



(19) **United States**

(12) **Patent Application Publication**
Rabinovich et al.

(10) **Pub. No.: US 2007/0289291 A1**

(43) **Pub. Date: Dec. 20, 2007**

(54) **APPARATUS AND METHOD FOR NOX REDUCTION**

Publication Classification

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(51) **Int. Cl.**
F01N 3/00 (2006.01)
F01N 3/10 (2006.01)
(52) **U.S. Cl.** **60/286; 60/295; 60/297; 60/301**

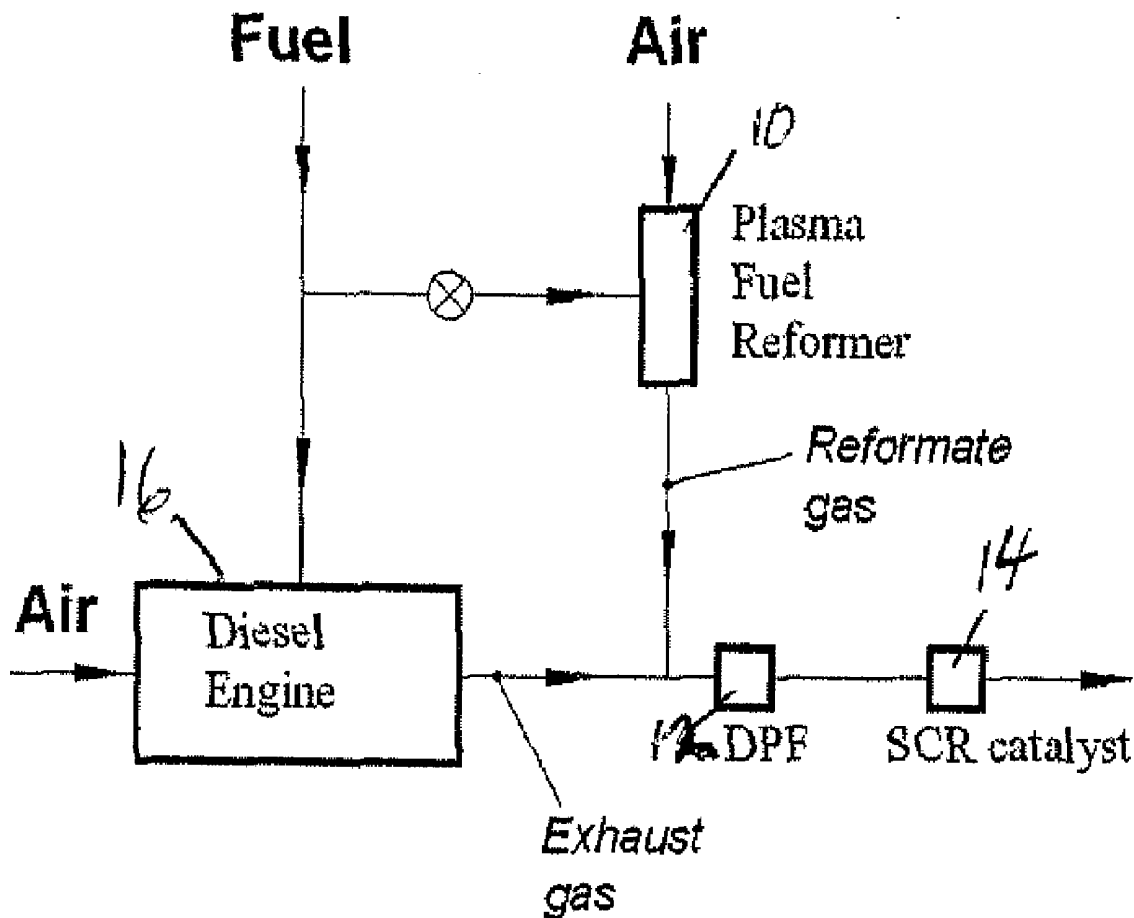
(57) **ABSTRACT**

Apparatus and method for NOx reduction. A reducing catalyst is provided on a monolith or other suitable catalytic converter element. A multi-mode fuel processor of liquid hydrocarbon fuel is capable of delivering a required quantity and composition of a reducing agent while operating in a desired sequence of the following modes: partial oxidation, incomplete pyrolysis, evaporation, combustion, and atomization. Temperature sensors detect the catalyst temperature and means are provided to introduce the reducing agent into the exhaust stream at a rate correlated to the measured temperature. Means also provided to implement a predetermined control algorithm.

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(21) **Appl. No.: 11/423,979**

