



US00RE48525E

(19) **United States**
(12) **Reissued Patent**
Muntean et al.

(10) **Patent Number: US RE48,525 E**
(45) **Date of Reissued Patent: Apr. 20, 2021**

(54) **AIR CURTAIN FOR UREA MIXING CHAMBER**

(71) Applicant: **Cummins Emission Solutions, Inc.**,
Columbus, IN (US)
(72) Inventors: **George L. Muntean**, Columbus, IN
(US); **Steve Holl**, Columbus, IN (US);
Joydeep Chakrabarti, Columbus, IN
(US); **John Anthis**, Columbus, IN (US);
Joshua D. Henry, Indianapolis, IN
(US); **Samuel Johnson**, Bloomington,
IN (US); **Andrew Myer**, Greenwood,
IN (US); **John K. Heichelbech**,
Columbus, IN (US)

(73) Assignee: **Cummins Emission Solutions Inc.**,
Columbus, IN (US)

(21) Appl. No.: **16/575,187**

(22) Filed: **Sep. 18, 2019**

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **9,926,822**
Issued: **Mar. 27, 2018**
Appl. No.: **13/969,039**
Filed: **Aug. 16, 2013**

(51) **Int. Cl.**
F01N 3/20 (2006.01)
B01F 3/04 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **F01N 3/2066** (2013.01); **B01F 3/04049**
(2013.01); **B01F 5/045** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC **B01F 5/045**; **B01F 3/04049**; **B01F**
2005/0017; **F01N 2610/02**; **F01N**
2610/14;
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,234,387 A * 3/1941 Scott F16T 1/34
137/183
2,805,966 A * 9/1957 Etheridge C08B 30/16
127/28

(Continued)

FOREIGN PATENT DOCUMENTS

WO WO-2004/046513 6/2004
WO WO-2004/046513 A1 6/2004

(Continued)

OTHER PUBLICATIONS

Final Office Action on U.S. Appl. No. 15/895,809, dated Sep. 17,
2018. 11 pages.

(Continued)

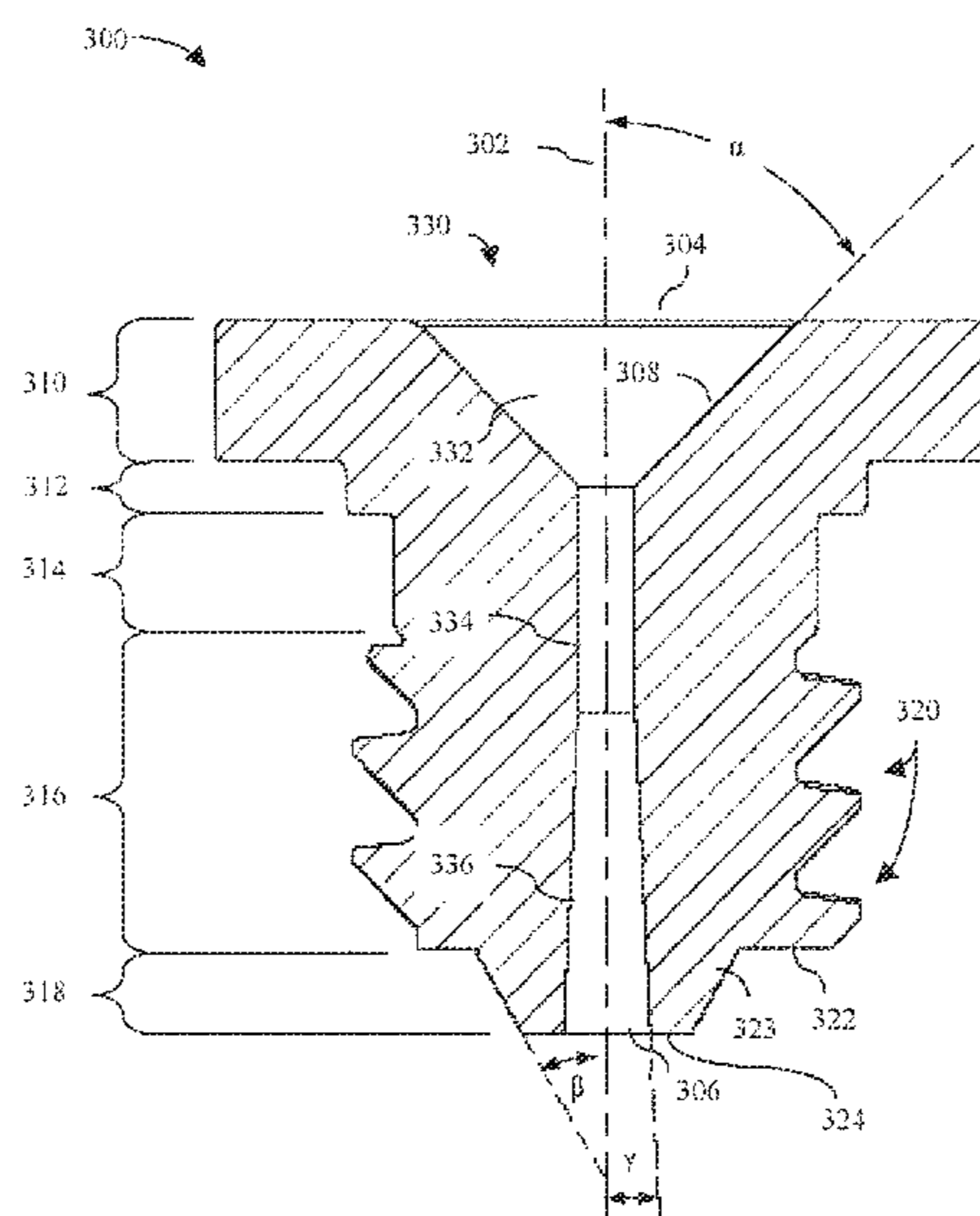
Primary Examiner — Norca L. Torres Velazquez

(74) *Attorney, Agent, or Firm* — Foley & Lardner LLP

(57) **ABSTRACT**

An exemplary embodiment includes a blending chamber having a urea inlet, a blending chamber gas inlet, and a blending chamber outlet. A urea source provides a pressurized urea solution to the urea inlet at a urea injection pressure, and a pressurized gas source transmits pressurized gas to the blending chamber gas inlet via a passageway. The passageway is configured to decrease pressure of the pressurized gas transmitted along its length from a first pressure of gas received from the pressurized gas source to a second pressure of gas provided to the blending chamber gas inlet. The first pressure of gas received from the pressurized gas source is greater than the urea injection pressure and the second pressure of gas provided to the blending chamber gas inlet is less than the urea injection pressure.

16 Claims, 5 Drawing Sheets



US RE48,525 E

- (51) **Int. Cl.**
B01F 5/04 (2006.01)
B01F 5/00 (2006.01)
- (52) **U.S. Cl.**
 CPC ... *B01F 2005/0017* (2013.01); *F01N 2610/02*
 (2013.01); *F01N 2610/14* (2013.01); *F01N*
2610/146 (2013.01); *F01N 2610/1493*
 (2013.01); *Y02T 10/12* (2013.01)
- (58) **Field of Classification Search**
 CPC *F01N 2610/146*; *F01N 2610/1493*; *F01N*
3/2066; *B60T 2270/82*; *B60T 8/321*;
B60T 8/885; *Y02T 10/12*
 See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,103,827	A *	8/1978	Kumazawa	B01F 5/20 239/427
5,322,222	A *	6/1994	Lott	B05B 7/0408 239/396
5,605,042	A	2/1997	Stutzenberger	
5,943,858	A	8/1999	Hofmann et al.	
6,157,774	A *	12/2000	Komino	B01F 3/04049 239/423
6,167,698	B1 *	1/2001	King	B01D 53/9431 60/274
6,266,955	B1 *	7/2001	Liang	F01N 3/2066 123/1 A
6,293,097	B1 *	9/2001	Wu	B01D 53/9431 417/38
6,878,359	B1	4/2005	Mathes et al.	
7,337,607	B2	3/2008	Hou et al.	
7,458,204	B2	12/2008	Plougmann	
7,685,810	B2 *	3/2010	Hirata	F01N 3/2066 123/479
8,201,393	B2 *	6/2012	Zapf	F01N 3/2066 60/286
8,240,137	B2 *	8/2012	Liu	F01N 3/2066 239/433
8,282,901	B2	10/2012	Petrocelli et al.	
8,881,507	B2 *	11/2014	Yan	F01N 3/2066 60/274
8,888,017	B2 *	11/2014	Ponnathpur	F01N 3/2066 239/289
9,162,198	B2	10/2015	Martinelle et al.	
9,255,512	B2 *	2/2016	Huang	F01N 3/2066
9,315,391	B2	4/2016	Gerhart et al.	
9,371,240	B2	6/2016	Gerhart et al.	
9,731,976	B2	8/2017	Gerhart et al.	
2003/0145580	A1	8/2003	Ripper et al.	

