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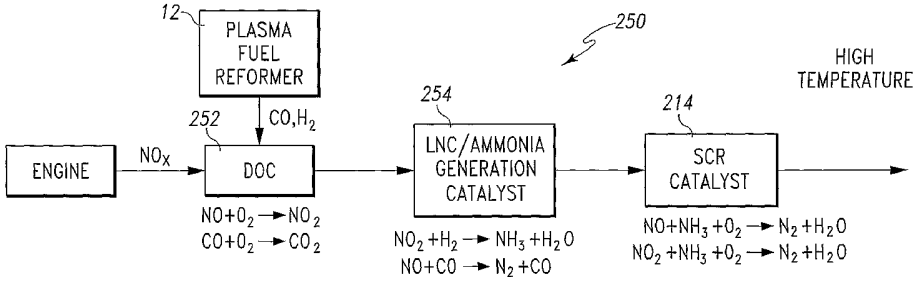

(57) Abstract: An emission abatement assembly includes a fuel reformer which supplies reformate gas to a catalyst. Exhaust gas from an internal combustion engine is advanced through the catalyst and into a downstream SCR catalyst.

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EMISSION ABATEMENT SYSTEMS AND METHODS

This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 60/660,361, entitled "Emission Abatement Systems and Methods" filed on March 10, 2005 by Navin Khadiya, Samuel N. Crane, Jr., and Robert Iverson, the entirety of which is hereby incorporated by reference.

FIELD OF THE DISCLOSURE

The present disclosure relates to generally to emission abatement systems for internal combustion engines.

BACKGROUND

Plasma fuel reformers reform hydrocarbon fuel into a reformate gas such as hydrogen-rich gas. In the case of a plasma fuel reformer onboard a vehicle or stationary power generator, the reformate gas produced by the reformer may be utilized as fuel or fuel additive in the operation of an internal combustion engine. The reformate gas may also be utilized to regenerate or otherwise condition an emission abatement device associated with the internal combustion engine (e.g., a NO_X trap, particulate filter, or SCR catalyst). The reformate gas may also be used as a fuel for a fuel cell.

SUMMARY

According to one aspect of the present disclosure, an emission abatement assembly includes a pair of NO_X traps arranged in a parallel arrangement. The NO_X traps are operated in tandem such that both traps are online (i.e., absorbing

NO_X) during operation of the engine. Periodically, one of the traps is taken offline for regeneration.

According to another aspect of the disclosure, an emission abatement assembly includes a catalyst positioned upstream of a urea SCR catalyst. Hydrogen from a fuel reformer is advanced into the upstream catalyst. At operating temperatures below a predetermined temperature, NO_X is converted by the upstream catalyst into N_2 in a similar manner as a H-SCR catalyst. At operating temperatures above the predetermined temperature, the upstream catalyst converts some of the NO_X in the exhaust gas into NH_3. The NH_3 is advanced, along with the remaining NO_X in the exhaust gas, into the SCR catalyst wherein it functions as a reductant fluid to covert the remaining NO_X into N_2.

In certain embodiments, the upstream catalyst is embodied as two separate catalysts – an oxidation catalyst, such as a diesel oxidation catalyst, and an ammonia generating catalyst.

In certain embodiments, the ammonia generating catalyst is positioned in a parallel flow path with a portion of the engine exhaust gas bypassing the ammonia generating catalyst through a second parallel flow path.

According to yet another aspect of the disclosure, a plasma fuel reformer is operated to generate oxygenated hydrocarbons. The oxygenated hydrocarbons are supplied to the intake of an internal combustion engine such as an HCCI engine.

The above and other features of the present disclosure will become apparent from the following description and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified block diagram of a fuel reforming assembly having a plasma fuel reformer under the control of an electronic control unit;

FIG. 2 is a diagrammatic cross sectional view of the plasma fuel reformer of FIG. 1;

FIG. 3 is a simplified block diagram of an emission abatement assembly;

FIG. 4 is a timing graph of a trap regenerating scheme;

FIG. 5 is a fragmentary perspective view of a diverter valve;

FIGS. 6-8 are simplified diagrammatic views of the diverter valve of FIG. 5 showing the valve in various valve positions;

FIGS. 9 and 10 are simplified block diagrams of another emission abatement assembly;

FIGS. 11-15 are simplified block diagrams of systems for generating oxygenated hydrocarbons by use of a fuel reformer;

FIGS. 16 and 17 are simplified block diagrams of an emission abatement assembly that is similar to the assemblies of FIGS. 9 and 10; and

FIG. 18 is a simplified diagram similar of an emission abatement assembly that is similar to the assembly of FIGS. 16 and 17.

DETAILED DESCRIPTION OF THE DRAWINGS

As will herein be described in more detail, a fuel reformer, according to the concepts of the present disclosure, may be utilized to regenerate or otherwise condition an emission abatement assembly. For example, a fuel reformer may be operated to generate and supply a reformate gas to a pair of NO_X traps or to a catalyst positioned upstream of an SCR catalyst. Reformate gas from the fuel reformer may

also be utilized as a fuel additive for an internal combustion engine such as an HCCI engine.

The fuel reformer described herein may be embodied as any type of fuel reformer such as, for example, a catalytic fuel reformer, a thermal fuel reformer, a steam fuel reformer, or any other type of partial oxidation fuel reformer. The fuel reformer of the present disclosure may also be embodied as a plasma fuel reformer. A plasma fuel reformer uses plasma to convert a mixture of air and hydrocarbon fuel into a reformate gas which is rich in, amongst other things, hydrogen gas and carbon monoxide. Systems including plasma fuel reformers are disclosed in U.S. Patent No. 5,425,332 issued to Rabinovich et al.; U.S. Patent No. 5,437,250 issued to Rabinovich et al.; U.S. Patent No. 5,409,784 issued to Bromberg et al.; and U.S. Patent No. 5,887,554 issued to Cohn, et al. Additional examples of systems including plasma fuel reformers are disclosed in: (1) copending U.S. Patent Application No. 10/158,615 which is entitled "Low Current Plasmatron Fuel Converter Having Enlarged Volume Discharges," which was filed on May 30, 2002 by A. Rabinovich, N. Alexeev, L. Bromberg, D. Cohn, and A. Samokhin, (2) copending U.S. Patent Application No. 10/411,917 which is entitled "Plasmatron Fuel Converter Having Decoupled Air Flow Control," which was filed on April 11, 2003 by A. Rabinovich, N. Alexeev, L. Bromberg, D. Cohn, and A. Samokhin, and is hereby incorporated by reference herein, (3) copending U.S. Patent Application No. 10/452,623 which is entitled "Fuel Reformer With Cap and Associated Method," which was filed on June 2, 2003 by Michael W. Greathouse and Jon J. Huckaby, (4) copending U.S. Patent Application No. 10/843,776 which is entitled "Plasma Fuel Reformer With One-Piece Body," which was filed on May 12, 2004 by Michael W. Greathouse and Jason Zhang, and (5) copending U.S. Patent Application No. 60/660,362 which is entitled "Plasma Fuel Reformer," which was filed on March 10, 2005 by Michael W.

Greathouse, Stephen Goldschmidt, Navin Khadiya, Samuel Crane, Robert Iverson, Kendall Duffield, Michael Blackwood, William Taylor, III, Rudolf Smaling, Michael Smith, Jon Huckaby, Christopher Huffmeyer, and Granville Hayworth, II. Each of the above-identified patents and patent applications are hereby incorporated by reference.

For purposes of the following description, the concepts of the present disclosure will herein be described in regard to a plasma fuel reformer. However, as described above, the fuel reformer of the present disclosure may be embodied as any type of fuel reformer.

Referring now to FIGS. 1 and 2, there is shown an exemplary embodiment of a plasma fuel reforming assembly 10 of an emission abatement assembly 14. The plasma fuel reforming assembly 10 includes a plasma fuel reformer 12 and a control unit 16. The plasma fuel reformer 12 reforms (i.e., converts) hydrocarbon fuels into a reformate gas that includes, amongst other things, hydrogen and carbon monoxide. As such, the plasma fuel reformer 12 may be used in the construction of an onboard fuel reforming system of a vehicle or a stationary power generator. In such a way, the reformate gas produced by the onboard plasma fuel reformer 12 may be utilized as a regenerating fluid to regenerate or otherwise condition an emission abatement device associated with an internal combustion engine (e.g., a diesel engine or a gasoline engine).

As shown in FIG. 2, the plasma fuel reformer 12 includes a plasma-generating assembly 42 and a reactor 44. The plasma-generating assembly 42 is secured to an upper portion of the reactor 44. The plasma-generating assembly 42 includes an upper electrode 54 and a lower electrode 56. The electrodes 54, 56 are spaced apart from one another so as to define an electrode gap 58 therebetween. An insulator 60 electrically insulates the electrodes from one another.

The electrodes 54, 56 are electrically coupled to an electrical power supply 36 such that, when energized, an electrical current is supplied to one of the electrodes thereby generating a plasma arc (not shown) across the electrode gap 58 (i.e., between the electrodes 54, 56). A fuel input mechanism such as a fuel injector 38 injects a hydrocarbon fuel 64 into the plasma arc. The fuel injector 38 may be any type of fuel injection mechanism which injects a desired amount of fuel into plasma-generating assembly 42. In certain configurations, it may be desirable to atomize the fuel prior to, or during, injection of the fuel into the plasma-generating assembly 42. Such fuel injector assemblies (i.e., injectors which atomize the fuel) are commercially available.

As shown in FIG. 2, the plasma-generating assembly 42 has an annular air chamber 72. Pressurized air is advanced into the air chamber 72 and is thereafter directed radially inwardly through the electrode gap 58 so as to "bend" the plasma arc inwardly. Such bending of the plasma arc ensures that the injected fuel 64 is directed through the plasma arc. Such bending of the plasma arc also reduces erosion of the electrodes 56, 58. Moreover, advancement of air into the electrode gap 58 also produces a desired mixture of air and fuel ("air/fuel mixture"). In particular, the plasma reformer 12 reforms or otherwise processes the fuel in the form of a mixture of air and fuel. The air-to-fuel ratio of the air/fuel mixture being reformed by the fuel reformer is controlled via control of the fuel injector 38 and an air inlet valve 40. The air inlet valve 40 may be embodied as any type of electronically-controlled air valve. The air inlet valve 40 may be embodied as a discrete device, as shown in FIG. 2, or may be integrated into the design of the plasma fuel reformer 12. In either case, the air inlet valve 40 controls the amount of air that is introduced into the plasma-generating assembly 42 thereby controlling the air-to-fuel ratio of the air/fuel mixture being processed by the plasma fuel reformer 12.

Gas (either reformed or partially reformed) exiting the plasma arc 62 is advanced into the reactor 44. A catalyst (not shown) may be positioned in the reactor 44. The catalyst completes the fuel reforming process, or otherwise treats the gas, prior to exit of the reformate gas from the reactor 44. In particular, some or all of the gas exiting the plasma-generating assembly 42 may only be partially reformed, and the catalyst is configured to complete the reforming process (i.e., catalyze a reaction which completes the reforming process of the partially reformed gas exiting the plasma-generating assembly 42). The catalyst may be embodied as any type of catalyst that is configured to catalyze such reactions. In one exemplary embodiment, the catalyst embodied as a substrate having a precious metal or other type of catalytic material disposed thereon. Such a substrate may be constructed of ceramic, metal, or other suitable material. The catalytic material may be, for example, embodied as platinum, rhodium, palladium, including combinations thereof, along with any other similar catalytic materials. The plasma fuel reformer 12 may be embodied without the catalyst.

As shown in FIG. 1, the plasma fuel reformer 12 and its associated components are under the control of the control unit 16. In particular, the fuel injector 38 is electrically coupled to the electronic control unit 16 via a signal line 20, the air inlet valve 40 is electrically coupled to the electronic control unit 16 via a signal line 22, and the power supply 36 is electrically coupled to the electronic control unit 16 via a signal line 24. Moreover, as will herein be described in greater detail, a number of other components associated with the emission abatement assembly 14 may also be under the control of the control unit 16, and, as a result, electrically coupled thereto. For example, a flow diverter valve 88 for selectively diverting an exhaust gas flow from an internal combustion engine and a flow of reformate gas from the plasma fuel reformer 12 between any number of components may be under the control of the

control unit 16. A number of sensors such as NO_X sensors and pressure sensors associated with the emission abatement assembly 14 are also electrically coupled to the control unit 16.

Although the signal lines 20, 22, 24 (and any of the signal lines used to couple other devices associated with the emission abatement assembly 14 to the control unit) are shown schematically as a single line, it should be appreciated that the signal lines may be configured as any type of signal carrying assembly which allows for the transmission of electrical signals in either one or both directions between the electronic control unit 16 and the corresponding component. For example, any one or more of the signal lines 20, 22, 24 (or any other signal line disclosed herein) may be embodied as a wiring harness having a number of signal lines which transmit electrical signals between the electronic control unit 16 and the corresponding component. It should be appreciated that any number of other wiring configurations may also be used. For example, individual signal wires may be used, or a system utilizing a signal multiplexer may be used for the design of any one or more of the signal lines 20, 22, 24 (or any other signal line). Moreover, the signal lines 20, 22, 24 may be integrated such that a single harness or system is utilized to electrically couple some or all of the components associated with the plasma fuel reformer 12 to the electronic control unit 16.

The electronic control unit 16 is, in essence, the master computer responsible for interpreting electrical signals sent by sensors associated with the plasma fuel reformer 12 and for activating electronically-controlled components associated with the plasma fuel reformer 12 in order to control the plasma fuel reformer 12, the flow of reformate gas exiting therefrom, and an exhaust gas flow from an internal combustion engine. For example, the electronic control unit 16 of the present disclosure is operable to, amongst many other things, determine the

beginning and end of each injection cycle of fuel into the plasma-generating assembly 42, calculate and control the amount and ratio of air and fuel to be introduced into the plasma-generating assembly 42, determine the power level to supply to the plasma fuel reformer 12, and determine when to commence and end a regeneration cycle of each of the emission components (e.g., NO_X traps or a soot filter).

To do so, the electronic control unit 16 includes a number of electronic components commonly associated with electronic units which are utilized in the control of electromechanical systems. For example, the electronic control unit 16 may include, amongst other components customarily included in such devices, a processor such as a microprocessor 28 and a memory device 30 such as a programmable read-only memory device ("PROM") including erasable PROM's (EPROM's or EEPROM's). The memory device 30 is configured to store, amongst other things, instructions in the form of, for example, a software routine (or routines) which, when executed by the processor 28, allows the electronic control unit 16 to control operation of the plasma fuel reformer 12 and other devices associated with the emission abatement assembly 14.

