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(54) NOX REDUCTION SYSTEM AND METHOD

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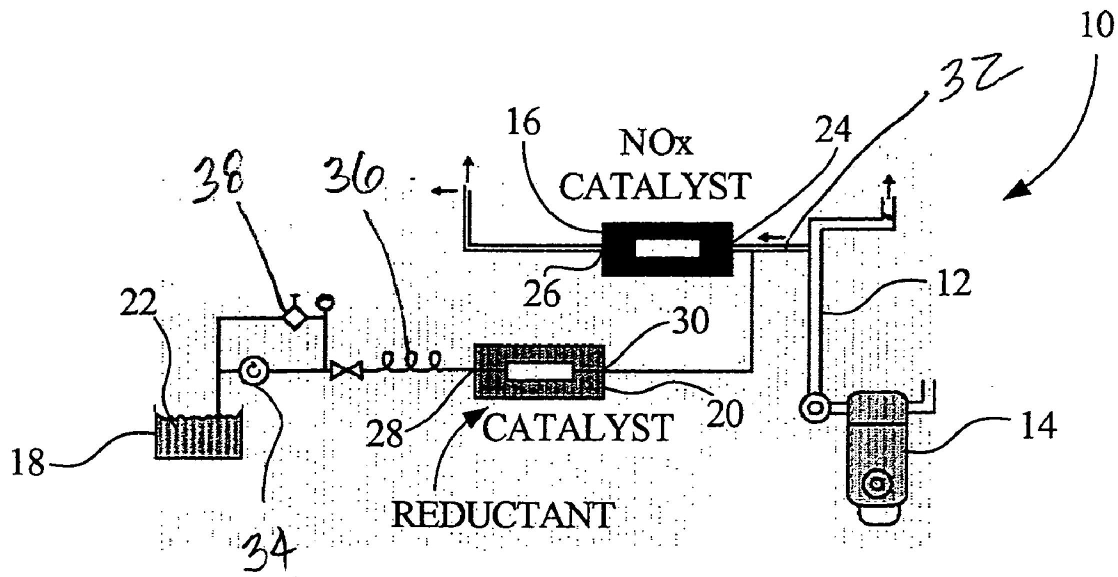
(57) **ABSTRACT**

A system for reduction of noxious oxides from an exhaust of an internal combustion engine. The internal combustion engine includes an engine exhaust. A NOx catalytic reactor has at least one inlet in communication with the engine exhaust. A reductant catalytic reactor includes an inlet in communication with a reductant fuel supply, and an outlet in communication with at least one inlet to the NOx catalytic reactor.



