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(54) **SYSTEM FOR DISPENSING FUEL INTO AN EXHAUST SYSTEM OF A DIESEL ENGINE**

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(57) **ABSTRACT**

A system is disclosed for dispensing fuel into the transient flow of an exhaust system to control exhaust emissions. A controller initiates the delivery of fuel into the exhaust when an emissions control device, such as a diesel particulate filter, requires increased exhaust temperatures for regeneration. In operation, pressurized fuel and pressurized air are supplied to a fuel delivery device, wherein a fuel injector pre-mixes fuel with air. The fuel-air mixture is then dispensed into the exhaust flow through a nozzle, causing a rapid pressure drop in the mixture that results in the pressurized air expanding rapidly, breaking the fuel spray into fine particles.

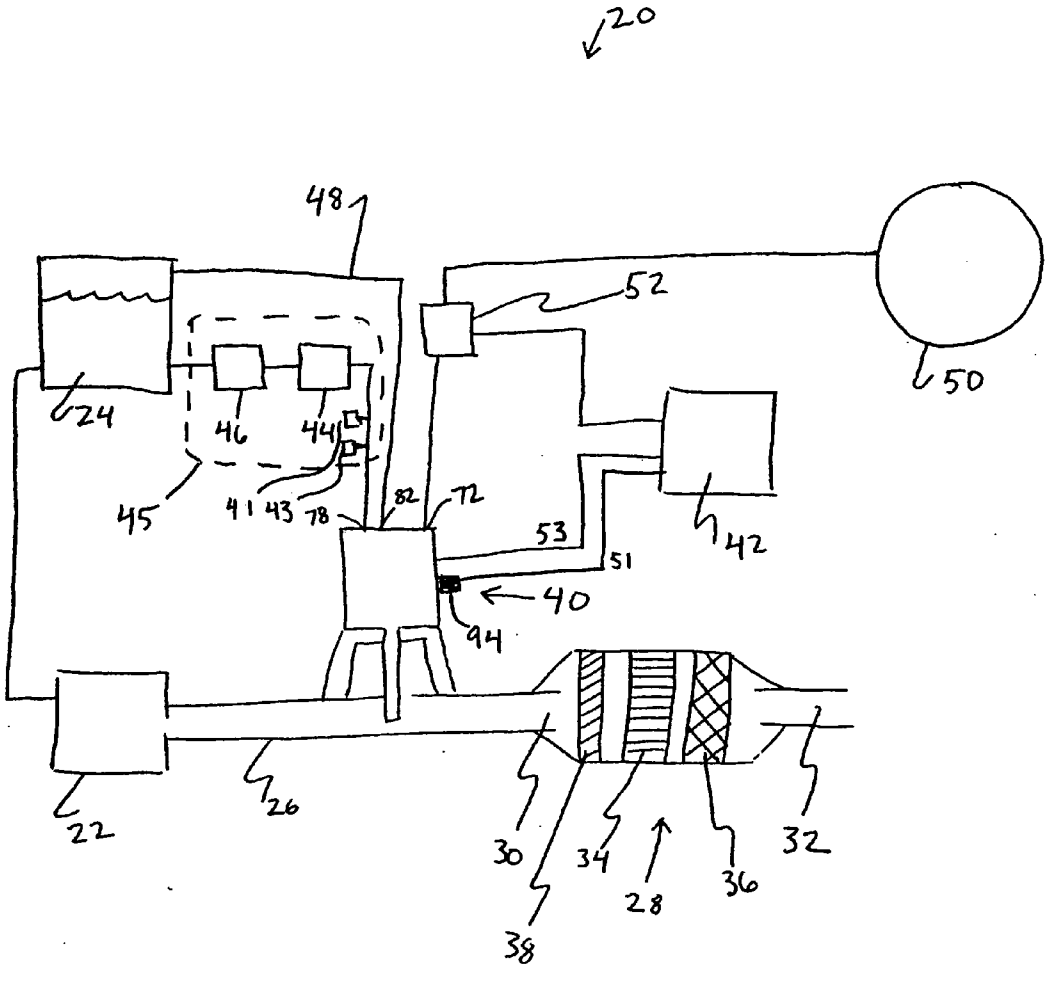


FIG. 1

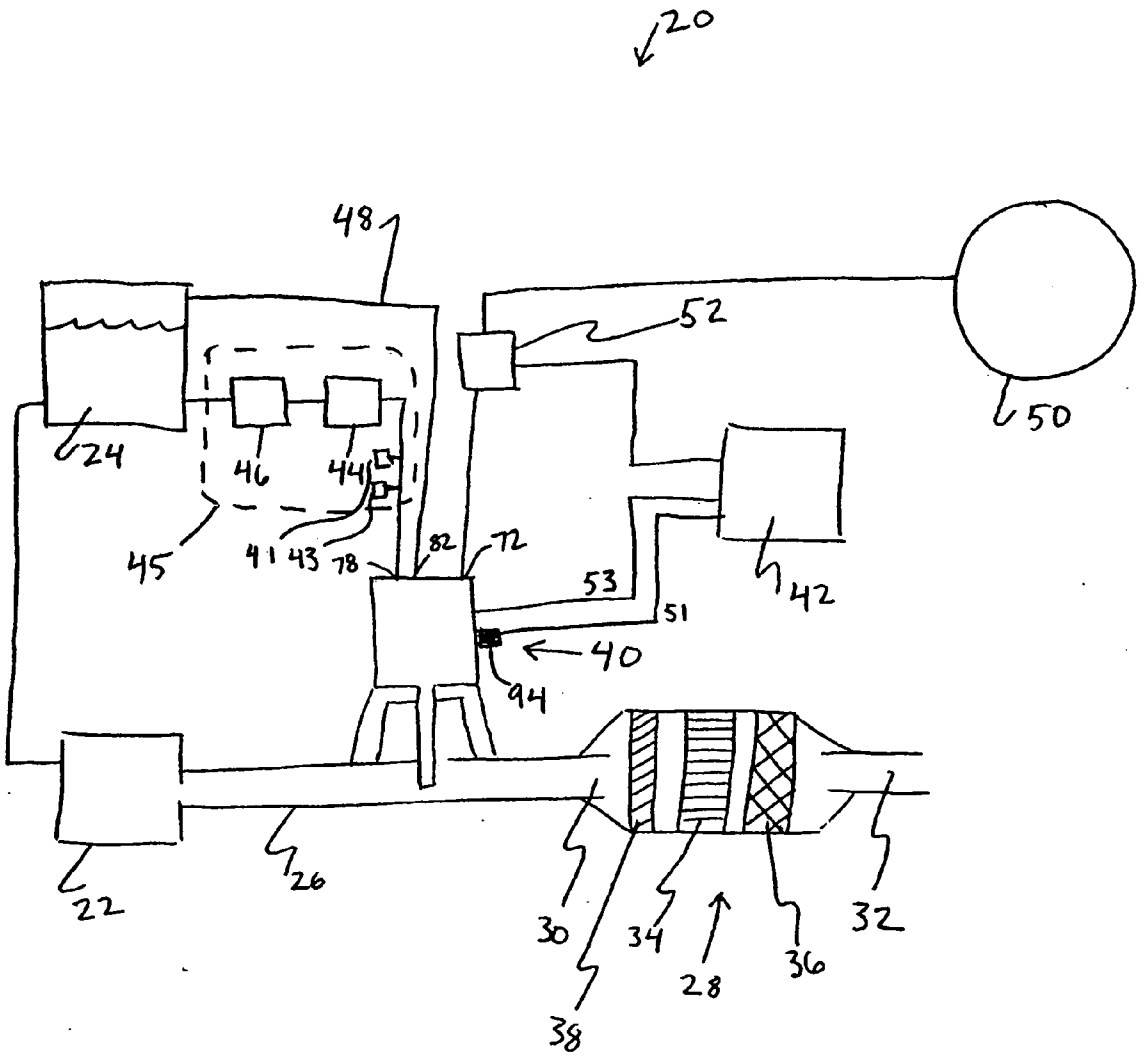

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FIG. 2A

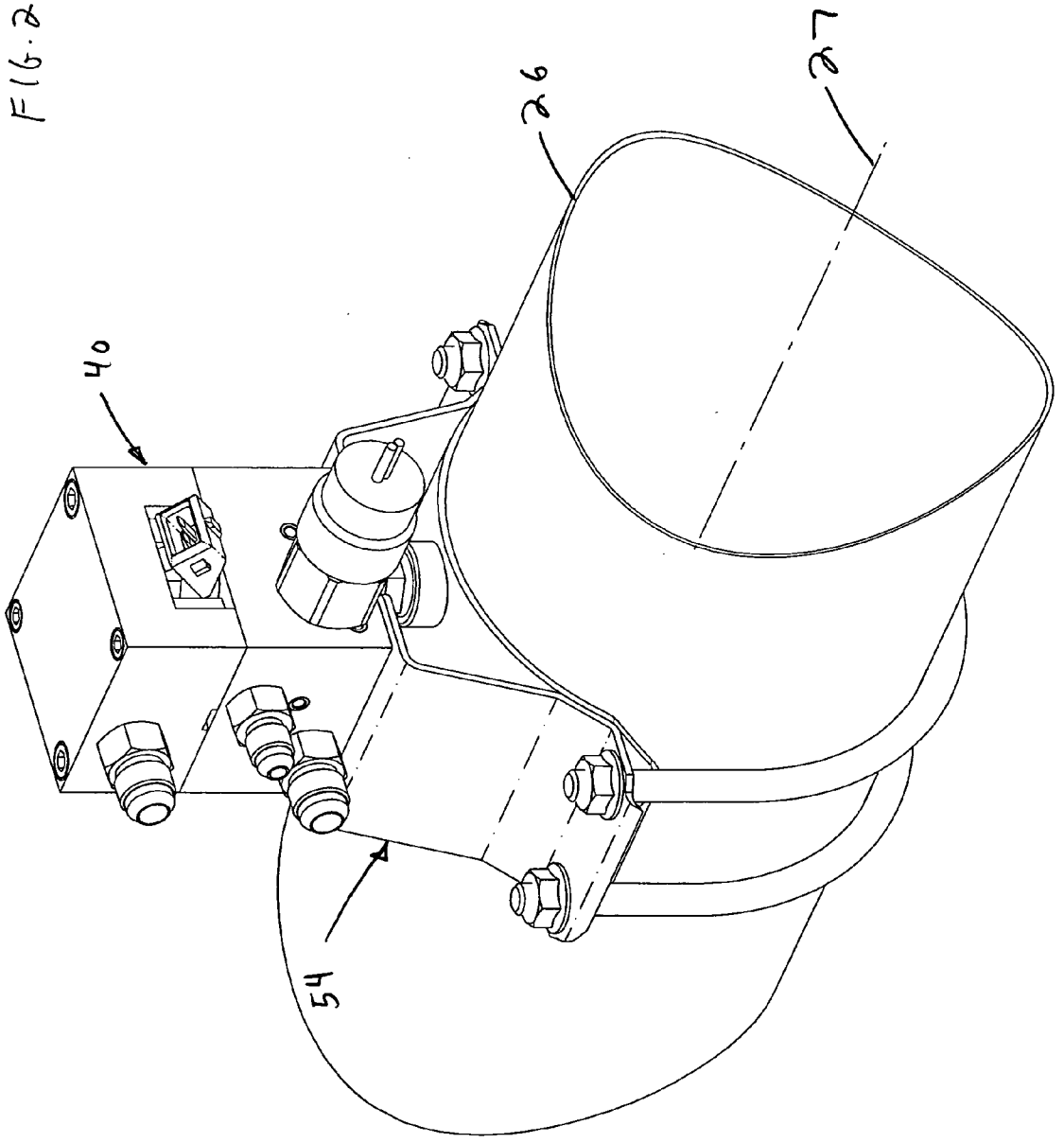


FIG. 2B

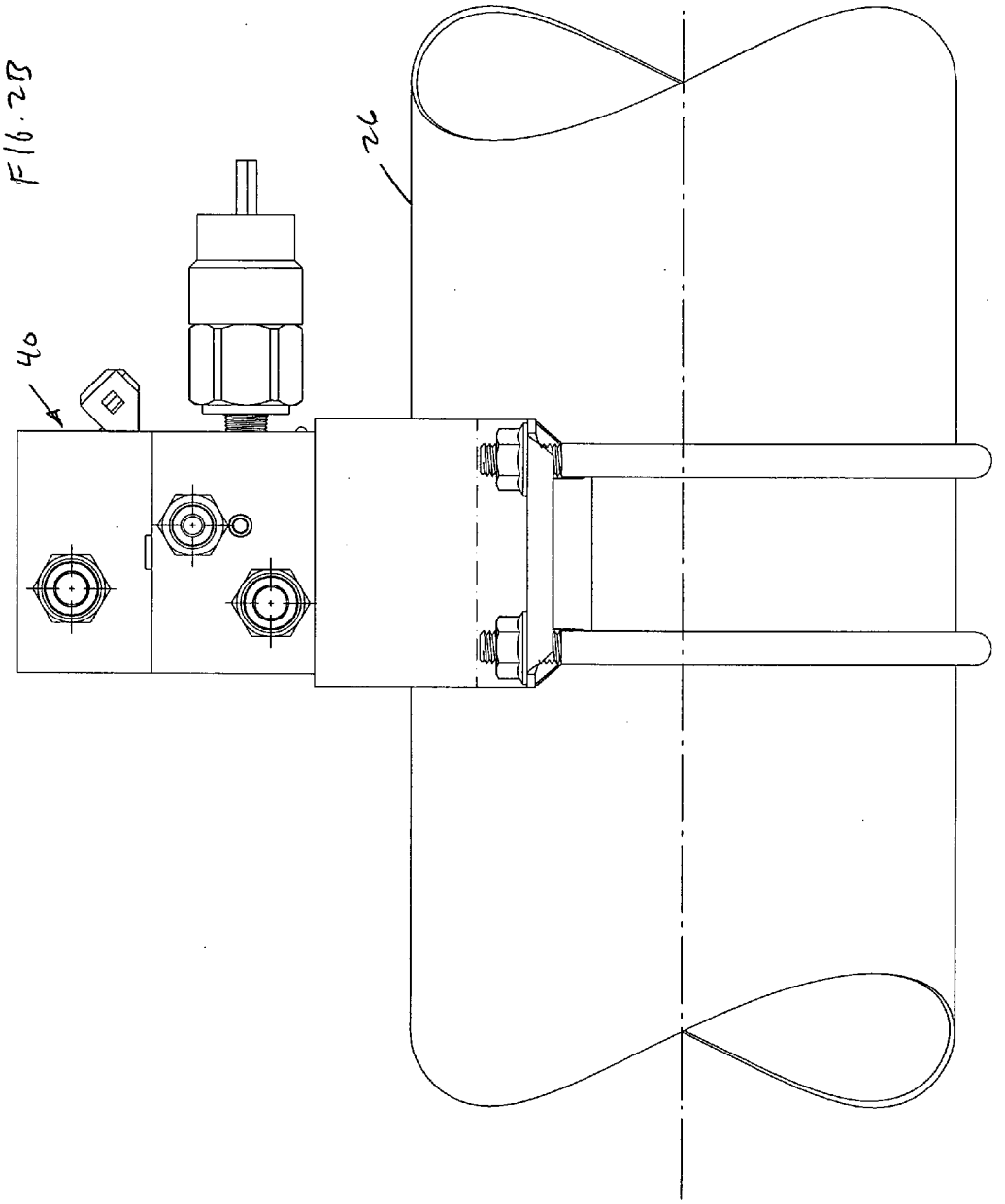


FIG. 2C

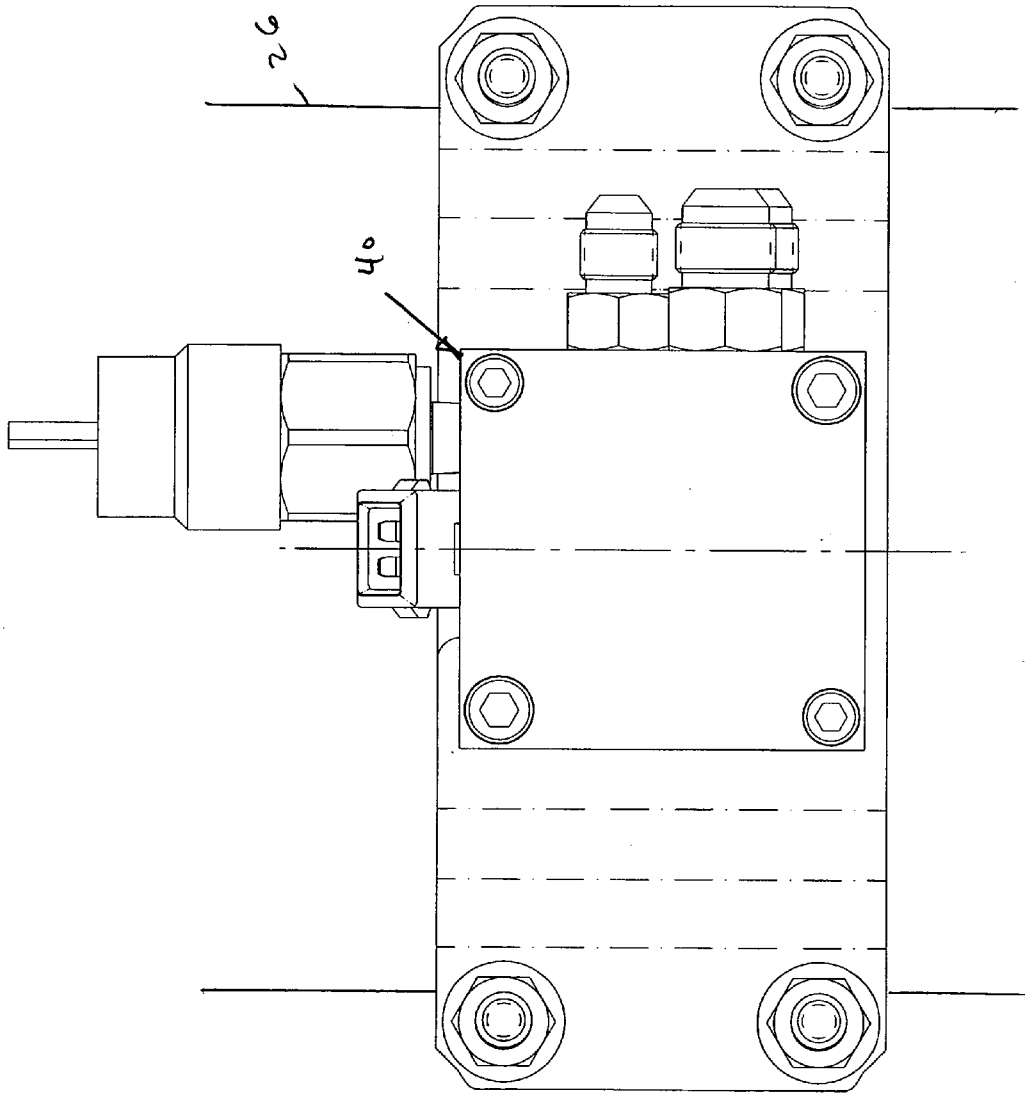
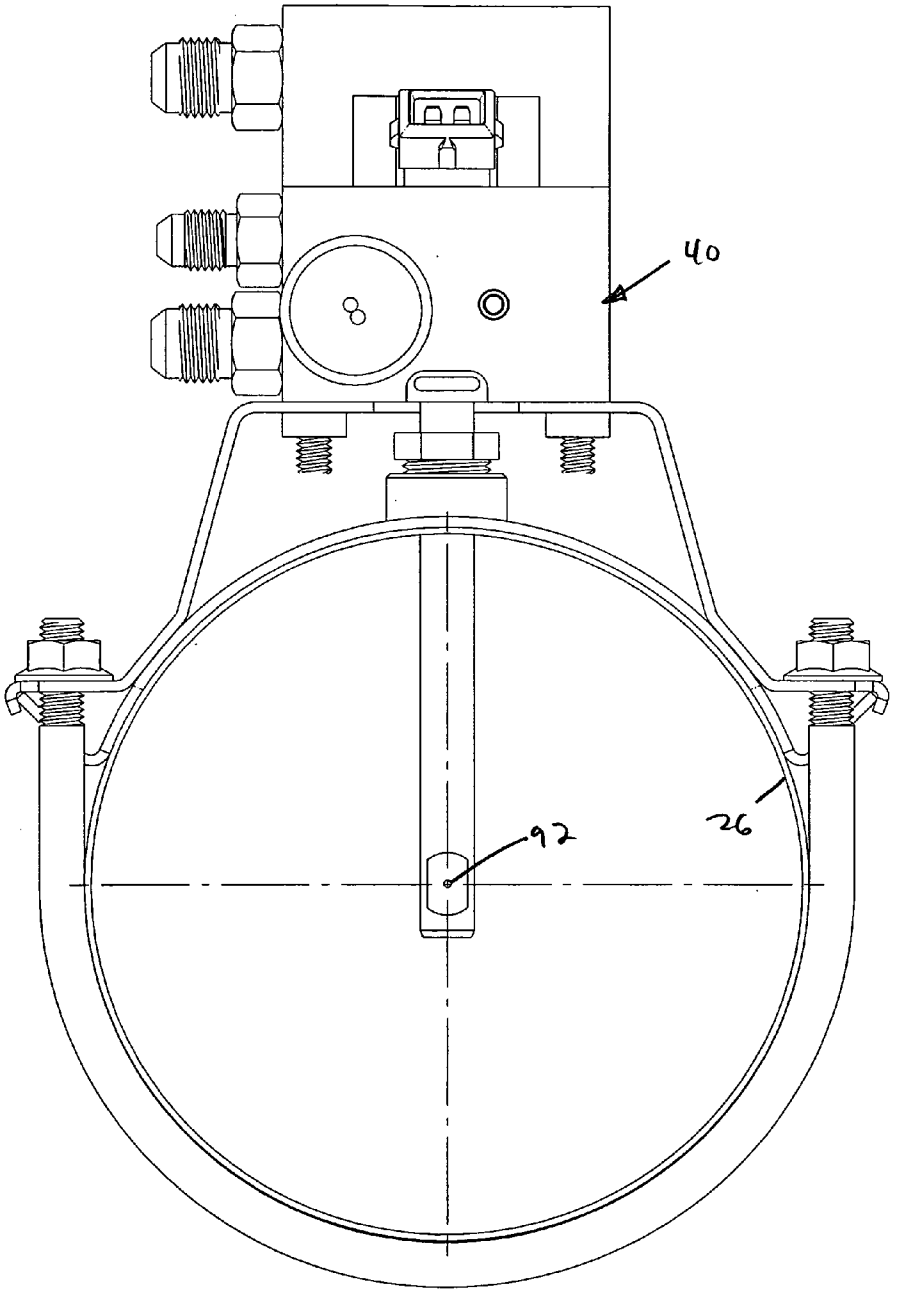
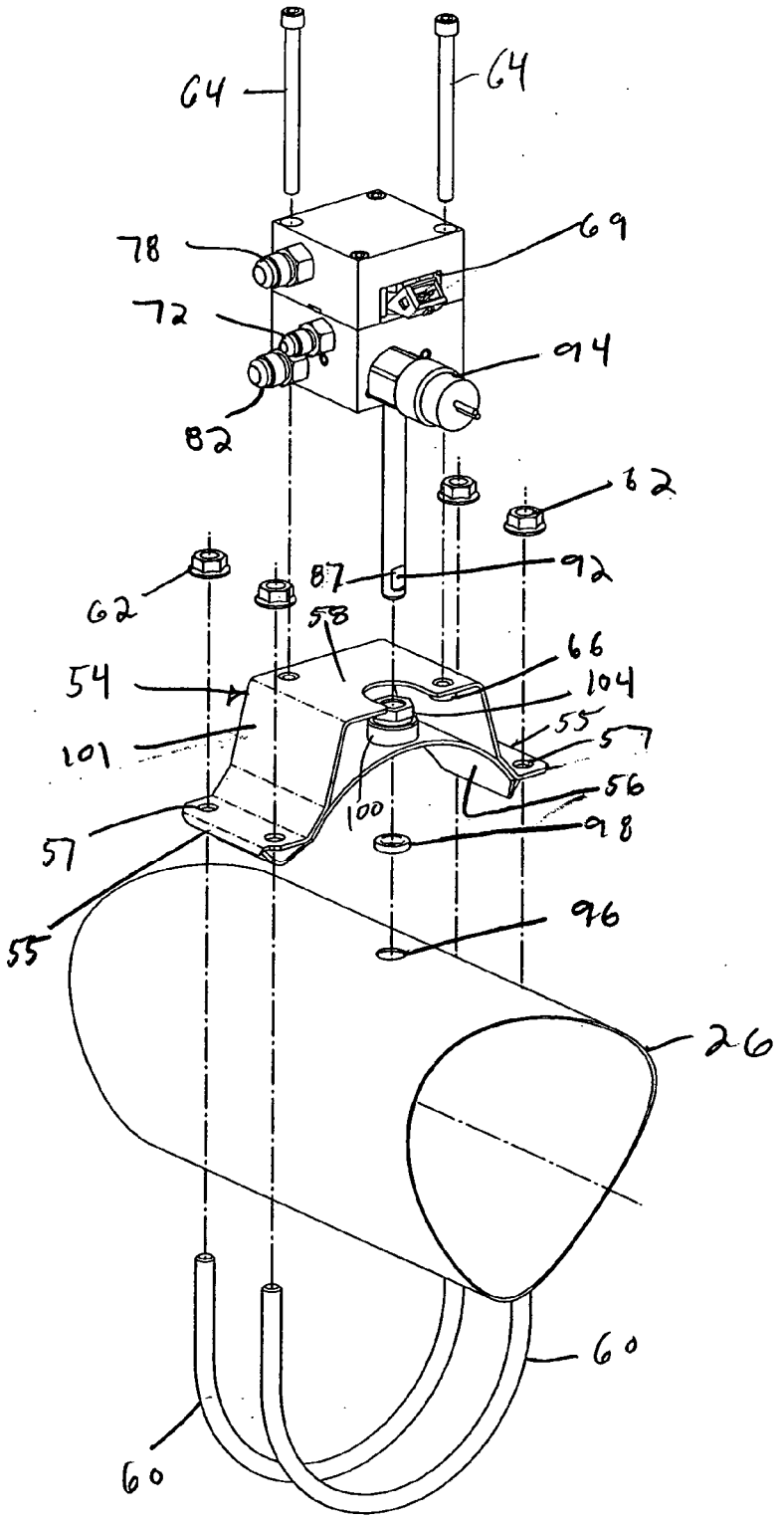