(22) **Filed: Jun. 14, 2006**



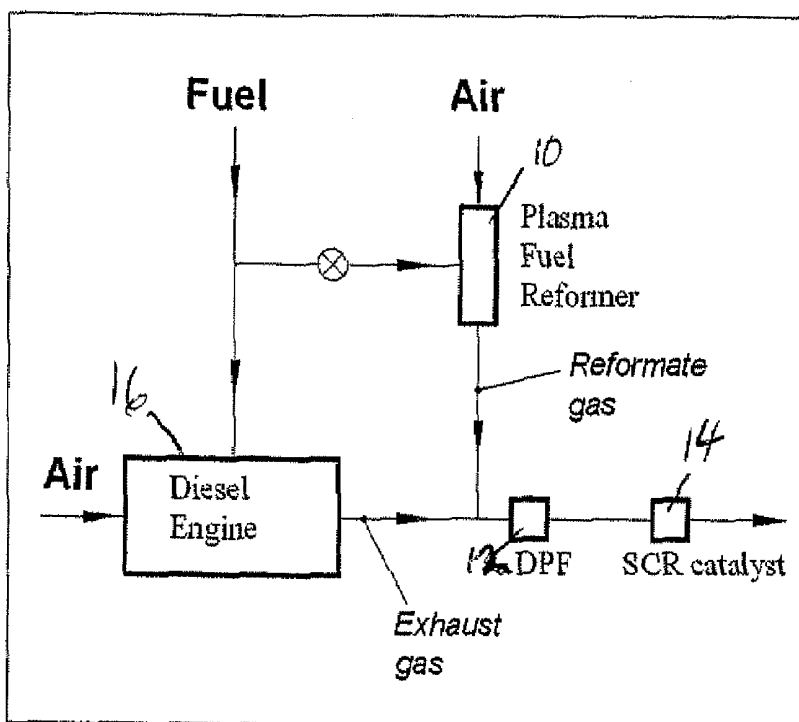


Fig. 1

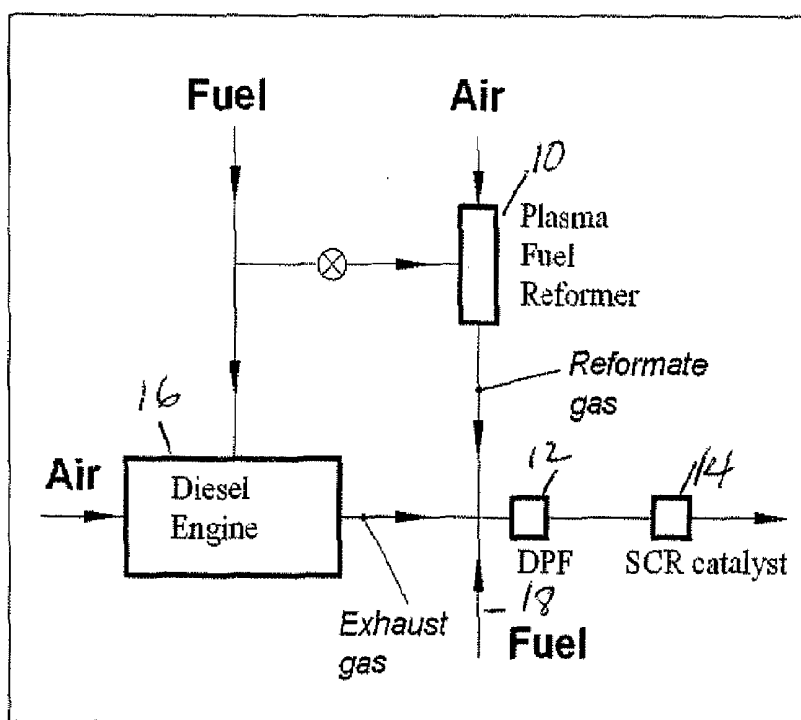


Fig. 2

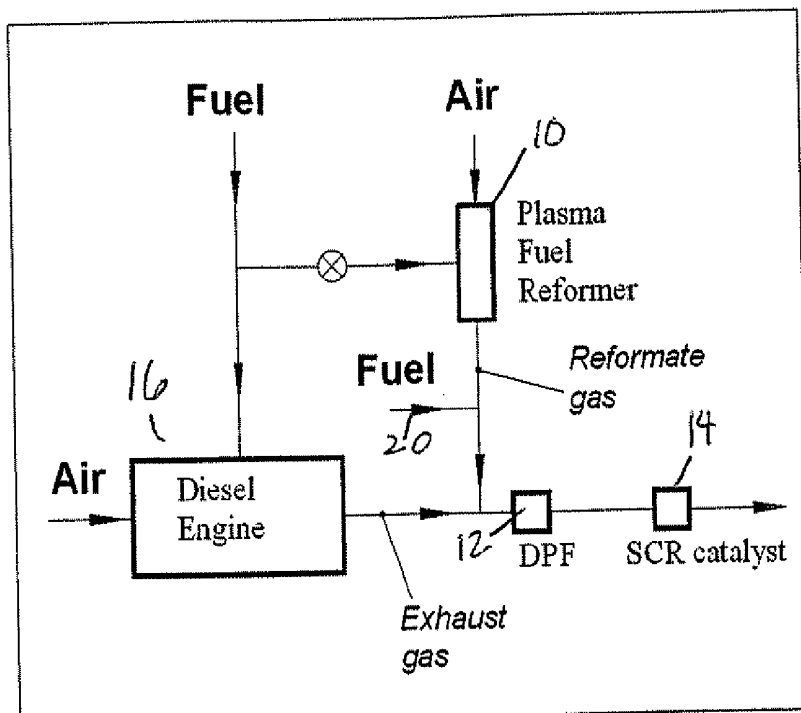


Fig. 3

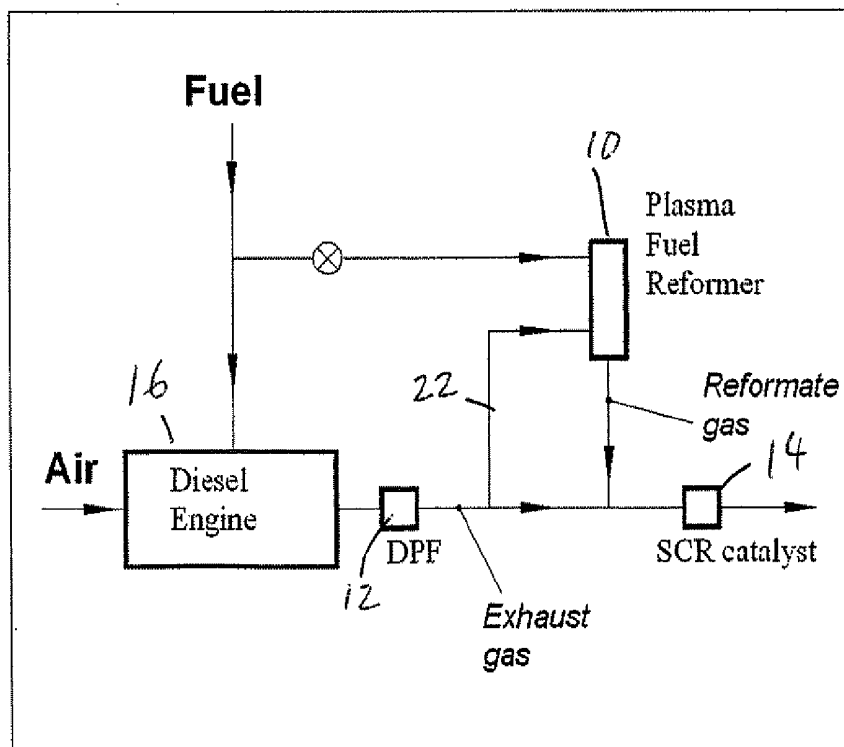


Fig. 4

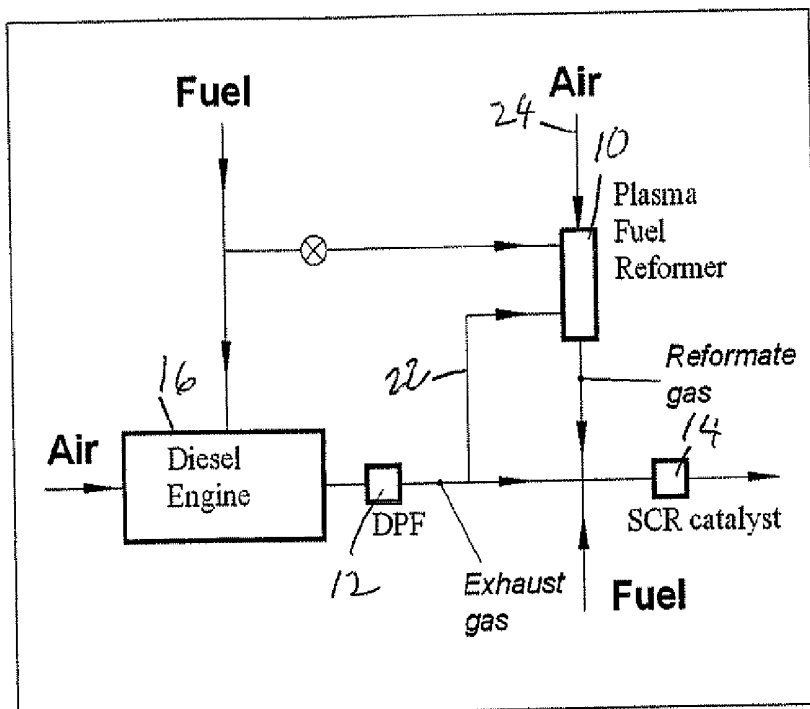


Fig. 5

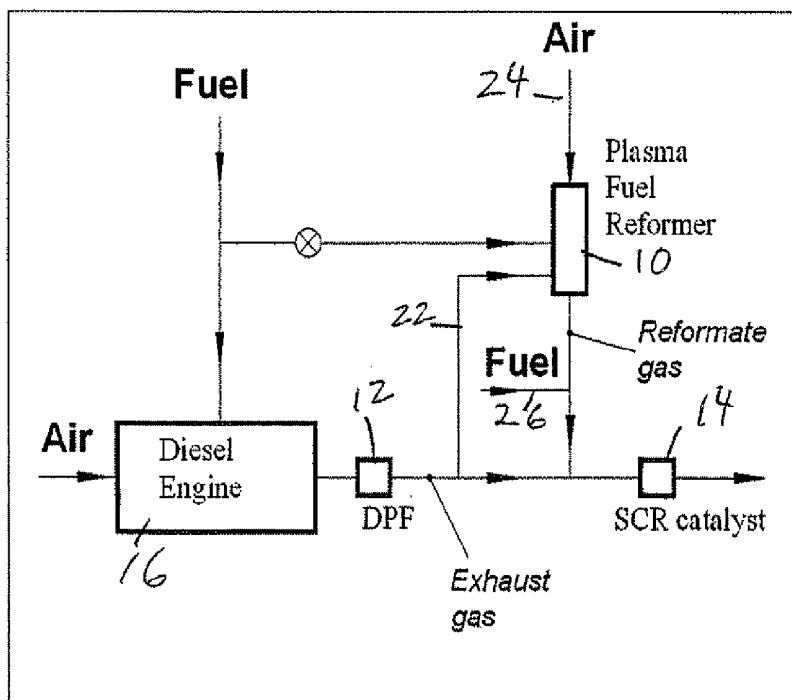


Fig. 6

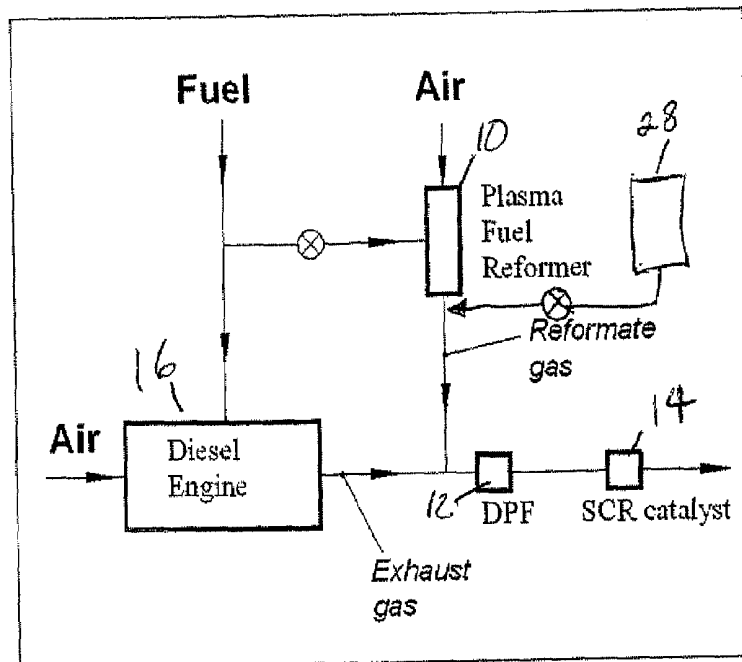


Fig. 7

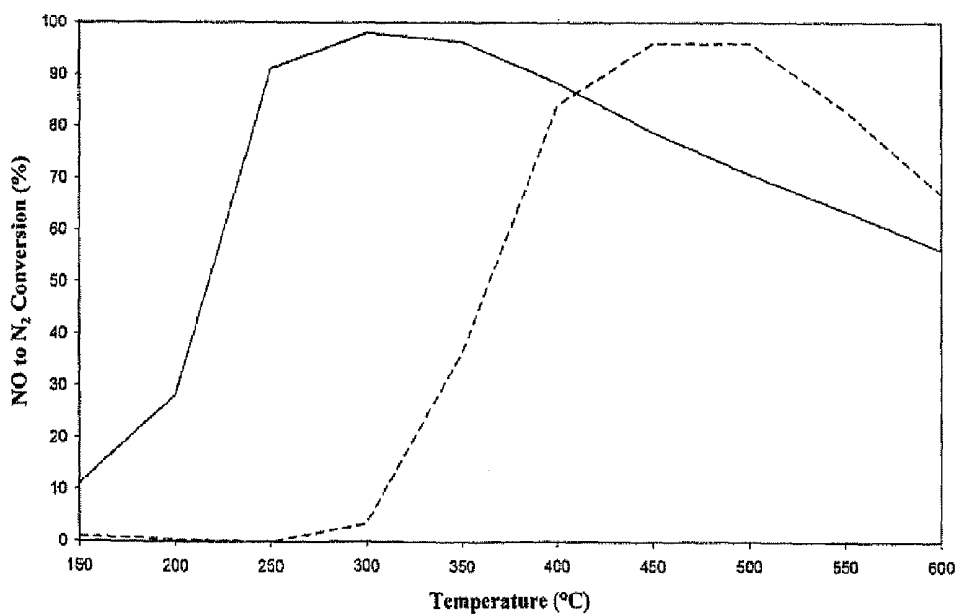


Fig. 8

APPARATUS AND METHOD FOR NOX REDUCTION

FIELD OF THE INVENTION

[0001] The present invention relates to the field of emission control devices for internal combustion engines, especially diesel engines and lean burn gasoline engines.

BACKGROUND OF THE INVENTION

[0002] NOx emissions from vehicles with internal combustion engines are an environmental problem recognized worldwide. Many countries, including the United States, are introducing ever-tightening regulations that limit NOx emissions from vehicles.