2006/0101810	A1	5/2006	Angelo et al.	
2007/0186543	A1	8/2007	Bakaj et al.	
2009/0031714	A1	2/2009	Jochumsen et al.	
2010/0005791	A1 *	1/2010	Ranganathan	F01N 3/36 60/310
2010/0180576	A1 *	7/2010	Wang	F01N 3/2066 60/276
2010/0319322	A1	12/2010	Huthwohl	
2011/0131959	A1 *	6/2011	Zhang	B01F 3/04049 60/295
2011/0139132	A1	6/2011	Smith et al.	
2011/0271660	A1 *	11/2011	Gonze	F01N 3/027 60/286
2012/0042631	A1 *	2/2012	Schmieg	B01D 53/9463 60/274
2012/0087840	A1	4/2012	Hirschberg	
2012/0160934	A1 *	6/2012	Ponnathpur	F01N 3/2066 239/289
2012/0222401	A1 *	9/2012	Scherer	F01N 3/0842 60/274
2014/0127100	A1	5/2014	Gerhart et al.	
2014/0223892	A1	8/2014	Martinelle et al.	

FOREIGN PATENT DOCUMENTS

WO	WO-2008/135332	11/2008
WO	WO-2008/135332 A1	11/2008
WO	WO-2013/028729	2/2013
WO	WO-2013/028729 A1	2/2013
WO	WO-2013/028741	2/2013
WO	WO-2013/028741 A1	2/2013

OTHER PUBLICATIONS

Non-Final Office Action on U.S. Appl. No. 15/895,809 dated Jun. 18, 2019. 13 pages.
 U.S. Notice of Allowance on U.S. Appl. No. 13/969,039 dated Dec. 7, 2017. 5 pages.
 U.S. Notice of Allowance on U.S. Appl. No. 13/969,039 dated Nov. 15, 2017. 8 pages.
 U.S. Office Action on U.S. Appl. No. 13/969,039 dated Apr. 18, 2016. 16 pages.
 U.S. Office Action on U.S. Appl. No. 13/969,039 dated Jul. 27, 2016. 11 pages.
 U.S. Office Action on U.S. Appl. No. 13/969,039 dated Jun. 30, 2017. 17 pages.
 U.S. Office Action on U.S. Appl. No. 13/969,039 dated Mar. 13, 2017. 15 pages.
 U.S. Office Action on U.S. Appl. No. 15/895,809 dated Mar. 19, 2018. 11 pages.
 International Search Report and Written Opinion for PCT Application No. PCT/US2014/45948, dated Oct. 27, 2014, 9 pages.