The electronic control unit 16 also includes an analog interface circuit 32. The analog interface circuit 32 converts the output signals from the various fuel reformer sensors (e.g., a temperature sensor or gas composition sensor) or other sensors associated with the with the emission abatement assembly (e.g., the NO_X sensor and the pressure sensors) into a signal which is suitable for presentation to an input of the microprocessor 28. In particular, the analog interface circuit 32, by use of an analog-to-digital (A/D) converter (not shown) or the like, converts the analog signals generated by the sensors into a digital signal for use by the microprocessor 28. It should be appreciated that the A/D converter may be embodied as a discrete device or number of devices, or may be integrated into the microprocessor 28. It should also

be appreciated that if any one or more of the sensors associated with the plasma fuel reformer 12 or the emission abatement assembly 14 generate a digital output signal, the analog interface circuit 32 may be bypassed.

Similarly, the analog interface circuit 32 converts signals from the microprocessor 28 into an output signal which is suitable for presentation to the electrically-controlled components associated with the plasma fuel reformer 12 (e.g., the fuel injector 38, the air inlet valve 40, the power supply 36), or other system components associated with the emission abatement assembly 14 (e.g., the diverter valve 88). In particular, the analog interface circuit 32, by use of a digital-to-analog (D/A) converter (not shown) or the like, converts the digital signals generated by the microprocessor 28 into analog signals for use by the electronically-controlled components associated with the fuel reformer 12 and the emission abatement assembly 14. It should be appreciated that, similar to the A/D converter described above, the D/A converter may be embodied as a discrete device or number of devices, or may be integrated into the microprocessor 28. It should also be appreciated that if any one or more of the electronically-controlled components associated with the plasma fuel reformer 12 or the emission abatement assembly 14 operate on a digital input signal, the analog interface circuit 32 may be bypassed.

Hence, the electronic control unit 16 may be operated to control operation of the plasma fuel reformer 12, and components associated therewith, and the components associated with the emission abatement assembly 14. In particular, the electronic control unit 16 executes a routine including, amongst other things, a closed-loop control scheme in which the electronic control unit 16 monitors the outputs from a number of sensors in order to control the inputs to the electronically-controlled components associated therewith. To do so, the electronic control unit 16 communicates with the sensors associated with the fuel reformer 12 and the emission

abatement assembly 14 to determine, amongst numerous other things, the amount, temperature, and/or pressure of air and/or fuel being supplied to the plasma fuel reformer 12, the amount of hydrogen and/or oxygen in the reformate gas, the temperature of the reformer or the reformate gas, the composition of the reformate gas, the accumulation level within an emission abatement device (e.g., a NO_X trap or soot filter), etcetera. Armed with this data, the electronic control unit 16 performs numerous calculations each second, including looking up values in preprogrammed tables, in order to execute algorithms to perform such functions as determining when or how long the fuel reformer's fuel injector or other fuel input device is opened, controlling the power level input to the fuel reformer, controlling the amount of air advanced through air inlet valve, controlling the position of a flow diverter valve responsible for directing the flow of reformate gas and exhaust gas to one component or the other, determining the quantity and/or composition of reformate gas to generate and deliver to a particular component, etcetera.

Referring now to FIG. 3, there is shown the emission abatement assembly 14 in greater detail. The emission abatement assembly 14 includes a pair of NO_X traps 84, 86 for removing and treating NO_X present in the exhaust gas from an internal combustion engine 82 such as a diesel engine, a gasoline engine, a gasoline direct injection (GDI) engine, or natural gas engine. The NO_X traps 84, 86 are arranged in a parallel relationship with one another. As such, for purposes of clarity of description, the NO_X trap 84 will herein be referred to as the right NO_X trap, whereas the NO_X trap 86 will herein be referred to as the left NO_X trap. However, such use of directional terms (i.e., right and left) is not intended to infer any particular orientation, but rather is only used herein only for ease of description.

The NO_X traps 84, 86 may be any type of commercially available NO_X trap, including a lean NO_X trap, which facilitates the trapping and removal of NO_X in

the lean conditions associated with exhaust gases from diesel engines, GDI engines, or natural gas engines. Specific examples of NO_X traps which may be used as the NO_X traps 84, 86 of the present disclosure include, but are not limited to, NO_X traps commercially available from, or NO_X traps constructed with materials commercially available from, EmeraChem, LLC of Knoxville, Tennessee (formerly known as Goal Line Environmental Technologies, LLC of Knoxville, Tennessee).

The emission abatement assembly 14 may also include one or more additional components downstream of the NO_X traps 84, 86. For example, a number of catalysts and/or soot filters may be positioned downstream of the NO_X traps 84, 86. It should be appreciated that although a specific exemplary embodiment is described herein in which an oxidation catalyst 94 and a catalyzed soot filter 96 are positioned downstream of the NO_X traps 84, 86, numerous other configurations may be used to fit the needs of a given system. For example, two soot filters (instead of one) may be used with each filter being positioned downstream from one of the NO_X traps 84, 86 in a parallel flow arrangement.

The catalyst 94 may be embodied as any type of catalyst that is configured to catalyze oxidation reactions in an exhaust gas stream. In one exemplary embodiment, the catalyst 94 is embodied as substrate having a precious metal or other type of catalytic material disposed thereon. Such a substrate may be constructed of ceramic, metal, or other suitable material. The catalytic material may be, for example, embodied as platinum, rhodium, palladium, including combinations thereof, along with any other similar catalytic materials. When positioned downstream of the NO_X traps 84, 86, the catalyst 94 may function to clean up any hydrogen or hydrocarbon "slip" from the NO_X traps 84, 86. For example, the oxidation catalyst 94 may be used to oxidize any H_2, certain hydrocarbons, or H_2S that may be present in the gases exiting the traps 84, 86. Moreover, as will be discussed herein in greater detail, when

positioned upstream of the soot filter 96, the catalyst 94 may be utilized during assisted regeneration of soot filter 96.

The soot filter 96 may be embodied as any type of commercially available particulate filter. For example, the soot particulate filter may be embodied as any known exhaust particulate filter such as a "deep bed" or "wall flow" filter. Deep bed filters may be embodied as metallic mesh filters, metallic or ceramic foam filters, ceramic fiber mesh filters, and the like. Wall flow filters, on the other hand, may be embodied as a cordierite or silicon carbide ceramic filter with alternating channels plugged at the front and rear of the filter thereby forcing the gas advancing therethrough into one channel, through the walls, and out another channel.

The soot filter 96 is impregnated with a catalytic material. The catalytic material may be, for example, embodied as platinum, rhodium, palladium, including combinations thereof, along with any other similar catalytic materials. By use of catalytic material, the temperature at which soot particles trapped in the filter combust is lowered such that regeneration of the soot filter 96 may occur in the presence of the heat of the engine exhaust gas. However, if the soot accumulation level within the soot filter 96 reaches a predetermined level (i.e., regeneration based on exhaust gas heat alone is not sufficient to clear the filter), reformate gas from the fuel reformer 12 may be used to regenerate the filter.

As shown in FIG. 3, a diverter valve 88 selectively diverts the flow of exhausts gas from the engine 82 between the traps 84, 86. In particular, the diverter valve 88 may be operated to divert a flow of exhaust gas from the engine 82 between a right flow path 102 and a left flow path 104. The right NO_X trap 84 is positioned in the right flow path 102 such that exhaust gas or reformate gas advancing through the right flow path 102 is advanced through the right NO_X trap 84. The left NO_X trap 86

is positioned in the left flow path 104 such that exhaust gas or reformate gas advancing through the left flow path 104 is advanced through the left NO_X trap 86.

As also shown in FIG. 3, the right flow path 102 and the left flow path 104 are recombined by a flow coupler 106. The flow coupler 106 is positioned downstream of the NO_X traps 84, 86 and upstream of oxidation catalyst 94 and the soot filter 96. As a result, gas exiting the NO_X traps 84, 86 is directed through both the oxidation catalyst 94 and the soot filter 96.

In the exemplary embodiment described herein, a number of fluid lines such as pipes, tubes, or the like are utilized to create the various flow paths. In particular, an exhaust gas inlet 108 of the diverter valve 88 is fluidly coupled to an exhaust manifold 110 of the engine 82 via a fluid line 112. A right outlet 114 of the diverter valve 88 is fluidly coupled to an inlet 116 of the right NO_X trap 84 via a fluid line 118, whereas a left outlet 120 of the diverter valve 88 is fluidly coupled to an inlet 122 of the left NO_X trap 86 via a fluid line 124. An outlet 126 of the right NO_X trap 84 is fluidly coupled to the flow coupler 106 via a fluid line 128, whereas an outlet 130 of the left NO_X trap 86 is fluidly coupled to the flow coupler 106 via the fluid line 132. A fluid line 134 fluidly couples the flow coupler 106 to an inlet 136 of the oxidation catalyst 94. An outlet 138 of the oxidation catalyst 94 is fluidly coupled to an inlet 140 of the soot filter 96 via a fluid line 142. Via a fluid line 144, an outlet 146 of the soot filter 96 is either open to the atmosphere or coupled to an additional exhaust system component (not shown) positioned downstream of the soot filter 96.

In such a configuration, exhaust gas from the engine 82 may be routed through the emission abatement assembly 14 to remove, amongst other things, NO_X and soot therefrom. To do so, exhaust gas may be selectively routed between the two NO_X traps 84, 86 to allow for both treatment of the exhaust gas and trap regeneration. For example, exhaust gas may be routed through the right NO_X trap 84 while the left

NO_X trap 86 is maintained "offline." While offline, the left NO_X trap 86 may undergo regeneration. In such a case, exhaust gas is advanced along a fluid path which includes the fluid line 112 from the exhaust manifold 110, the diverter valve 88, the fluid line 118 to the right NO_X trap 84, through the trap 84 and the fluid line 128 to the flow coupler 106, the fluid line 134 to the oxidation catalyst 94, through the catalyst 94 and the fluid line 142 to the soot filter 96, through the soot filter 96 and out the fluid line 144.

To regenerate the right NO_X trap 84, the position of the diverter valve 88 may be switched such that exhaust gas from the engine 82 is routed through the left NO_X trap 86 while the right NO_X trap 84 is offline for regeneration. In this case, exhaust gas is advanced along a fluid path which includes the fluid line 112 from the exhaust manifold 110, the diverter valve 88, the fluid line 124 to the left NO_X trap 86, through the trap 86 and the fluid line 132 to the flow coupler 106, the fluid line 134 to the oxidation catalyst 94, through the catalyst 94 and the fluid line 142 to the soot filter 96, through the soot filter 96 and out the fluid line 144.

As will be discussed herein in greater detail, in addition to diverting exhaust gas from the engine 82 to the appropriate NO_X trap 84, 86, the diverter valve 88 is also configured to divert reformate gas from the fuel reformer 12 to the appropriate NO_X trap 84, 86. In particular, the outlet 76 of the fuel reformer 12 is fluidly coupled to a regenerating fluid inlet 148 of the diverter valve 88 via a fluid line 150. The diverter valve 88 diverts reformate gas from the fuel reformer 12 to the offline NO_X trap 84, 86. In particular, as described above, engine exhaust gas is routed by the diverter valve 88 through one of the traps 84, 86 while the other trap is maintained offline for regeneration. The diverter valve 88 routes engine exhaust gas through one of the traps 84, 86, while routing reformate gas from the fuel reformer 12 through the other trap 84, 86.

The diverter valve 88 is electrically coupled to the electronic control unit 16 via a signal line 152. As such, the position of the diverter valve 88 is under the control of the electronic control unit 16. Hence, the electronic control unit 16, amongst its other functions, selectively directs the flow of exhaust gas from the engine 82 and the flow of reformate gas from the fuel reformer 12 to either the right NO_X trap 84 or the left NO_X trap 86, or a combination of both traps 84, 86.

The control scheme for controlling the position of the diverter valve 88 may be designed in a number of different manners. For example, a sensor-based control scheme may be utilized. In such a case, the position of the diverter valve 88 is changed as a function of output from one or more sensors associated with the NO_X traps 84, 86. For instance, regeneration of one of the NO_X traps 84, 86 may commence when the output from an associated NO_X sensor 154 is indicative of a predetermined NO_X accumulation level within one of the NO_X traps 84, 86. More specifically, each of the NO_X sensors 154 is positioned to sense the NO_X content of exhaust gas passing through traps 84, 86. In such a downstream position relative to the NO_X traps 84, 86, the sensor 154 may be used to monitor the NO_X accumulation level of the NO_X trap 84, 86. As such, when the output from one of the NO_X sensors 154 indicates that a particular NO_X trap 84, 86 is in need of regeneration, the control unit 16 takes the trap 84, 86 in need of regeneration offline.

Alternatively, a timing-based control scheme may be utilized in which the position of the diverter valve 88 is changed as a function of time. For instance, regeneration of the traps 84, 86 may be performed at predetermined timed intervals. In such a case, the NO_X sensor 154 may be all together eliminated, or used merely as a "failsafe" to ensure that regeneration is not prematurely needed during a timed interval.

One specific exemplary timing-based control scheme is shown in FIG. 4. Unlike conventional arrangements in which one trap is maintained offline during the entire absorption cycle of the other trap, the control scheme demonstrated in FIG. 4 allows for both traps to be maintained online for predetermined periods of time thereby increasing the NO_X absorption capability of the system. To do so, the regeneration cycle of the NO_X traps 84, 86 are staggered in a manner which allows for both traps NO_X traps 84, 86 to absorb NO_X during a majority of the time during operation of the engine 82.

For example, in the exemplary embodiment described, both NO_X traps 84, 86 absorb NO_X during sixty seconds of a given interval of seventy seconds. Indeed, as shown in FIG. 4, the process may begin with the right NO_X trap 84 being maintained offline for regeneration for a predetermined period of time (e.g., five seconds) as shown by the arrow labeled t1. During this period time, the entire flow exhaust gas is advanced through the left NO_X trap 86. After the right NO_X trap 84 has been regenerated, the left NO_X trap 86 is maintained offline for regeneration for a predetermined period of time (e.g., five seconds) as shown by the arrow labeled t2. During this period time, the entire flow exhaust gas is advanced through the right NO_X trap 84. Once regenerated, the left NO_X trap 86 is put back online to absorb NO_X in tandem with the right NO_X trap 84 for a predetermined period of time (e.g., sixty-five seconds) until the right NO_X trap 84 is again taken offline for regeneration and the cycle repeats as shown by the arrow labeled t3.

