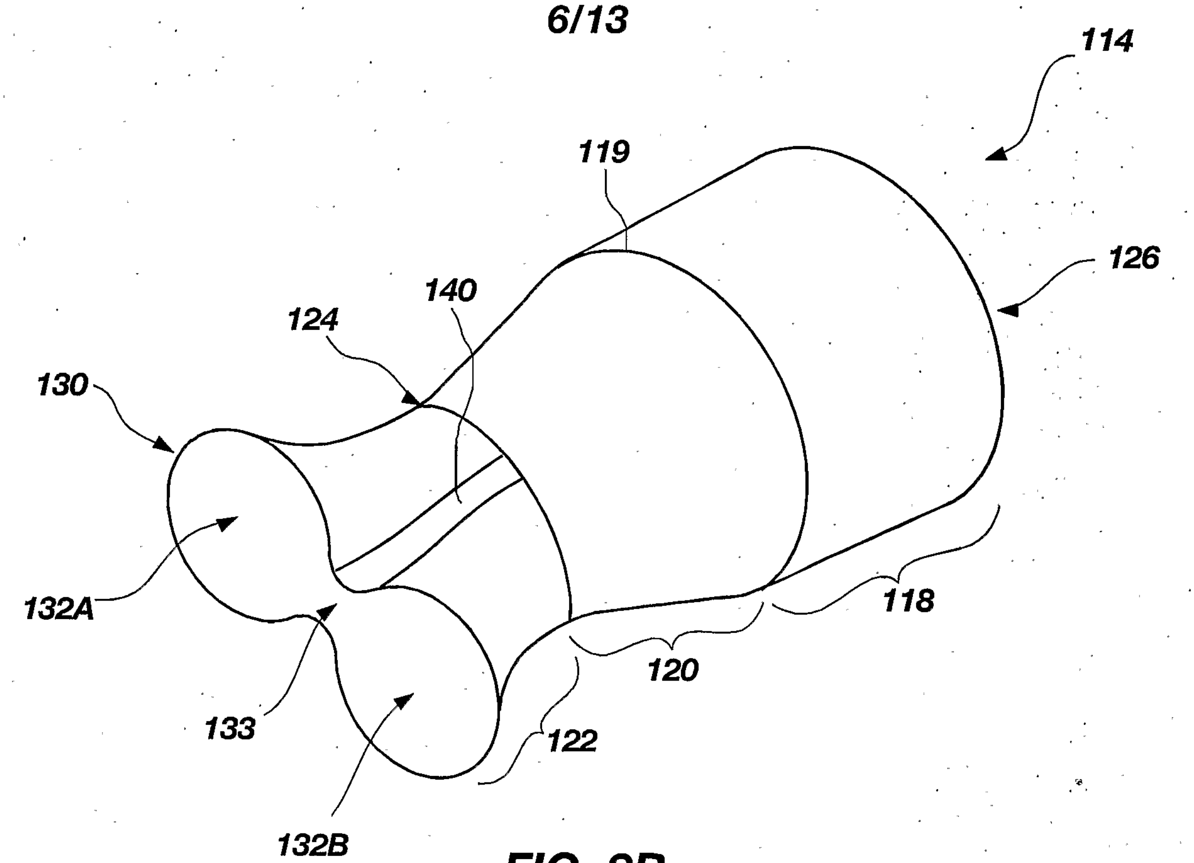
114
119
126
140
124
130
132A
118
120
133
122
132B