[0003] Manufacturers and researchers have put considerable effort toward meeting those regulations. In conventional gasoline powered vehicles that use stoichiometric fuel-air mixtures, three-way catalysts have been shown to control NOx emissions. In diesel powered vehicles and vehicles with lean-burn gasoline engines, however, the exhaust is too oxygen-rich for three-way catalysts to be effective.

[0004] Several solutions have been proposed for controlling NOx emissions from diesel powered vehicles and lean-burn gasoline engines. One set of approaches focuses on the engine. Techniques such as exhaust gas recirculation, homogenizing fuel-air mixtures and fuel switching can reduce NOx emissions. These techniques alone, however, do not eliminate NOx emissions.

[0005] Another set of approaches removes NOx from the vehicle exhaust. These include lean NOx traps (LNTs) and selective catalytic reduction (SCR).

[0006] The LNTs are NOx adsorbers combined with catalysts for NOx reduction. The adsorber removes NOx from the exhaust stream. The LNTs have to be frequently regenerated by introducing a reducing environment. In the reducing environment, NOx are desorbed and reduced over a suitable catalyst.

[0007] U.S. Pat. No. 6,560,958 describes an LNT system in which hydrogen-rich gas, including hydrogen and carbon monoxide, is used as a reductant to regenerate the adsorber. By "reductant" is meant a reducing agent. The reductant is produced from diesel fuel in a plasma converter. However, NOx reduction efficiency of a typical LNT is lower than that of an SCR system. Moreover, LNTs are prone to sulfur poisoning that further reduces their effectiveness. Additionally, constant regeneration of LNTs leads to thermal aging that results in a significant drop of an already low NOx reduction efficiency.

[0008] Also, the '958 patent describes a dual-branch adsorber system, whereby during regeneration of a LNT in one branch, all or part of the exhaust flow can be diverted to the other branch. Apart from increasing the system cost, such a method requires the use of at least one exhaust valve. Experience with similar EGR valves suggests durability and reliability present substantial challenges for such valves.