FIG. 2D




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F16.3

FIG. 4

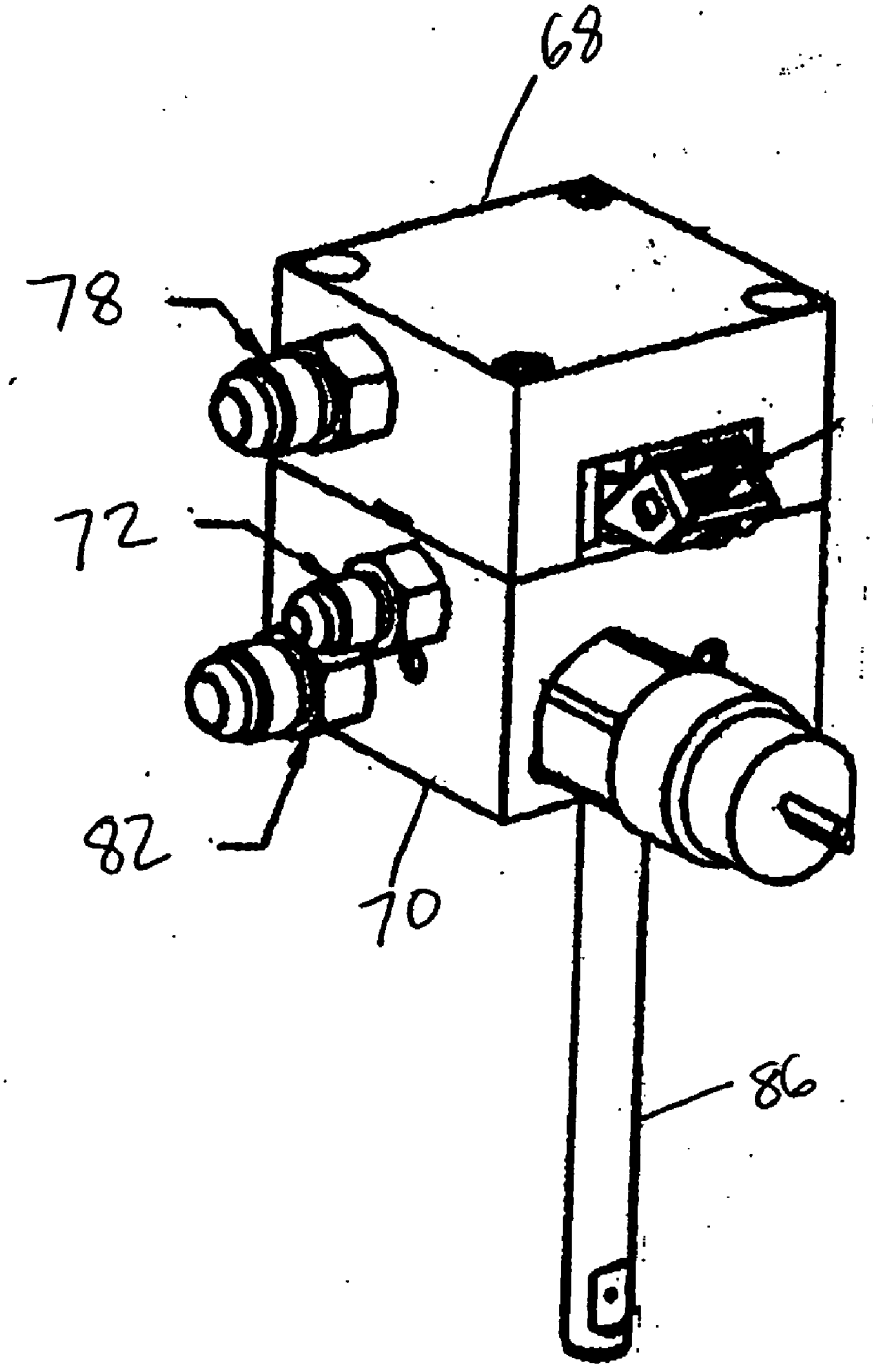


FIG. 5

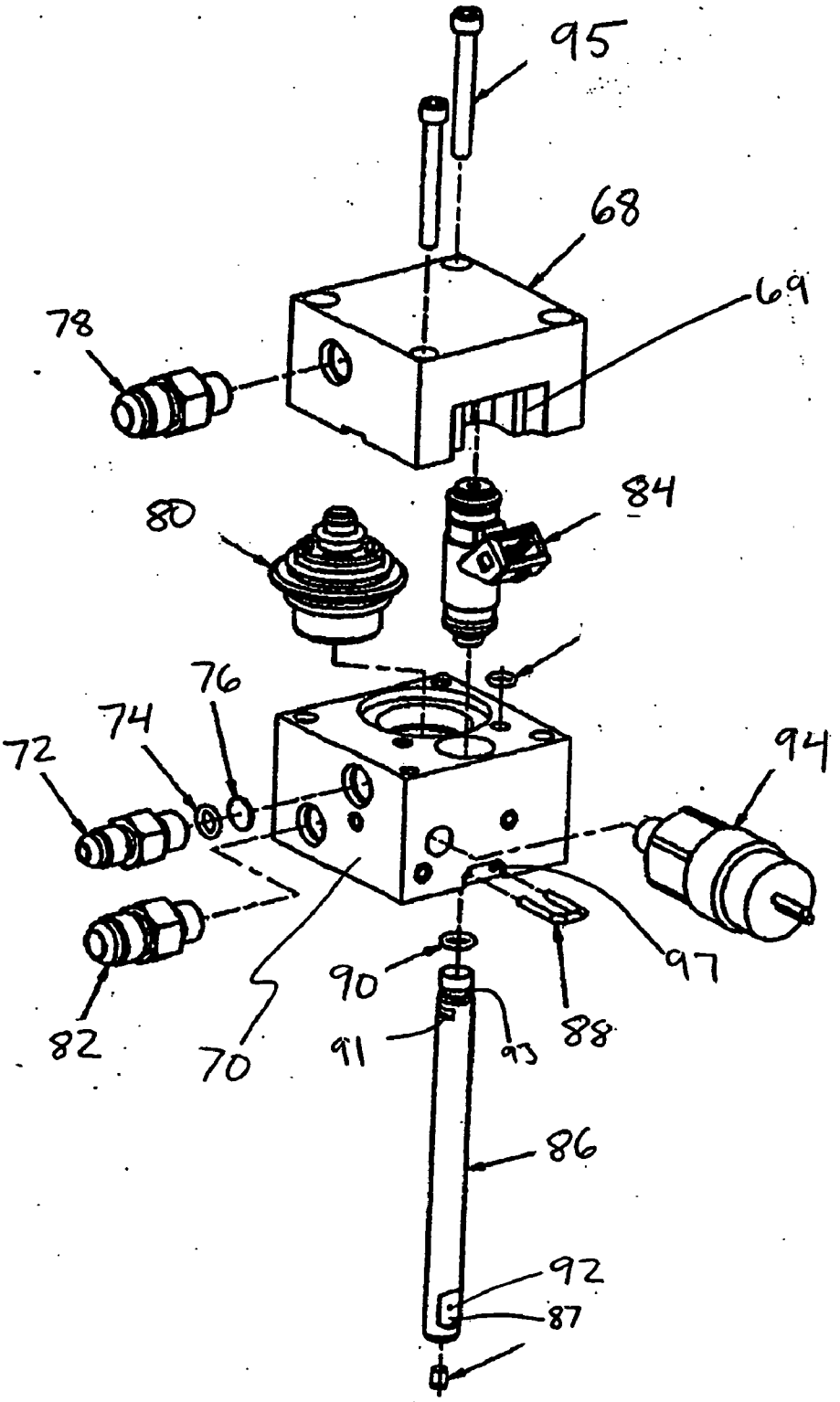
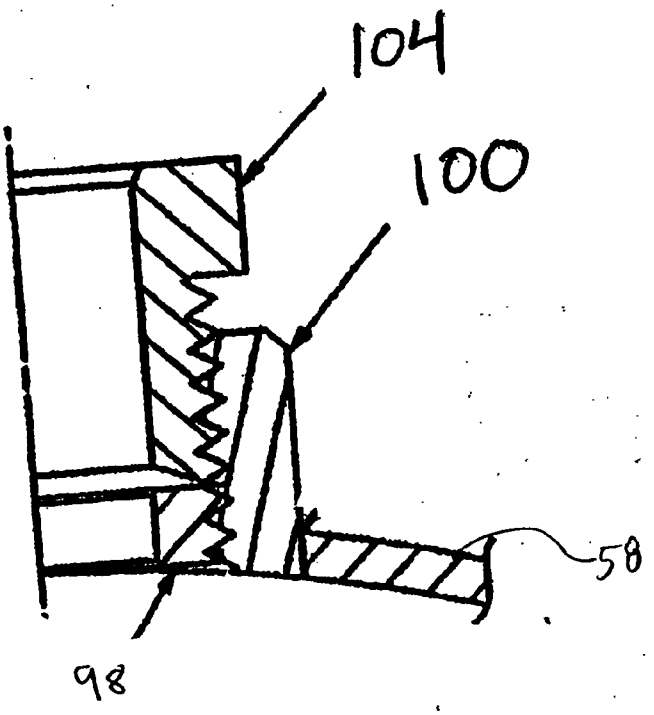