* cited by examiner

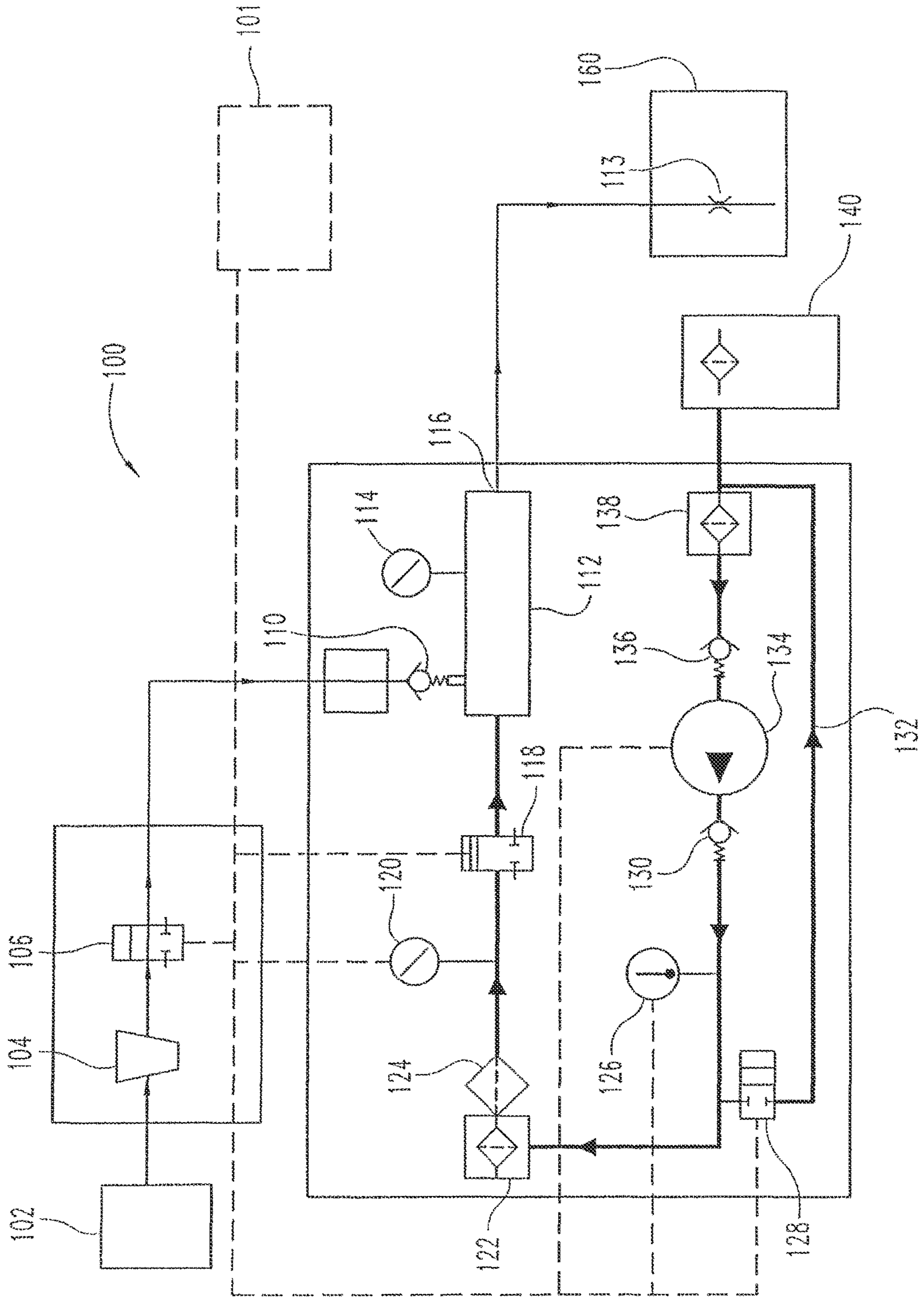


Fig. 1

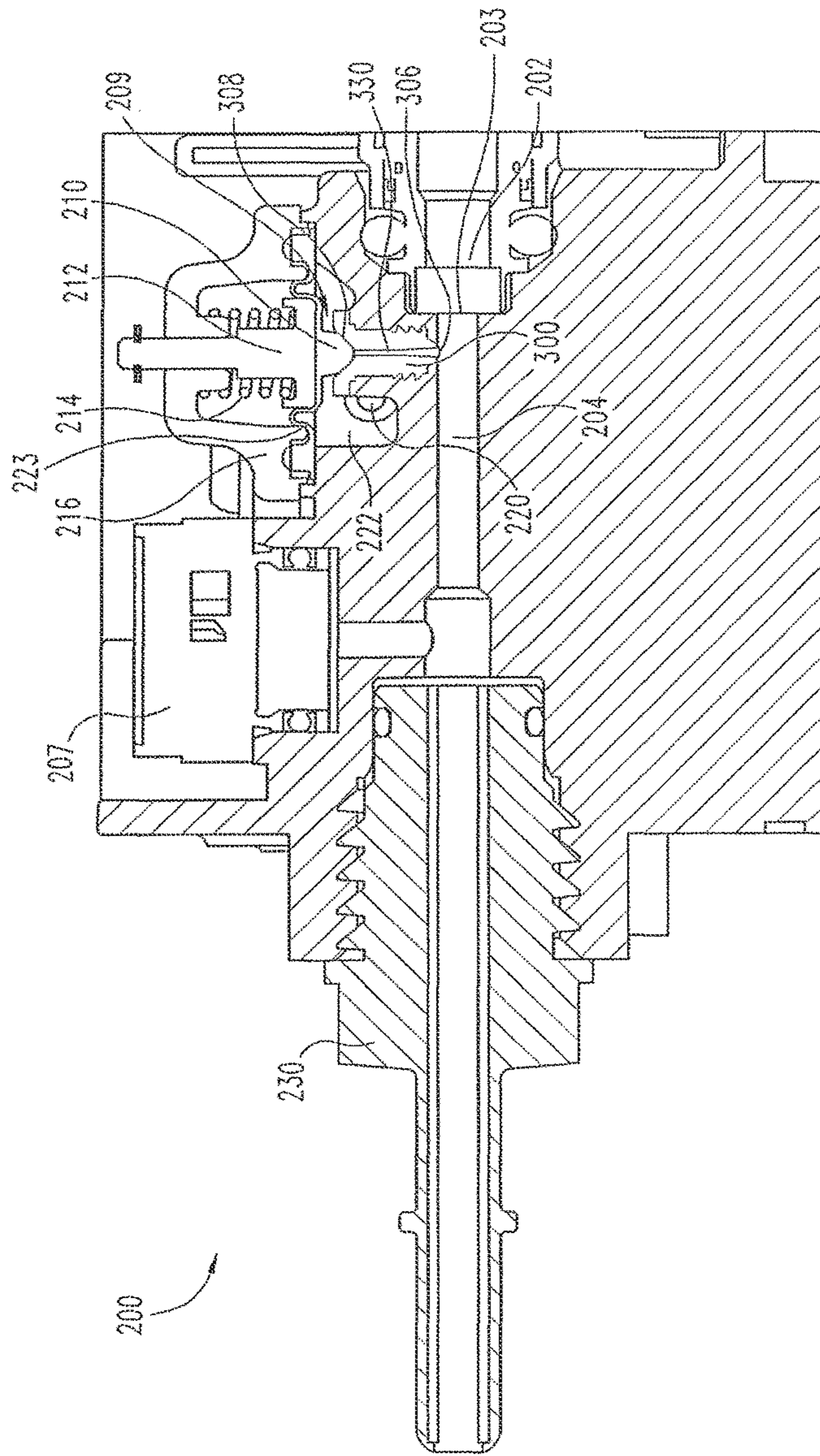


Fig. 2

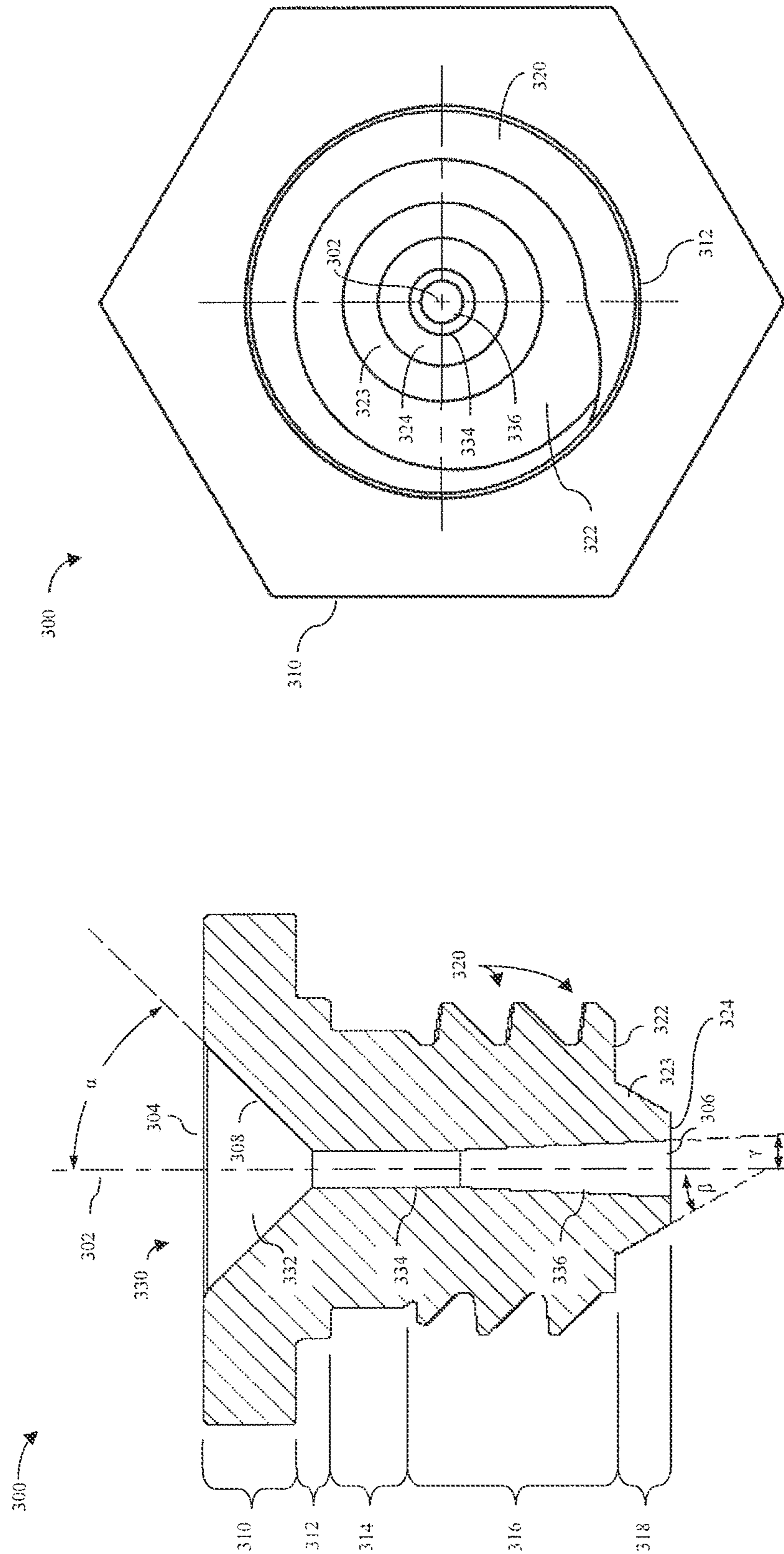


Fig. 4

Fig. 3

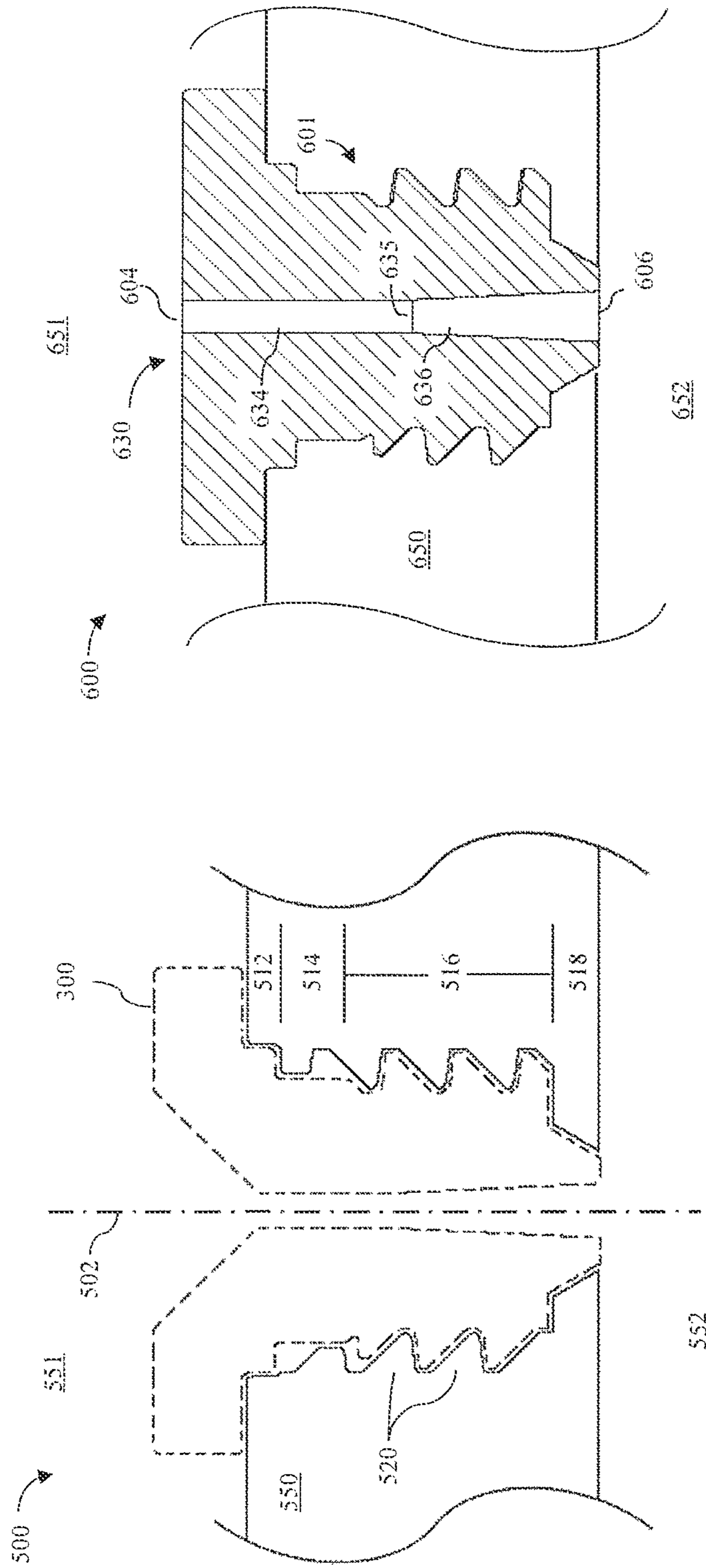


Fig. 6

Fig. 5

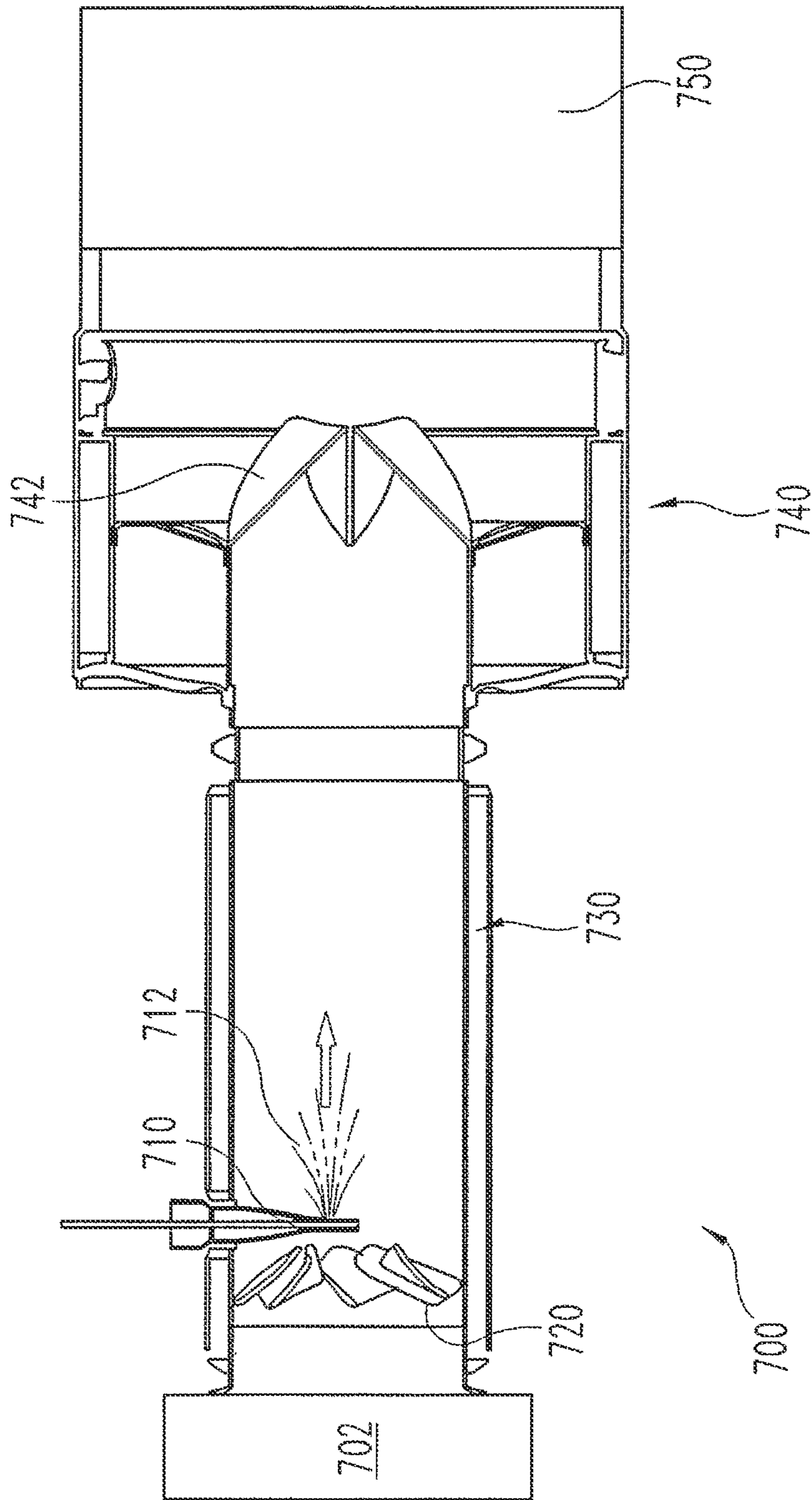


Fig. 7

1

AIR CURTAIN FOR UREA MIXING CHAMBER

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED APPLICATION

This application is an application for reissue of U.S. Pat. No. 9,926,822, which issued from U.S. application Ser. No. 13/969,039, filed Aug. 16, 2013, the entire disclosure of which is incorporated by reference herein.

BACKGROUND

Selective catalytic reduction (“SCR”) exhaust aftertreatment systems are an important technology for reducing NO_x emissions from internal combustion engines such as diesel engines. SCR systems generally include a source of urea solution, a pump unit for pressurizing the urea solution, a metering unit for providing a controlled amount or rate of urea solution, and an injector which provides urea solution to an exhaust flowpath including an SCR catalyst. Many SCR systems also utilize pressurized gas to assist the flow of urea solution to the injector. While providing important reductions in NO_x emissions, SCR systems suffer from a number of shortcomings and problems. Use of urea solutions in SCR systems may result in growth of urea crystals or deposits on various components of the system, which may disrupt their operation. When the urea comes into contact with a hot injector nozzle, the urea may undergo flash-boiling, resulting in pressure waves forcing urea backward through the blending chamber and into the pressurized air supply passage. This may result in urea crystals forming within the pressurized air supply passage, which may obstruct the air supply passage, and may corrode or otherwise degrade the walls of the air supply passage. Additionally, if an injector nozzle becomes blocked, either permanently or intermittently, there is a risk that injected urea may flow into the pressurized air supply passage which may result in urea crystal formation within the pressurized air supply passage. There is a long felt need for advancements mitigating these and other shortcomings associated with SCR systems utilizing urea solution.