[0009] Another solution for controlling NOx emissions is represented by selective catalytic reduction (SCR) that involves the selective reduction of NOx to N₂ by a suitable reductant. Ammonia is the most widely-used reductant, typically in a form of a urea solution. The reaction takes place even in an oxidizing environment. The reductant is fed continuously into the exhaust. SCR can achieve NOx reduc-

tions in excess of 90%, however, there is concern over the lack of infrastructure for distributing ammonia/urea or a suitable precursor. SCR also raises concerns relating to the possible release of unreacted ammonia into the environment (so called "ammonia slip"). More importantly, urea/ammonia needs to be regularly refilled by a driver. Such a change in driver habits is difficult to enforce and, therefore, it leads to a serious compliance issue.

[0010] To overcome the disadvantages of SCR based on urea/ammonia, it was proposed to use hydrocarbons as a reducing agent (HC—SCR). For example, an HC—SCR process using propane as the reducing agent is discussed in U.S. Pat. No. 5,993,764. U.S. Pat. No. 5,824,621 discusses ethanol as a reducing agent and U.S. patent application No. 20050002843 discusses usage of gasoline, kerosene, biodiesel oils etc. for the same purpose. However, the use of those hydrocarbons for the HC—SCR process requires, as is the case with urea-SCR, an additional tank for a reductant and a dedicated reductant delivery infrastructure in the case of propane and ethanol.

[0011] Using vehicle's primary fuel, such as diesel or gasoline (petrol), as a reductant or a source thereof represents a more practical, cost-effective, and environmentally sound approach. Thus, U.S. Pat. No. 6,202,407 describes an apparatus and a method for catalytically reducing NOx emissions, particularly emissions from diesel engine exhaust, by intermittently injecting diesel fuel into engine exhaust, including an option for using non-thermal plasma for converting NO to NO₂.

[0012] U.S. Pat. No. 5,727,385 describes a system in which an HC—SCR catalyst is configured upstream of an LNT. The two components together are said to provide higher NOx conversion than either of the components individually. U.S. Pat. No. 6,677,264 describes a combined LNT/HC—SCR catalyst.

[0013] None of these SCR systems that use alternative reductants can match the NOx reduction efficiency of SCR based on urea/ammonia. Also, the use of hydrocarbons is associated with high fuel penalties. Moreover, the use of hydrocarbons for an SCR process could result in soot and sulfur deposition on a hot catalyst surface that would lead to a gradual decrease of catalytic activity.

[0014] Recently, it was found that the addition of a small, controlled amount of hydrogen to hydrocarbons has a remarkably positive effect on the NOx reducing efficiency of the HC—SCR process. The research indicated that hydrogen has a direct role in the reaction mechanism by either promoting the formation and storage of organic C≡N compositions which can then readily reduce NOx, and/or by removing compositions which act as a poison to the SCR reaction at low temperatures. Thus, for example, it has been shown that an addition of 1% of H₂ to hydrocarbons (octane) increases NOx conversion from 5% to 70% at 300° C. (temperature of the catalyst), and from 40% to 90% at 350° C. ("On the mechanism of the selective catalytic reduction of NO with higher hydrocarbons over a silver/alumina catalyst", Kari Eranen, Fredrik Klingstedt, *Journal of Catalysis* 227 (2004) 328-343).

[0015] A hydrogen rich gas—a mix that contains a controlled amount of hydrocarbons and hydrogen—could be produced in plasma fuel reformers. Such reformers are ideally suited for the SCR application: they can produce on-demand without any catalyst hydrogen rich gas in

required quantities and of required composition, and offer a wide dynamic range of operation.

[0016] It should be noted that the '958 patent mentions an SCR application, suggesting the use of a hydrogen-rich gas. However, the patent teaches that the reducing agents in the hydrogen rich gas should be hydrogen and carbon monoxide. More specifically, the '958 patent suggests the use of an additional catalyst or water shift reaction in order to increase the concentration of hydrogen. There are no known catalysts that can selectively reduce NO_x to N₂ using a gas mixture based on hydrogen and carbon monoxide. In the HC—SCR process a high concentration of hydrogen leads to its oxidation by free oxygen contained in exhaust gas. High concentration of hydrogen could also generate excessive amount of heat on a catalytic surface and eventually cause sintering and melting of the catalyst.

[0017] More importantly, although the patent '958 fully describes an LNT application, it does not teach how to use that invention for an SCR application, nor does it disclose any specific control strategy. SCR requires a much more complex and precise control than LNT. Several parameters, including O/C ratio and the catalyst temperature, need to be closely monitored as they, being linked to engine operation, are changing constantly. To achieve the desired optimum performance, specifically high NO_x conversion efficiency and low fuel penalty, an SCR system should operate in several modes and provide for a continuous control of these parameters.

[0018] Also, SCR is very efficient for NO_x reduction as long as the exhaust temperature is within the active temperature range of the catalyst (e.g. >300° C.). Unfortunately diesel exhaust temperatures are often lower than those required for good catalyst efficiency (i.e., below "light-off" level). This is especially true for light duty diesel applications such as diesel vehicles which operate at light load for the most part, resulting in very low exhaust temperatures (150-250° C.). Even heavy-duty diesel vehicles operate under conditions which result in exhaust temperatures below the optimum temperatures for SCR catalysts.

[0019] In such cases, for example during a cold start, it is possible to improve NO_x reduction efficiency by heating catalytic converters to rapidly reach the operating temperature for selective catalytic reduction. However, the use of an electric heater for such a purpose leads to significant electric power consumption.