FIG. 2B

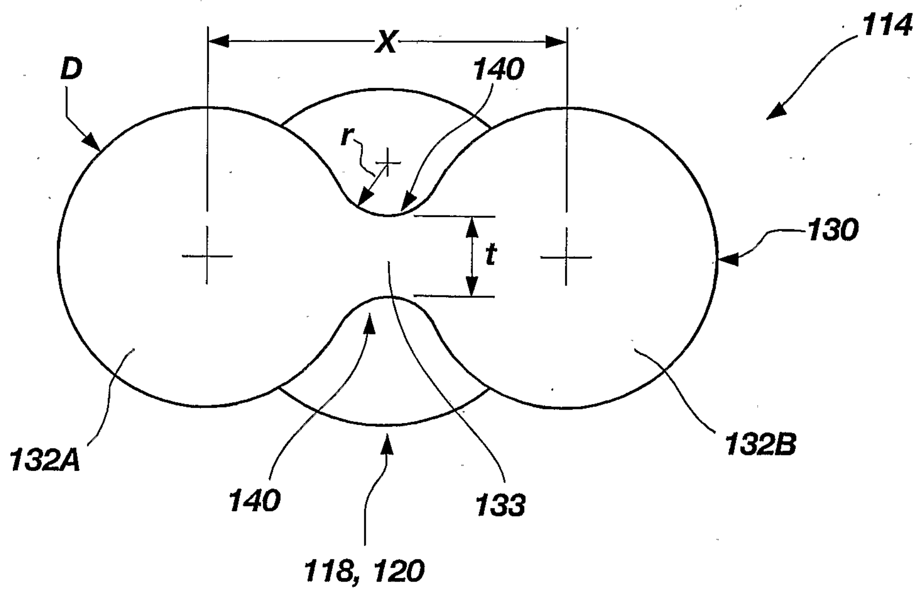
114
X
D
140
r
130
t
132A
132B
140
133
118, 120