FIG. 6



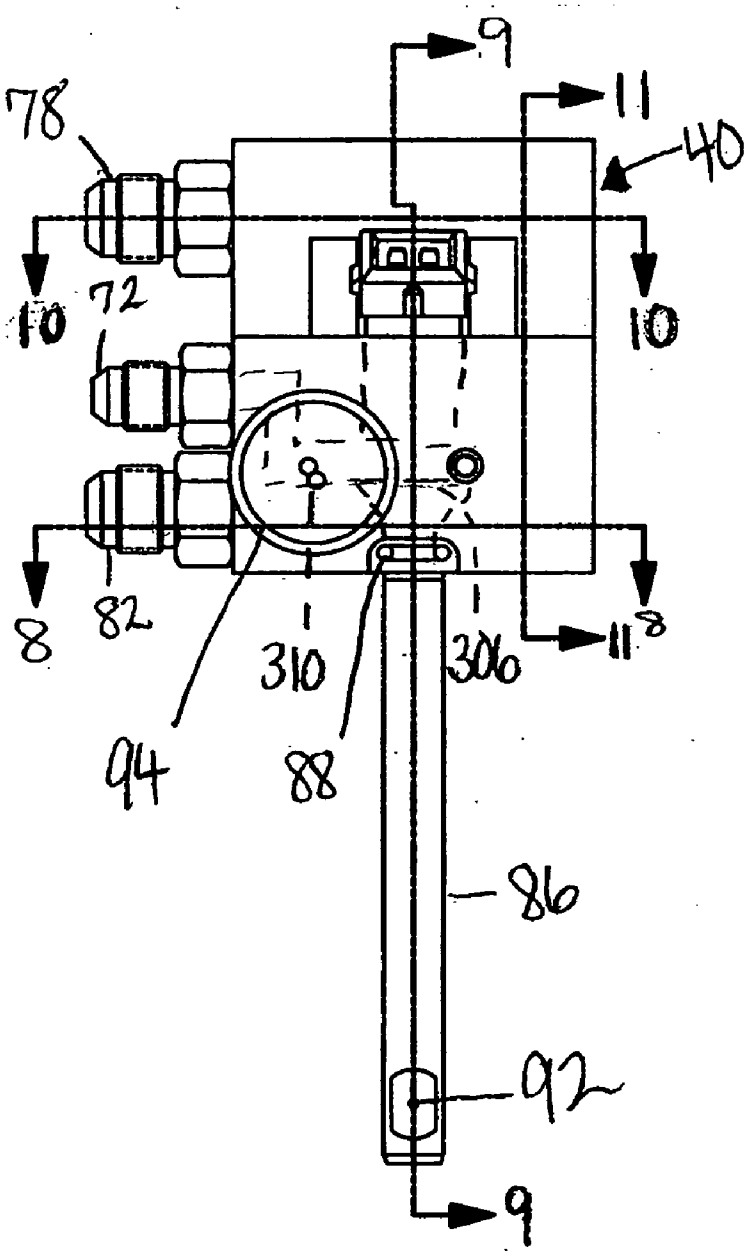


FIG. 7

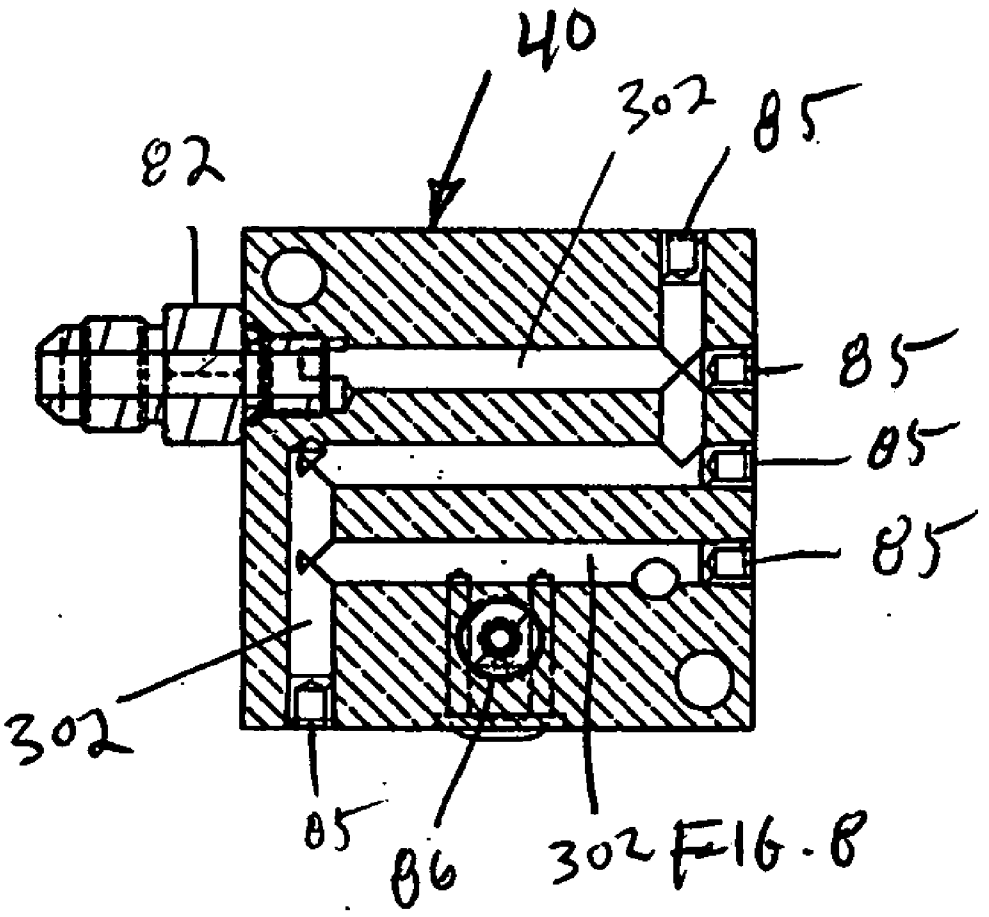
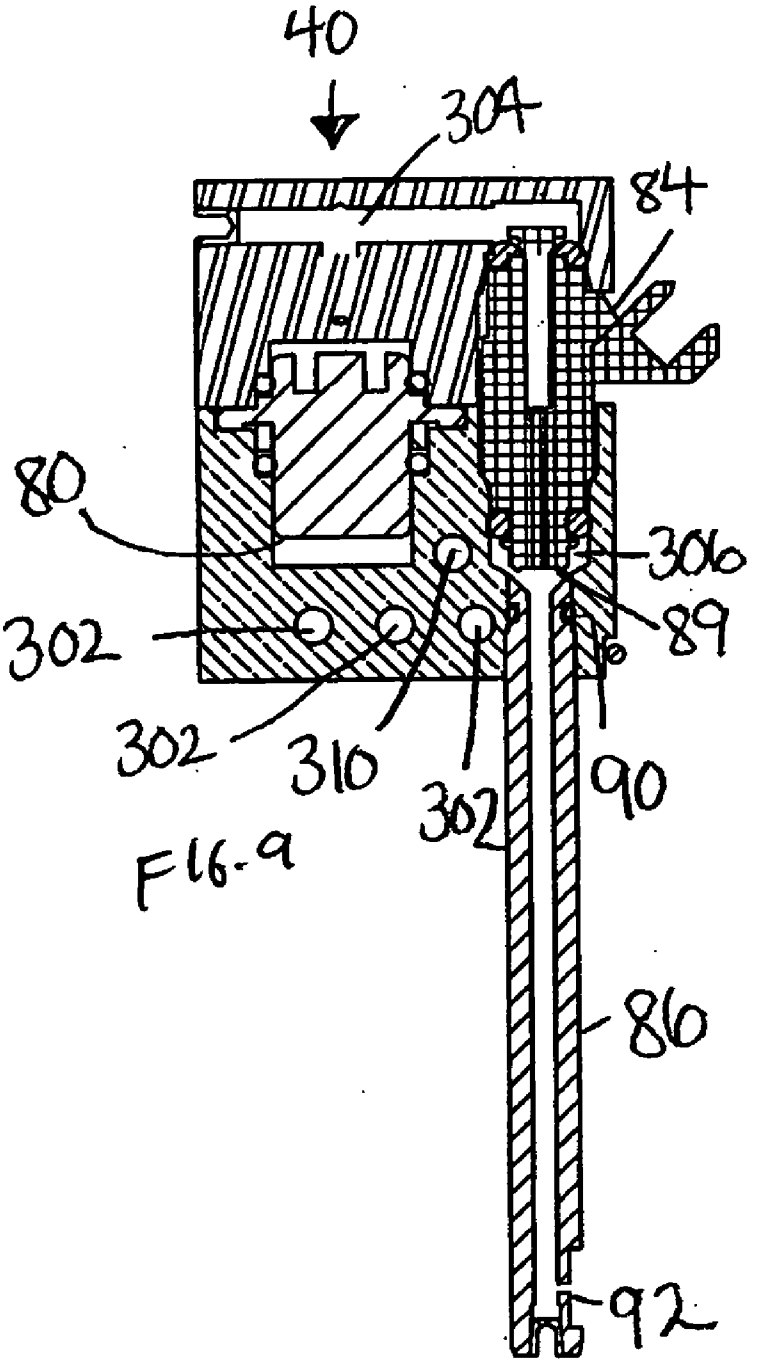