[0020] Therefore, there continues to be a long felt need for an affordable and reliable exhaust aftertreatment system that is durable, has a manageable operating cost (including fuel penalty), and can practically be used to reduce NO_x emissions across the spectrum of diesel engines to a satisfactory extent in the sense of meeting U.S. Environmental Protection Agency (EPA) regulations effective in 2010 and other similar regulations. Such an improved system should be able to use liquid hydrocarbon fuel as a reductant or a source of a reductant, while matching NO_x conversion efficiencies of urea- or ammonia-based SCR systems across all engine cycles.

SUMMARY OF THE INVENTION

[0021] The following presents a simplified summary in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. The primary purpose of this summary is to

present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented later.

[0022] It is an object of the present invention to provide a safe, reliable and efficient SCR system for reducing NO_x emissions from an internal combustion engine.

[0023] It is another object of the invention to eliminate the problems associated with the use of ammonia or urea as a reductant in a mobile SCR system.

[0024] It is another, more specific, object of one aspect of the invention to provide a simple, robust SCR system capable of rapid response time in order to meet transient conditions prevailing in diesel engines.

[0025] It is a yet further and more specific object of the invention to provide thermal management of an SCR system in order to improve its overall NO_x reduction efficiency.

[0026] It is a yet further and more specific object of the invention to provide an SCR system that enables integration with an engine management system (EMS), thereby avoiding the need for an extra controller. It is a yet further, more specific object of the invention to provide an SCR system with a dedicated controller including the features necessary for SCR, using either dedicated sensors or sharing inputs and outputs where possible with the EMS.

[0027] These and other objects are achieved by the present invention, which provides an improved method and a modular apparatus for NO_x reduction.

[0028] One aspect of the invention relates to an exhaust treatment system having a suitable SCR catalyst, a multi-mode plasma fuel processor, temperature sensors, an optional controller, a predetermined controlling algorithm, and reductant delivery means.

[0029] Another aspect of the invention relates to an exhaust treatment system also including an additional source of hydrogen. Yet another aspect of the invention relates to an exhaust treatment system that also includes a diesel particulate filter (DPF).

[0030] Additional aspects of the invention relate to control of an exhaust treatment system. One aspect of the control strategy provides for maintaining catalyst temperature within a predetermined range to offer, in particular, improvements in emission control during start-up of diesel engines and thus offer the potential to control emissions to meet expected future regulations.

[0031] Other aspects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] FIG. 1 is a schematic illustration of an embodiment of the invention.

[0033] FIG. 2 is a schematic illustration of another embodiment of the invention.

[0034] FIG. 3 is a schematic illustration of yet another embodiment of the invention.

[0035] FIG. 4 is a schematic illustration of still another embodiment of the invention.

[0036] FIG. 5 is a schematic illustration of an embodiment of the invention using exhaust gas in the plasma fuel reformer.

[0037] FIG. 6 is a schematic illustration of an embodiment of the invention in which the fuel is injected into the reformate gas stream.

[0038] FIG. 7 is a schematic illustration of an embodiment of the invention including an alternate source for hydrogen.

[0039] FIG. 8 is a graph of NO to N₂ conversion (%) vs. temperature.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0040] The proposed system includes an internal combustion engine or a turbine as a source of emissions, a multi-mode plasma fuel processor, selective catalytic reduction (SCR) catalyst and means to implement a predetermined control algorithm.

[0041] The SCR catalyst suitable for this system is usually a silver/alumina catalyst. The fuel processor is able to process liquid hydrocarbon fuel such as diesel or petrol to deliver the reducing agent in required quantity and of required composition while operating in a certain sequence of the following modes in accordance with a predetermined control algorithm: partial oxidation (POX), incomplete pyrolysis, evaporation, combustion, atomization.

[0042] The fuel processor could be based on one of the plasmatrons described in a U.S. patent application No. 11/330,515 entitled "Plasma Reformer With Extended Volume Discharge" and U.S. patent application No. 11/352,138 entitled "High Enthalpy Low Power Plasma Reformer".

[0043] The system can also be equipped with a diesel particulate filter (DPF) installed before or after the SCR catalyst. The system can further be equipped with temperature sensors. The system can also be equipped with a source of hydrogen such as an electrolysis apparatus and/or an on-board hydrogen storage device.

[0044] The fuel processor should also be able to:

[0045] (a) Increase or decrease the total throughput at approximately the same composition in response to engine requirements (from idle to high speed). The dynamic range of the fuel processor shall be as high as 1:20.

[0046] (b) Operate in one steady state mode providing a certain amount of the reducing agent composed of hydrocarbons and a small amount of hydrogen sufficient for NO_x reduction. At higher engine speeds, the amount of reducing agent delivered by the fuel processor can be increased; in addition, atomized diesel fuel can be injected into the exhaust stream in close proximity to the SCR catalyst.

[0047] Possible soot formation could be controlled by changing O/C ratio to a higher value. The O/C ratio could also control the concentration of hydrocarbons in the reducing agent. For example, by changing O/C ratio from 1 to 1.3 the concentration of (C₂H₂+C₂H₄+C₂H₆) decreased from 3.78 vol. % to 1.82 vol. %. The diesel flow rate to the fuel reformer decreased by 25% (from 0.8 g/s to 0.6 g/s). The hydrogen concentration remained the same.

[0048] FIG. 1 describes a system in which a plasma fuel processor or reformer 10 is installed upstream of a DPF 12 followed by an SCR catalyst 14. The advantage of such arrangement is that the fuel processor 10 could periodically operate in a lean combustion mode (at O/C>3) oxidizing particulates collected in the DPF 12 from a diesel engine 16.