DISCLOSURE

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications in the illustrated embodiments, and any further applications of the principles of the invention as illustrated therein as would normally occur to one skilled in the art to which the invention relates, are contemplated herein.

SUMMARY

An illustrative embodiment includes a blending chamber having a urea inlet, a blending chamber gas inlet, and a

2

blending chamber outlet. A urea source provides a pressurized urea solution to the urea inlet at a urea injection pressure, and a pressurized gas source transmits pressurized gas to the blending chamber gas inlet via a passageway. The passageway is configured to decrease pressure of the pressurized gas transmitted along its length from a first pressure of gas received from the pressurized gas source to a second pressure of gas provided to the blending chamber gas inlet. The first pressure of gas received from the pressurized gas source is greater than the urea injection pressure, and the second pressure of gas provided to the blending chamber gas inlet is less than the urea injection pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an exemplary air-assisted urea injection system.

FIG. 2 is a sectional view of an exemplary blending device.

FIG. 3 is a cross-sectional view of an illustrative air supply nozzle.

FIG. 4 is a bottom-up elevational view of the illustrative air supply nozzle of FIG. 3.

FIG. 5 is a cross-sectional view of an illustrative cavity configured to receive an air supply nozzle.

FIG. 6 is a cross-sectional view of an illustrative air supply nozzle installed in a threaded bore.

FIG. 7 is a side sectional view of an exemplary exhaust flowpath of an SCR aftertreatment system.