FIG. 8



F16.9

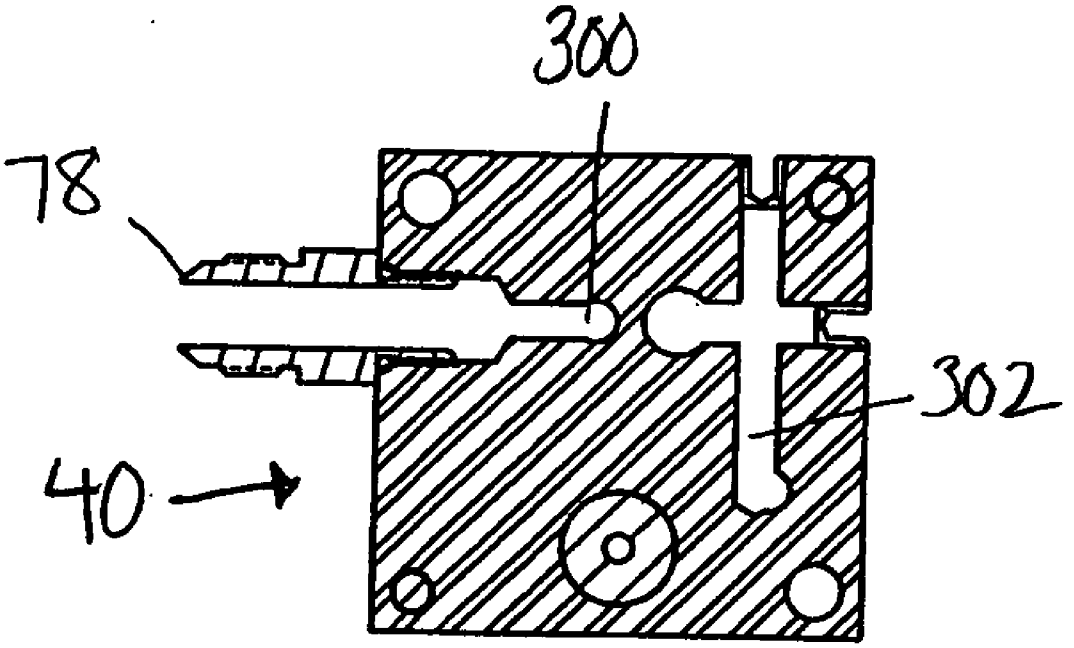


FIG. 10

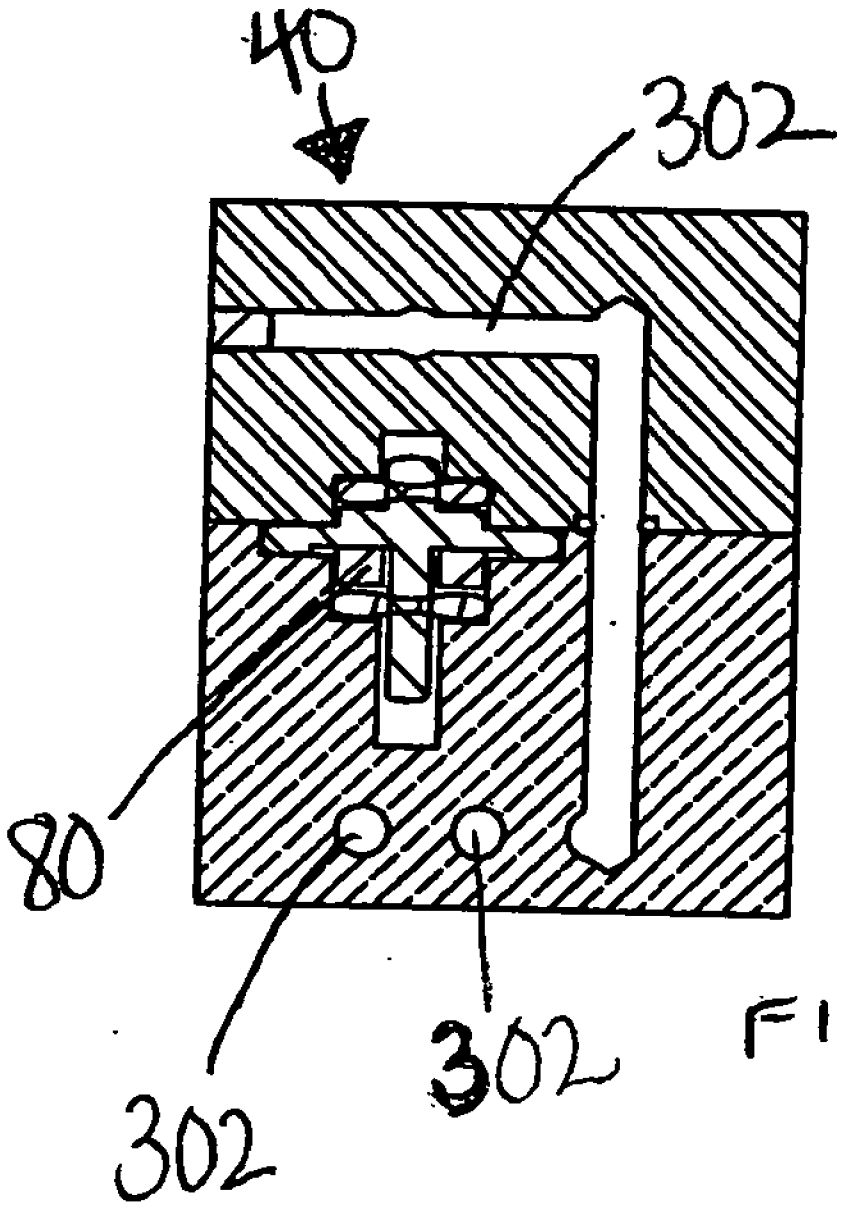


FIG. 11

FIG. 12

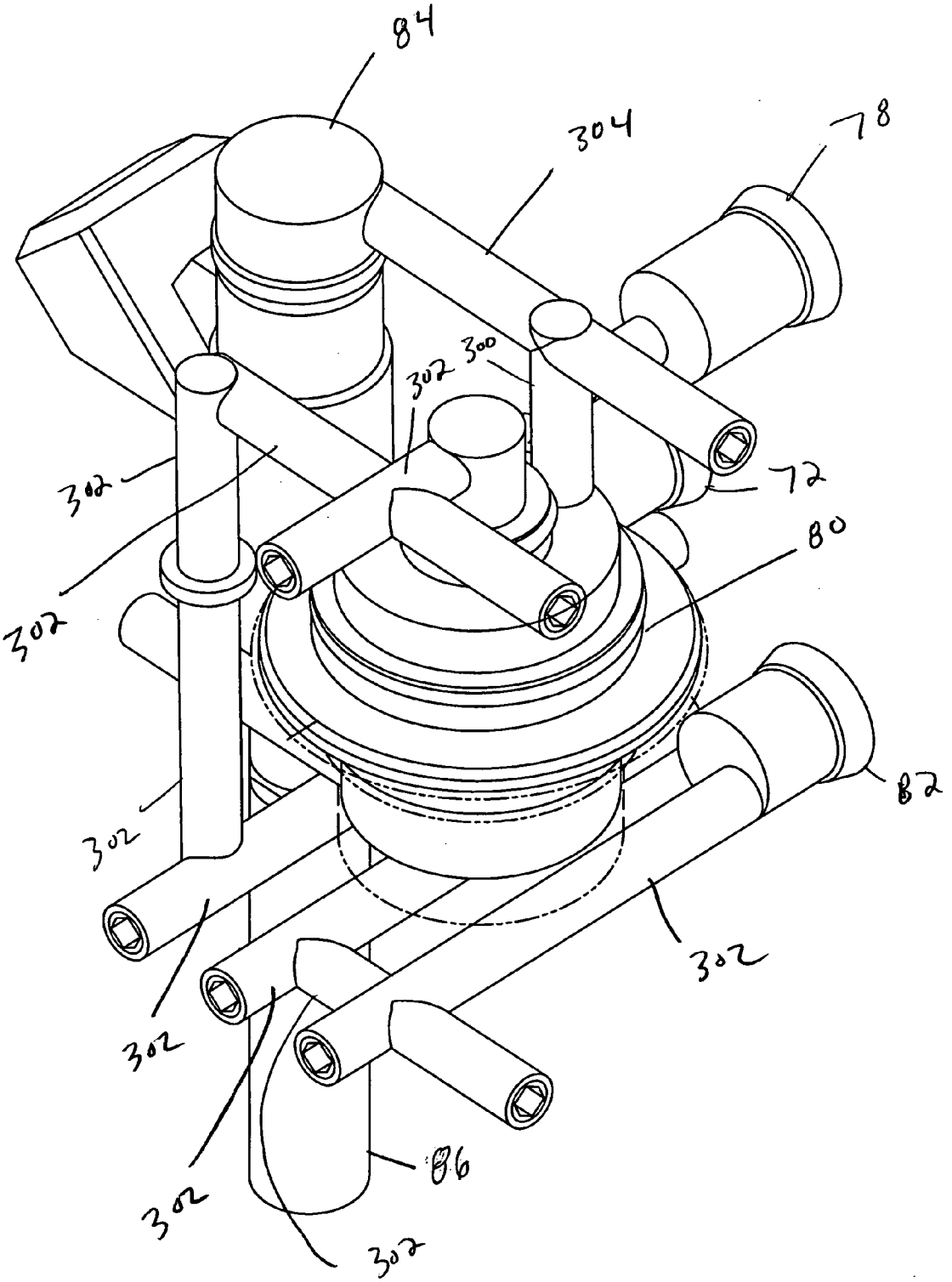


FIG. 13

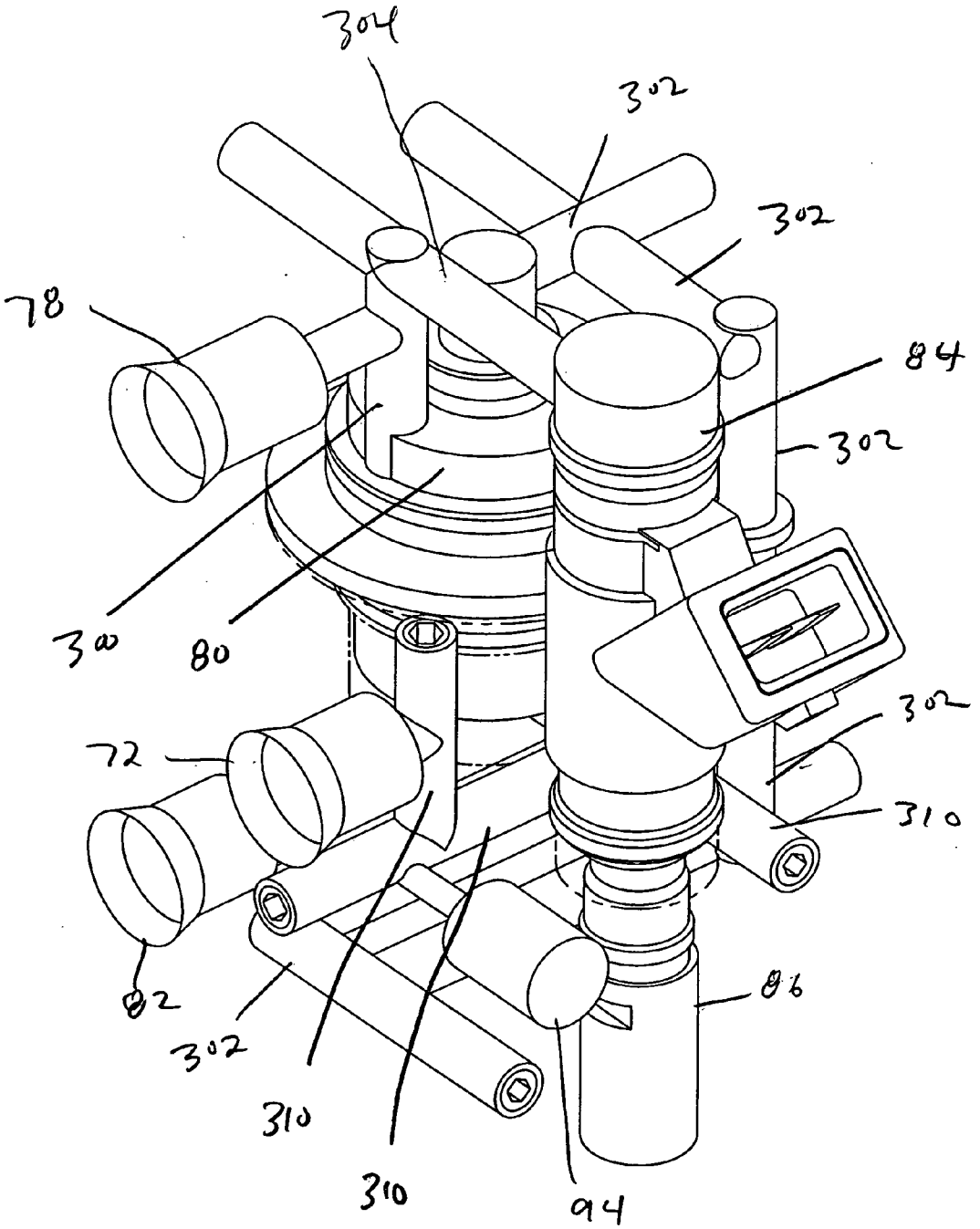


FIG. 14

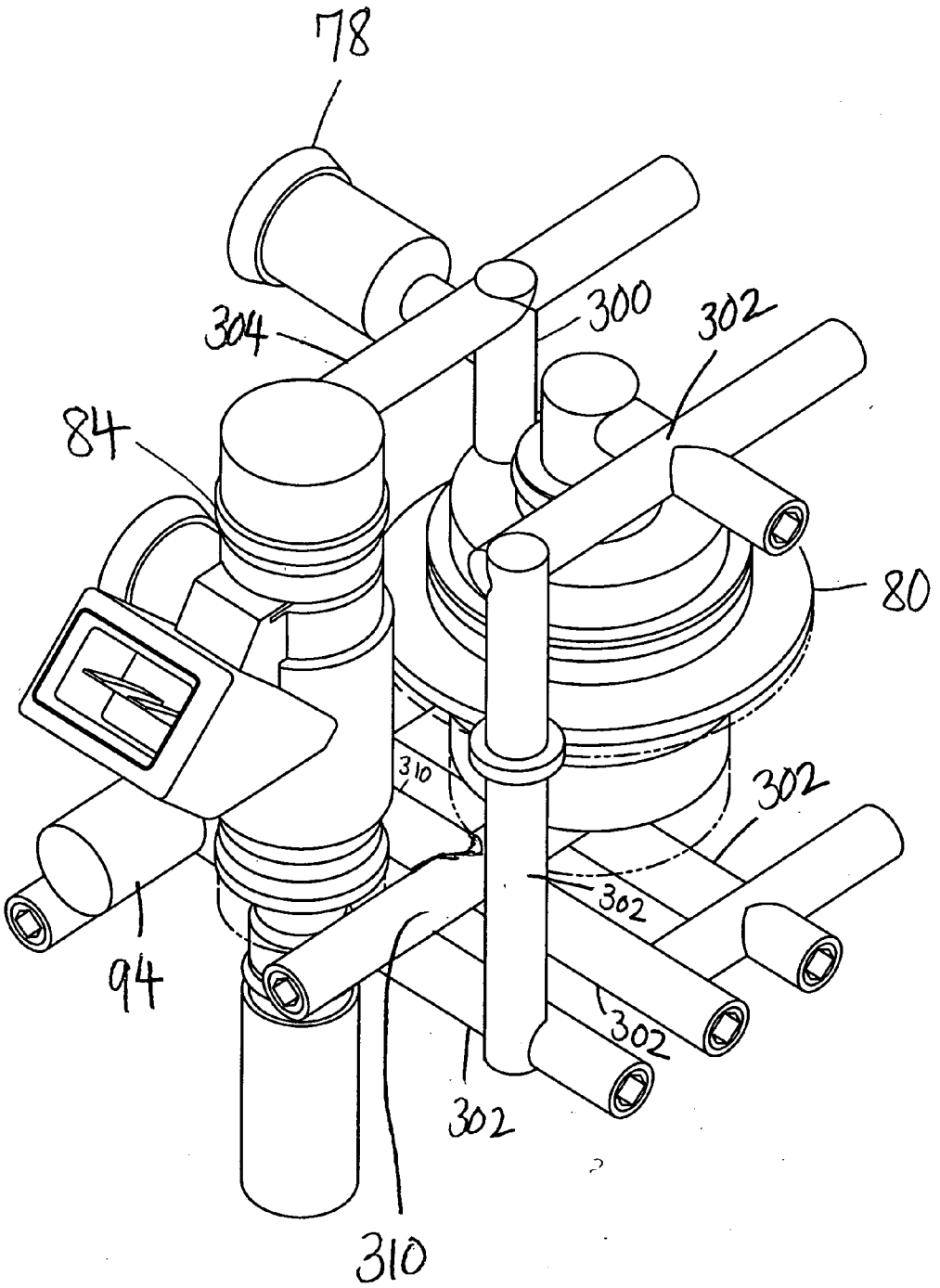


FIG. 15

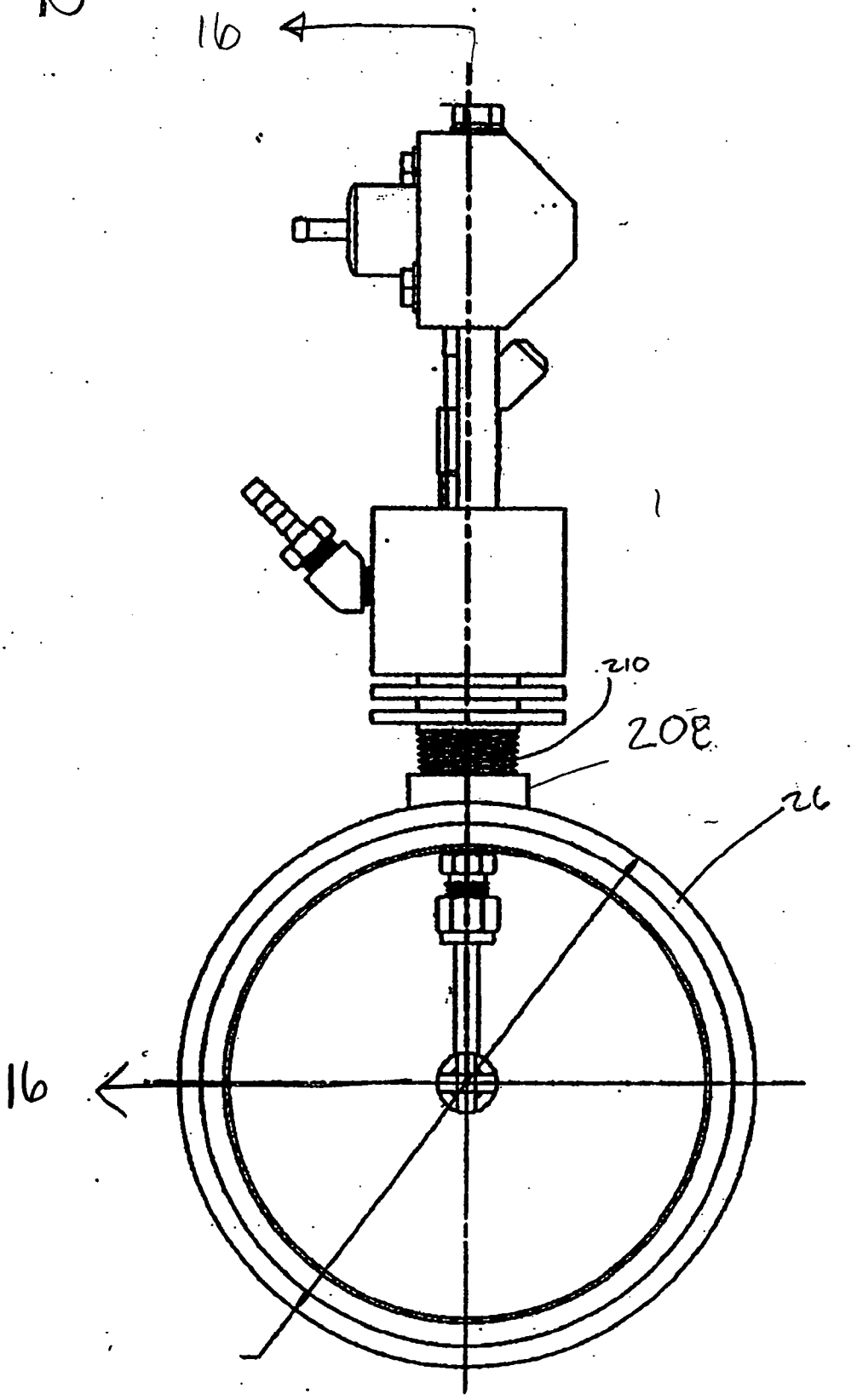


FIG. 16

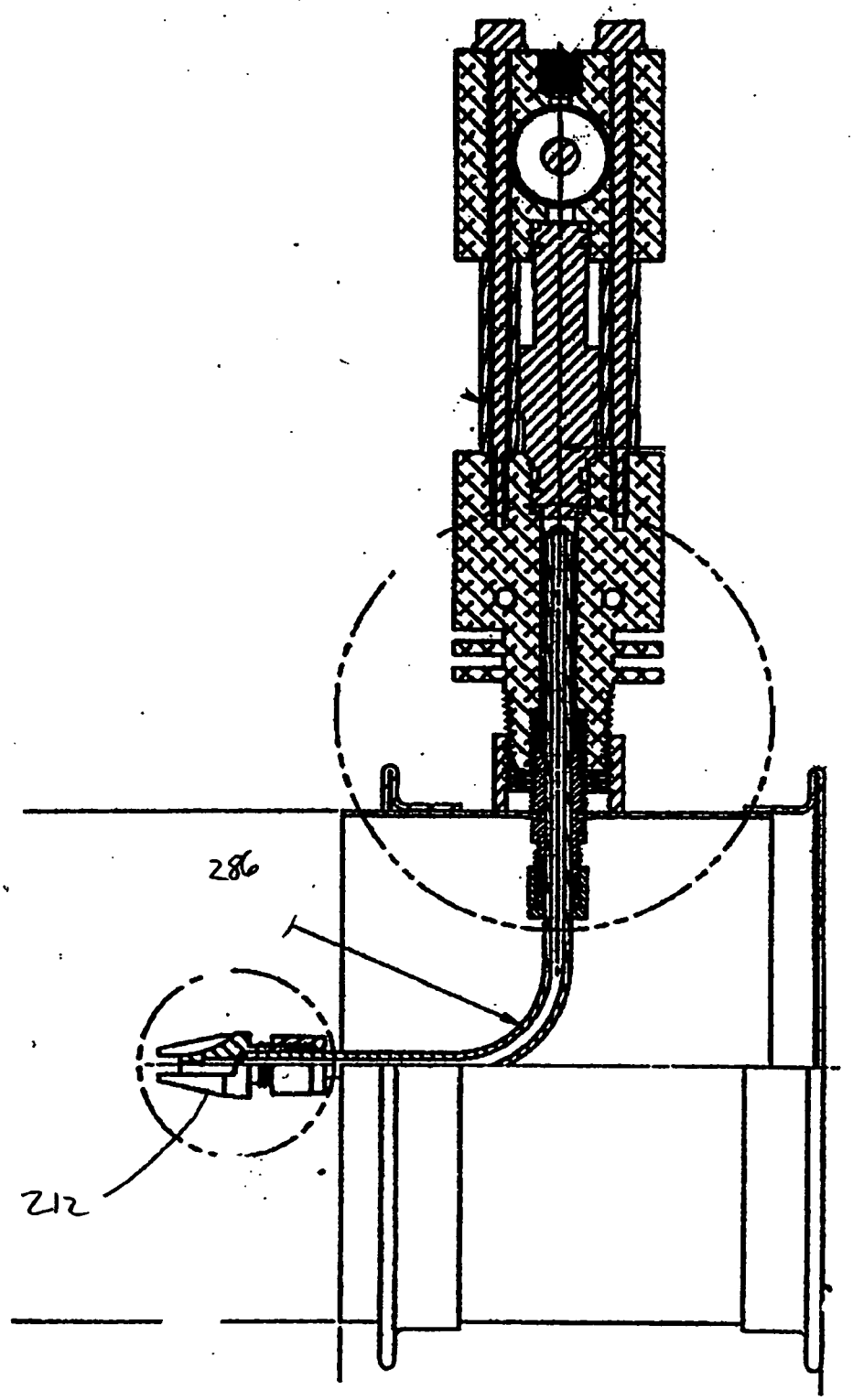
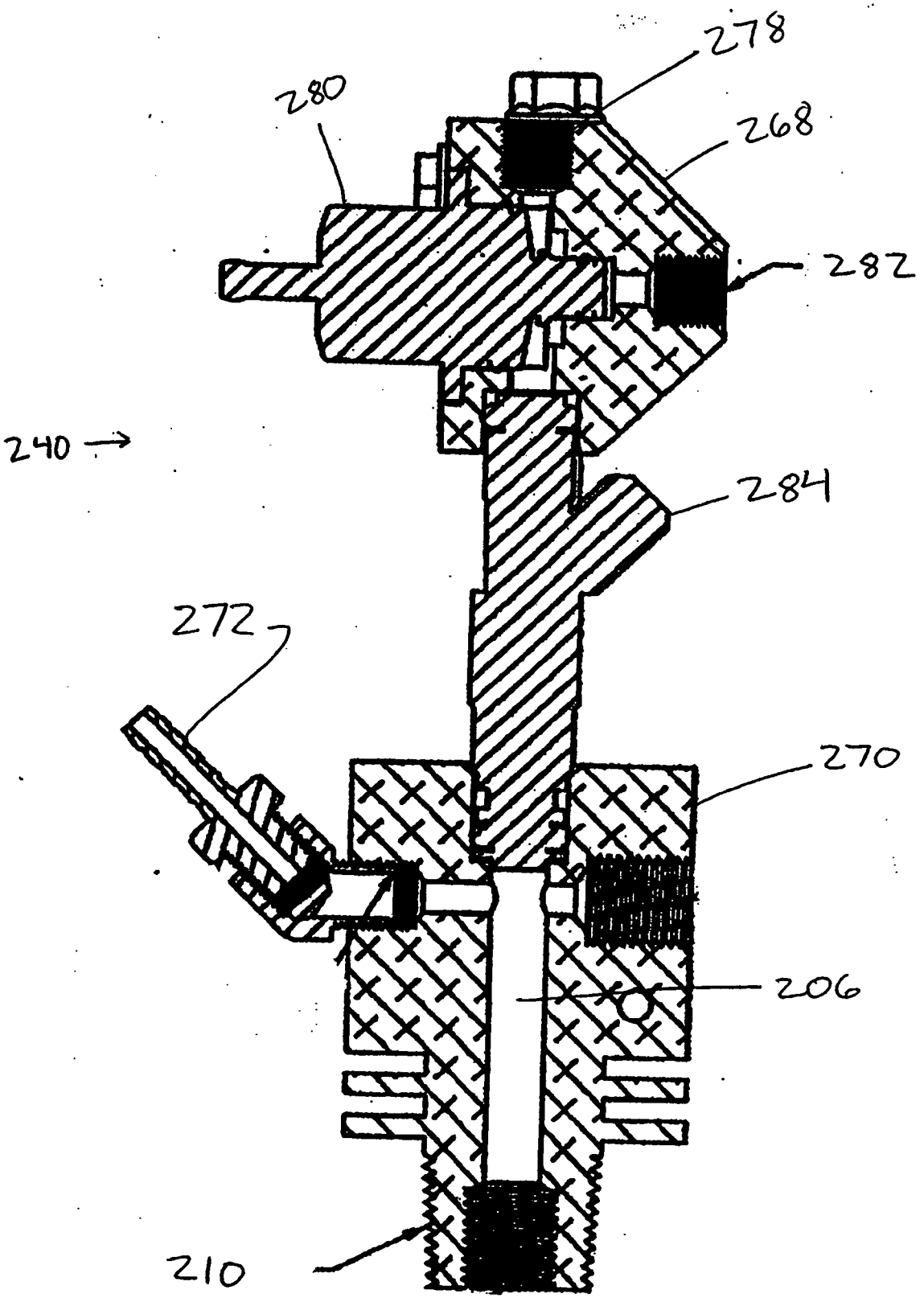


FIG. 17



SYSTEM FOR DISPENSING FUEL INTO AN EXHAUST SYSTEM OF A DIESEL ENGINE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application Ser. No. not yet received, filed Nov. 15, 2004, having Attorney Docket No. 758.1794USP1, entitled "System for Dispensing Fuel Into an Exhaust System of a Diesel Engine", which application is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates generally to diesel engine exhaust systems. More particularly, the present disclosure relates to systems and methods for controlling diesel engine exhaust emissions.

BACKGROUND

[0003] Vehicles equipped with diesel engines may include exhaust systems that have diesel particulate filters for removing particulate matter from the exhaust stream. With use, soot or other carbon-based particulate matter accumulates on the diesel particulate filters. As particulate matter accumulates on the diesel particulate filters, the restriction of the filters increases causing the buildup of undesirable back pressure in the exhaust systems. High back pressures decrease engine efficiency. Therefore, to prevent diesel particulate filters from becoming excessively loaded, diesel particulate filters should be regularly regenerated by burning off (i.e., oxidizing) the particulates that accumulate on the filters. Since the particulate matter captured by diesel particulate filters is mainly carbon and hydrocarbons, its chemical energy is high. Once ignited, the particulate matter burns and releases a relatively large amount of heat.

[0004] Systems have been proposed for regenerating diesel particulate filters. Some systems use a fuel fed burner positioned upstream of a diesel particulate filter to cause regeneration (see U.S. Pat. No. 4,167,852). Other systems use an electric heater to regenerate a diesel particulate filter (see U.S. Pat. Nos. 4,270,936; 4,276,066; 4,319,896; 4,851,015; and British Published Application No. 2,134,407). Detuning techniques are also used to regenerate diesel particulate filters by raising the temperature of exhaust gas at selected times (see U.S. Pat. Nos. 4,211,075 and 3,499,260). Self regeneration systems have also been proposed. Self regeneration systems can use a catalyst on the substrate of the diesel particulate filter to lower the ignition temperature of the particulate matter captured on the filter. An example of a self regeneration system is disclosed in U.S. Pat. No. 4,902,487.

[0005] In addition to particulate filters for removing particulate matter, exhaust systems can be equipped with structures for removing other undesirable emissions such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). Catalytic converters are typically used to remove CO and HC. NOx can be removed by structures such as lean NOx catalysts, selective catalytic reduction (SCR) catalysts and lean NOx traps.

[0006] Lean NOx catalysts are catalysts capable of converting NOx to nitrogen and oxygen in an oxygen rich environment with the assistance of low levels of hydrocarbons. For diesel engines, hydrocarbon emissions are too low to provide adequate NOx conversion, thus hydrocarbons are required to be injected into the exhaust stream upstream of the lean NOx catalysts. SCR's are also capable of converting NOx to nitrogen and oxygen. However, in contrast to using HC's for conversion, SCR's use reductants such as urea or ammonia that are injected into the exhaust stream upstream of the SCR's. NOx traps use a material such as barium oxide to absorb NOx during lean burn operating conditions. During fuel rich operations, the NOx is desorbed and converted to nitrogen and oxygen by catalysts (e.g., precious metals) within the traps.

SUMMARY

[0007] The present disclosure relates to a system for delivering fuel into the exhaust stream of a diesel engine to control emissions. A fuel delivery device dispenses a mixture of fuel and pressurized air into the exhaust flow. This system causes the fuel to be well-atomized within the exhaust stream without requiring excessive fuel pressure, thereby uniformly raising the temperature of the exhaust stream to a temperature suitable for regeneration of the diesel particulate filter without creating hot spots or exceeding a temperature that would damage the diesel particulate filter. Further, this system causes the fuel to be well-atomized within the exhaust stream without requiring an excessively small nozzle orifice that would be prone to plugging.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] **FIG. 1** schematically illustrates an exhaust system having features that are examples of inventive aspects in accordance with the principles of the present disclosure;