[0049] An alternative embodiment is depicted in FIG. 2. Atomized diesel fuel 18 can be injected into the exhaust stream in close proximity to the SCR catalyst 14 if an increased amount of reducing agent is needed. One possible modification of this scheme is injection of additional fuel 20

into the hot stream of the reducing agent generated by the fuel processor 10 (FIG. 3). The high temperature of the reducing agent (800-1000° C.) could provide conditions for vaporization and incomplete pyrolysis of the additionally injected fuel 20 thus increasing the overall amount of the reducing agent.

[0050] Yet another embodiment is shown in FIG. 4. In this variation a part 22 of the engine exhaust stream after the DPF 12 is diverted into the fuel processor 10. The advantages of utilizing exhaust gas as an oxidizer instead of air for plasma fuel reforming are:

[0051] (a) High temperature of exhaust gas (up to 300-500° C.) improves conditions for fuel atomization, vaporization and mixing; it also improves ignition stability.

[0052] (b) Since exhaust gas contains much less oxygen compared to air (~6 vol. % instead of 21 vol. %), a much higher amount (over ×3) of exhaust gas is needed to achieve the same O/C ratio. Using higher volume of an oxidizer improves fuel atomization and plasma discharge stability. More importantly, under such conditions a significant part of NO_x emissions would be reduced to N₂ within the plasma fuel processor.

[0053] (c) High concentration of water vapor (up to 12%) in exhaust gas could prevent soot formation during partial oxidation or incomplete pyrolysis modes of operation.

[0054] FIG. 5 describes yet another modification of the previous arrangement. For an additional flexibility, both air 24 and exhaust gas 22 are used as an oxidizer. This embodiment could be used, for example, when the plasma fuel processor 10 operates in combustion mode.

[0055] Yet another embodiment is shown in FIG. 6, where both air 24 and exhaust gas 22 are used as an oxidizer, and an additional fuel 26 is injected into a hot stream of the reducing agent generated by the fuel processor 10. With this arrangement the reducing agent would contain products of incomplete pyrolysis. Additional air could prevent soot formation by changing the O/C ratio.

[0056] FIG. 7 describes yet another system arrangement. For an additional flexibility, a source of hydrogen 28 such as an electrolysis apparatus or an on-board hydrogen storage device can be installed and used in addition to or instead of the fuel processor 10 under certain conditions.

[0057] FIG. 8 provides a comparison of NO_x to N₂ reduction activities over Ag/Al₂O₃ catalyst achieved by the proposed multi-mode emission control system (solid line) and a conventional HC—SCR system based on diesel (dashed line). The almost complete conversion of NO_x to N₂ occurs at much lower temperature (250 C. instead of 450 C. compared to using only diesel as a reducing agent).

[0058] It should be noted that in all described embodiments the use of additional oxidation catalyst (not shown) might be required. This catalyst could be installed after the SCR catalyst for oxidation of unreacted H₂, CO and HC.

[0059] The present invention must not be regarded as being limited to the exemplary embodiments described above as several further modifications are feasible without departing from the scope of the claims contained herewith.

[0060] The present invention also relates to a method of controlling the system, especially its NO_x reduction efficiency. As opposed to a simple single-mode SCR operating scheme offered by the prior art whereby the system is controlled primarily by varying the amount of the reducing agent, the present invention in several of its aspects contemplates control over various operating modes and param-

eters. More specifically, the proposed control strategy is based on choosing the most appropriate operating mode or a sequence thereof for any given condition to provide an optimum combination of the quantity, composition, thermal properties and feed rate in respect of the reducing agent.

[0061] Implementing this control strategy generally involves estimation of the catalytic activity by measuring the catalyst temperature using temperature sensors or other suitable means. Also, the control parameters can be based on an engine map and, therefore, can be modified or adjusted via the EMS or any other suitable controller.

[0062] One aspect of the invention improves over conventional methods by first operating the fuel processor in a combustion mode to enable fast "light off" of the SCR catalyst. According to this aspect of the present invention, the system operates in this mode until the temperature of the SCR catalyst reaches its activation point (i.e. NOx reduction efficiency over 60% and/or temperature over 150° C.). Activation of the catalyst can be determined by temperature sensors.

[0063] As an additional step, with a view of improving overall NOx reduction efficiency of the system, when the catalyst is nearing its activation temperature (i.e. is from about 10 to about 50% or more preferably from about 20 to about 30% of the target temperature) the fuel processor may intermittently alternate between the combustion and POX modes in a predetermined sequence, for example 5 sec of combustion followed by 5 sec of POX, or 10 sec of combustion followed by 5 sec of POX, or 5 sec of combustion followed by 10 sec of POX. Such a change of modes could be accomplished by changing fuel flowrate at the constant air flowrates. In addition to the simplicity of such an approach, the liquid fuel is not compressible and mode change could be done very fast,

[0064] According to yet another aspect of the present invention, once the catalyst reaches its activation point, the fuel processor is automatically switched into POX mode. It would operate in that mode until the temperature of the catalyst reaches the range of 300° C. -500° C. after which the fuel processor would be automatically switched into the evaporation mode or fuel atomization mode or an intermittent alternating sequence thereof.

[0065] As an option, in any of these modes an additional fuel may be injected either into the hot stream of the reducing agent generated by the fuel processor or into the exhaust stream in close proximity to the SCR catalyst in order to increase the overall volume of the reducing agent and improve NOx reduction efficiency of the system.

[0066] The fuel that is injected may be in liquid or gaseous form. It may be the same fuel that is used to propel the vehicle, for example diesel or petrol, or any other suitable hydrocarbon fuel.