It should be appreciated that the duration of the periods of time noted above are exemplary in nature, and may be varied to fit the needs of a given system. Of note is that by operating the two NO_X traps in tandem significantly extends the absorption cycle of each trap when compared to conventional methodologies in the which the traps are "toggled". In particular, in conventional systems, one trap is

maintained offline for the entire absorption cycle of the other trap. When the online trap saturates, the two traps are toggled with the saturated trap going offline for the entire absorption cycle of the other trap. Depending on the type of the NO_X trap and the type of regeneration fluid, a NO_X trap may have a regeneration cycle of around five seconds and an absorption cycle (i.e., time to saturation) of around thirty seconds. This means that the offline trap is regenerated, and then merely "waiting" for twenty-five seconds out of every thirty second cycle.

However, when working in tandem according to the methods of the present disclosure, the absorption cycle of each trap can be extended to, for example, seventy seconds (versus thirty seconds), and in some cases, upwards of ninety seconds. This is due to the other trap sharing some of the work of NO_X absorption. Another benefit is that the exhaust gas velocity is lowered since the flow is shared by both traps.

It should be appreciated that the flow-sharing method described above is not limited to two NO_X traps. Indeed, such a method could be used in a system having any number of NO_X traps.

Referring now to FIGS. 5-8, there is shown the diverter valve 88 in greater detail. The diverter valve 88 includes a valve housing 164 having a valve chamber 166 defined therein. Note that in FIG. 5, all but a small portion of the top plate 172 of the valve housing 164 has been cut away for clarity of view into the valve chamber 166.

The exhaust gas inlet 108, the regenerating fluid inlet 148, the right outlet 114, and the left outlet 120 are also defined in the valve housing 164. Although each of the inlets and outlets associated with the diverter valve 88 are exemplary embodied as an orifice defined in the walls of the valve housing 164, it should be appreciated that any or all of such inlets and outlets may, alternatively, be embodied

to include a tube, coupling assembly, or other structure which extends through the wall of the housing 164.

The fluid lines 112, 118, 124, and 150 are secured to the valve housing 164 such that fluids conducted therein may be advanced into or out of the valve chamber 166 thereby fluidly coupling the valve chamber 166 to a particular component. In particular, as shown in FIG. 5, one end of the fluid line 112 (shown as a pipe in FIG. 5) extends through the exhaust gas inlet 108 of the valve housing 164 thereby fluidly coupling the valve chamber 166 to the exhaust manifold 110 of the engine 82. An end of the fluid line 118 (shown as a pipe in FIG. 5) extends through the right outlet 114 of the valve housing 164 thereby fluidly coupling the valve chamber 166 to the inlet 116 of the right NO_X trap 84, whereas one end of the fluid line 124 (shown as a pipe in FIG. 5) extends through the left outlet 120 of the valve housing 164 thereby fluidly coupling the valve chamber 166 to the inlet 122 of the left NO_X trap 86. An end of the fluid line 150 (shown as a pipe in FIG. 5) extends through the regenerating fluid inlet 148 of the valve housing 164 thereby fluidly coupling the valve chamber 166 to the outlet 76 of the fuel reformer 12.

A valve member 168 in the form of a movable plate or "flap" is positioned in the valve chamber 166. The flap 168 is movable between a number of valve positions to selectively divert both exhaust gas from the engine 82 and reformate gas from the fuel reformer 12 to either one of the NO_X traps 84, 86. Specifically, the flap 168 is positionable to direct engine exhaust gas to one or both of the NO_X traps 84, 86 (i.e., the "online" trap(s)) while directing reformate gas from the fuel reformer 12 to the one of the NO_X traps 84, 86 (i.e., the "offline" trap).

For example, when positioned in the valve position shown in FIG. 6, the flap 168 diverts engine exhaust gas to the right NO_X trap 84, while also diverting reformate gas from the fuel reformer 12 to the left NO_X trap 86. Specifically, when

positioned in the valve position of FIG. 6, the flap 168 fluidly couples the exhaust gas inlet 108 to the right outlet 114, but fluidly isolates the exhaust gas inlet 108 from the left outlet 120. When positioned in the valve position of FIG. 6, the flap 168 also fluidly couples the regenerating fluid inlet 148 to the left outlet 120, but fluidly isolates the regenerating fluid inlet 148 from the right outlet 114.

Conversely, when positioned in the valve position shown in FIG. 7, the flap 168 diverts engine exhaust gas to the left NO_X trap 86, while also diverting reformate gas from the fuel reformer 12 to the right NO_X trap 84. Specifically, when positioned in the valve position of FIG. 7, the flap 168 fluidly couples the exhaust gas inlet 108 to the left outlet 120, but fluidly isolates the exhaust gas inlet 108 from the right outlet 114. When positioned in the valve position of FIG. 7, the flap 168 also fluidly couples the regenerating fluid inlet 148 to the right outlet 114, but fluidly isolates the regenerating fluid inlet 148 from the left outlet 120.

Additionally, when positioned in the valve position shown in FIG. 8, the flap 168 splits or otherwise diverts the flow engine exhaust gas between both the NO_X traps 84, 86. Specifically, when positioned in the valve position of FIG. 8, the flap 168 fluidly couples the exhaust gas inlet 108 to both the right outlet 114 and the left outlet 120. When positioned in the valve position of FIG. 8, the flap 168 also fluidly couples the regenerating fluid inlet 148 to both the right outlet 114 and the left outlet 120. The fuel reformer 12 may be idled or otherwise operated to not supply reformate gas to the valve 88 when the flap 168 is positioned in the valve position shown in FIG. 8.

The diverter valve 88 also includes a valve actuator 170 which, as alluded to above, is electrically coupled to the control unit 16 via the signal line 152. As such, the position of the diverter valve 88 is under the control of the control unit 16. As a result, the control unit 16, amongst its other functions, may selectively direct

the flow of exhaust gas from the engine 82 and reformate gas from the plasma fuel reformer 12 to either the right NO_X trap 84 or the left NO_X trap 86 (or both). Specifically, the control unit 16 may generate control signals on the signal line 152 which cause the valve actuator 170 to selectively position the flap 168 in either the valve positions of FIG. 6-8. The valve actuator 170 may be embodied as any type of electrically-controlled actuator for moving the flap 168 in such a manner. For example, the valve actuator may be embodied as a linear solenoid or a stepper motor.

It should be appreciated that although the diverter valve 88 is herein described as a three position, other control configurations of the diverter valve 88 are also contemplated. For example, a variable flow configuration is also contemplated in which a desired amount of engine exhaust gas may be directed through the offline trap 84, 86 and/or a desired amount of reformate gas may be directed through the online trap 84, 86.

The components of the diverter valve 88 may be constructed with any type of material suitable for withstanding the operating conditions to which the valve 88 is subjected. For example, the components of the diverter valve 88 may be constructed with any of the 300-series or 400-series stainless steels. In a specific implementation, the components of the diverter valve 88 may be constructed with either "304" stainless steel or "409" stainless steel. The components of the diverter valve 88 may also be constructed with other materials such as ceramic coated metals or the like.

Referring now to FIGS. 9 and 10, there is shown another emission abatement system 210. Note that the system 210 utilizes a number of the same components as the system 10. Like reference numerals are used for like components.

Exhaust gas containing NO_X is advanced through a catalyst 212. The catalyst 212 may be embodied as a substrate having a precious metal or other type of

catalytic material disposed thereon. Such a substrate may be constructed of ceramic, metal, or other suitable material. The catalytic material may be, for example, embodied as platinum, rhodium, palladium, including combinations thereof, along with any other similar catalytic materials.

The output from the catalyst 212 is then advanced through an SCR catalyst 214. The SCR catalyst 214 may be embodied as a conventional urea SCR catalyst.

The output from the plasma fuel reformer 12 (i.e., reformate gas containing hydrogen) is advanced into an inlet of the catalyst 212. This arrangement allows for the conversion of NO_X to N_2 at the various operating temperatures of the system. For example, as shown in FIG. 9, at operating temperatures above 200°C, the catalyst 212 catalyzes a reaction which converts the hydrogen in the reformate gas and some of the NO_X in the exhaust stream into ammonia (NH_3) and water. The ammonia is then subsequently used by the SCR catalyst 214 to convert the remaining NO_X into N_2. As such, at temperatures above 200°C, use of the catalyst 212 allows for the onboard production of ammonia for use as a reductant fluid for the SCR catalyst 214 thereby eliminating the need for urea storage.

It should be appreciated that both the operating parameters of the plasma fuel reformer 12 and the design of the catalyst 212 may be configured to produce ammonia and NO_X in a desired ratio. For example, a conventional SCR catalyst efficiently converts NO_X when the ratio of NH_3 to NO_X is ~1:1. Operation of the plasma fuel reformer 12 and the design of the catalyst 212 may be configured such that NO_X and NH_3 exit the catalyst 212 in such a ratio.

As shown in FIG. 10, at operating temperatures below 200°C, the catalyst 212 catalyzes a reaction which converts the hydrogen in the reformate gas and the NO_X in the exhaust stream into nitrogen (N_2) and water. In essence, at

operating temperatures below 200°C, the catalyst 212 functions as a hydrogen-SCR catalyst.

It should be appreciated that the specific transition temperature identified above (i.e., 200°C) at which the production of ammonia begins is exemplary in nature, and is largely based on the type of catalytic material(s) utilized in the construction of the catalyst 212. For example, such a transition temperature (i.e., 200°C) is indicative of use of a platinum catalytic material. Other catalytic materials may produce different transition temperatures. For example, the transition temperature of a catalyst constructed with palladium catalytic material or a rhodium may be around 230°C. It should also be appreciated that the gas composition of the reformate gas may also affect the transition temperature of the catalyst.

Referring now to FIGS. 16 and 17, there is shown another emission abatement system 250. Note that the system 250 utilizes a number of the same components as the systems 10, 210. Like reference numerals are used for like components. Note that the chemical references in FIGS. 16 and 17 are not intended to connote specific chemical reactions (i.e., they are not balanced (or even unbalanced) chemical equations), but rather are used merely to show some of the reactants going into a particular catalyst and some of the products coming out of the catalyst.

In the system of 250, the single ammonia-generating catalyst 212 has been replaced with a pair of catalysts – an oxidation catalyst 252 and a lean-NO_X/ammonia-generating catalyst 254. Although shown a separate devices in FIGS. 16 and 17, the two catalysts 252, 254 may be disposed on the same structure, e.g., the same substrate.

The oxidation catalyst 252 may be embodied as any type of precious metal oxidation catalyst such as platinum catalyst or palladium catalyst. One such oxidation catalyst is a commercially available diesel oxidation catalyst.

The lean-NO_X/ammonia-generating catalyst 254 may be embodied as any type of catalyst which, as described in more detail below, functions as a lean NO_X catalyst that converts NO_X to N_2 under certain temperature conditions and an ammonia generating catalyst under others. Examples of such catalysts are found in the following articles, the entirety of each of which is hereby incorporated by reference: (1) *Optimal promotion by rubidium of the NO+CO Reaction over Pt/g-Al_2O_3 Catalysts.* Michalis Konsolakis, Iannis V. Yentekakis, Alejandra Palermo and Richard M. Lambert, Applied Catalysis B (Environmental) 33 335 (2001), (2) *Lean NOx reduction with CO + H_2 mixtures over Pt/Al_2O_3 and Pd/Al_2O_3 catalysts.* Norman Macleod and Richard M. Lambert, Journal of Applied Catalysis B (Environmental) 35 269 (2001), (3) *Efficient low-temperature NOx reduction with CO + H_2 under fuel-lean conditions over a Pd/TiO_2/Al_2O_3 catalyst.* Norman Macleod and Richard M. Lambert, Catalysis Communications 3 (2002) 61, (4) *Efficient reduction of NO_x by H_2 under oxygen-rich conditions over Pd/TiO_2 catalysts: an in situ DRIFTS study.* Norman Macleod, Rachael Cropley and Richard M. Lambert, Catalysis Letters 86 69 (2003), (5) *In situ ammonia generation as a strategy for catalytic NO_x reduction under oxygen rich conditions.* Norman Macleod and Richard M. Lambert, Chemical Communications 1300 (2003), (6) *An in situ DRIFTS study of efficient lean NO_x reduction with H_2+CO over Pd/Al_2O_3: the key role of transient NCO formation in the subsequent generation of ammonia.* Norman Macleod and Richard M. Lambert, Applied Catalysis B: Environmental 46 (2003) 483, (7) *Exploiting the synergy of titania and alumina in lean NO_x reduction: in situ ammonia generation during the Pd/TiO_2/Al_2O_3 - catalysed /CO/NO/O_2 reaction.* Norman Macleod, Rachael Cropley, James M. Keel and Richard M. Lambert, Journal of Catalysis 221 (2004) 20, (7) *An Investigation of catalysts for on-board synthesis of NH3. A possible route to low temperature NOx reduction for lean burn engines.* Breen, Burch, and Lingaiah,

Catalysis Letters, v. 79, 2002, and (8) *In-Situ NH3 Generation for SCR NOx Applications*. S. Ogunwumi, R. Fox, M. D. Patil and L. He; SAE 2002-01-2872.

Exhaust gas containing NO_X is advanced through the DOC catalyst 252 and the lean NO_X/ammonia generating catalyst 254. The output from the catalysts 252, 254 is then advanced through the SCR catalyst 214.

The output from the plasma fuel reformer 12 (i.e., reformate gas containing H_2 and CO) is advanced into an inlet of the catalyst 252. This arrangement allows for the conversion of NO_X to N_2 at the various operating temperatures of the system. For example, as shown in FIG. 17, at higher operating temperatures (e.g., above 250°C), the catalysts 252, 254 catalyze a reaction which converts the hydrogen in the reformate gas and some of the NO_X in the exhaust stream into ammonia (NH_3) and water. Specifically, some NO is oxidized to NO_2 and CO is oxidized to CO_2 by the DOC catalyst 252. These reactions consume some of the free O_2 in the exhaust gas. A portion of the remaining NO_X is converted to NH_3 by the lean-NO_X/ammonia-generating catalyst 254. The dosage of reformate gas provided the plasma fuel reformer 12 is controlled such that NO_X and NH_3 exit the catalyst 254 in the desired ~1:1 ratio. The NH_3 is then subsequently used by the SCR catalyst 214 to convert the remaining NO_X into N_2. As such, at temperatures above 250°C, use of the catalysts 252, 254 allow for the onboard production of ammonia for use as a reductant fluid for the SCR catalyst 214 thereby eliminating the need for urea storage.