DETAILED DESCRIPTION

With reference to FIG. 1 there is illustrated an exemplary system 100 for injection of urea solution into an SCR exhaust aftertreatment system. System 100 may be provided on a vehicle powered by an engine such as a diesel engine, or on an engine utilized in other applications such power generation or pumping systems. System 100 includes a pump 134 which draws urea solution from tank 140 through filter screen 138 and check valve 136. A preferred urea solution is diesel exhaust fluid (DEF) which comprises a solution of 32.5% high purity urea and 67.5% deionized water. It shall be appreciated, however, that other urea solutions may also be utilized. In a preferred form pump 134 is a diaphragm pump, though it shall be appreciated that other types of pumps may be utilized. Pump 134 is controlled to output pressurized urea solution at a predetermined pressure which flows through check valve 130, pulsation dampener 122, and filter 124 to provide pressurized urea solution to metering valve 118. System 100 may further include a bypass valve 128 which is operable to open and close to permit or prevent the flow of urea solution through bypass line 132 to a location downstream of screen 138 where it may be returned to the tank 140, for example during a purging operation.

Metering valve 118 is operable to provide urea solution to blending device 112 at a controllable rate. In certain embodiments, blending device 112 may include metering valve 118. Blending device 112 also receives a flow of pressurized air from an air supply 102 and discharges a combined flow of pressurized air and urea solution at outlet 116. Air supply 102 may be integral to a vehicle, integral to an engine, or may be an air supply dedicated to system 100. It shall be understood that additional embodiments may utilize pressurized gases other than air, for example, combinations of one or more inert gases. Air supply 102 provides pressurized air to air regulator 104. From air regulator 104 pressurized

air proceeds to air shutoff valve **106** which can be selectively opened to allow pressurized air to flow to check valve **110** and closed to obstruct the flow of pressurized air. Check valve **110** opens when the air pressure at its inlet is above a threshold pressure and closes when the air pressure is below the threshold. From check valve **110** pressurized air flows to blending device **112**. A combined flow of aqueous urea solution entrained in pressurized air exits blending device outlet **116** and is provided to nozzle **113** which is configured to inject the combined flow into an exhaust aftertreatment system **160** such as a urea decomposition tube or exhaust flow passage leading to an SCR catalyst. In the illustrated embodiment, outlet **116** is fluidly coupled to a single nozzle **113** via a fluid line. It is also contemplated that nozzle **113** may be coupled directly to outlet **116**, and that outlet **116** may be fluidly coupled to a plurality of nozzles, for example via a plurality of fluid lines.

System **100** may be controlled and monitored by a controller **101** such as an engine control module (ECM) or a doser control module (DCM). It shall be appreciated that the controller or control module may be provided in a variety of forms and configurations including one or more computing devices having non-transitory memory storing computer executable instructions, processing, and communication hardware. It shall be further appreciated that the controller may be a single device or a distributed device, and the functions of the controller may be performed by hardware or software.

Controller **101** is operatively coupled with and configured to store instructions in a memory which are readable and executable by controller **101** to control diaphragm pump **134**, air shut off valve **106**, metering valve **118**, and bypass valve **128**. Controller **101** is also operatively coupled to and may receive a signal from a pressure sensor **114**, pressure sensor **120** and temperature sensor **126**. Pressure sensor **114** is operable to provide a signal indicating the pressure in blending device **112** at a location downstream from the urea inlet and the pressurized air inlet. The pressure at this location may be pressure of a combined flow of pressurized air and urea, pressure of air alone, pressure of urea alone, or pressure in the absence of urea and compressed air depending on the operational state of metering valve **118** and air shut off valve **106**. Temperature sensor **126** is operable to provide a signal to controller **101** indicating the temperature of urea solution at a location between diaphragm pump **134** and metering valve **118**. Pressure sensor **120** is operable to provide a signal to controller **101** indicating the pressure of the urea solution upstream from of metering valve **118**.

With reference to FIG. 2, there is illustrated an exemplary blending device **200** which is operable to output a combined flow of urea solution and pressurized air. Blending device **200** includes a metering valve **202** having an outlet **203** which provides urea solution at a urea supply pressure to a blending chamber **204**. Metering valve **202** can be controlled by controller **101** to provide urea solution at a controlled rate in a controlled amount. Blending chamber **204** also receives a flow of pressurized air from flow passage **330**, which extends from an outlet **306** to a seating surface **308**. Flow passage **330**, outlet **306**, and seating surface **308** are each defined by a nozzle **300**. Nozzle **300** is installed in a cavity which is formed in a wall of blending device **200** between air supply chamber **222** and blending chamber **204**. It shall be appreciated that the illustrated blending device **200** is but one example and that a variety of alternate blending devices including different configurations, geometries and components may also be utilized in additional embodiments.

The flow passage may **330** may be provided in a number of different configurations. In the embodiment illustrated in FIG. 2, a set of threads defined by an outer surface of nozzle **300** matingly engage a corresponding set of threads defined by a surface of the cavity. It is also contemplated that nozzle **300** may be coupled to blending device **200** by other methods, or that passage **330** may be defined by the wall through which it extends without use of an insert. The flow of pressurized air through flow passage **330** is controlled to have a velocity and flow characteristics effective to provide an air curtain which resists formation and migration of urea crystals and accommodates elevated pressure conditions which would otherwise inhibit injection of urea solution into blending chamber **104**.

In the illustrated form, blending chamber **204** is a substantially cylindrical passage which is configured so that urea received from metering valve **202** is entrained in a flow of pressurized air received from flow passage **330**, and a combined flow of pressurized air and urea solution is provided to outlet member **230** which is connected to an injector configured to provide the combined flow to an exhaust aftertreatment system. Pressure sensor **207** is operable to sense the pressure of the blended flow at a location downstream from urea outlet **203** and air outlet **306**.

The flow of pressurized air to flow passage **330** is controlled by air supply and valve components which are configured to control a supply of air to flow passage **330**. One example of a preferred embodiment includes check valve **209** and an upstream air shut off valve. Check valve **209** includes a closing member **210** which extends from a flexible diaphragm **223** in a direction toward seating surface **308**. In FIG. 2, closing member **210** is illustrated in a closed position in which it contacts seating surface **308** to form a seal and prevent flow from air supply chamber **222** to flow passage **330**. Biasing member **214** applies force to plunger **212** which applies force to closing member **210** to maintain check valve **209** in the closed position. Biasing member **214** is illustrated in the form of a spring but may be a variety of other biasing members operable to provide force to closing member **210** in a direction toward seating surface **308**. Valve cover **216** contacts biasing member **214** and holds it in position relative to plunger **212**. Valve cover **216** also contacts diaphragm **223** and secures it to the underlying structure of blending device **200**. It shall be appreciated that a number of alternate valve and air supply embodiments may also be utilized to control the supply of air to flow passage **330**. Such further embodiments may include an air supply control valve, a check valve or various combinations thereof.

The lower surface of diaphragm **223** is exposed to air supply chamber **222** which receives pressurized air from air inlet **220**. As used herein, directional terms such as "lower" and "upper" are used to refer to the orientation of the drawings. Such terms are not restrictive of the orientation of the system with respect to the environment. For example, descriptions that reference a vertical direction are equally applicable when the system is in a horizontal orientation or off-axis orientation.

The pressurized air in air supply chamber **222** provides a force against the portions of the lower surface of diaphragm **223** and closing member **210** in contact with air supply chamber **222**. This force opposes the force applied to closing member **210** by plunger **212** and biasing member **214**. When the force provided by pressurized air in air supply chamber **222** is greater than the force provided by biasing member **214** check valve **209** opens and pressurized air flows from air supply chamber **222** past check valve **209**, and into flow

5

passage 330. The opening/closing threshold pressure is established by the pre-loading of biasing member 214. The pre-loading of biasing member 214 is preferably tuned to provide rapid opening of check valve 209 at a pressure at or near a threshold pressure. The threshold pressure is preferably selected to be at or near the normal operating air pressure during urea injection, for example, 90% or more of the normal operating air pressure. This allows check valve 209 to open only when there is sufficient pressure for injection. As further described below, the threshold pressure is selected to be a pressure higher than the urea supply pressure.

The threshold pressure is also preferably selected to provide air flow characteristics effective to inhibit urea crystal growth in flow passage 330 and urea crystal migration toward closing member 210. The inventors have determined that a threshold air flow velocity of at least 47 meters per second (m/s) is effective to inhibit urea crystal growth and migration in flow passage 330. The threshold pressure may be selected to provide a margin of error on the threshold velocity; for example, the pressure may be selected to provide air flow velocity in flow passage 330 of about 50 m/s or between 50 m/s and 60 m/s. It shall be appreciated that the threshold air flow velocity may be provided at one location along or over a portion of flow passage 330.