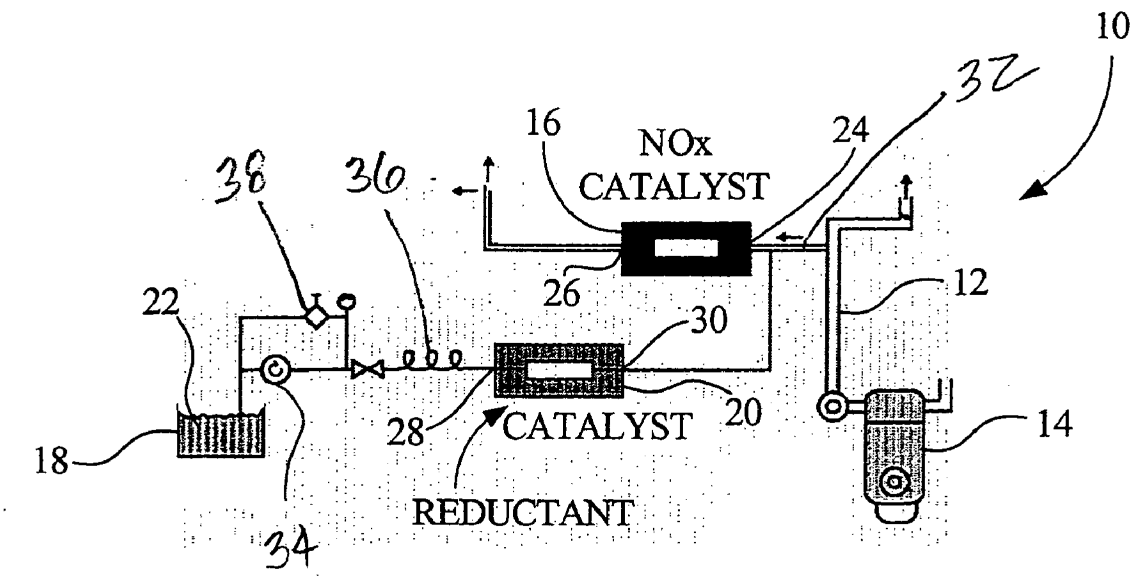

10
32
16
NOx
CATALYST
24
38
36
26
12
22
30
28
CATALYST
20
14
18
REDUCTANT
34

Fig. 1

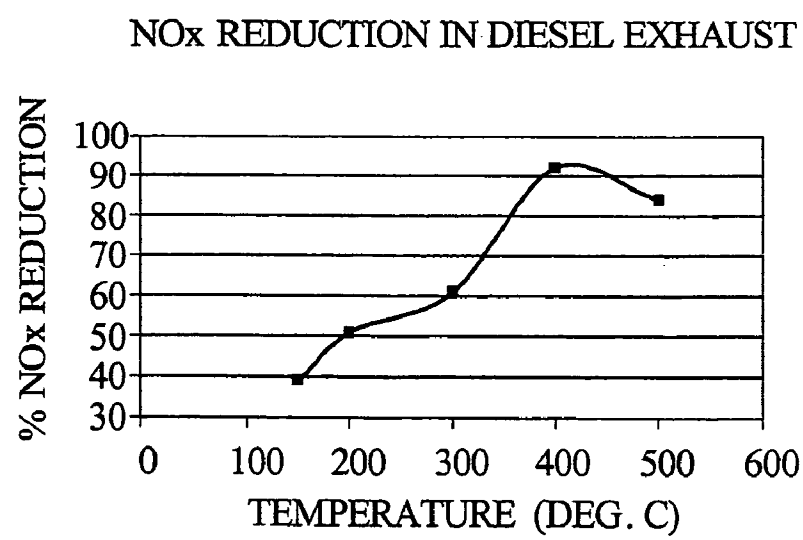

NOx REDUCTION IN DIESEL EXHAUST
% NOx REDUCTION
100
90
80
70
60
50
40
30
0
100
200
300
400
500
600
TEMPERATURE (DEG. C)

Fig. 2

NOX REDUCTION SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a system and method for reducing noxious oxides from an exhaust gas of an internal combustion engine, and, more particularly, to such a system and method using a catalytic process.

[0003] 2. Description of the Related Art

[0004] Noxious oxides (NOx) has been the subject of air pollution regulations and control efforts for over 30 years. These efforts began in southern California, but under the direction of the U.S. Environmental Protection Agency (EPA), NOx control efforts are spreading throughout the U.S. and to many major cities worldwide. Increasingly stringent control efforts continue to be mandated by regulatory bodies, both domestically and internationally. In southern California and other areas of the U.S. (representing over 60% of the population) that have not attained EPA's ambient air quality standards, an active trading market exists for NOx "credits", which have economic value and can be created when controls are installed whose performance exceeds regulatory requirements.

[0005] Emission standards in the U.S. will require reduction of diesel emissions for transportation vehicles (light and heavy-duty diesel powered trucks and buses) by as much as 90% from current levels in the 2005-2010 time frame. In addition, emissions levels for boilers-electric generators (especially coal fired boilers) and internal combustion (IC) engine (gas and diesel) powered electric generators are required to meet even more stringent NOx emissions levels. Achieving these levels with acceptable costs and durability will be very difficult for these industries.

[0006] NOx reduction approaches presently being developed may present problems and difficulties. Catalyst poisoning, thermal cycling and supplying a practical reductant make the performance and life of NOx adsorbers and lean NOx catalysts problematic. Selective Catalytic Reduction (SCR) requires an external fluid be distributed and carried on commercial vehicles. Combustion control technologies such as Exhaust Gas Recirculation, high injection pressures, variable geometry turbines for air handing and other similar mechanisms used to control NOx emissions from diesel engines add complexity and cost.

[0007] What is needed in the art is a NOx reduction system and method which is simpler and does not require an additional fluid (reductant) source on board moving vehicles.