As shown in FIG. 16, at lower operating temperatures (e.g., below 150°C), the catalysts 252, 254 catalyze a reaction which converts the hydrogen in the reformate gas and the NO_X in the exhaust stream into nitrogen (N_2) and water. Specifically, in the DOC catalyst 252, some NO is oxidized to NO_2 and CO is oxidized to CO_2 by the DOC catalyst 252. These reactions consume some of the free O_2 in the exhaust gas. The H_2 supplied by the plasma fuel reformer 12 reacts with NO

and NO_2 in the lean-NO_X/ammonia-generating catalyst 254 to form N_2 using the principles of lean NO_X catalysis or hydrogen-SCR. Thereafter, the SCR catalyst 214 acts as a pass through catalyst (i.e., without any chemical participation).

In an intermediate range (e.g., between 150°C - 250°C), somewhat of a combination of the two conditions occurs. In particular, in the DOC catalyst 252, some NO is oxidized to NO_2 and CO is oxidized to CO_2 by the DOC catalyst 252. These reactions consume some of the free O_2 in the exhaust gas. The H_2 supplied by the plasma fuel reformer 12 reacts with NO and NO_2 in the lean-NO_X/ammonia-generating catalyst 254 to form N_2 using the principles of lean NO_X catalysis or hydrogen-SCR. However, some of the NO_X is converted to NH_3 in the lean-NO_X/ammonia-generating catalyst 254. The dosage of reformate gas provided the plasma fuel reformer 12 is controlled such that not all of the NO_X is converted to NH_3 so that enough NO_X remains for reaction with the NH_3 in the SCR catalyst 214 (i.e., for conversion into N_2).

It should be appreciated that the specific temperature ranges identified above in which the production of ammonia begins is exemplary in nature, and is largely based on the type of catalytic material(s) utilized in the construction of the catalysts. Other catalytic materials may produce different temperature ranges. It should also be appreciated that the gas composition of the reformate gas may also affect the temperature ranges.

It should be appreciated that the position of the oxidation catalyst 252 may be altered based on the desired reaction products. For example, in certain embodiments, it may be desirable to convert NO to NO_2 upstream of the lean-NO_X/ammonia-generating catalyst 254, but it may not be necessary, or even desirable, to convert CO to CO_2. In such a case, the oxidation catalyst 252 would be positioned upstream of the point at which reformate gas from the plasma fuel reformer 12 is

introduced into the system (i.e., reformate gas is not advanced through the oxidation catalyst 252). This may be done based on the type of lean-NO_X/ammonia-generating catalyst 254 being used. For example, certain types of lean-NO_X/ammonia-generating catalysts, such as those that are palladium-based, actually benefit from the presence of CO. As such, it is desirable to not convert the CO in the reformate gas to CO_2. On the other hand, other types of lean-NO_X/ammonia-generating catalysts, such as those that are platinum-based, are inhibited by the presence of CO. Hence, it is desirable to convert the CO in the reformate gas to CO_2 in this case.

It should also be appreciated that the oxidation catalyst 252 may be embodied as two separate catalysts. In such a case, one of such catalysts is positioned upstream of the point at which reformate gas from the plasma fuel reformer 12 is introduced into the system (i.e., reformate gas would not be advanced through the first catalyst) to convert NO in the exhaust gas to NO_2. The other of such catalysts is positioned downstream of the point at which reformate gas from the plasma fuel reformer 12 is introduced into the system (i.e., reformate gas is advanced through the second catalyst). If the lean-NO_X/ammonia-generating catalyst 254 is inhibited by CO, then the second catalyst may be embodied as a CO oxidation catalyst such as the Pt/Al_2O_3 or $Pt/Ce_xZr_{x-1}O_2$ catalysts described in The Journal of Catalysis, Volume 225, Issue 2, 25 July 2004, Pages 259-266, the entirety of which is hereby incorporated by reference. In such a case, the second catalyst will remove CO while preserving or enhancing the H_2 concentration of the reformate gas.

Moreover, in lieu of, or in addition to, a CO oxidation catalyst, a water/gas shift catalyst may be utilized upstream of the lean-NO_X/ammonia-generating catalyst 254. In such an arrangement, CO will react with H_2O in the water/gas shift catalyst to form H_2 and CO_2. This is particularly useful in cases where the lean-NO_X/ammonia-generating catalyst 254 is inhibited by CO.

Referring now to FIG. 18, there is shown another emission abatement system 260. Note that the system 260 utilizes a number of the same components as the systems 10, 210, 250. Like reference numerals are used for like components.

In the system 260, the exhaust gas flow is split into two parallel flow paths 262, 264 such that approximately 50% of the exhaust gas flows through the ammonia generating catalyst 254 and the other 50% is bypassed around the ammonia generating catalyst 254. The exhaust gas flow is split at a point downstream of the DOC catalyst 252, and then recombined at a point upstream of the SCR catalyst 254. In this embodiment, the DOC catalyst 252 converts NO to NO_2 and CO to CO_2 which enhances operation of the ammonia generating catalyst 254 by removing O_2 from the exhaust gas. In certain embodiments, the DOC catalyst 252 may be omitted.

The plasma fuel reformer 12 introduces reformate gas into the flow path containing the ammonia generating catalyst 254 (i.e., the flow path 262). As with the other systems described herein, any number of fluid lines such as pipes, tubes, or the like are utilized to create the various flow paths.

In the system 260, ammonia generation is desired at all temperatures, and the hydrogen-SCR function at low temperatures is not needed. The formulation of the catalyst 254 may be adjusted accordingly. A relatively high ammonia conversion efficiency is desired so that the NH_3 leaving the first parallel flow path 262 and the NO_X leaving the second parallel flow path 264 are near the desired ~1:1 ratio.

A flow diverter valve 256 may be used to adjust the ratio of the exhaust gas flowing through each of the flow paths 262, 264. In this way, desired ammonia conversion efficiency may be provided. In other words, the position of the valve 256 may be controlled to produce a desired amount of NH_3 while also allowing a desired amount of NO_X to reach the SCR catalyst 214 by virtue of bypassing the

ammonia generating catalyst 254. In lieu of the point where the two flow paths are split, the valve 256 may also be positioned at the point where the two flow paths are recombined.

Optionally, a water/gas shift catalyst may be utilized upstream of the ammonia generating catalyst 254. In such an arrangement, CO will react with H_2O in the water/gas shift catalyst to form H_2 and CO_2. This is particularly useful in cases where the ammonia generating catalyst 254 is inhibited by CO. In lieu of, or in addition to, use of such a water/gas shift catalyst, a CO oxidation catalyst may be utilized upstream of the lean-NO_X/ammonia-generating catalyst 254 to remove CO.

It should be appreciated that in the case of any of the systems 210, 250, 260, the SCR catalyst 214 generally has some ammonia storage capacity. As a result, during periods when excess NH_3 is made, such excess may be stored. During deficient periods, stored NH_3 can be utilized so that desired efficiency is obtained under diverse conditions.

Moreover, the ammonia generation catalyst 254 can optionally have NO_X storage components (or a NO_X adsorber catalyst can be used as the ammonia generation catalyst in certain embodiments). During periods when an excess H_2:NO_X ratio exists, some adsorbed NO_X can be desorbed and utilized for NH_3 production. In situations where the H_2:NO_X ratio is too low, excess NO_X may be stored.

Referring now to FIGS. 11-15, there is shown a number of systems in which the plasma fuel reformer 12 is being utilized for combustion enhancement. In such arrangements, the gas produced by the plasma fuel reformer 12 is supplied to the intake of an internal combustion engine such as an HCCI engine. Indeed, research and calculations suggest that auto ignition of fuel can be enhanced by the addition of a small amount of partially reformed fuel molecules to the air/fuel mixture. In particular, partially reformed fuels have been shown to alter the temperature

requirements for successful combustion in HCCI engines. Research has shown that molecules such as oxygenated hydrocarbons are particularly desirable partially reformed fuels. Examples of such oxygenated hydrocarbons include Acetaldehyde, Propenal, Butanal, and Butanone. As will be discussed below in greater detail, there are a number of methods for using the plasma fuel reformer 12 to attain these partially reformed molecules.

Referring now to FIG. 11, the plasma fuel reformer 12 may be used in conjunction with a heat exchanger 310. In such an arrangement, thermal energy could be removed from the hot H_2 and CO mixture as it exits the plasma fuel reformer 12. This thermal energy may be used to heat an ultra lean mixture of air and fuel that is in a reservoir 312 that is remote from the fuel reformer 12. If the lean air/fuel mixture is heated to temperatures near 300°C, the fuel will begin to break up and be partially reformed. The air/fuel ratio of the ultra lean mixture may be >25.

Another way to attain partially reformed molecules is shown in FIG. 12. In this case, the reactions within the plasma fuel reformer 12 are quenched before they go to completion (i.e., before the H_2 and CO is produced in large quantities). To do so, a heat exchanger 314 or some other device is used to quickly cool the gasses as they leave the fuel reformer 12 thereby freezing the chemistry in such a way that the fuel molecule remains primarily intact or is only slightly reformed. This arrangement differs from the arrangement of FIG. 11 in that the normal operation of the fuel reformer 12 is altered in order to manipulate the chemical composition of the gasses as they leave the reformer.

Another arrangement for attaining partially reformed molecules is shown in FIG. 13. Computations suggest that the reformate gas exiting a normally operating fuel reformer 12 contains a small amount of partially reformed fuel fragments. The hydrogen and CO, which inhibit auto ignition, may be separated from

the partially reformed fuel molecules which help enable auto ignition by use of a separator 316 positioned downstream of the fuel reformer 12. This would allow for a wide amount of control over the effective octane number of a fuel. Hydrogen and CO could be added to the intake of an engine when a high octane fuel is required. Partially reformed fuel could be added to the intake of the engine when auto ignition may be beneficial.

As shown in FIG. 14, the magnitude of the power supplied to the plasma fuel reformer may be reduced to initiate a small number of reactions in the plasma fuel reformer system without allowing for enough initial energy release to trip the reaction into full fuel reforming. For example, depending on, amongst other things, the air/fuel ratio of the fuel being reformed and the operating temperature of the reformer, full fuel reforming (i.e., the production of significant quantities of H_2 and CO) can be achieved at power levels of 70-100W. Oxygenated hydrocarbons may be generated at lower power levels in the range of, for example, 25-100W.

As shown in FIG. 15, a stoichiometric mixture of air and fuel is processed in the fuel reformer 12 to generate a large amount of heat (carbon dioxide and water would also be generated). This high temperature mixture may then be directed into a mixing chamber 318 along with an ultra lean mixture of air and some secondary fuel which is at a very low temperature (room temperature). By manipulating the flow rate of the stoichiometric mixture and the mass of the ultra lean mixture, the resulting temperature of the final mixture may be controlled to a temperature of about 300°C. This mixture will begin to react, thus reforming the fuel. This method allows for control over the temperature of the mixture, which also allows for control over the amount of the secondary fuel that reforms.

While the disclosure is susceptible to various modifications and alternative forms, specific exemplary embodiments thereof have been shown by way

of example in the drawings and has herein be described in detail. It should be understood, however, that there is no intent to limit the disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure.

There are a plurality of advantages of the present disclosure arising from the various features of the apparatus, systems, and methods described herein. It will be noted that alternative embodiments of the apparatus, systems, and methods of the present disclosure may not include all of the features described yet still benefit from at least some of the advantages of such features. Those of ordinary skill in the art may readily devise their own implementations of apparatus, systems, and methods that incorporate one or more of the features of the present disclosure and fall within the spirit and scope of the present disclosure.

Moreover, although the diverter valve 88 is herein described in regard to the directing of engine exhaust gas, along with a regenerating fluid in the form of reformate gas from a fuel reformer, it should be appreciated that the valve 88 may be used in regard to other types of regenerating fluids. For example, the diverter valve 88 may be used to direct regenerating fluids in the form of reductant gases which originate from sources other than onboard reformers such as tanks or other storage devices.

The diverter valve 88 may also be used to direct regenerating fluids in forms other than gases. For example, in certain embodiments, the diverter valve 88 may be used to direct regenerating fluids in the form of liquid hydrocarbon fuels. For instance, the diverter valve 88 may be used to direct regenerating fluid in the form of untreated diesel fuel. In such a case, for example, the untreated diesel fuel may be injected into the valve 88 (e.g., through the regenerating fluid inlet 148) by use of a

fuel injector assembly (including a fuel injector assembly that atomizes the diesel fuel prior to or during injection thereof).

CLAIMS

1. An emission abatement assembly comprising:

an ammonia-generating catalyst positioned to receive exhaust gas from an internal combustion engine,

an SCR catalyst positioned downstream of the ammonia-generating catalyst, and

a fuel reformer configured to generate a reformate gas comprising H_2, the fuel reformer being positioned to introduce the reformate gas into the ammonia-generating catalyst.

2. The emission abatement assembly of claim 1, wherein the fuel reformer comprises a plasma fuel reformer.

3. The emission abatement assembly of claim 1, further comprising an oxidation catalyst positioned upstream of the ammonia-generating catalyst.

4. The emission abatement assembly of claim 1, wherein the ammonia-generating catalyst comprises platinum.

5. The emission abatement assembly of claim 1, wherein the ammonia-generating catalyst comprises palladium.

6. The emission abatement assembly of claim 1, wherein:

the ammonia-generating catalyst is configured to utilize the reformate gas from the fuel reformer to convert NO_X to NH_3 when the temperature of the ammonia-generating catalyst is above a predetermined value, and

the ammonia-generating catalyst is configured to utilize the reformate gas from the fuel reformer to convert NO_X to N_2 when the temperature of the ammonia-generating catalyst is below the predetermined value.

7. The emission abatement assembly of claim 6, wherein the SCR catalyst is configured to utilize NH_3 generated by the ammonia-generating catalyst to convert NO_X to N_2.

8. The emission abatement assembly of claim 1, wherein the SCR catalyst is configured to store NH_3.

9. The emission abatement assembly of claim 1, wherein the ammonia-generating catalyst is configured to store NO_X.

10. A method of operating an emission abatement assembly, the method comprising the steps of:

operating a fuel reformer to generate a reformate gas comprising H_2,

advancing exhaust gas from an internal combustion engine and the reformate gas through an ammonia-generating catalyst such that (i) a portion of the NO_X in the exhaust gas is converted into NH_3 when the temperature of the ammonia-generating catalyst is above a predetermined value, and (ii) a portion of the NO_X in the exhaust gas is converted to N_2 when the temperature of the ammonia-generating catalyst is below the predetermined value, and

advancing the exhaust gas exiting the ammonia-generating catalyst through an SCR catalyst.