FIG. 2C

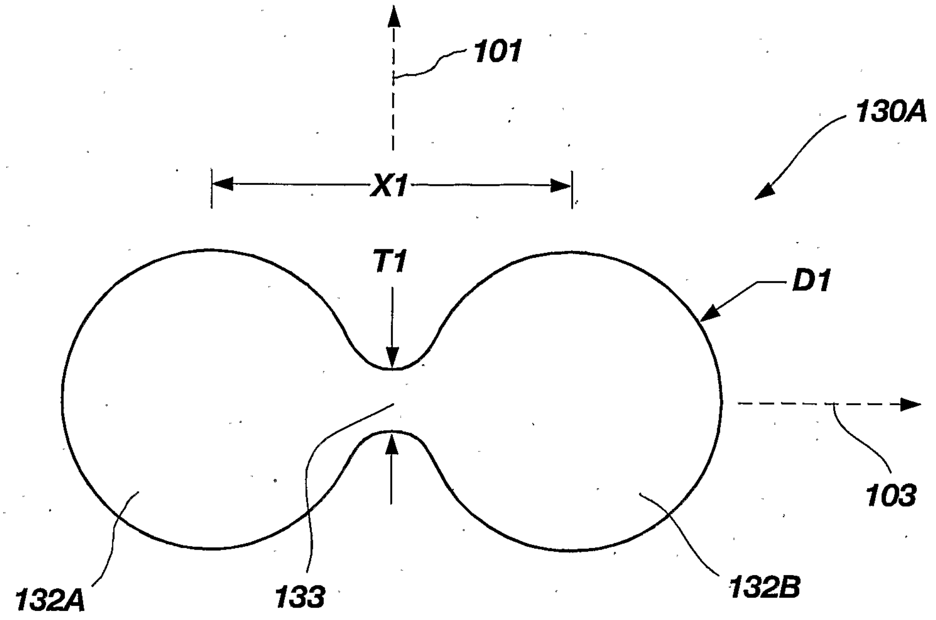
101
130A
X1
T1
D1
103
132A
133
132B

FIG. 3A

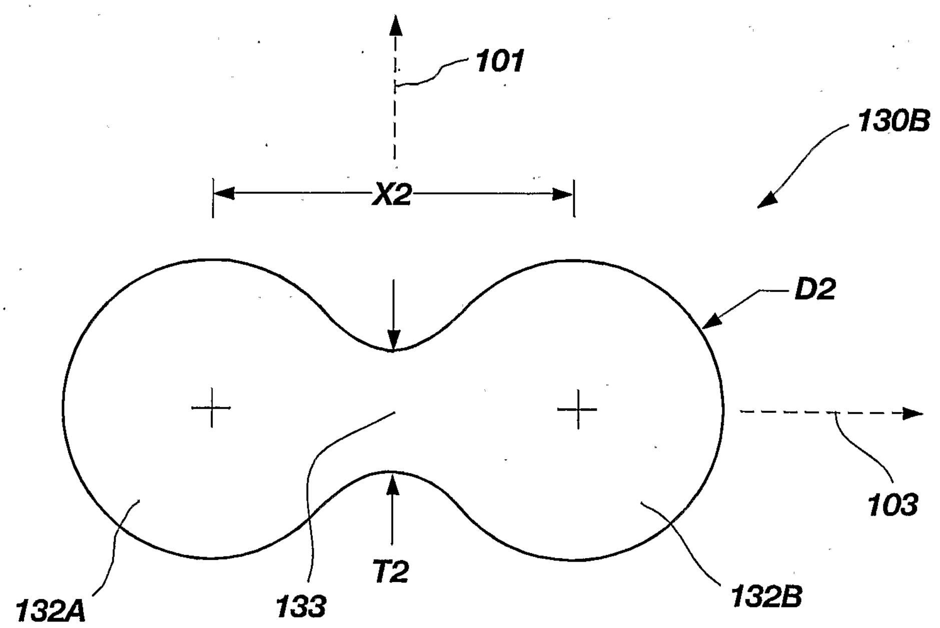
101
130B
X2
D2
103
T2
132A
133
132B

FIG. 3B

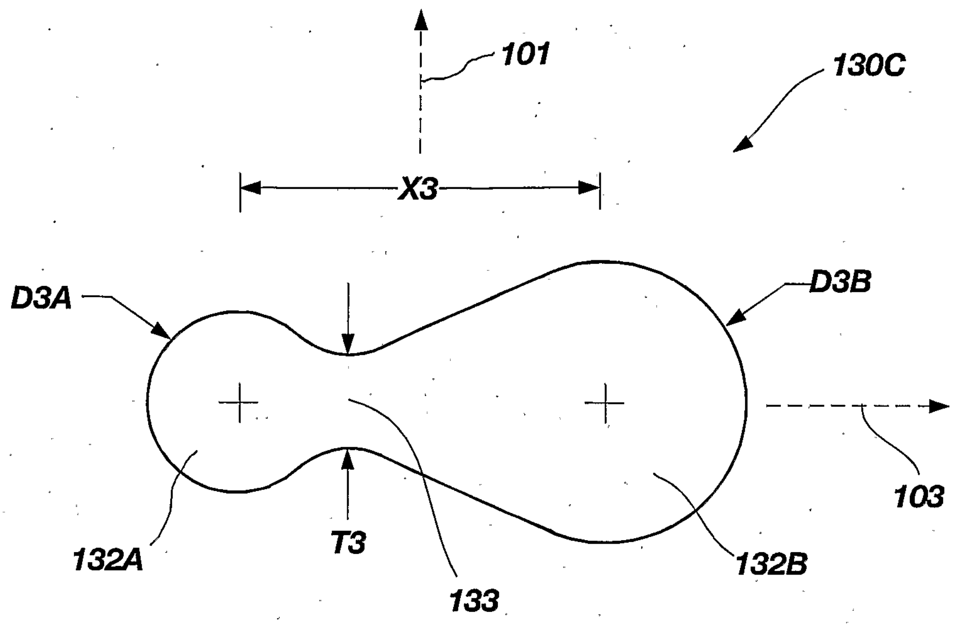
101
130C
X3
D3A
D3B
103
132A
T3
133
132B