The magnitude of the air flow velocity effective to inhibit urea crystal growth may vary depending upon the characteristics of flow passage 330, check valve 209 and blending chamber 204. Additional embodiments include air supply passages with different characteristics and have different threshold air pressure values and associated air flow velocities effective to inhibit urea crystal growth. Flow passage 330 is further configured to reduce the velocity of air flow provided to the blending chamber below the threshold air flow velocity. A diffuser section of flow passage 330 may be utilized to provide a desired outlet air flow velocity. The outlet air flow velocity may be selected to avoid damage to blending chamber 204.

Flow passage 330 is further configured to provide a pressure drop along its length such that the air pressure at the inlet of flow passage 330 is greater than the urea injection pressure into the blending chamber 204 and the air pressure at the outlet of flow passage 330 is less than the urea injection pressure into the blending chamber 204. In the illustrated embodiment, flow passage 330 extends over a length of about 6 mm and is configured to provide an outlet pressure of 3.45 bar gauge \pm 0.4 bar gauge. This pressure was selected because the nominal urea injection pressure was 4.5 bar gauge and the an air pressure about 1 bar gauge below the nominal urea injection pressure was desired. The desired air pressure in the blending chamber may be used to determine the regulation pressure upstream and the nominal orifice sizing leading to the flow passage 330 to ensure that the air velocity in the air curtain is maintained at or above a threshold velocity.

During normal operation of blending device 200, the pressure at or around the outlet of blending chamber 204 is configured to be less than the air pressure at the outlet of the flow passage 330 and less than the urea injection pressure into the blending chamber 204. Abnormal operating conditions may arise in which the pressure at or downstream of the outlet of blending chamber 204 exceeds the urea injection pressure. This may occur, for example, due to flash boiling of urea injected into a hot exhaust flow path which causes pressure waves to travel toward blending chamber 204. Under such abnormal conditions the pressure drop along flow passage 330 is effective to permit urea injection

6

which would otherwise be inhibited. Additional abnormal operating conditions may arise when a urea injection nozzle becomes blocked either permanently or intermittently. Blockages intermediate the blending chamber 204 and the urea injection nozzle represent further potential abnormal operating conditions.

When abnormal operating conditions are present urea injected into a blending chamber can flow into a portion of flow passage 330 as the pressure at the outlet of flow passage 330 is less than the urea injection pressure, but is prevented from flowing to or past the inlet of flow passage 330 as the pressure at the inlet of flow passage 330 is greater than the urea injection pressure. Once normal operating conditions are restored, the urea solution is expelled from flow passage 330, returns to the blending chamber 204 for injection into the exhaust flowpath. This operation allows system 200 to provide a predetermined amount of urea injection when abnormal operating conditions would otherwise inhibit injection and thus avoids or mitigates disruptions in the supply of the desired amount of urea solution to the exhaust flowpath.

With reference to FIGS. 3 and 4 in addition to FIG. 2, an illustrative nozzle 300 includes a head 310, a ledge 312, a cylindrical portion 314, a threaded portion 316, a tip 318, and a flow passage 330. Flow passage 330 extends along an axial centerline 302 from an inlet 304 to outlet 306, and includes a seating portion 332, a restriction 334, and diffuser 336. Flow passage 330 is configured to transmit pressurized air from air supply passage 222 to blending chamber 204 through inlet 304, seating portion 332, restriction 334, diffuser 336, and outlet 306.

Head 310 has formed therein seating surface 308, which tapers radially inward from inlet 304 to restriction 334, defining seating portion 332. In the illustrated embodiment, seating surface 308 is offset from axial centerline 302 by an offset angle α , defining seating portion 332 as a frustoconical portion. It is also contemplated that other geometries may be employed, depending upon design parameters such as desired flow profile, and properties of stopping member 210. For example, a portion of seating surface 308 may be offset from axial centerline 302 by an angle other than offset angle α , and may be curvilinear. It is also contemplated that seating surface 308 and seating portion 332 may be omitted, an illustrative embodiment of which is described with reference to FIG. 6.

In the illustrated embodiment, head 310 is hexagonal, facilitating torque transmission during installation into the corresponding cavity in blending chamber 200. In other embodiments, head 310 may be defined by another geometric shape. Ledge 312 and cylindrical portion 314 are configured to seal an air supply passage from a cavity in which nozzle 300 is seated. The radius of ledge 312 is slightly greater than the pitch radius of threads 320. In the illustrated embodiment, the diameter of cylindrical portion 314 is less than the major diameter of threaded portion 316, and greater than the pitch diameter of threaded portion 316. It is also contemplated that cylindrical portion 314 may be of another diameter, or may be replaced with a radially-inward tapering nozzle body portion.

Threaded portion 316 defines a plurality of threads 320. As used herein, "plurality of threads" indicates that a cross-section of threaded portion 316 along axial centerline 302 reveals a plurality of ridges, which may of course be formed by a single ridge wrapping around the outer circumference of threaded portion 316. Threads 320 are configured to

matingly engage a corresponding set of threads formed in the corresponding cavity. The lower end of threaded portion 316 defines face 322.

Tip 318 includes a tapered surface 323 connecting face 322 to nozzle face 324. Tapered surface 323 tapers radially inward at a tip angle β , and may be closely engaged with a correspondingly-shaped frustoconical portion of a cavity in which nozzle 300 is seated such that the cavity is sealed from the blending chamber. Tip 318 defines outlet 306, through which pressurized air is discharged into blending chamber 204. In the illustrated embodiment, outlet 306 is defined by a second end of diffuser 336. In other embodiments, outlet 306 may be connected to diffuser 336 by way of an intermediate flow passage portion.

Seating portion 332 is configured to receive pressurized air from air supply chamber 222 when check valve 209 is open. Seating portion 332 has an inlet of a first diameter and an outlet of a second diameter less than the first diameter. The second diameter of the outlet is configured to provide pressurized air flow exceeding the threshold velocity. In further embodiments, seating surface 308 and seating portion 332 may be omitted, in which case an orifice leading to restriction 334 may be formed in the upper surface of head 310 and configured with a diameter providing pressurized air flow meeting or exceeding the threshold velocity.

When seating portion 332 is included, restriction 334 is downstream of seating portion 332. In the embodiment of FIG. 3, the outlet of seating portion 332 is the inlet of restriction 334, such that a diameter of restriction 334 is the second diameter. It is also contemplated that restriction 334 may be fluidly coupled to seating portion 332 by way of an intermediate flow passage portion, in which case the diameter of restriction 334 may not be equal to the second diameter. The diameter and axial length of restriction 334 are selected to reduce the pressure and increase the velocity of the pressurized air by a predetermined amount. In the illustrated embodiment, the axial length of restriction 334 is about thirty percent of the total length of nozzle 300. For example, the axial length of nozzle 300 may be about 8 mm, and the axial length of restriction 334 may be about 2.5 mm. In other embodiments, other configurations are contemplated. Furthermore, while restriction 334 is cylindrical, in other embodiments a restriction may be of varying diameters.

Diffuser 336 is located downstream of restriction 334, and is configured to decrease the velocity of the pressurized air. In the illustrated embodiment, the outlet of restriction 334 is the inlet of diffuser 336, such that the inlet diameter of diffuser 336 is the second diameter. It is also contemplated that diffuser 334 may be fluidly coupled to restriction 334 by way of an intermediate flow passage portion, in which case the inlet diameter of restriction diffuser 336 may not be the second diameter.

Diffuser 336 tapers radially outward at a diffuser angle of γ from a diffuser inlet diameter to a diffuser outlet diameter greater than the diffuser inlet diameter. In the embodiment of FIG. 3, the diffuser inlet diameter is the second diameter, the diffuser outlet diameter is a third diameter, and diffuser angle γ is selected such that diffuser 336 extends from restriction 334 to outlet 306. The diffuser outlet diameter is selected such that the velocity of the pressurized air is decreased to an outlet velocity at which wear resulting from high pressure impact with the walls of blending chamber 204 is reduced to a desired velocity which may be selected to mitigate wear or damage on the blending chamber from air provided thereto.

As previously noted, when the velocity of the pressurized air in the flow passage is above a threshold velocity, urea

crystal migration in flow passage 330 is inhibited. Restriction 334 and diffuser 336 of flow passage 330 are configured to provide pressurized air having a velocity greater than the threshold velocity when supplied with pressurized air at the threshold pressure, thereby preventing urea crystal migration upstream through restriction 334. Flow passage 330 may alternatively be configured to provide a margin of error on the threshold velocity; for example, flow passage 330 may be configured to provide a velocity of at least about 50 m/s, or between 50 m/s and 60 m/s when supplied with pressurized air at the threshold pressure.