[0009] **FIG. 2A** shows an isometric view of a fuel injection arrangement having features that are examples of inventive aspects in accordance with the principles of the present invention;

[0010] **FIG. 2B** is a side view of the arrangement of **FIG. 2A**;

[0011] **FIG. 2C** is a top view of the arrangement of **FIG. 2A**;

[0012] **FIG. 2D** is an end view of the arrangement of **FIG. 2A**;

[0013] **FIG. 3** is an exploded view of the arrangement of **FIGS. 2A-2D**;

[0014] **FIG. 4** is an isometric view of one embodiment of a fuel supply device that is part of the arrangement of **FIG. 3**;

[0015] **FIG. 5** is an exploded view of the embodiment of the fuel supply device of **FIG. 4**;

[0016] **FIG. 6** is a detail view of a portion of the sealing mechanism apparent in **FIG. 3**;

[0017] **FIG. 7** is a side view of the fuel supply device of **FIG. 4**;

[0018] **FIG. 8** is a cross-sectional view taken along section line **8-8** of **FIG. 7**;

[0019] **FIG. 9** is a cross-sectional view taken along section line **9-9** of **FIG. 7**;

[0020] **FIG. 10** is a cross-sectional view taken along section line **10-10** of **FIG. 7**;

[0021] **FIG. 11** is a cross-sectional view taken along section line **11-11** of **FIG. 7**;

[0022] **FIG. 12** shows a first perspective view of a passage layout for the fuel supply device of **FIG. 4**;

[0023] **FIG. 13** shows a second perspective view of a passage layout for the fuel supply device of **FIG. 4**;

[0024] **FIG. 14** shows a third perspective view of a passage layout for the fuel supply device of **FIG. 4**;

[0025] **FIG. 15** is an end view of an alternative embodiment of a fuel supply device;

[0026] **FIG. 16** is a cross-sectional view of the fuel supply device of **FIG. 15** taken along section line **16-16**; and

[0027] **FIG. 17** is an alternative cross sectional view of the fuel supply device of **FIG. 15**.

DETAILED DESCRIPTION

[0028] The present disclosure relates to a system for regenerating a diesel emissions control device, such as a diesel particulate filter. The system includes a fuel supply device positioned upstream in the exhaust flow from the diesel particulate filter. A controller governs the rate at which fuel is dispensed by the fuel supply device. The controller interfaces with input sources that provide data representative of characteristics of the exhaust gas being conveyed through the exhaust system. Based on the characteristics of the exhaust gas and catalyst system, the controller causes the fuel supply device to dispense fuel into the exhaust stream at a rate sufficient to cause the controlled regeneration of the diesel particulate filter. In one embodiment, the fuel supply device is positioned upstream from a catalytic converter (i.e., a diesel oxidation catalyst (DOC)) that is positioned upstream from the diesel particulate filter. The diesel particulate filter may or may not include a catalyst. The desired fuel injection rate is preferably selected such that when the fuel combusts within the catalytic converter, the temperature of the exhaust gas exiting the catalytic converter and traveling to the diesel particulate filter is in the range of 500 to 700° C. In a more preferred embodiment, the temperature of the exhaust gas exiting the catalytic converter is in the range of 550 to 650° C. In a most preferred embodiment, the gas exiting the catalytic converter is about 600° C.

[0029] In alternative embodiments, the fuel injector can inject fuel directly into the diesel particulate filter without having a preheating process provided by combustion within an upstream catalytic converter. In such embodiments, the fuel ignites with a catalyst on the diesel particulate filter thereby causing oxidation of the particulate matter on the filter.

[0030] I. System Overview

[0031] **FIG. 1** illustrates an exhaust system **20** having features that are examples of inventive aspects in accordance with the principles of the present disclosure. The system includes an engine **22** (e.g., a diesel engine), a fuel tank **24** for supplying fuel (e.g., diesel fuel) to the engine **22**, and an exhaust conduit **26** for conveying exhaust gas away from the engine **22**. The system **20** also preferably includes a muffler **28** positioned along the conduit **26**. The muffler **28** includes an inlet pipe **30** and an outlet pipe **32**. The inlet pipe **30** preferably includes a structure for distributing flow as described in U.S. Pat. No. 6,550,573, that is hereby incorporated by reference in its entirety.