FIG. 3C

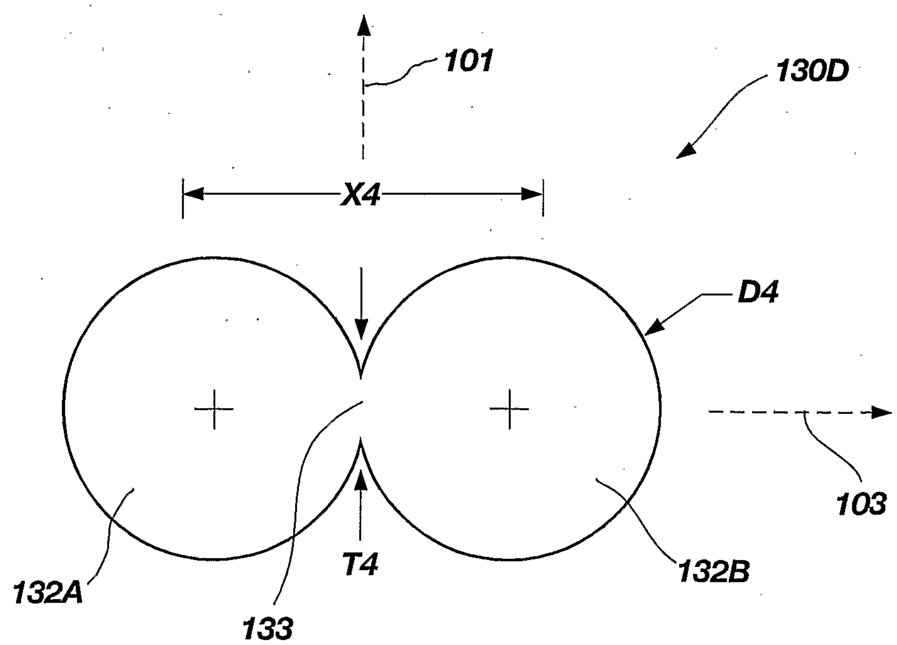
101
130D
X4
D4
103
132A
T4
133
132B

FIG. 3D

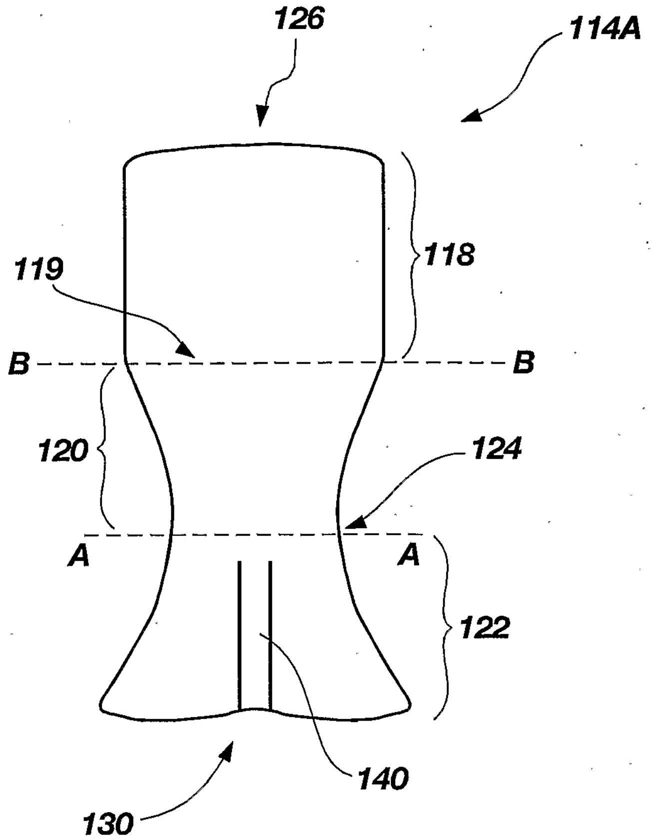

FIG. 4A-1

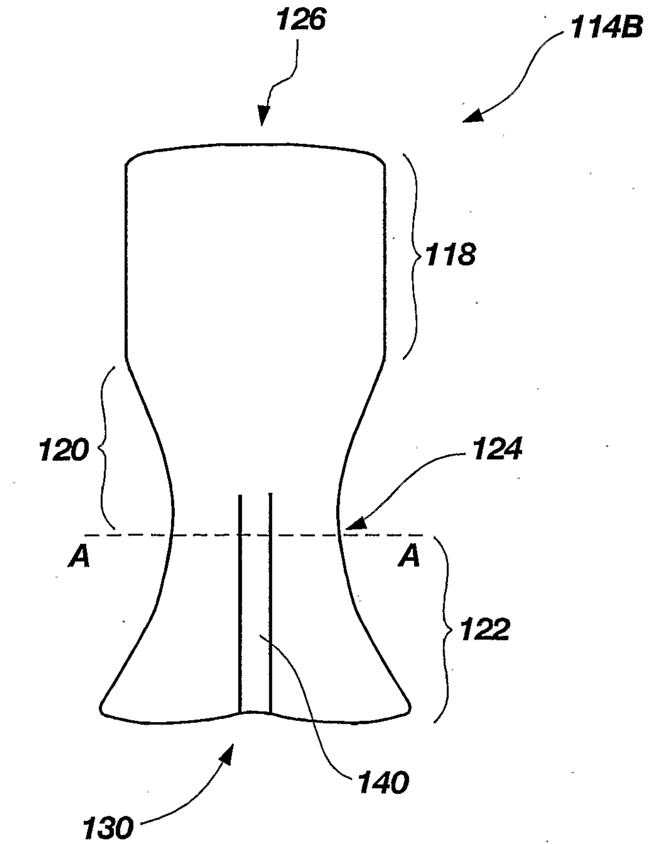