In certain embodiments, the diffuser angle is relatively small— 10° or less—and the diffuser may extend substantially to the nozzle outlet. For example, in the embodiment of FIG. 3, diffuser angle γ is less than about 5° , and diffuser 336 extends to outlet 306. In other embodiments, diffuser angle γ may be selected from another range, for example less than 10° , or 3° to 15° . In further embodiments, the diffuser angle is relatively large—for example, 20° or more—and the diffuser may be connected to the nozzle outlet by way of a connecting passage. Preferably the transitions between different orifice diameters and straight/angled sections of flow passage 330 are configured to maintain a boundary layer connection to the curtain walls and smooth laminar flow throughout. Undesired operation may result if the diffuser angle is too high as the laminar flow in the curtain may separate forming a vortices in the curtain which can significantly increase crystal growth and may ultimately leading to failure.

Restriction 334 and diffuser 336 are configured to provide a pressure drop along their combined length such that the air pressure at the inlet of restriction 334 is greater than the urea injection pressure into a blending chamber in communication with nozzle 300 and the air pressure at the outlet of diffuser 336 is less than the urea injection pressure into the blending chamber. During normal operation, the pressure at or around the outlet of the blending chamber is configured to be less than the air pressure at the outlet of the diffuser 336 and less than the urea injection pressure into the blending chamber. Abnormal operating conditions may arise in which the pressure at or downstream of the outlet of the blending chamber exceeds the urea injection pressure. This may occur, for example, due to flash boiling of urea injected into a hot exhaust flow path which causes pressure waves to travel toward the blending chamber. Under such abnormal conditions the pressure drop along restriction 334 and diffuser 336 is effective to permit urea injection which would otherwise be inhibited. When such abnormal conditions are present urea injected into blending chamber can flow into a portion of diffuser 336 and restriction 334 up to the point at which the pressure exceeds the injection pressure. The blending chamber may be configured to allow such urea flow at various distances along diffuser 336 or restriction 334 but to prevent urea from flowing to or past the inlet of flow passage 330 as the pressure at the inlet of flow passage 330 is greater than the urea injection pressure. Once normal operating conditions are restored, the urea solution is expelled from flow passage 330, returns to the blending chamber for injection into the exhaust flowpath. This operation allows a system including nozzle 300 to provide a predetermined amount of urea injection when abnormal operating conditions would otherwise inhibit injection and thus avoids or mitigates disruptions in the supply of the desired amount of urea solution to the exhaust flowpath.

FIG. 5 depicts an exemplary embodiment of a cavity 500. Cavity 500 is formed in a wall 550—for example a wall of blending device 200—between an air supply chamber 551

and a blending chamber 552. Cavity 500 includes a ledge-accepting portion 512, a cylinder-accepting portion 514, a threaded portion 516, and a tip-accepting portion 518. Cavity 500 is depicted with nozzle 300 installed (illustrated in phantom), such that cavity 500 and nozzle 300 share a common axial centerline 502.

Ledge-accepting portion 512 is configured to closely engage ledge portion 312. Ledge-accepting portion 512 and ledge 312 cooperate to form a seal such that cavity 500 is substantially sealed from air supply chamber 551. The diameter of ledge-accepting portion 512 corresponds to the diameter of ledge 312.

Cylinder-accepting portion 514 is configured to closely engage at least a section of cylinder portion 314. Cylinder-accepting portion 514 has a diameter corresponding to that of cylinder portion 314. Cylinder-accepting portion 514 also defines a plurality of recesses sized to accept nozzle threads 320. The recesses have a maximum radius corresponding to the pitch radius of threads 320.

Threaded portion 516 includes a plurality of cavity threads 520 defined by a plurality of alternating recesses and protrusions. Cavity threads 520 are configured to matingly engage nozzle threads 320, thereby securing nozzle 300 within cavity 500.

Tip-accepting portion 518 is configured to closely engage nozzle tip 318. Tip-accepting portion 518 includes a flat portion configured to closely engage face 322, and a tapered portion configured to closely engage tapered surface 323. Tip-accepting portion 518 also defines cavity outlet 508, which is of a diameter corresponding to that of nozzle face 324. In the illustrated embodiment, tip-accepting portion 518 is configured such that nozzle face 324 is substantially flush with a bottom surface 524 of wall 550. In other embodiments, tip-accepting portion 518 may be of a lesser axial length than nozzle tip 318, such that nozzle tip 318 extends into blending chamber 552. In further embodiments, tip-accepting portion 518 may be of a greater axial length than nozzle tip 318, such that cavity 500 includes a connecting passageway that connects nozzle outlet 306 to blending chamber 552.

FIG. 6 illustrates an exemplary nozzle 600 which does not include a seating portion. Nozzle 600 is seated in a cavity 601 which is formed in a wall 650 between an air supply chamber 651 and a blending chamber 652. Nozzle 600 defines a flow passage 630, which includes an inlet 604, a restriction 634, a diffuser 636, and an outlet 604. Restriction 634 is fluidly coupled to air supply passage 602 at inlet 604, and to diffuser 636 at interface 635. Diffuser 636 is fluidly coupled to restriction 634 at interface 635, and to blending chamber 603 at outlet 606.

With reference now to FIG. 7, there is illustrated an exemplary exhaust flow path 700 for an SCR aftertreatment system. Exhaust flow path 700 includes an exhaust source 702 which may be a diesel engine for example. Exhaust source 702 provides a flow of exhaust comprising a NO_x constituent through conduit 730. A mixer 720 is disposed in the conduit 730. An injection nozzle 710 is disposed in a location downstream from the mixer 720 at or about the centerline of conduit 730. A blending device, such as blending device 200, supplies a pressurized urea-gas mixture to injection nozzle 710, which injects the mixture in the direction of exhaust flow as indicated by spray 712 and the associated arrow. Spray 712 is distributed generally uniformly in the central region of flow path 730 but not distributed uniformly in the peripheral region of flow path 730.

Mixer 720 imparts a swirl in exhaust flowing through the peripheral region of conduit 730 while allowing flow to continue to proceed normally through the central portion of conduit 730. In this manner exhaust back pressure is minimized by providing minimal instruction to obtain exhaust swirl only in the location where it is needed. The spray of urea solution 712 introduced into conduit 730 decomposes along the length of conduit 730 downstream from injection nozzle 710 to form ammonia. Ammonia is provided from outlet 742 to an SCR catalyst 750 of a catalyst unit 740, which functions to reduce at least a portion of the NO_x constituent in the exhaust.

With reference now to FIGS. 2 and 3 as well as FIG. 7, further aspects of the operation of an exemplary system including nozzle 300 and injection nozzle 710 is described. A pressurized urea solution is supplied to blending chamber 204 through metering valve 202 at a nominal urea supply pressure, for example, about 65 psig. Pressurized air is supplied to blending chamber 204 at a nominal pressure of about 50 psig. Urea injection pressure is normally 1-1.5 bar gauge above air pressure. Depending on operation the urea pressure and air pressure may vary from the nominal pressures.

In the illustrated form, the pressurized air enters seating portion 332, which increases the velocity to a first velocity and reduces the pressure to a first pressure while conveying the pressurized air toward restriction 334. The first pressure is preferably also greater than the urea supply pressure. The pressurized air enters restriction 334 at a second velocity and a second pressure. In embodiments which include seating portion 332, the second velocity and the second pressure correspond to the first velocity and the first pressure. In embodiments in which seating portion 332 is not included, the second velocity and the second pressure correspond to the inlet velocity and the inlet pressure. In either case, the second pressure is less than the chamber pressure, and the velocity of the compressed air in restriction 334 and diffuser 336 of flow passage 330 is greater than a threshold velocity sufficient to inhibit urea crystal growth and migration. By way of non-limiting example, the threshold velocity may be 47 m/s, about 50 m/s, or between 50 m/s and 60 m/s.

Restriction 334 further reduces the pressure of the pressurized air. The pressurized air exits restriction 334 and enters diffuser 336 at a third velocity and a third pressure. The third pressure may be greater than or less than the urea supply pressure, and the third velocity may be greater than or equal to the threshold velocity. Diffuser 336 expands and slows the pressurized air, and discharges the pressurized air into blending chamber 204 through outlet 306. At outlet 306, the pressurized air has a fourth velocity and a fourth pressure. The fourth velocity is lower than the threshold velocity, and is sufficiently low to reduce wear which would otherwise result from high pressure impact with the walls of blending chamber 204. The fourth pressure is less than the urea supply pressure, and may be, for example, about 20 psig. The fourth pressure is less than the inlet pressure by at least a minimum pressure loss, and is preferably less than the first pressure by at least the minimum pressure loss. The minimum pressure loss is at least 15 psi, and is preferably 20 psi or 30 psi.