[0032] Preferably, a number of structures for treating exhaust gas are positioned within the muffler **28**. For example, a catalytic converter **34** (i.e., a diesel oxidation catalyst (DOC)) is shown mounted within the muffler near the inlet end of the muffler **28**. Also, a diesel particulate filter **36** is preferably mounted immediately downstream from the catalytic converter **34**, adjacent to the outlet end of the muffler **28**. Moreover, an optional lean NOx filter **38** is shown mounted within the muffler **28** upstream of the catalytic converter **34**. Alternatively, the catalytic converter **34**, diesel particulate filter **36**, and optional lean NOx filter **38** may be housed within separate enclosures in the exhaust conduit **26**. It will be appreciated that the catalytic converter **34** and the diesel particulate filter **36** function to treat the exhaust gas that passes through the conduit **26**. Other structures for treating the exhaust gas such as Selective Catalytic Reduction (SCR) catalysts, lean NOx catalytic converters, and NOx traps/absorbers can also be provided along the conduit **26**.

[0033] The system further includes a fuel supply device **40** for dispensing fuel into the exhaust stream. Controller **42** regulates the supply of compressed air and pressurized fuel into fuel supply device **40**. Fuel pump **44** draws fuel (i.e., diesel fuel) from tank **24** through filter **46**, supplying pressurized fuel to fuel supply device **40**. A high pressure switch **41** is positioned downstream of the fuel pump **44** and trips if the fuel supply pressure exceeds a threshold value, for instance where a restriction is formed in the fuel passages. A low pressure switch **43** is positioned downstream of the fuel pump **44** and trips if the fuel supply pressure drops below a threshold value, for instance where a fuel leak develops in the system. The fuel pump **44**, fuel filter **46**, and fuel pressure switches **41**, **43** may be housed within a pump box **45**. Further, if fuel pump **44** is an electrically-driven fuel pump, pump box **45** may also contain associated electrical relays. Excess fuel is returned from fuel supply device **40** to fuel tank **24** by way of return fuel line **48**. Pressurized air is provided to fuel supply device **40** from an air tank **50**. It will be appreciated that the air tank **50** can be provided with pressurized air by the vehicle air compressor, or can be provided by an auxiliary air compressor (e.g., an electric air compressor). A solenoid valve **52** controls air flow to the fuel supply device **40**. A check valve can also be used to prevent fuel from entering the compressed air line.

[0034] The fuel supply device **40** preferably dispenses fuel into the exhaust stream at a location between the engine **22** and catalytic converter **34**. Preferably, the fuel supply device **40** inputs fuel into the conduit **26** at a location approximately 36 inches from the catalytic converter **34**. In one embodiment, fuel is supplied to the exhaust stream at a location within 24 inches of the catalytic converter **34**. In another embodiment, the fuel is supplied at a location within 48 inches of the catalytic converter.

[0035] The fuel dispensed into the exhaust conduit **26** by the fuel supply device **40** combusts within the catalytic

converter **34**, thereby generating heat. Preferably, sufficient fuel is dispensed into the exhaust gas so that the combustion within the catalytic converter **34** raises the temperature of the exhaust gas exiting the catalytic converter **34** to a temperature above the combustion temperature of the particulate matter accumulated on the diesel particulate filter **36**. In this manner, by burning fuel in the catalytic converter **34**, sufficient heat is generated to cause regeneration of the diesel particulate filter **36**. Preferably, the rate that fuel is dispensed into the exhaust stream is also controlled to prevent temperatures from exceeding levels which may be detrimental to the diesel particulate filter **36**.

[**0036**] II. Controller

[**0037**] The controller **42** functions to control the rate that fuel is dispensed by the fuel supply device **40** to cause regeneration of the diesel particulate filter **36**. The controller **42** interfaces with a number of sensing devices or other data inputs that provide data representative of the exhaust gas traveling through the conduit **26**. This data may include the temperature, pressure, and mass flow of the exhaust gas. The controller **42** can use this data to determine the rate that fuel should be dispensed into the exhaust gas stream to regenerate the diesel particulate filter **36** in a controlled manner.

[**0038**] To promote a controlled and efficient regeneration of the diesel particulate filter **36**, it is desirable for the temperature of the exhaust gas exiting the catalytic converter **34** to have a target temperature in the range of 500 to 700° C., as indicated above. Thus, the rate that fuel is dispensed upstream of the catalytic converter **34** is preferably selected so that upon combustion of the fuel within the catalytic converter **34**, the exhaust gas exiting the catalytic converter is within the target temperature range.

[**0039**] The controller **42** can also be used to determine when the diesel particulate filter **36** is in need of regeneration. Any number of strategies can be used for determining when the diesel particulate filter **36** should be regenerated. For example, the controller **42** can initiate regeneration of the diesel particulate filter **36** when the pressure sensors indicate that the back pressure in the exhaust conduit **26** exceeds a predetermined level. The controller **42** can also initiate regeneration of the filter **36** at predetermined time intervals. The controller **42** can also be programmed to delay regeneration if conditions of the exhaust system are not suitable for regeneration (e.g., if the exhaust flow rate or exhaust temperature is not suitable for controlled regeneration). For such an embodiment, the controller **42** can be programmed to monitor the operating conditions of the exhaust system and to initiate regeneration only when predetermined conditions suitable for regeneration have been satisfied.

[**0040**] An example of a control system is disclosed in PCT application PCT US04/18536, filed Jun. 10, 2004, entitled Method of Dispensing Fuel into Transient Flow of an Exhaust System, that is hereby incorporated by reference in its entirety.

[**0041**] III. Diesel Particulate Filter

[**0042**] The diesel particulate filter **36** can have a variety of known configurations. An exemplary configuration includes a monolith ceramic substrate having a "honey-comb" configuration of plugged passages as described in U.S. Pat. No. 4,851,015 that is hereby incorporated by reference in its entirety. Wire mesh configurations can also be used. In certain embodiments, the substrate can include a catalyst. Exemplary catalysts include precious metals such as platinum, palladium and rhodium, and other types of components such as base metals or zeolites.

[**0043**] The diesel particulate filter **36** preferably has a particulate mass reduction efficiency greater than 75%. More preferably, the diesel particulate filter **36** has a particulate mass reduction efficiency greater than 85%. Most preferably, the diesel particulate filter **36** has a particulate mass reduction efficiency equal to or greater than 90%. For purposes of this specification, the particulate mass reduction efficiency is determined by subtracting the particulate mass that enters the diesel particulate filter from the particulate mass that exits the diesel particulate filter, and by dividing the difference by the particulate mass that enters the diesel particulate filter.

[**0044**] IV. Catalytic Converter

[**0045**] The catalytic converter **34** can have a variety of known configurations. Exemplary configurations include substrates defining channels that extend completely therethrough. Exemplary catalytic converter configurations having both corrugated metal and ceramic substrates are described in U.S. Pat. No. 5,355,973, that is hereby incorporated by reference in its entirety. The substrates preferably include a catalyst. For example, the substrate can be made of a catalyst, impregnated with a catalyst or coated with a catalyst. Exemplary catalysts include precious metals such as platinum, palladium and rhodium, and other types of components such as base metals or zeolites.

[**0046**] In one non-limiting embodiment, the catalytic converter **34** can have a cell density of at least 200 cells per square inch, or in the range of 200-400 cells per square inch. A preferred catalyst for the catalytic converter is platinum with a loading level greater than 30 grams/cubic foot of substrate. In other embodiments the precious metal loading level is in the range of 30-100 grams/cubic foot of substrate. In certain embodiments, the catalytic converter can be sized such that in use, the catalytic converter has a space velocity (volumetric flow rate through the DOC/volume of DOC) less than 150,000/hour or in the range of 50,000-150,000/hour.

[**0047**] V. Fuel Supply Device

[**0048**] In one embodiment, a fuel supply device capable of achieving relatively high levels of atomization at relatively low injection pressures is used. In one embodiment, twin-fluid atomization (e.g., effervescent atomization) is used. For example, in one twin-fluid embodiment, two fluids (e.g., fuel and air/gas) are pre-mixed before reaching an injection orifice. The fluids can be pre-mixed by using an injector to meter fuel into a chamber where it mixed with a supply of gas/air to form a two-phase fuel-gas mixture. The mixture is forced, via pressure differential, through an orifice and into the exhaust stream. The drop in pressure of the mixture upon entering the exhaust stream causes rapid expansion. This rapid expansion breaks the liquid portion of the mixture into fine droplets providing a high level of atomization.

[**0049**] One possible embodiment of fuel supply device **40** is shown mounted to exhaust conduit **26** in **FIGS. 2A-2D**. **FIG. 3** shows an exploded view of the fuel supply device **40** of **FIGS. 2A-2D**. Support base **54** comprises a curved plate

56 that corresponds with the external profile of the exhaust conduit 26. The base 54 also includes an offset plate 101 including a relatively flat surface 58 that is offset from the surface of exhaust conduit 26. In one embodiment, the surface 58 is spaced at least one-half inch from the surface of exhaust conduit 26 to provide a gap (e.g., an air gap) that minimizes undesirable heat transfer from the hot exhaust gas within exhaust conduit 26 to fuel supply device 40. In certain embodiments, insulation material such as fiberglass can be used within the gap.

[0050] Support base 54 further comprises a pair of flanges 55 that extend in a direction generally normal to exhaust conduit 26. The flanges 55 define fastener openings 57. A pair of U-bolts 60 and corresponding nuts 62 secure support base 54 to exhaust conduit 26. The shanks of U-bolts 60 extend through the openings 57 of flanges 55. Fuel supply device 40 is secured to support base 54 by means of two bolts 64 that extend through fuel supply device 40 to engage nuts 66 secured to support base 54.

[0051] Referring now to **FIGS. 4 and 5**, fuel supply device 40 comprises a housing (e.g., a manifold) including an upper housing block 68 and a lower housing block 70. Provision is made in lower housing block 70 for a pressurized air inlet fitting 72 which is threaded into lower housing block 70. Air inlet fitting 72 seats against O-ring 74, which in turn secures orifice plate 76 within a counterbore within lower housing block 70. Orifice plate 76 limits the quantity of pressurized air that can enter fuel supply device 40. Provision is made in upper housing block 68 for a fuel inlet fitting 78 which is threaded into upper housing block 68. A passageway 300 (see **FIGS. 10 and 13**) communicates between fuel inlet fitting 78 and fuel pressure regulator 80. If the fuel pressure exceeds a preset value, fuel pressure regulator 80 will open, allowing pressurized fuel to flow into a passageway 302 (see **FIGS. 10-13**) that communicates with fuel return fitting 82, from which it flows through fuel return line 48 to the fuel tank. This causes the fuel pressure to drop. When the fuel pressure drops below a preset value, fuel pressure regulator 80 will then close, causing the fuel pressure to build. In this way, the fuel pressure is maintained within a suitable range.

[0052] An additional passageway 304 (see **FIGS. 9, 12 and 13**) in upper housing block 68 allows fuel communication between fuel inlet fitting 78 and the inlet of fuel injector 84. In one embodiment, fuel injector 84 is a customary gasoline-engine style fuel injector that comprises an internal electrical solenoid that actuates a needle valve to control fuel flow through a discharge opening. Fuel injector 84 is preferably a Synerject DEKA IV short injector, but other injectors can be used as well. A cylindrical surface is provided in upper housing block 68 to allow upper O-rings on the body of fuel injector 84 to securely seal against the supply fuel pressure. Upper housing block 68 also comprises a clearance portion 69 that enables electrical connection to be made to the fuel injector 84. Further, a cylindrical surface is provided in lower housing block 70 to allow lower O-rings on the body of fuel injector 84 to securely seal against the discharge fuel pressure and pressurized air. Bolts 95 secure upper housing block 68 to lower housing block 70.

[0053] In one embodiment, the fuel return passage 302 within the lower housing block 70 forms a cooling passage structure (see **FIG. 8**) including a plurality of sections of passageway. In the depicted embodiment, the cooling passage structure includes a plurality of parallel lengths of passage adjacent the bottom of the block. Tortuous or convoluted pathways can also be used. These sections increase the total passage length and surface area of return fuel flowing within lower housing block 70, promoting heat transfer out of lower housing block 70 into the return fuel. The ends of the sections are sealed with press-fit plugs 85.

[0054] A region 306 (see **FIGS. 7 and 9**) is provided in lower housing block 70 that allows fluid communication between the outlet end of the fuel injector 84, the pressurized air inlet fitting 72, and a nozzle tube 86. This region 306 forms a pre-mixing chamber. An air passage 310 (see **FIGS. 7, 13** and **14**) provides fluid communication between the inlet fitting 72 and the region 306. The entry of nozzle tube 86 defines a chamfer 89 which promotes efficient fluid flow into nozzle tube 86. As best shown at **FIG. 5**, nozzle tube 86 is retained within region 306 by means of U-clip 88, which engages with slot portions 91 of nozzle tube 86 and holes 97 in lower housing block 70. Further, nozzle tube O-ring 90 is installed in annular groove 93 of nozzle tube 86 and seals the fuel-air mixture from escaping from the joint between nozzle tube 86 and lower housing block 70. A fuel atomization nozzle orifice 92 is provided near the lower end of nozzle tube 86.

[0055] The fuel pressure regulator 80 is preferably a differential fuel pressure regulator that references the pressure of the pre-mixing chamber and is used to ensure that the pressure difference between the fuel supply and the pre-mixing chamber is constant. In one embodiment, passage 310 (shown at **FIG. 14**) is in fluid communication with the regulator 80 to allow the regulator to reference the pressure of the pre-mixing chamber. The regulator 80 regulates pressure by routing fuel back to the supply tank through the return passage 302 and return line 48. In one embodiment, fuel is continuously cycling, even when the unit is not injecting fuel into the exhaust stream.