FIG. 4A-2

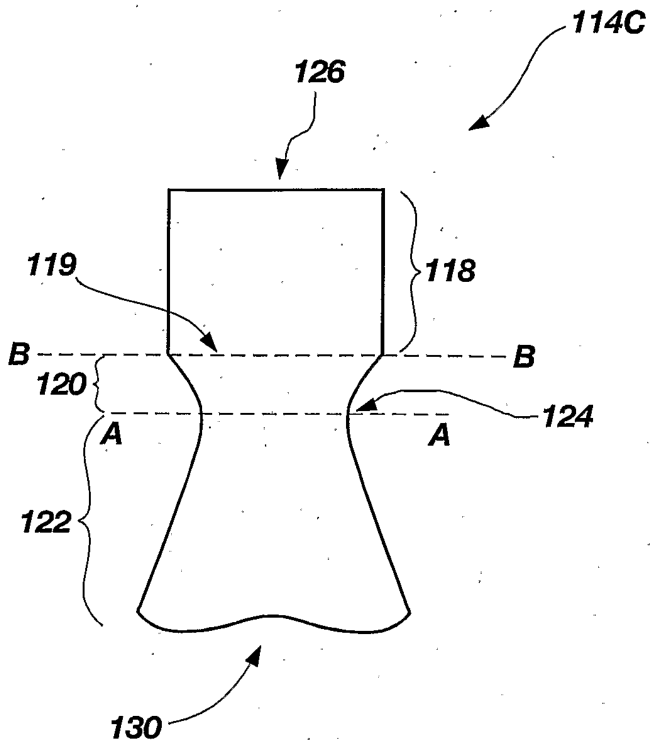
114C
126
119
118
B
B
120
124
A
A
122
130

FIG. 4B

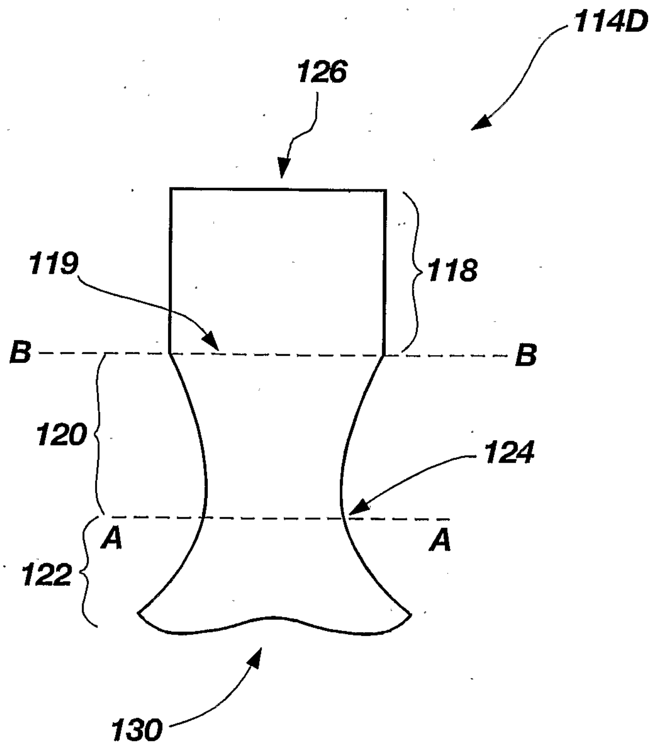
114D
126
119
118
B
B
120
124
A
A
122
130