During normal operation of the system, the pressurized urea and the pressurized air enter blending chamber 204, and the urea becomes entrained in the pressurized air. This urea-air mixture is conveyed to injection nozzle 710 via a mixture supply line. Due to the high temperature exhaust flowing through conduit 730, injection nozzle 710 can become very hot. When injection nozzle 710 is at a high

11

enough temperature, the urea-gas mixture may undergo flash-boiling upon contacting injection nozzle 710. This flash-boiling sends a pressure wave back through the mixture supply line and toward blending chamber 204.

When the pressure wave increases the pressure at the outlet of the blending chamber 204 above the urea injection pressure, the pressurized urea can no longer exit via outlet member 230, and instead flows into air flow passage 330. Because the pressure at the inlet of air flow passage 330 is greater than the urea injection pressure, the pressurized urea is prevented from traveling beyond the inlet where urea crystal formation can be problematic. At the same time injection is not inhibited because the pressure at the outlet of air flow passage 330 is less than the urea injection pressure.

Once the pressure wave has dissipated, the pressurized urea exits flow passage 330, and the system returns to functioning as before. The high velocity of the pressurized air within flow passage 330 creates a shear force sufficient to remove any urea droplets or crystals which may be present on the walls of the flow passage. This mitigates the reliability and warranty issues associated with crystallization and loss of air flow due to flash boil crystallization at hot exhaust conditions. As noted above, during operation of the system it is also possible that a urea injection nozzle may become blocked either permanently or intermittently. In the event of such blockage, the pressure at the inlet of air flow passage 330, which is greater than the urea injection pressure, prevents the injected urea from traveling beyond the inlet where urea crystal formation can be problematic. When the blockage is removed, injection may proceed according to normal operation.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only certain exemplary embodiments have been shown and described and that all changes and modifications that come within the spirit of the inventions are desired to be protected. It should be understood that while the use of words such as preferable, preferably, preferred or more preferred utilized in the description above indicate that the feature so described may be more desirable, it nonetheless may not be necessary and embodiments lacking the same may be contemplated as within the scope of the invention, the scope being defined by the claims that follow. In reading the claims, it is intended that when words such as "a," "an," "at least one," or "at least one portion" are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. When the language "at least a portion" and/or "a portion" is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

The invention claimed is:

1. A system comprising:

- a urea blending chamber having a urea inlet, a blending chamber gas inlet, and a blending chamber outlet, the urea blending chamber defining a first axial flow path;
- a source of pressurized urea solution configured to provide pressurized urea solution to the urea inlet at a urea injection pressure, the urea inlet axially aligned with the first axial flow path so as to insert the pressurized urea solution along the first axial flow path; and
- a pressurized gas source configured to transmit pressurized gas to the blending chamber gas inlet via a gas flow passageway extending along a length from the pressurized gas source to the blending chamber gas inlet, the gas flow passageway defining a second axial

12

flow path oriented orthogonal to the first axial flow path of the urea blending chamber, the gas flow passageway including:

- an inwardly tapered gas flow seating portion including a seating portion inlet having a first diameter,
- a gas flow restriction portion adjacent to and downstream of the inwardly tapered gas flow seating portion, the gas flow restriction portion having a second diameter and an axial length, the second diameter and the axial length being configured to cause an increase in a velocity of the pressurized gas passing through the gas flow restriction portion to a value above a threshold velocity at which urea crystal migration upstream through the gas flow restriction portion is inhibited, and
- a gas flow diffuser including a gas flow diffuser outlet having a third diameter larger than the second diameter and smaller than the first diameter, thus forming an outward taper to decrease the velocity of the pressurized gas;

wherein the gas flow passageway is configured to provide a pressure drop along a combined length of the gas flow restriction portion and the gas flow diffuser from a first pressure of gas received from the pressurized gas source to a second pressure of gas provided to the blending chamber gas inlet; and

wherein the first pressure of gas received from the pressurized gas source is greater than the urea injection pressure and the second pressure of gas provided to the blending chamber gas inlet is less than the urea injection pressure.

2. The system of claim 1, wherein when a pressure at the blending chamber outlet is greater than the urea injection pressure, the pressurized urea solution injected into the urea blending chamber travels along a portion of the length of the gas flow passageway in which the pressure of the pressurized gas is equal to the second pressure of gas.

3. The system of claim 1, wherein the gas flow passageway is configured to decrease velocity of the pressurized gas transmitted along its length from a first velocity at a first location along its length to a second velocity provided to the urea blending chamber.

4. The system of claim 3, wherein the second velocity provided to the urea blending chamber is 47 meters per second or greater.

5. The system of claim 1, wherein the gas flow passageway is defined in a nozzle extending through a cavity formed by a wall of the urea blending chamber, an outer surface of the nozzle defining a plurality of threads matingly engaged with a plurality of counter-shaped threads defined by an inner surface of the cavity.

6. The system of claim 1 wherein the gas flow passageway has a uniform cross sectional area between a first location downstream of the pressurized gas source and a second location downstream of the first location and an increasing cross sectional area between the second location and a third location downstream from the second location and upstream from the urea blending chamber gas inlet.

7. The system of claim 6 wherein the increasing cross sectional area is defined by a frustoconical surface of the gas flow passageway.

8. The system of claim 1, wherein the blending chamber outlet is fluidly coupled to an injector nozzle configured to inject a urea-gas mixture into an exhaust gas conduit having a selective catalytic reduction (SCR) catalyst disposed therein at a position downstream of the injector nozzle.

13

9. The system of claim 8, wherein the exhaust gas conduit is configured to receive an exhaust stream from a diesel engine, the exhaust stream comprising a NO_x constituent as a byproduct of operation of the diesel engine.

10. The system of claim 1 wherein the decrease in pressure value of the pressurized gas from the first pressure to the second pressure is 2 bar or greater.

11. The system of claim 1 wherein the gas flow passage-way is configured to provide the pressurized gas to the blending chamber gas inlet at a first velocity of at least 47 meters per second and to provide the pressurized gas at a second velocity greater than the first velocity at a location upstream from the blending chamber gas inlet.

12. The system of claim 1 wherein the gas flow passage-way is configured to provide the pressurized gas to the blending chamber gas inlet at a first velocity of at least 50 meters per second and to provide the pressurized gas at a second velocity greater than the first velocity at a location upstream from the blending chamber gas inlet.

13. The system of claim 12, wherein the second velocity is between 50 meters per second and 60 meters per second at the location upstream from the blending chamber gas inlet.

14. An apparatus comprising:

a urea blending chamber having a urea inlet, a gas inlet, and an outlet, the urea blending chamber defining a first axial flow path;

an injector configured to provide pressurized urea solution to the urea inlet at a urea injection pressure, the urea inlet axially aligned with the first axial flow path so as to insert the pressurized urea solution along the first axial flow path; and

a valve configured to provide pressurized gas to a gas flow passage in flow communication with the valve and the gas inlet, the gas flow passage defining a second axial

14

flow path oriented orthogonal to the first axial flow path of the urea blending chamber, the gas flow passage including:

an inwardly tapered gas flow seating portion including a seating portion inlet having a first diameter,

a gas flow restriction portion adjacent to and downstream of the inwardly tapered gas flow seating portion, the gas flow restriction portion having a second diameter and an axial length, the second diameter and the axial length being configured to cause an increase in a velocity of the pressurized gas passing through the gas flow restriction portion to a value above a threshold velocity at which urea crystal migration upstream through the gas flow restriction portion is inhibited, and

a gas flow diffuser including a gas flow diffuser outlet having a third diameter larger than the second diameter and smaller than the first diameter, thus forming an outward taper to decrease the velocity of the pressurized gas;

wherein the gas flow passage is configured to provide a pressure drop along a combined length of the gas flow restriction portion and the gas flow diffuser from a first pressure of gas received from the pressurized gas source to a second pressure of gas provided to the blending chamber gas inlet; and

wherein the first pressure is greater than the urea injection pressure and the second pressure is less than the urea injection pressure.

15. The apparatus of claim 14 wherein the decrease from the first pressure to the second pressure is 1-2 bar gauge.

16. The apparatus of claim 14 wherein the second pressure is less than the first pressure by at least 1 bar gauge.

* * * * *