11. The method of claim 10, further comprising the step of converting NH_3 and NO_X into N_2 in the SCR catalyst.

12. The method of claim 10, further comprising the step of advancing the exhaust gas and the reformate gas through an oxidation catalyst prior to being introduced into the ammonia-generating catalyst.

13. The method of claim 12, wherein the operating step comprises operating the fuel reformer to generate a predetermined quantity of the reformate gas such that exhaust gas exiting the ammonia-generating catalyst has a predetermined ratio of NO_X and NH_3.

14. A method of operating an emission abatement assembly, the method comprising the steps of:

advancing exhaust gas and a reformate gas comprising H_2 from a fuel reformer into a ammonia-generating catalyst,

generating NH_3 with the ammonia-generating catalyst when the temperature of the ammonia-generating catalyst is above a predetermined value,

generating N_2 with the ammonia-generating catalyst when the temperature of the ammonia-generating catalyst is below the predetermined value, and

advancing the exhaust gas out of the ammonia-generating catalyst and through an SCR catalyst.

15. The method of claim 14, further comprising the step of advancing the exhaust gas and the reformate gas through an oxidation catalyst prior to introduction into the ammonia-generating catalyst.

16. The method of claim 14, further comprising the step of converting NH_3 and NO_X into N_2 with the SCR catalyst.

17. An emission abatement assembly comprising:

an ammonia-generating catalyst positioned in a first parallel flow path,

a fuel reformer positioned to supply a reformate gas comprising H_2 to the ammonia-generating catalyst,

an oxidation catalyst positioned upstream of a point which splits an exhaust flow of an internal combustion engine into the first parallel flow path and a second parallel flow path which bypasses the first parallel flow path, and

an SCR catalyst positioned downstream of a point which recombines the first parallel flow path and the second parallel flow path.

18. The assembly of claim 17, wherein the fuel reformer comprises a plasma fuel reformer.

19. The assembly of claim 17, further comprising a flow diverter valve operable to divert the exhaust gas flow between the first parallel flow path and the second parallel flow path.

20. A method of operating an emission abatement assembly, the method comprising the steps of:

advancing exhaust gas from an internal combustion engine through an oxidation catalyst,

splitting the exhaust gas downstream of the oxidation catalyst into (i) a first flow of exhaust gas which is advanced through a first parallel flow path, and (ii) a second flow of exhaust gas which is advanced through a second parallel flow path which bypasses the first flow path,

advancing the first flow of exhaust gas and a reformate gas comprising H_2 from a fuel reformer through an ammonia-generating catalyst positioned in the first parallel flow path,

recombining the first flow of exhaust gas and the second flow of exhaust gas, and

advancing the exhaust gas through an SCR catalyst subsequent to the recombining step.

21. The method of claim 20, wherein the splitting step comprises operating a flow diverter valve to divert the exhaust gas into the first parallel flow path and the second parallel flow path.

22. A method of operating a diverter valve of an emission abatement assembly, the method comprising the steps of:

positioning the diverter valve in a first valve position so as to (i) direct exhaust gas from an internal combustion engine to a first emission abatement device, and (ii) direct a reformate gas from a fuel reformer to a second emission abatement device,

positioning the diverter valve in a second valve position so as to (i) direct exhaust gas from the internal combustion engine to the second emission abatement device, and (ii) direct the reformate gas from a fuel reformer to the first emission abatement device, and

positioning the diverter valve in a third valve position so as to direct exhaust gas from the internal combustion engine to both the first emission abatement device and the second emission abatement device.

23. The method of claim 22, wherein:

the diverter valve comprises (i) an exhaust gas inlet, (ii) a reformate gas inlet, (iii) a first outlet fluidly coupled to the first emission abatement device, and (iv) a second outlet fluidly coupled to the second emission abatement device,

the step of positioning the diverter valve in the first valve position comprises fluidly coupling (i) the exhaust gas inlet to the first outlet, and (ii) the reformate gas inlet to the second outlet,

the step of positioning the diverter valve in the second valve position comprises fluidly coupling (i) the exhaust gas inlet to the second outlet, and (ii) the reformate gas inlet to the first outlet, and

the step of positioning the diverter valve in the third valve position comprises fluidly coupling the exhaust gas inlet to both the first outlet and the second outlet.

24. The method of claim 23, wherein:

the step of positioning the diverter valve in the first valve position further comprises fluidly isolating (i) the exhaust gas inlet from the second outlet, and (ii) the reductant fluid inlet from the first outlet, and

the step of positioning the diverter valve in the second valve position further comprises fluidly isolating (i) the exhaust gas inlet from the first outlet, and (ii) the reductant fluid inlet from the second outlet.

25. The method of claim 22, further comprising the steps of:

operating the fuel reformer to generate reformate gas when the diverter valve is positioned in either the first valve position or the second valve position, and

shutting down the fuel reformer when the diverter valve is positioned in the third valve position.

26. The method of claim 23, wherein the operating step comprises operating a plasma fuel reformer to generate reformate gas comprising H_2.

27. A method of operating an emission abatement assembly having a first NO_X trap and a second NO_X trap, the method comprising the steps of:

advancing exhaust gas from an internal combustion engine through both the first NO_X trap and the second NO_X trap,

determining if regeneration of the first NO_X trap is to be performed and generating a regenerate-first-trap signal in response thereto,

operating a fuel reformer so as to produce and advance reformate gas to the first NO_X trap in response to generation of the regenerate-first-trap signal,

advancing exhaust gas through the second NO_X trap in response to generation of the regenerate-first-trap signal,

determining if regeneration of the first NO_X trap is complete and generating a regeneration-complete signal in response thereto, and

advancing exhaust gas through both the first NO_X trap and the second NO_X trap in response to generation of the regeneration-complete signal.

28. The method of claim 27, further comprising the step of ceasing operation of the fuel reformer in response to generation of the regeneration complete signal.

29. The method of claim 27, further comprising the steps of:

determining if regeneration of the second NO_X trap is to be performed and generating a regenerate-second-trap signal in response thereto,

operating the fuel reformer so as to produce and advance reformate gas to the second NO_X trap in response to generation of the regenerate-second-trap signal, and

advancing exhaust gas from the internal combustion engine through the first NO_X trap in response to generation of the regenerate-second-trap signal.

30. The method of claim 29, wherein:

the step of advancing exhaust gas from the internal combustion engine through the first NO_X trap comprises positioning a diverter valve in a first valve position so as to (i) direct exhaust gas from an exhaust manifold of the internal combustion engine to the first NO_X trap, and (ii) isolate the second NO_X trap from the exhaust manifold,

the step of advancing exhaust gas from the internal combustion engine through the second NO_X trap comprises positioning the diverter valve in a second valve position so as to (i) direct exhaust gas from the exhaust manifold to the second NO_X trap, and (ii) isolate the from first NO_X trap from the exhaust manifold, and

the steps of advancing exhaust gas from the internal combustion engine through both the first NO_X trap and the second NO_X trap comprise positioning the diverter valve in a third valve position so as to direct exhaust gas from the exhaust manifold to both the first NO_X trap and the second NO_X trap.

31. A method of operating an emission abatement assembly having a first NO_X trap and a second NO_X trap, the method comprising the steps of:

advancing exhaust gas from an internal combustion engine through both the first NO_X trap and the second NO_X trap to adsorb NO_X with both the first NO_X trap and the second NO_X trap during a first period of time,

advancing exhaust gas through the first NO_X trap to adsorb NO_X with the first NO_X trap during a second period of time, the second period of time being less than the first period of time,

regenerating the second NO_X trap with reformate gas from a fuel reformer during the second period of time,

advancing exhaust gas through the second NO_X trap to adsorb NO_X with the second NO_X trap during a third period of time, the third period of time being less than the first period of time, and

regenerating the first NO_X trap with reformate gas from the fuel reformer during the third period of time.

32. The method of claim 31, wherein the second period of time is equal to the third period of time.

33. The method of claim 31, wherein:

the first period of time is about seventy seconds in duration, and

the second period of time is about five seconds in duration.

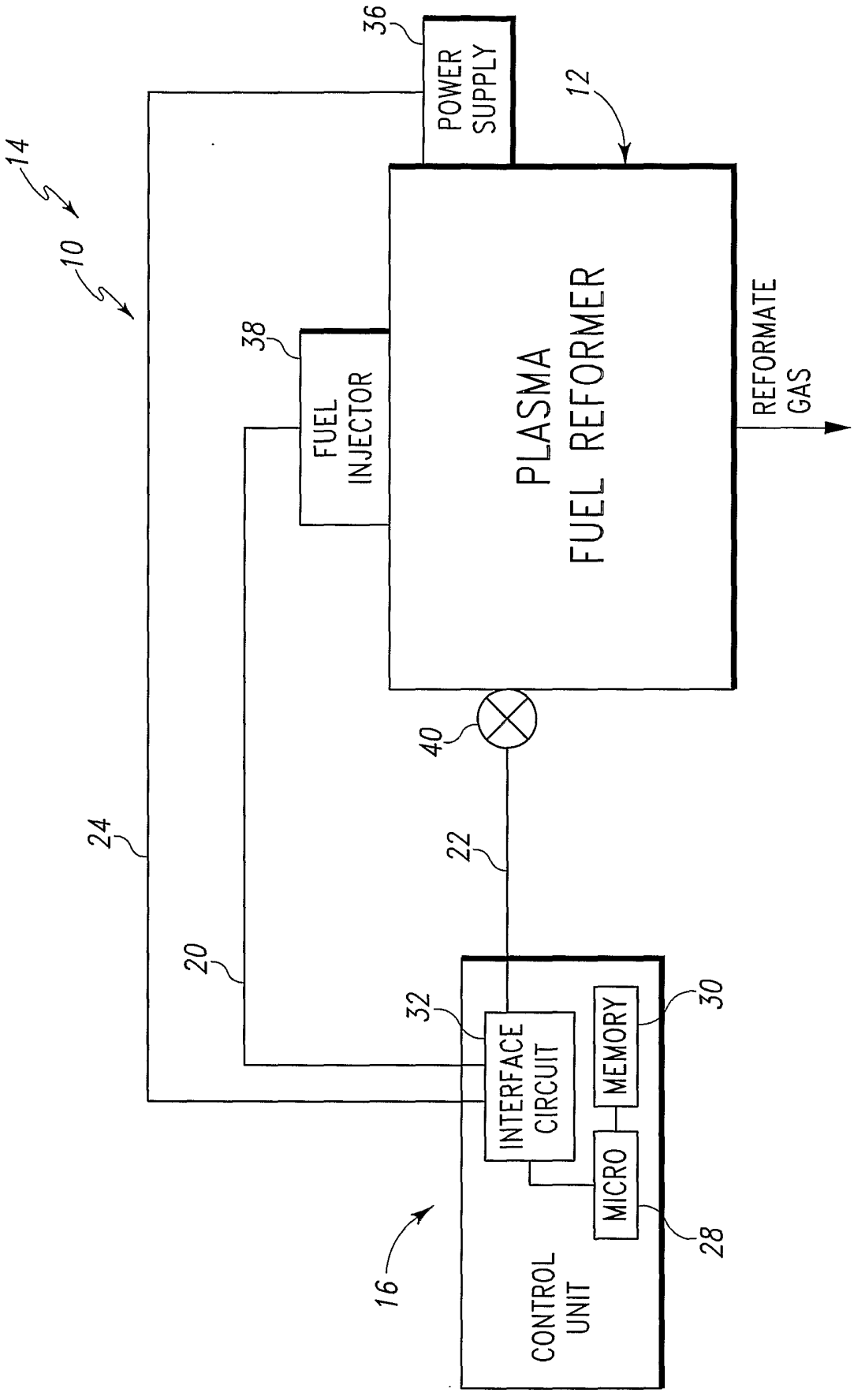
14
10
36
POWER SUPPLY
12
38
FUEL INJECTOR
PLASMA FUEL REFORMER
REFORMATE GAS
40
24
22
20
32
INTERFACE CIRCUIT
MEMORY
30
MICRO
28
16
CONTROL UNIT

Fig. 1

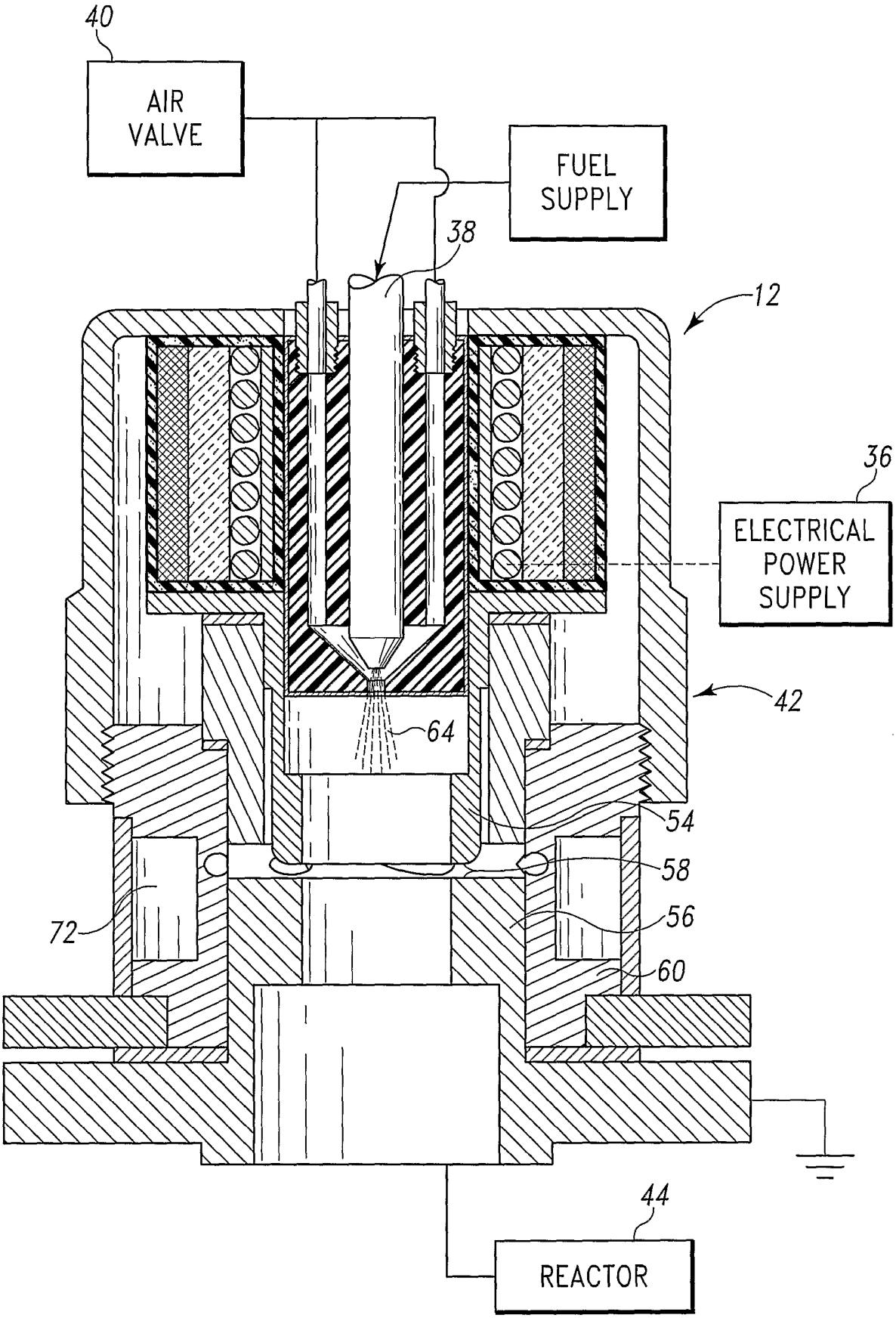
40
AIR VALVE
FUEL SUPPLY
38
12
36
ELECTRICAL POWER SUPPLY
42
64
54
58
56
60
72
44
REACTOR