SUMMARY OF THE INVENTION

[0008] The present invention provides a system for reduction of noxious oxides including an additional reductant catalytic reactor providing a catalyzed reductant fuel to a NOx catalytic reactor.

[0009] The invention comprises, in one form thereof, a system for reduction of noxious oxides from an exhaust of an internal combustion engine. The internal combustion engine includes an engine exhaust. A NOx catalytic reactor has at least one inlet in communication with the engine exhaust. A reductant catalytic reactor includes an inlet in communication with a reductant fuel supply, and an outlet in communication with at least one inlet to the NOx catalytic reactor.

[0010] An advantage of the present invention is that a higher NOx reduction is effected (based on the chemical stability/sulfur resistance of the catalyst used) in the exhaust from a diesel engine burning high sulfur diesel fuel.

[0011] Another advantage is that one liquid can be used for fuel and to catalytically generate the NOx reductant.

[0012] Yet another advantage is that the system is thermally and chemically stable.

[0013] Still another advantage is that the system uses only about 3% of the system total fuel for NOx reduction.

[0014] A further advantage is that the NOx catalyst, constituting the bulk of the system's catalysts, does not use precious metal catalysts.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

[0016] **FIG. 1** is a schematic view of an embodiment of the NOx reduction system of the present invention; and

[0017] **FIG. 2** is graphical representation of NOx reduction which may be achieved using the NOx reduction system shown in **FIG. 1**.

[0018] Corresponding reference characters indicate corresponding parts throughout the several views. The exemplification set out herein illustrates one preferred embodiment of the invention, in one form, and such exemplification is not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE INVENTION

[0019] Referring now to the drawings, and more particularly to **FIG. 1**, there is shown an embodiment of a system **10** for reduction of NOx from an exhaust **12** of an internal combustion engine **14**. System **10** also generally includes a NOx catalytic reactor **16**, reductant fuel supply **18** and reductant catalytic reactor **20**.

[0020] Reductant fuel supply **18** contains diesel fuel, gasoline and/or one or more other hydrocarbons. In one embodiment, reductant fuel supply **18** is the same fuel tank which supplies fuel to IC engine **14**, and thus reductant fuel **22** within reductant fuel supply **18** is also the same as the fuel supplied to IC engine **14** (e.g., diesel fuel). Configured as such, it will be appreciated that a separate supply line leads from reductant fuel supply **18** to IC engine **14**. Although the present invention is described and shown herein with reference to a diesel engine, it should be understood that the present invention is applicable to any hydrocarbon combustion source (e.g., diesel, natural gas, gasoline, coal, alcohols, etc.).

[0021] NOx catalytic reactor **16** has an inlet **24** in communication with engine exhaust **12**, and an outlet **26** in communication with the ambient environment, and optionally in communication with analyzers for determining a NOx level within the exhaust.

[0022] In one embodiment, NOx catalytic reactor **16** includes a ceramic catalyst material comprised of Al_2O_3, doped with (either integrated into the crystal structure of the Al_2O_3 or impregnated with) with an alkaline earth element (Na, Li, K or CS), Zr, Ti, V, Ce or La. In another embodiment, NOx catalytic reactor **16** includes a ceramic catalyst material comprised of Y zeolites, doped with (either integrated into the crystal structure of the zeolite or impregnated with) an alkaline earth element (Na, Li, K, or CS), Zr, Ti, V or La or Beta zeolites doped with Fe.

[0023] Reductant catalytic reactor **20** includes an inlet **28** in fluid communication with reductant fuel supply **18**, and an outlet **30** in communication with inlet **24** to NOx catalytic reactor **16**. More particularly, outlet **30** is coupled with branch exhaust **32** upstream from inlet **24** to NOx catalytic reactor **16**. Gases transported from outlet **30** of reductant catalytic reactor **20** therefore mix with engine exhaust gases from exhaust **12**, prior to entering NOx catalytic reactor **16** at inlet **24**.

[0024] Pump **34** and coil heater **36** are disposed in a series arrangement between reductant fuel supply **18** and reductant catalytic reactor **20**. Regulator **38** controls the volumetric fluid flow through pump **34**, and ultimately to reductant catalytic reactor **20**. Heater **36** heats the reductant fuel outputted from pump **34** to a temperature of between approximately 450-600° F., which is necessary to maintain a minimum temperature required to drive the reforming/cracking process of the reductant fuel within reductant catalytic reactor **20**.