[0067] Another method of the present invention relates to the use of an on-board source of hydrogen such as an electrolysis apparatus or a hydrogen storage device. Such a source can be used in addition to the fuel processor or instead of it in conjunction with an additional injection of diesel fuel into the exhaust stream. Alternatively, for additional flexibility a hydrogen storage could also be used to store the hydrogen rich gas produced by the fuel processor.

[0068] According to yet another aspect of the present invention, the fuel processor can be operated in several modes intermittently, with the ratio of on/off cycles with the mode being 1:1, 2:1, 1:2, 3:1, 1:3, 4:1, 1:4, 5:1 or 1:5. A

predetermined sequence of alternating modes allows to reduce the fuel penalty and improve NOx reduction efficiency.

[0069] According to yet another aspect of the present invention, should the temperature of the catalyst drop below or start dropping towards its activation point, the fuel processor should operate in a combustion mode as described above.

[0070] According to yet another aspect of the present invention, should the temperature of the catalyst rise above or start approaching a certain predetermined point (typically 650° C.-700° C.), means to cool the exhaust stream and/or the reducing agent will be automatically activated.

[0071] The invention has been shown and described with respect to certain aspects, examples, and embodiments. While a particular feature of the invention may have been disclosed with respect to only one of several aspects, examples, or embodiments, the feature may be combined with one or more other features of the other aspects, examples, or embodiments as may be advantageous for any given or particular application.

[0072] A well-controlled temperature in the exhaust system improves NOx reduction efficiency as well as minimizes the risk of an incomplete reaction of the reducing agent or the risk of the reducing agent being destroyed by excessively high temperatures. Also, an appropriate temperature and thermal mass management provides for an increased duty cycle of a catalyst.

What is claimed is:

1. A system for reducing oxides of nitrogen (NOx) in the exhaust stream produced by an internal combustion engine operating at lean air/fuel ratios into non polluting emissions comprising:

- (a) a reducing catalyst on a monolith or other suitable catalytic converter;
- (b) a multi-mode fuel processor of liquid hydrocarbon fuel such as diesel capable of delivering a required quantity and composition of a reducing agent while operating in a desired sequence of at least the following modes: partial oxidation, incomplete pyrolysis, evaporation, combustion, atomization;
- (c) means to introduce said reducing agent into said exhaust stream; and
- (d) means to implement a predetermined control algorithm.

2. A system according to claim 1, further comprising means to introduce atomized liquid hydrocarbon fuel into said exhaust stream in addition to the amount of reducing agent already delivered by said fuel processor.

3. A system according to claim 2 wherein the atomized liquid hydrocarbon fuel is introduced into the hot stream of reducing agent generated by the fuel processor.

4. A system according to claim 1, further comprising temperature sensors.

5. A system according to claim 1 wherein a multi-mode fuel processor of liquid hydrocarbon fuel is a plasma fuel reformer.

6. A system according to claim 1, further comprising an on-board source of hydrogen.

7. A system according to claim 1, further comprising a diesel particulate filter (DPF).

8. A system according to claim 1, further comprising means to cool gases upstream of the said catalyst.

9. A system according to claim 1, further comprising means to cool gases upstream of the said catalyst if the temperature of said catalyst is above a predetermined level.

10. A system according to claim 9, further comprising control means such that said means to cool gases are activated only when a high catalyst temperature is detected or conditions are determined that are expected to lead to high catalyst temperatures.

11. The method of reducing oxides of nitrogen (NOx) in the exhaust stream by controlling the system described in claim 1 via the following steps:

- (a) Determining temperature of the catalyst and/or temperature of exhaust stream;
- (b) Changing the control parameters and/or operating mode of said fuel processor on the basis of said measurements in accordance with a predetermined control algorithm.

12. The method according to claim 11, wherein the fuel processor is specifically operating in the combustion mode to provide for fast light off of the catalyst.

13. The method according to claim 11, wherein a setpoint value for a reducing agent feed is based on the engine's parameters.

14. The method according to claim 11, wherein the output of said fuel processor is also delivered upstream of DPF.

15. The method according to claim 11, wherein a diesel internal combustion engine is equipped with exhaust gas recirculation, and wherein the exhaust gas is partially directed to said fuel processor.

16. The method of claim 11 wherein in order to decrease a response time only one control parameter (namely fuel flow rate) is changed when switching from one operation

mode to another whilst other control parameters (primarily air flow rate) remains constant.

17. A system according to claim 11 wherein the fuel processor's mode of operation is changing from complete combustion to partial oxidation to incomplete pyrolysis to vaporization inversely proportional to catalyst temperature increase.

18. A method according to claim 11, wherein at least one of the control parameters is processed by a dedicated signal processor.

19. A method according to claim 11, wherein at least one of the control parameters is processed by a main engine control unit or EMS.

20. The method of reducing oxides of nitrogen (NOx) in the exhaust stream by controlling the system described in claim 1 using a predetermined control algorithm based on an engine map.

21. A system according to claim 1, wherein the reducing catalyst is an SCR catalyst comprising silver on alumina.

22. A system according to claim 1, wherein the reducing catalyst is an SCR catalyst comprising a combination of silver and one or more other metals on a metal oxide (e.g. Al₂O₃ or SiO₂) or on a zeolite (MFI, MOR, BEA or Y).

23. A system according to claim 1, wherein the catalyst is an SCR catalyst comprising silver or any other catalyst showing increased low temperature reduction activity in the presence of hydrogen and hydrocarbons.

24. A system according to claim 1, wherein such fuels as bio-diesel, ethanol, gasoline, propane, methane and biofuels or their mixtures are used as a source of hydrocarbons in the reducing agent.

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