Fig. 2

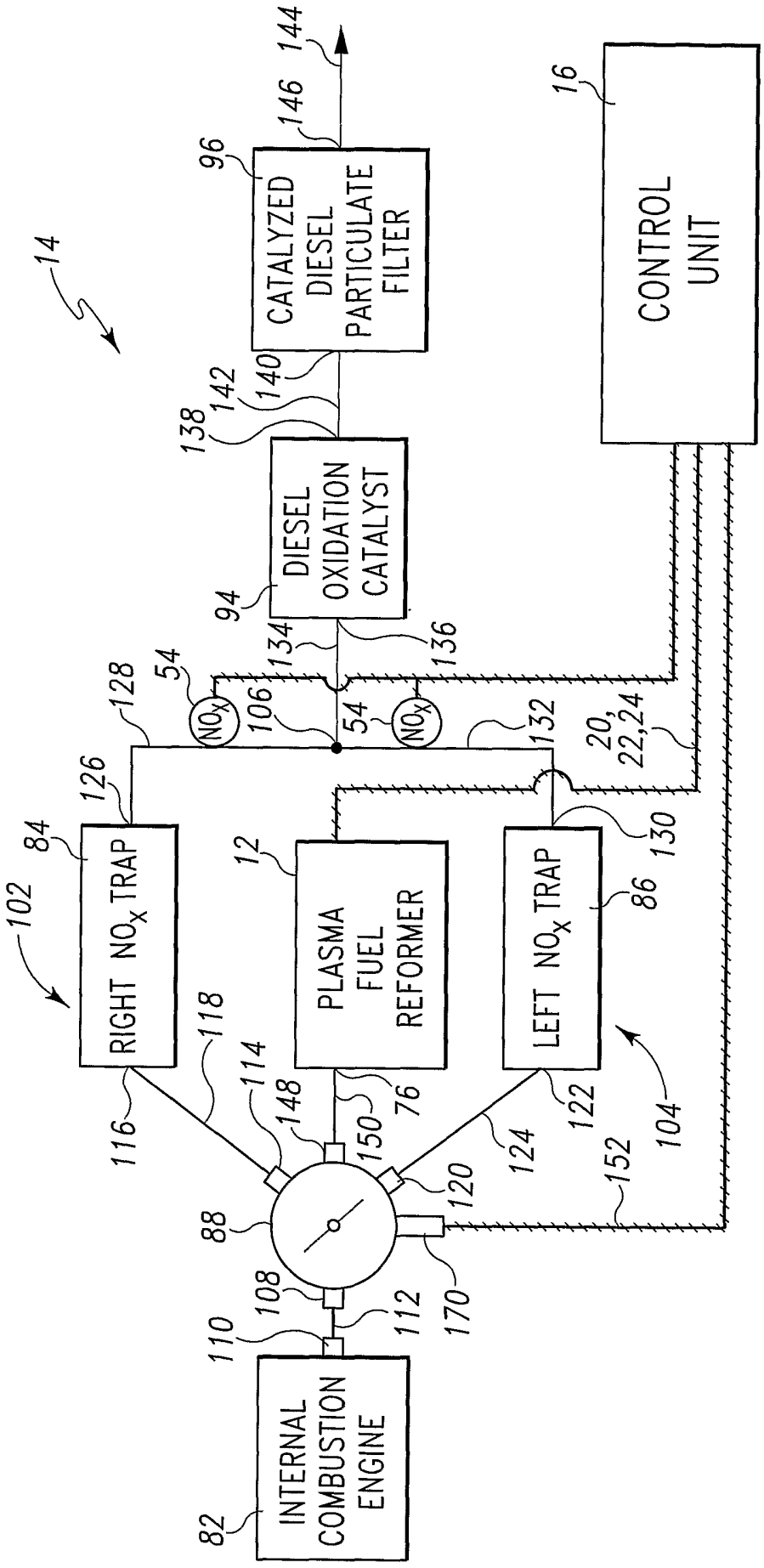
14
CATALYZED DIESEL PARTICULATE FILTER
96
144
146
CONTROL UNIT
16
DIESEL OXIDATION CATALYST
94
138
140
142
134
136
54
NO_x
106
128
126
132
20, 22,24
RIGHT NO_x TRAP
84
102
PLASMA FUEL REFORMER
12
LEFT NO_x TRAP
86
130
116
118
114
148
150
76
122
124
104
120
152
88
108
110
112
170
INTERNAL COMBUSTION ENGINE
82

Fig. 3

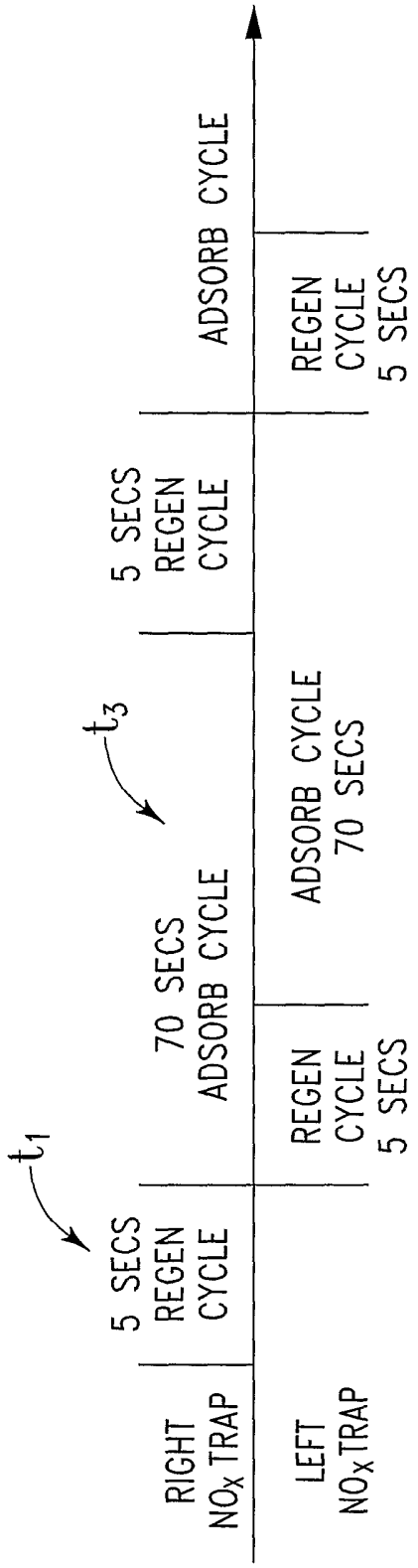
RIGHT NOx TRAP
LEFT NOx TRAP
5 SECS REGEN CYCLE
70 SECS ADSORB CYCLE
REGEN CYCLE 5 SECS
ADSORB CYCLE 70 SECS
5 SECS REGEN CYCLE
REGEN CYCLE 5 SECS
ADSORB CYCLE
t1
t2
t3
t

Fig. 4

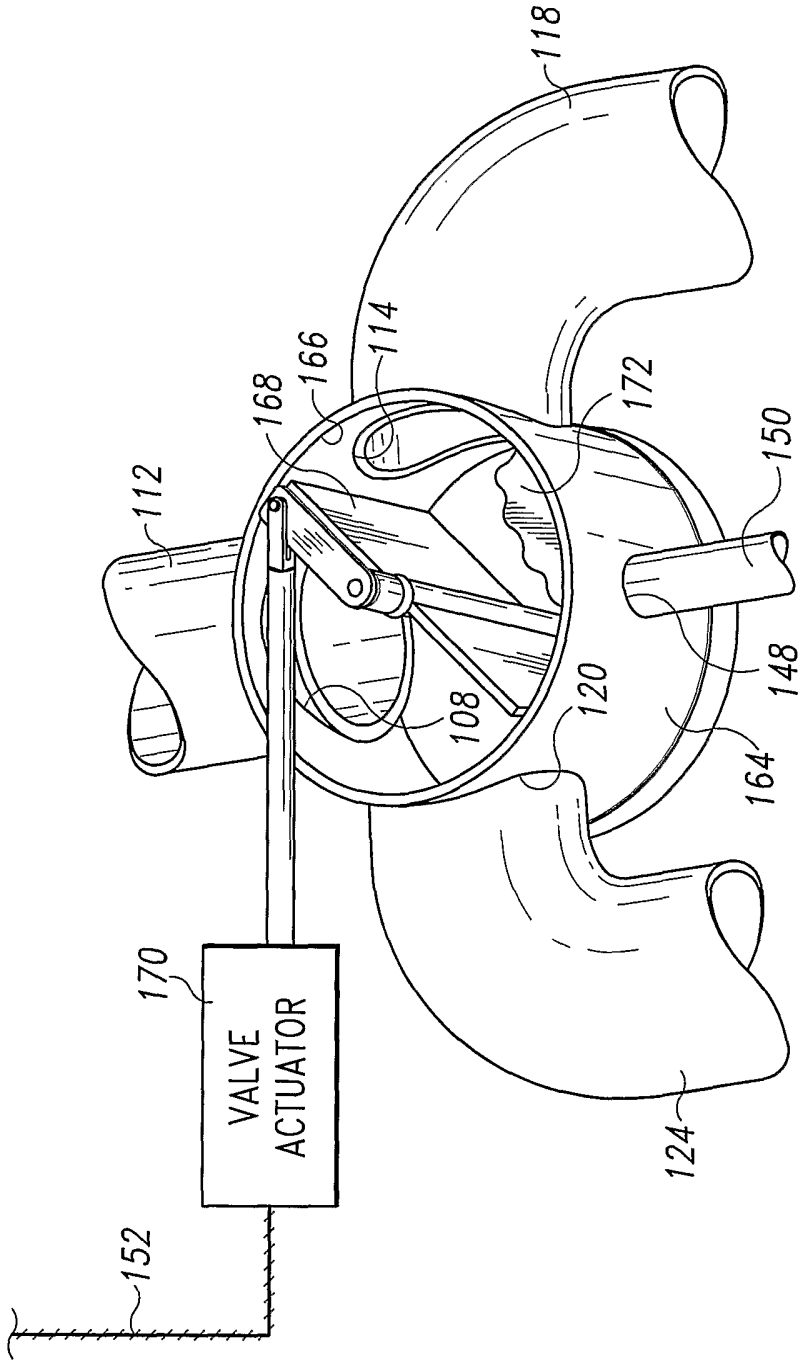
118
114
166
168
172
150
112
148
108
120
164
170
VALVE ACTUATOR
152
124

Fig. 5

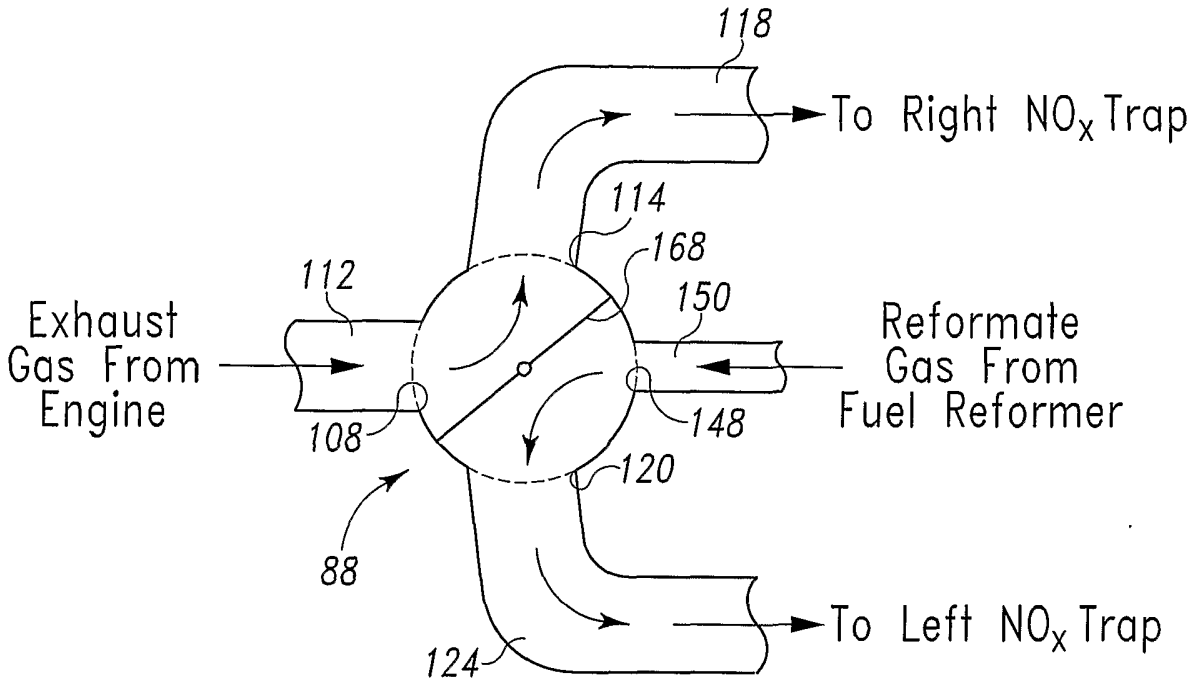
118
To Right NO_x Trap
114
168
112
150
Exhaust Gas From Engine
Reformate Gas From Fuel Reformer
108
148
120
88
124
To Left NO_x Trap