[0056] In one non-limiting embodiment, nozzle tube 86 has an outside diameter of approximately ⅜ inch and an inside diameter of approximately ⅛ inch. It is preferred to minimize the amount of volume within nozzle tube 86 so as to improve the transient response of the fuel delivery device 40, but the nozzle tube 86 inner diameter preferably is not so small as to cause excessive flow restriction of the fuel-air mixture therein. It is also preferred that the diameter of the fuel atomization nozzle orifice 92 be in the range of 0.04 to 0.07 inches for proper atomization. In another embodiment, the injection nozzle defines a single orifice having a diameter in the range of 0.02-0.10 inches. In another embodiment, the nozzle may include a plurality of orifices of a diameter such that the total equivalent flow area is comparable to the flow area of a single-hole orifice embodiment.

[0057] In the depicted embodiment, the wall section of the nozzle tube 86 includes a thinned portion 87 near the fuel atomization nozzle orifice 92 so as to reduce the ratio of orifice length to orifice diameter, in order to promote more complete atomization. In one embodiment, the ratio of the orifice length to the orifice diameter is 1.0.

[0058] The tube 86 projects downwardly from the lower block 70 and extends across the spacing between the offset plate 58 and the curved plate 56. The tube further extends through the plate 56, and through hole 96 and into the

interior of the conduit **26**. The length of nozzle tube **86** is preferably sized so that nozzle orifice **92** is located at approximately the central axis **27** (see **FIG. 2**) of exhaust conduit **26** when fuel delivery device **40** is mounted to exhaust conduit **26**, and that nozzle orifice **92** is facing downstream within the exhaust conduit **26**. In one embodiment, the tube **86** projects at least **2** inches outwardly from the bottom of the block **70**. Of course, the length of the tube will vary with different applications and may be less than 2 inches in certain embodiments.

[**0059**] In one embodiment, air flow is regulated using a flow regulator such as orifice plate **76**. The orifice plate **76** is located adjacent the air inlet **72** and has an orifice diameter of about 0.02-0.03 inches. The orifice plate **76** controls air flow rates without requiring regulation of the incoming air pressure. However, in other embodiments, air pressure regulators can be used to regulate the air pressure provided to the mixing chamber.

[**0060**] It will be appreciated that to maintain desired liquid to fuel ratios within the mixing chamber, the size of the orifice plate **76** is dependent upon the size of the dispensing orifice **92**. In certain embodiments, example gas to liquid mixing ratios in the range of 0.1-2.3, or in the range of 0.3-0.7, are used. In one embodiment, the air flow rate preferably does not exceed **1** standard cubic foot per minute (SCFM). In another embodiment, air flow is regulated in the range of 0.25-5 SCFM. By using relatively low air flow rates, existing sources of compressed air provided on a vehicle (e.g., compressed air for brakes and suspension) can be used as an air supply for the injector system.

[**0061**] Pressure within the mixing region **306** is monitored by a pressure switch **94** which is threaded into lower housing block **70**. The pressure switch **94** is in fluid communication with the air passage **310** (see **FIG. 13**). Electrical connection **51** is provided from pressure switch **94** to controller **42**. Pressure switch thereby is able to communicate with controller **42** to facilitate controlling the pressure and detecting failure conditions.

[**0062**] Referring now to **FIG. 3**, support base **58** is positioned over opening **96** in exhaust conduit **26**. Packing material **98** is positioned circumferentially around nozzle tube **86**. Referring now to **FIG. 6**, boss **100** is attached to support base **58** and contains internal threads. Gland nut **104** is threaded into boss **100**. To seal the exhaust gases within exhaust conduit **26** so as to prevent exhaust gases from leaking between opening **96** and nozzle tube **86**, gland nut **104** is tightened against packing material **98**, which forces packing material **98** against exhaust conduit **26** and also causes packing material **98** to expand radially inward into sealing contact against nozzle tube **86**. Packing material **98** is preferably a graphite material.

[**0063**] In operation, when controller **42** determines that fuel should be dispensed into the exhaust stream, controller **42** sends an electrical signal to solenoid valve **52** to initiate a flow of pressurized air to fuel delivery device **40**. Approximately simultaneously, controller **42** sends an electrical signal to fuel injector **84** by way of electrical connection **53** to initiate a flow of fuel within fuel delivery device **40**. Fuel discharged by fuel injector **84** is mixed with pressurized air in pre-mixing chamber **106**, forming a multi-phase fuel-air mixture. Fuel-air mixing can also occur in nozzle tube **86**. In one embodiment, the fuel pressure provided to the injector is at least 30 pounds per square inch (psi) greater than the air pressure provided at the air inlet **72**. In other embodiments, the fuel pressure is in the range of 30-50 psi greater than the air pressure. (All pressures given are gauge pressures.) In still other embodiments, the fuel pressure is at least 40 psi greater than the air pressure. In certain embodiments, the air pressure provided to the inlet **72** is in the range of 10-50 psi or 20-40 psi, and the fuel pressure provided to the injector is in the range of 40-150 psi. In other embodiments, the air pressure is about 30 psi, and the fuel pressure is about 70 psi. Because the diameter of the orifice in the air inlet orifice plate **76**, the air supply pressure in tank **50**, and the fuel pressure regulator setting **80** are all fixed mechanically, the controller **42** adjusts the fuel dispensing rate by regulating the on-cycle time of the electric signal provided to the fuel injector **84**.

[**0064**] In one embodiment, the multi-phase fuel-air mixture is dispensed into the exhaust stream through nozzle orifice **92**. The pressure of the mixture drops rapidly as it travels through the orifice, from a pressure of preferably approximately 40-60 psi inside the nozzle tube **86** to a pressure of preferably approximately 0.1 to 3.0 psi inside the exhaust conduit **26**. This rapid decrease in pressure causes the air that is entrained within the air-fuel mixture to expand rapidly, thereby providing turbulence and mixing within the fuel spray that causes the fuel to atomize into small particles. Smaller fuel particles are advantageous because they combust more effectively and uniformly in the catalytic converter **34**.

[**0065**] An alternative embodiment of fuel delivery device **240** is shown in **FIGS. 15-17**. Fuel delivery device **240** comprises an upper housing block **268** and a lower housing block **270**. A pressurized air inlet fitting **272** threads into lower housing block **270** and is in fluid communication with pre-mixing chamber **206**. Upper housing block **268** contains a fuel inlet port **278** which is in fluid communication with a fuel pressure regulator **280**. If the fuel pressure exceeds a preset value, fuel pressure regulator **280** opens a fluid communication passageway to fuel return port **282**. Fuel return line **48** (not shown) is attached to fuel return port **282**, providing a passageway for the fuel to return to fuel tank **24**.

[**0066**] Upper housing block **268** further comprises a cylindrical surface that receives fuel injector **284**, formed with appropriate dimensions to allow the O-rings on the top of fuel injector **284** to properly seal the fuel in the fuel passageway in the upper housing block **268**. Similarly, a cylindrical surface is provided in lower housing block **270** to receive injector **284** and to allow the lower O-rings on the body of fuel injector **284** to securely seal against the discharge fuel pressure and pressurized air present in pre-mixing chamber **206**. Lower housing block **270** additionally comprises a threaded cylindrical surface **210**. Referring now to **FIG. 15**, internally-threaded boss **208** is attached to exhaust conduit **26**. Fuel delivery device **140** is secured to exhaust conduit **26** by being threaded into boss **208**. Referring now to **FIG. 16**, fuel dispensing tube **286** is threaded into lower housing block **270** and passes through an opening in exhaust conduit **26**. Fuel dispensing tube **286** preferably is partially curved so as to form an end portion that is approximately coaxial with the exhaust conduit **26**. A delivery nozzle **212** is attached to the end portion of fuel dispensing tube **286** from which the fuel-air mixture is dispensed.

[0067] In the above embodiments, fuel is injected into the exhaust stream to raise exhaust temperatures to a target temperature suitable for regenerating a diesel particulate filter. In other embodiments, the fuel injection systems disclosed herein can be used to inject fuel into an exhaust stream for other purposes, such as to provide hydrocarbons to promote the conversion of NOx at a lean NOx catalyst or to provide hydrocarbons for regenerating NOx traps. In yet other embodiments, the fuel injection systems disclosed herein can be used to inject a reductant, such as ammonia or urea, into an exhaust stream for use with a selective catalytic reduction system for reducing NOx emissions. A variety of control models can be used to control fuel injection rates for these alternative systems.

[0068] It will be appreciated that the specific dimensions disclosed herein are examples applicable for certain embodiments in accordance with the principles of the disclosure, but that other embodiments in accordance with this disclosure may or may not include such dimensions.

1. A system for dispensing a mixture of liquid and air into an exhaust stream comprising:

an injector housing defining an air passage and a liquid passage, the injector housing also defining a cooling passage structure that includes a plurality of passage lengths that extend along a side of the housing for cooling the side of the housing;

an air inlet for providing pressurized air to the air passage of the injector housing;

a liquid inlet for providing liquid to the liquid passage of the injector housing;

a mixing location in fluid communication with the air passage;

an injector mounted within the injector housing for injecting liquid from the liquid passage into the mixing location, wherein the liquid injected by the injector mixes with pressurized air from the air passage at the mixing location;

a dispenser for dispensing the mixture of liquid and air into the exhaust stream.

2. The system of claim 1, wherein the mixing location includes a mixing chamber defined at least partially within the injector housing.

3. The system of claim 1, wherein the dispenser includes a dispensing tube that projects outwardly from the injector housing, the dispensing tube including an orifice spaced from the injector housing, wherein the mixing location includes a mixing chamber defined at least partially within the dispensing tube.

4. The system of claim 1, wherein the dispenser includes a dispensing tube that projects outwardly from the injector housing, the dispensing tube including an orifice spaced from the injector housing.

5. The system of claim 1, further comprising a source of liquid for supplying liquid to the liquid inlet of the injector housing, wherein the injector housing also defines a liquid return outlet for returning undispensed liquid from the injector housing back to the source of liquid, and wherein at least some of the liquid from the source of liquid flows through the passage lengths of the cooling passage structure to cool the injector housing.

6. The system of claim 5, wherein the passage lengths of the cooling passage structure are generally parallel to one another.

7. The system of claim 1, wherein the injector housing includes a first block coupled to a second block, and wherein the injector is mounted between the first and second blocks.

8. The system of claim 7, further comprising a liquid pressure regulator mounted between the first and second blocks.

9. The system of claim 8, further comprising a liquid return outlet in fluid communication with the liquid pressure regulator, the liquid return outlet and the air inlet being defined by the second block and the liquid inlet being defined by the first block.

10. The system of claim 1, further comprising a pressure sensor mounted to the injector housing for determining a pressure at the mixing location.

11. The system of claim 1, further comprising a pressurized air flow regulating orifice for regulating air flow through the air passage.

12. The system of claim 1, wherein the orifice diameter is approximately 0.04 to 0.07 inches.

13. The system of claim 1, further comprising a pump box for providing liquid to the liquid inlet, the pump box containing a pump, a liquid filter and one or more safety switches.

14. The system of claim 1, wherein the pressure of the liquid within the liquid passage is approximately 30 to 50 pounds per square inch (gauge) greater than the pressure of the supply air.

15. The system of claim 1, wherein the pressure is approximately 40 to 60 pounds per square inch gauge pressure at the mixing location.

16. An apparatus for dispensing a substance into an exhaust stream within an exhaust conduit comprising:

a mounting base including a first portion having a curved surface for engaging an exterior surface of the exhaust conduit, and a second portion including a mounting surface offset from the curved surface by a spacing; and

an injector housing mounted at the mounting surface of the mounting base and a tube through which the substance is dispensed, the tube extending from the injector housing across the spacing and through the curved surface, wherein the tube is adapted to project into the exhaust conduit when the apparatus is mounted to the exhaust conduit.

17. The apparatus of claim 16, wherein the mounting base is secured to the exhaust conduit by at least one u-bolt.

18. The apparatus of claim 16, wherein the spacing includes an air gap of at least one-half of an inch.

19. An exhaust system for treating engine exhaust, the exhaust system comprising:

an exhaust conduit receiving exhaust from a combustion engine;

a treatment device positioned within the exhaust conduit for treating the exhaust; and

an injector device mounted to the exhaust conduit at a location between the treatment device and the engine, the injector device including:

an injector housing positioned outside the exhaust conduit, the injector housing defining an air passage and a liquid passage;

an air inlet for providing pressurized air to the air passage of the injector housing;

a liquid inlet for providing liquid to the liquid passage of the injector housing;

a mixing location in fluid communication with the air passage;

an injector mounted within the injector housing for injecting liquid from the liquid passage into the mixing location, wherein the liquid injected by the injector mixes with pressurized air from the air passage at the mixing location;

a dispensing tube that projects outwardly from the injector housing, the tube extending from the injector housing, through a wall of the exhaust conduit, to an interior of the exhaust conduit, the dispensing tube including an orifice for dispensing the mixture of liquid and air into the exhaust within the exhaust conduit.

20. The exhaust system of claim 19, wherein the orifice is located adjacent a central axis of the exhaust conduit.

21. The exhaust system of claim 19, wherein the orifice diameter is approximately 0.04 to 0.07 inches.

22. The exhaust system of claim 19, further comprising a mount secured to the exhaust conduit for spacing the injector housing from the exhaust conduit.

23. The exhaust system of claim 19, wherein an air flow rate within the air passage does not exceed 1 standard cubic foot per minute.

24. A method for introducing a liquid reactant into a vehicle exhaust pipe, the method comprising:

mixing the liquid reactant with compressed air at a location outside the exhaust pipe to form a liquid/air mixture, the compressed air having a flow rate that never exceeds 1 standard cubic foot per minute;

delivering the liquid/air mixture to an orifice of a dispenser; and

introducing the liquid/air mixture into the interior or the exhaust pipe through the orifice of the dispenser.

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