[0025] Reductant catalytic reactor **20** includes a cracking and/or reforming catalyst used for reductant formation. In one embodiment, the cracking and/or reforming catalyst is comprised of zeolites, silica aluminas, precious metals wash coated on Al203 wash coated onto extruded corrigated monolith cylinders and/or Al_2O_3 or a combination of these compounds (needed to produce the desired combination of reductants to optimize NOx reduction at a given exhaust condition). The zeolites are preferably of ZSM5 configuration with a SiO2 to Al2O3 ratio of from 5-1000. These zeolites may be used in the pure form or doped with (impregnated or integrated into the crystal structure) Mo, Ti, Fe. The Silica Aluminas are solid solutions of SiO2 and Al2O3 oxides that are doped with Mo, Ti, and/or Fe.

[0026] During use, diesel fuel, gasoline or other hydrocarbons are catalytically cracked and/or reformed to produce H_2, CO and/or short chain hydrocarbons (oxidized and partially unsaturated) to act as reductants for NOx when passed over NOx catalytic reactor **16** in conjunction with the NOx from exhaust **12** originating from IC engine **14**. The cracked and/or reformed reductant fuel is mixed with the engine exhaust in branch exhaust **32** and transported to inlet **24** of NOx catalytic reactor **16**. The equation for the reductant reaction in NOx catalytic reactor **16** is:

[0027] HC, CO and/or H_2 (one or all)+NOx=>N_2+CO_2+H_20 (dependent upon the reductant mix).

[0028] Unlike three-way catalysts used on automobiles for NOx reduction, system **10** reduces NOx in the presence of high concentrations of O_2 (less than 1%) and sulfur oxides (less than 15 ppm) normally found in the exhaust of diesel and lean burn natural gas/gasoline engine powered vehicles as well as most coal and natural gas fired boilers.

[0029] System **10** uses a unique cracking/reforming catalyst to produce a tailored, very active reductant to activate a normally very thermally and chemically inactive ceramic catalyst to reduce NOx in the presence of high levels of sulfur oxide and oxygen. This unique combination of catalysts produces a NOx reduction after treatment system that is very sulfur tolerant and thermally stable and cost effective since the NOx catalyst (constituting the bulk of the system catalyst) does not use precious metals and is very efficient since it only involves a 2-3 fuel penalty. System **10** has demonstrated over 90% NOx reduction (**FIG. 2**) in the exhaust from an IC engine **14** burning high sulfur (500 ppm) diesel fuel.

[0030] In contrast with conventional systems, the present invention catalytically and thermally produces, under controlled conditions, taylored reductants from commercially available hydrocarbons (such as diesel fuel and gasoline) that will cause materials that are not normally able to (or catalytically active for) effectively reduce the oxides of nitrogen from the exhausts of combustion sources. These normally inactive materials are preferably ceramics and are very stable thermally and chemically (are not poisoned by active compounds in the exhaust such as SOx) giving these materials the double benefit of being both very active for NOx but very stable thermally and chemically otherwise.

[0031] While this invention has been described as having a preferred design, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.

1. A system for reduction of noxious oxides from an exhaust of an internal combustion engine, comprising;

an internal combustion engine including an engine exhaust;

a NOx catalytic reactor having at least one inlet in communication with said engine exhaust;

a reductant fuel supply;

a reductant catalytic reactor including an inlet in communication with said reductant fuel supply and an outlet in communication with said at least one inlet to said NOx catalytic reactor, said reductant catalytic reactor not directly connected to the atmosphere and operating without ambient air being introduced directly thereto:

a heater in communication with said reductant catalytic reactor inlet whereby said fuel supply is heated prior to entering the reductant catalytic reactor, and,

wherein said reductant catalytic reactor comprises one of a zeolites and precious metals.

2. The system for reduction of noxious oxides of claim 1, further including a pump in communication with and between said reductant fuel supply and said reductant catalytic reactor.

3. The system for reduction of noxious oxides of claim 2, further including a regulator for controlling fluid flow through said pump.

4. The system for reduction of noxious oxides of claim 2, wherein said heater is in communication with and between said pump and said reductant catalytic reactor.

5. The system for reduction of noxious oxides of claim 4, wherein said heater heats reductant fuel from said reductant fuel supply to a temperature of between approximately 450 to 600 degF.