Fig. 6

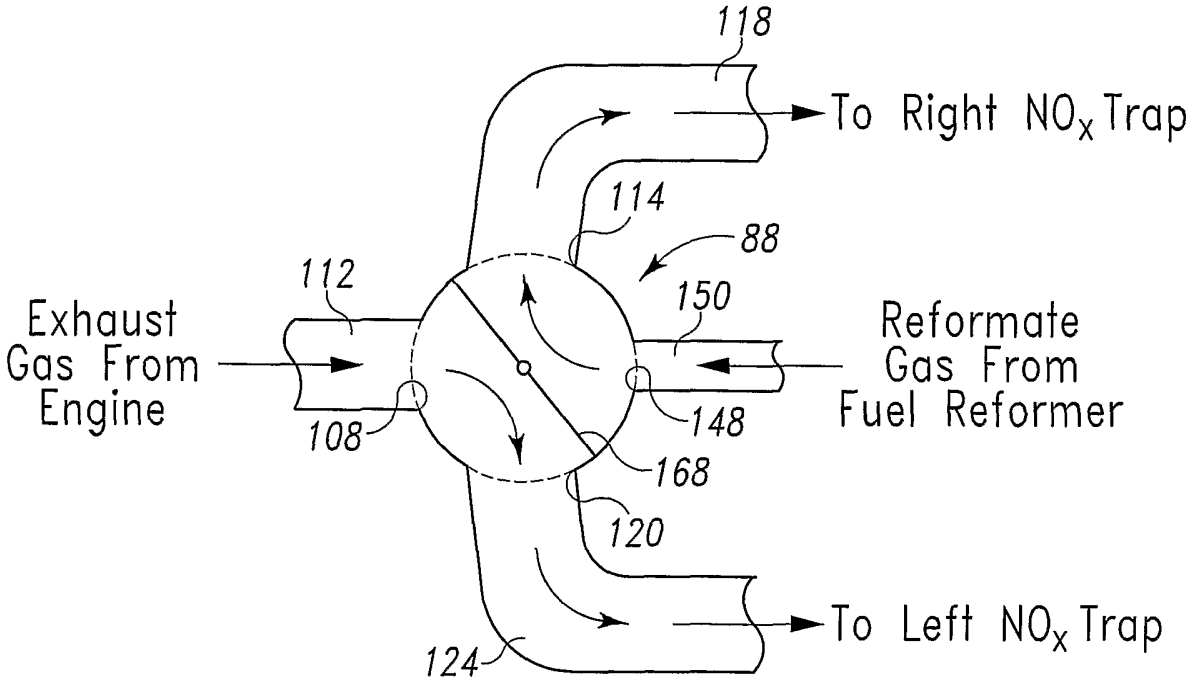
118
To Right NO_x Trap
114
88
112
150
Exhaust Gas From Engine
Reformate Gas From Fuel Reformer
108
148
168
120
124
To Left NO_x Trap

Fig. 7

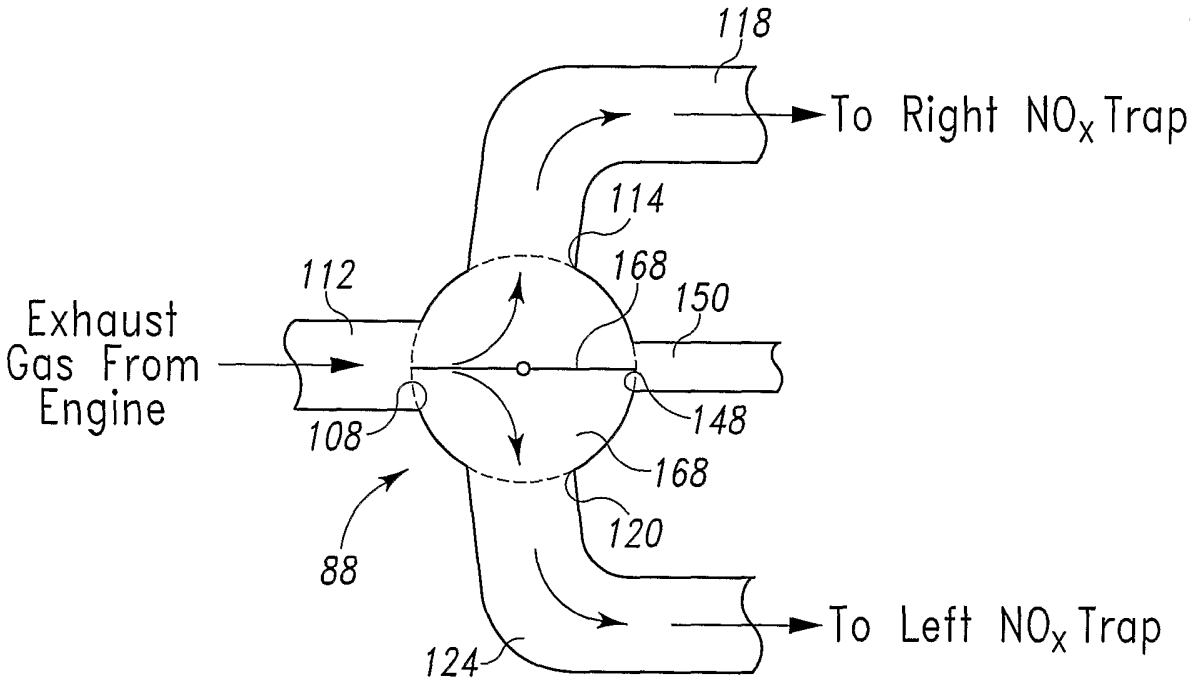
118
To Right NO_X Trap
114
168
150
112
Exhaust
Gas From
Engine
148
108
168
120
88
To Left NO_X Trap
124

Fig. 8

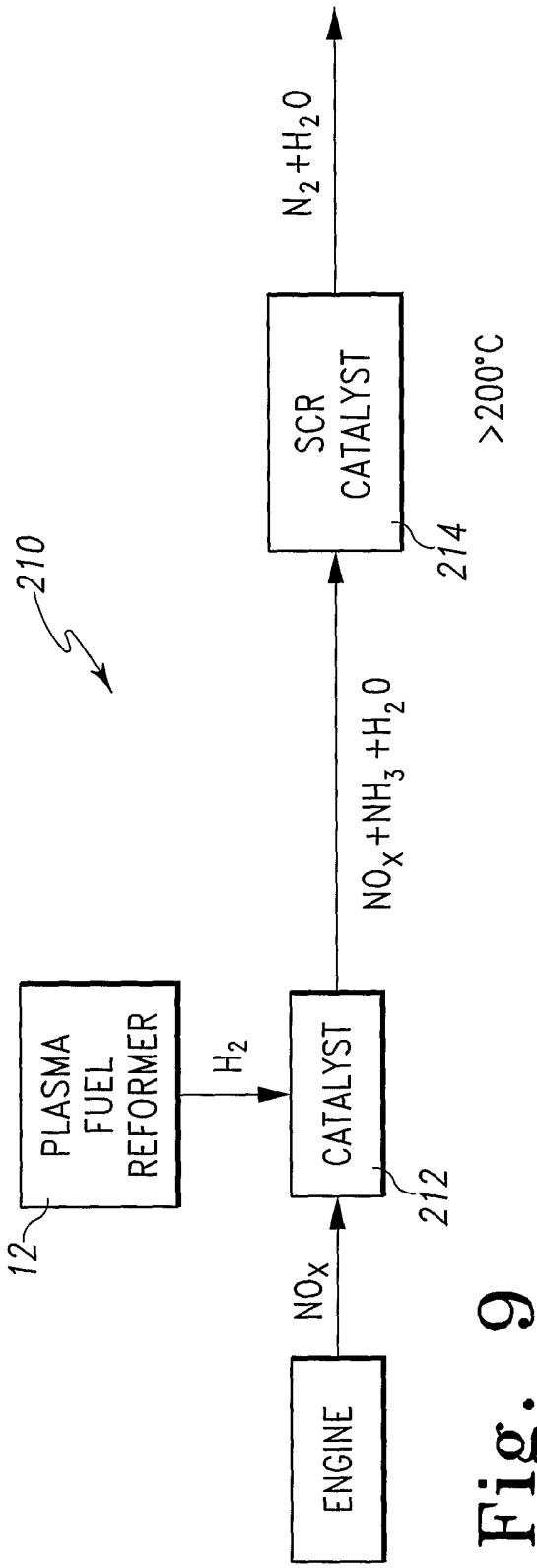
210
PLASMA FUEL REFORMER
12
H_2
CATALYST
212
ENGINE
NO_x
$NO_x+NH_3+H_2O$
SCR CATALYST
214
N_2+H_2O
>200°C

Fig. 9

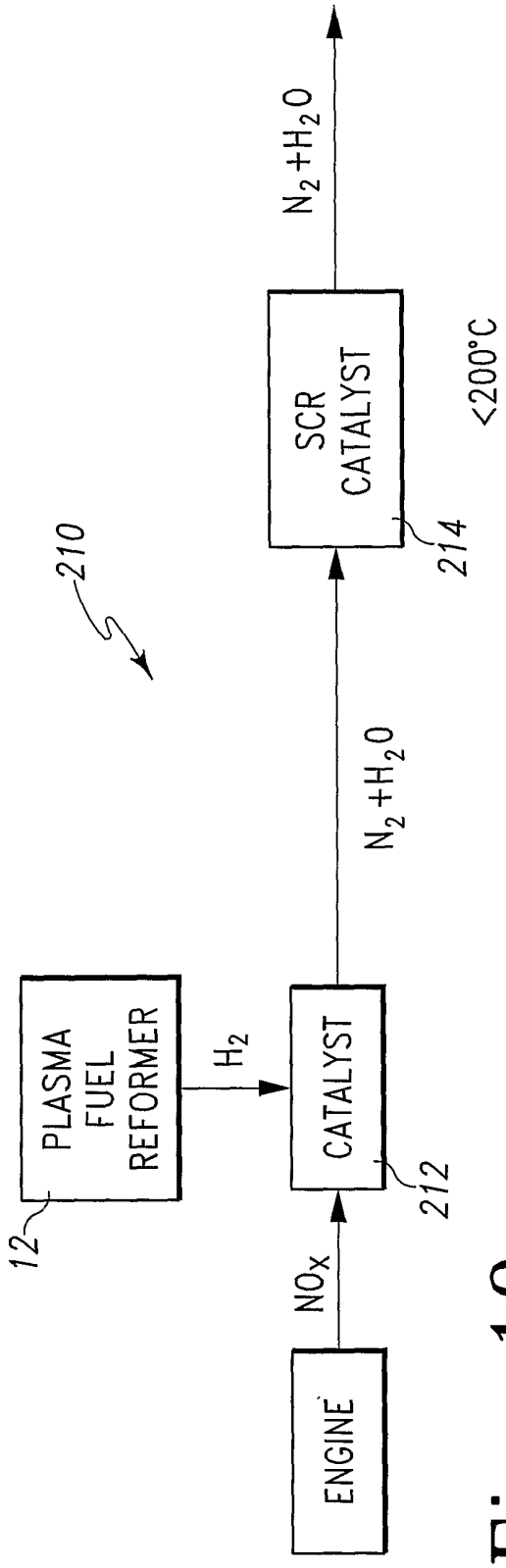
210
PLASMA FUEL REFORMER
12
H_2
CATALYST
212
ENGINE
NO_x
N_2+H_2O
SCR CATALYST
214
N_2+H_2O
<200°C

Fig. 10

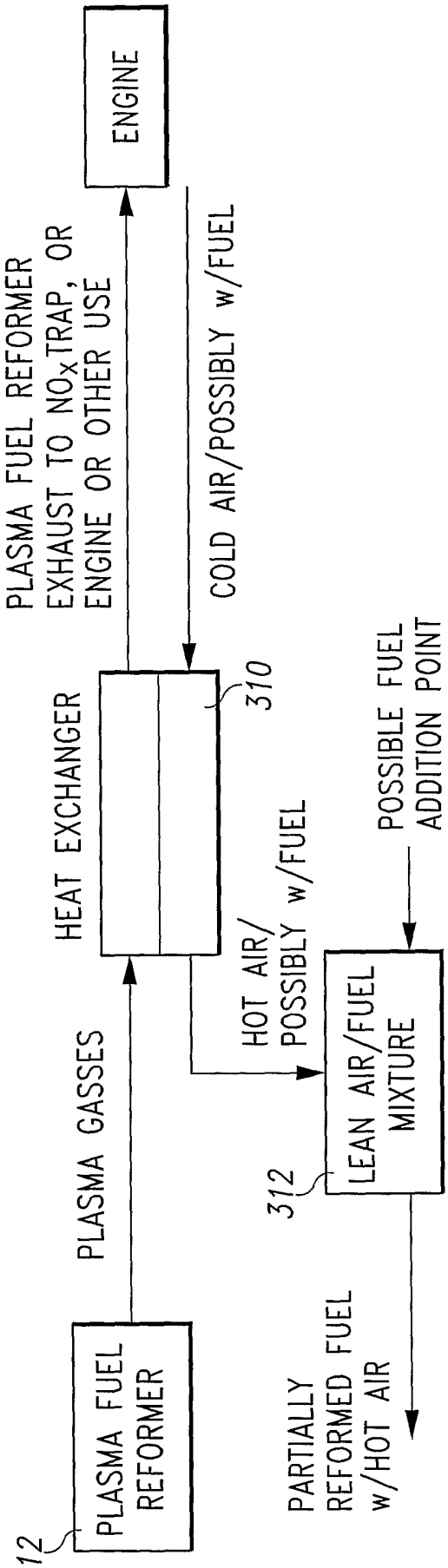
ENGINE
PLASMA FUEL REFORMER EXHAUST TO NO_x TRAP, OR ENGINE OR OTHER USE
COLD AIR/POSSIBLY w/FUEL
HEAT EXCHANGER
310
HOT AIR/ POSSIBLY w/FUEL
POSSIBLE FUEL ADDITION POINT
PLASMA GASSES
312
LEAN AIR/FUEL MIXTURE
PARTIALLY REFORMED FUEL w/HOT AIR
12
PLASMA FUEL REFORMER