FIG. 4C

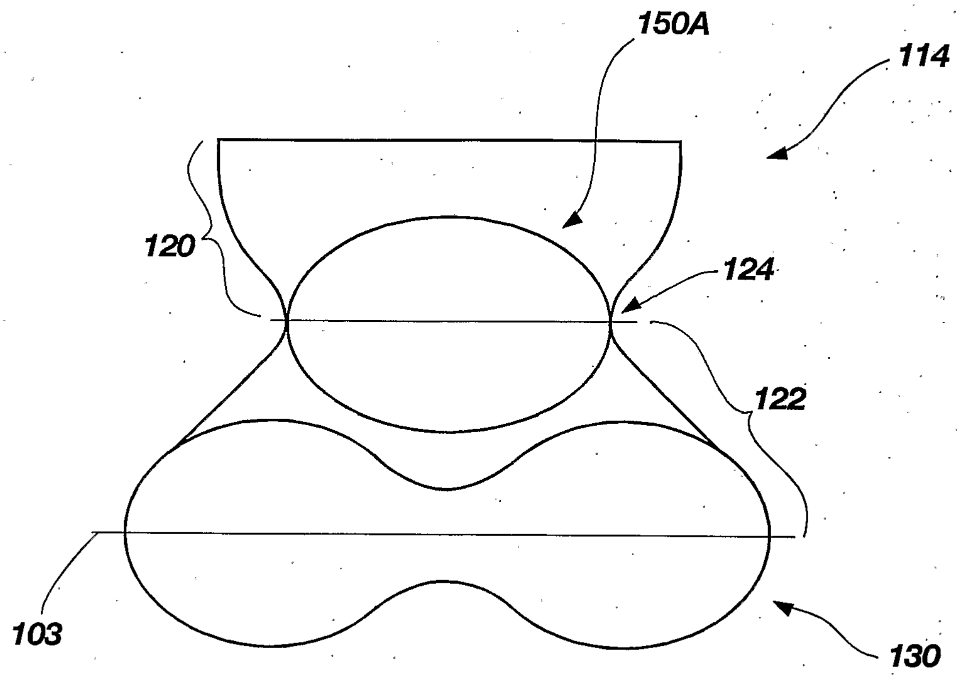

FIG. 5A

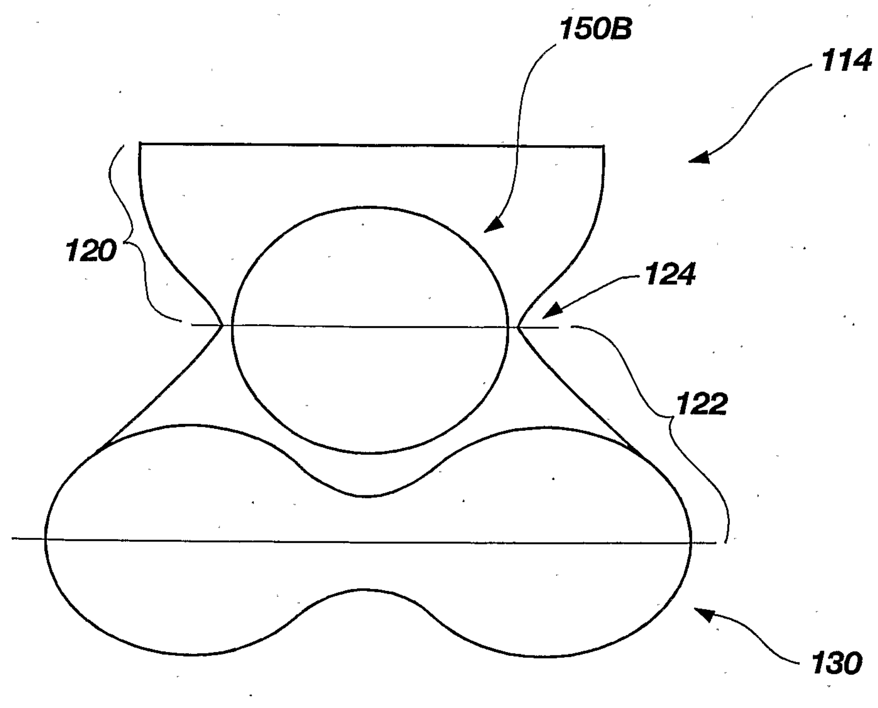

FIG. 5B

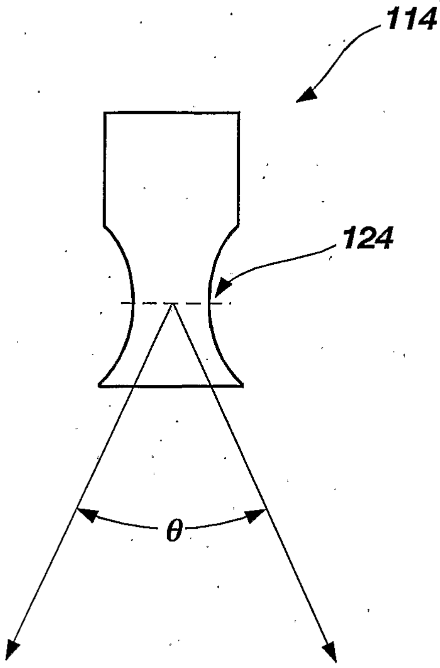