6. A system for reduction of noxious oxides from an exhaust of an internal combustion engine, comprising;

an internal combustion engine including an engine exhaust;

a NOx catalytic reactor having at least one inlet in communication with said engine exhaust;

a reductant fuel supply;

a reductant catalytic reactor including an inlet in communication with said reductant fuel supply and an outlet in communication with said at least one inlet to said NOx catalytic reactor, said reductant catalytic reactor not directly connected to the atmosphere and operating without ambient air being introduced directly thereto;

a heater in communication with said reductant catalytic reactor inlet whereby said fuel supply is heated prior to entering the reductant catalytic reactor, and,

wherein said NOx catalytic reactor includes a ceramic catalyst material comprised of Al_20_3, doped with one of Na, Zr and La.

7. A system for reduction of noxious oxides from an exhaust of an internal combustion engine, comprising;

an internal combustion engine including an engine exhaust;

a NOx catalytic reactor having at least one inlet in communication with said engine exhaust;

a reductant fuel supply;

a reductant catalytic reactor including an inlet in communication with said reductant fuel supply and an outlet in communication with said at least one inlet to said NOx catalytic reactor, said reductant catalytic reactor not directly connected to the atmosphere and operating without ambient air being introduced directly thereto;

a heater in communication with said reductant catalytic reactor inlet whereby said fuel supply is heated prior to entering the reductant catalytic reactor, and,

wherein said NOx catalytic reactor includes a ceramic catalyst material comprised of Y zeolite, doped with Na.

8. (canceled)

9. The system for reduction of noxious oxides of claim 1, wherein said reductant catalytic reactor is doped with at least one of Mo, Ti and Fe.

10. The system for reduction of noxious oxides of claim 9, wherein said reductant fuel supply can be any one of diesel fuel, gasoline and one or more other hydrocarbons.

11. The system for reduction of noxious oxides of claim 9, wherein said internal combustion engine utilizes fuel in the form of at least one of diesel, natural gas, gasoline, coal, and alcohol.

12. A system for reduction of noxious oxides from an exhaust of an internal combustion engine, comprising;

a NOx catalytic reactor having at least one inlet configured for communication with said engine exhaust;

a reductant fuel supply;

a reductant catalytic reactor including an inlet in communication with said reductant fuel supply and an outlet in communication with said at least one inlet to said NOx catalytic reactor, said reductant catalytic reactor not directly connected to the atmosphere and operating without ambient air being introduced directly thereto;

a heater in communication with said reductant catalytic reactor inlet whereby said fuel supply is heated prior to entering the reductant catalytic reactor; and,

said reductant catalytic reactor operating with said fuel supply in the absence of water being provided thereto.

13. The system for reduction of noxious oxides of claim 12, further including a pump in communication with and between said reductant fuel supply and said reductant catalytic reactor.

14. The system for reduction of noxious oxides of claim 13, further including a regulator for controlling fluid flow through said pump.

15. The system for reduction of noxious oxides of claim 13, wherein said heater is in communication with and between said pump and said reductant catalytic reactor.

16. The system for reduction of noxious oxides of claim 12, wherein said reductant catalytic reactor includes at least one of zeolites, silica aluminas, dispersed precious metals on monolith, and aluminum trioxide.

17. The system for reduction of noxious oxides of claim 16, wherein said reductant catalytic reactor is doped with at least one of these metals Mo, Ti and Fe.

18. A method of reducing noxious oxides from an exhaust of an internal combustion engine, comprising the steps of:

heating a reductant fuel;

at least one of cracking and reforming a said reductant fuel in the absence of ambient air in a reductant catalytic reactor comprising one of a zeolites and precious metals;

mixing the at least one of cracked and reformed reductant fuel with exhaust gas from the internal combustion engine; and

catalytically converting the mixed reductant fuel and exhaust gas in a NOx catalytic reactor.

19. The method of reducing noxious oxides of claim 18, wherein said reductant fuel comprises any one of diesel fuel, gasoline and one or more other hydrocarbons prior to being at least one of cracked and reformed.

20. (canceled)

21. The method of reducing noxious oxides of claim 18, wherein said reductant catalytic reactor is doped with at least one of Mo, Ti and Fe.

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