Fig. 11

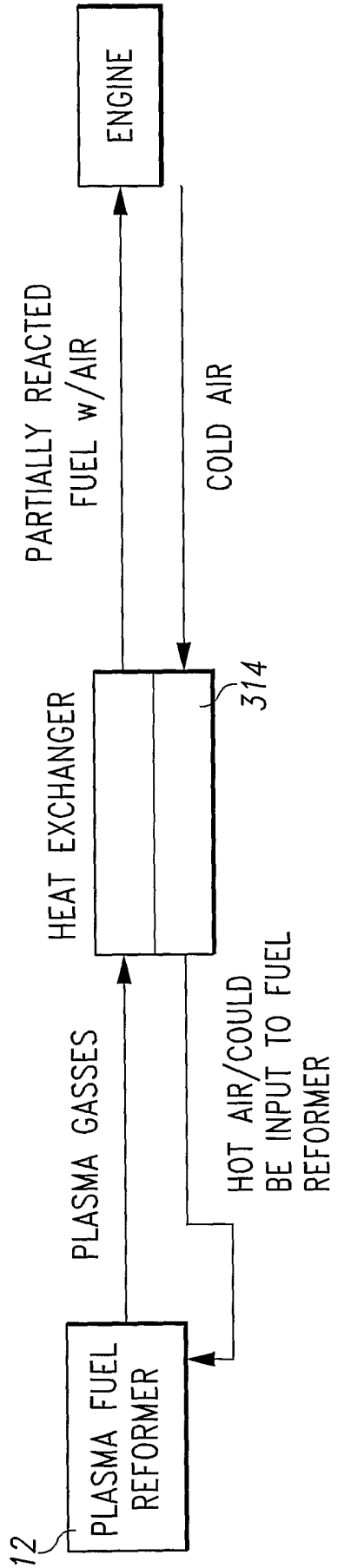
ENGINE
PARTIALLY REACTED FUEL w/AIR
COLD AIR
HEAT EXCHANGER
314
PLASMA GASSES
HOT AIR/COULD BE INPUT TO FUEL REFORMER
12
PLASMA FUEL REFORMER

Fig. 12

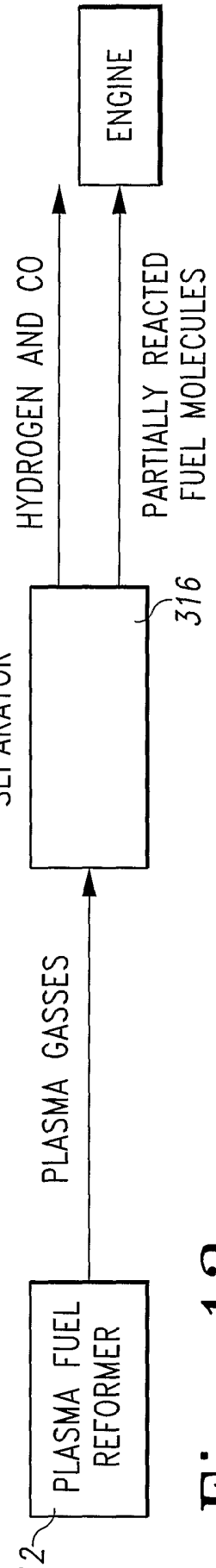

Fig. 13

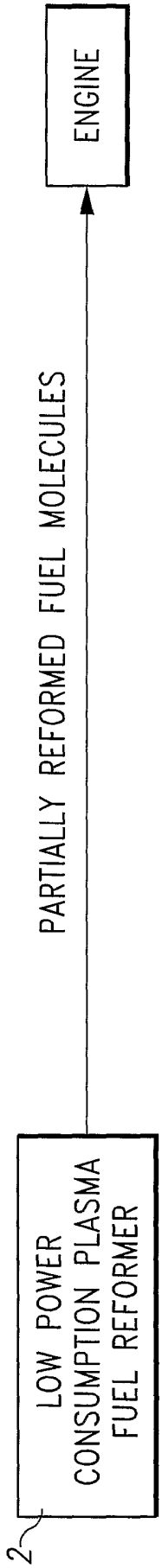

Fig. 14

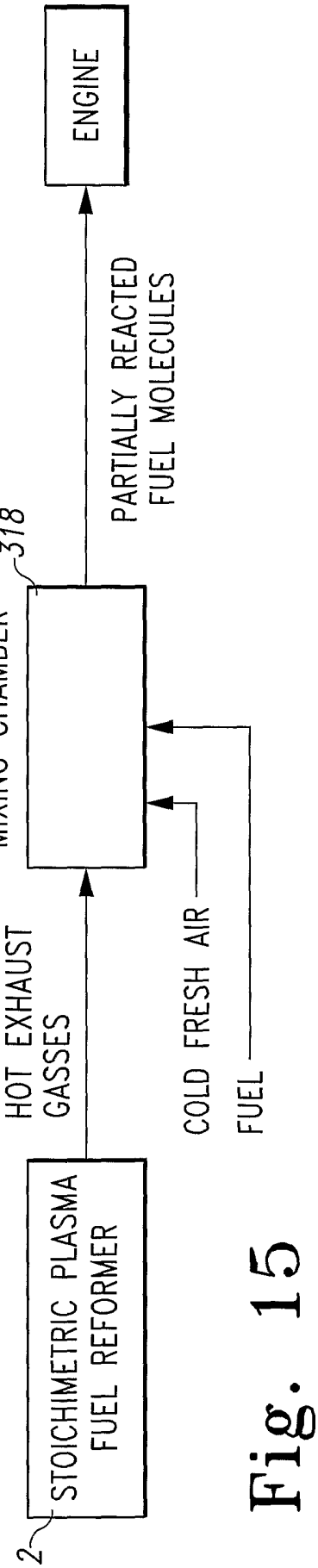

Fig. 15

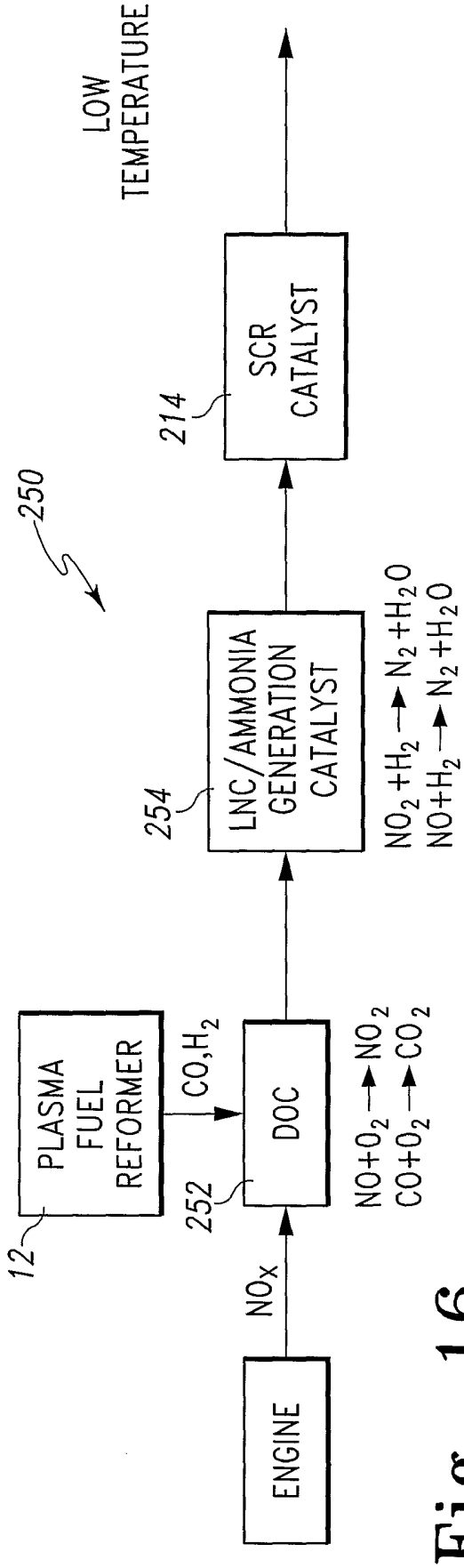
LOW TEMPERATURE
250
214
SCR CATALYST
254
LNC/AMMONIA GENERATION CATALYST
$NO_2+H_2 \rightarrow N_2+H_2O$
$NO+H_2 \rightarrow N_2+H_2O$
12
PLASMA FUEL REFORMER
CO,H_2
252
DOC
$NO+O_2 \rightarrow NO_2$
$CO+O_2 \rightarrow CO_2$
NO_x
ENGINE

Fig. 16

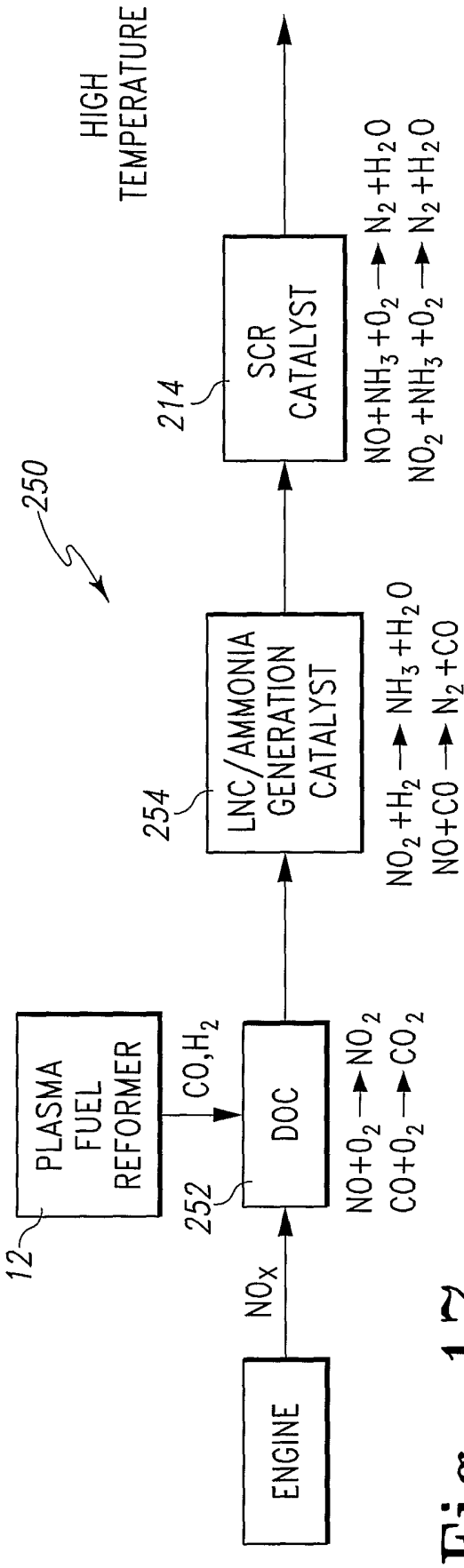
HIGH TEMPERATURE
250
214
SCR CATALYST
$NO+NH_3+O_2 \rightarrow N_2+H_2O$
$NO_2+NH_3+O_2 \rightarrow N_2+H_2O$
254
LNC/AMMONIA GENERATION CATALYST
$NO_2+H_2 \rightarrow NH_3+H_2O$
$NO+CO \rightarrow N_2+CO$
12
PLASMA FUEL REFORMER
CO,H_2
252
DOC
$NO+O_2 \rightarrow NO_2$
$CO+O_2 \rightarrow CO_2$
NO_x
ENGINE

Fig. 17

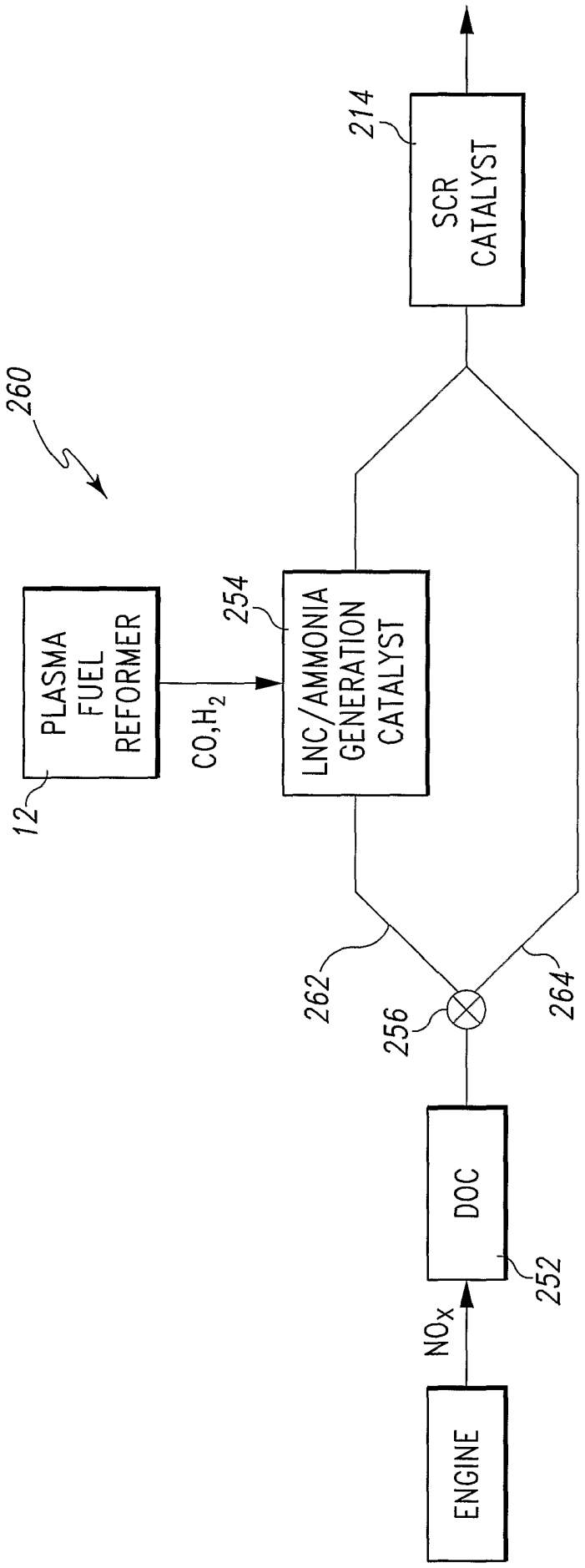
ENGINE
NO_x
DOC
252
256
262
264
LNC/AMMONIA GENERATION CATALYST
254
CO, H_2
PLASMA FUEL REFORMER
12
260
SCR CATALYST
214

Fig. 18