114
124
θ

FIG. 6A

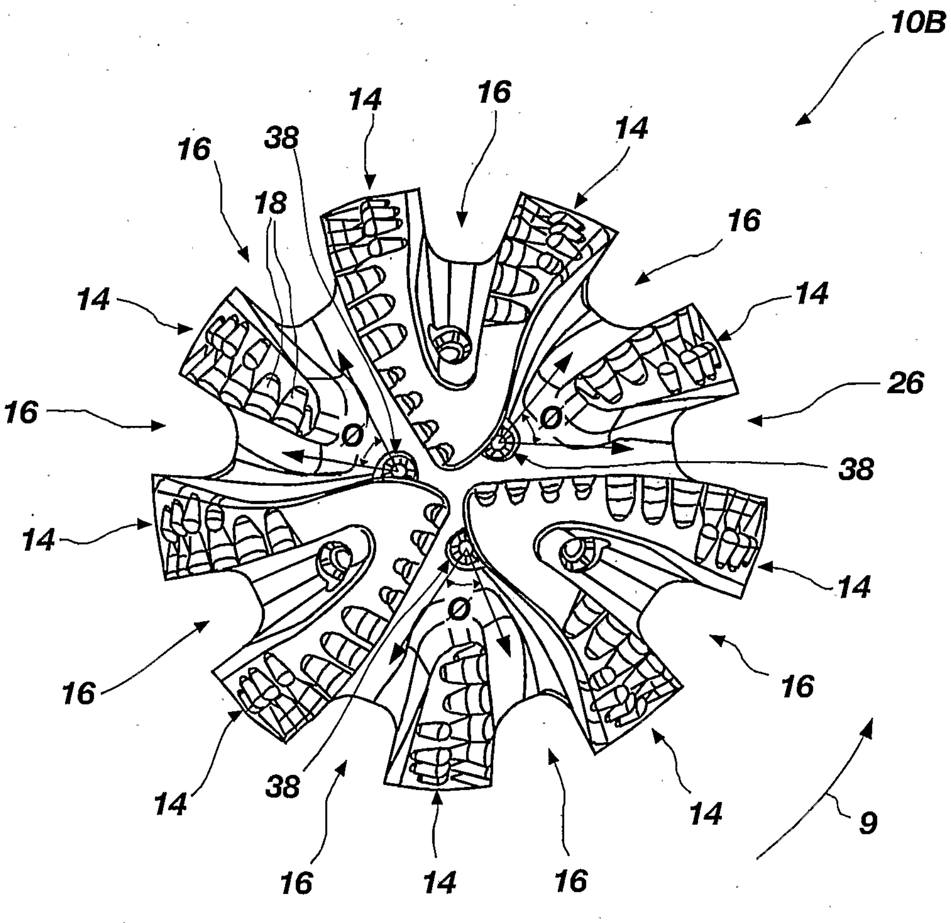
10B
14
16
14
16
38
18
16
14
14
16
26
Ø
Ø
38
14
14
Ø
16
16
14
38
14
9
16
14
16

FIG. 6B

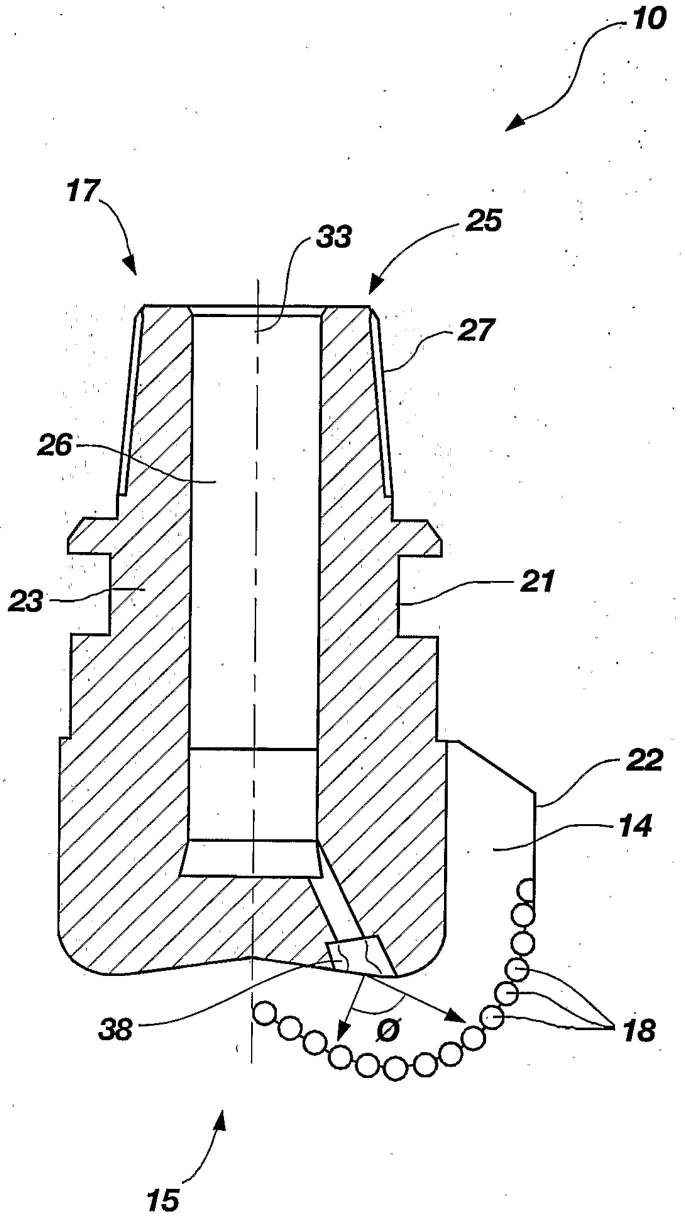

FIG. 6C

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/002735

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B10/60

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)
E21B

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2004/069534 A1 (LARSEN JAMES L ET AL) 15 April 2004 (2004-04-15) paragraphs [0046] - [0141]; claim 157; figures 1-5,8,11,17,18,28	1-5, 8-11,17 12-16, 18-20
X	EP 0 959 224 A (DICKEY, WINTON B) 24 November 1999 (1999-11-24) figure 1c	1-5, 8-11,17
Y	WO 96/24744 A (ASTEC DEVELOPMENTS LIMITED; SIMPSON, NEIL; WARDLEY, MICHAEL) 15 August 1996 (1996-08-15) figures 1-12	12-16, 18-20
A	US 6 186 251 B1 (BUTCHER TRENT N) 13 February 2001 (2001-02-13) figure 4	12-16
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] 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

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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	Date of mailing of the international search report
17 May 2006	24/05/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	van Berlo, A

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/002735

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 6 311 793 B1 (LARSEN JAMES L ET AL) 6 November 2001 (2001-11-06) cited in the application figures 1-18	1
A	US 5 785 258 A (AKIN ET AL) 28 July 1998 (1998-07-28) figure 28	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2006/002735

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			CA	2173733	A1	20-04-1995
			EP	0719375	A1	03-07-1996
			WO	9510684	A1	20-04-1995
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