Regeneration system in which a hydrogen-rich gas from an onboard reformer flows into an aftertreatment unit in a direction opposite to the flow of engine exhaust to regenerate the unit. The aftertreatment unit is segmented with independent regeneration capability for each segment. Regeneration is performed with hydrogen-rich gas produced by an onboard reformer. A hydrogen-rich gas switchbox is used to direct the flow of the reformate to the segment of the aftertreatment unit that is undergoing regeneration.
Subsections of aftertreatment unit

Exhaust

AFTERTREATMENT UNIT NORMAL OPERATION

FIG. 1a

Subsection under regeneration

Exhaust

Reformate

AFTERTREATMENT UNIT PARTIAL REGENERATION

FIG. 1b
FIG. 4a

Opening for pipe (one of several)

Pipe to aftertreatment unit segment

30 Sleeve opening

32 Rotating sleeve

FIG. 4b

14 Sleeve opening

34 Pipe openings
SensOr Signal Reformate Subsection under regeneration

AFTERTREATMENT UNIT PARTIAL REGENERATION

FIG. 5

Sensor signal

Sensor

Exhaust

Subsection under regeneration

Reformate

10

12

FIG. 6

Subsection under regeneration

Exhaust

Sensor

Sensor signal

AFTERTREATMENT UNIT PARTIAL REGENERATION
ENHANCED AFTERTREATMENT APPARATUS REGENERATION USING SPATIALLY CONTROLLED HYDROGEN-RICH GAS


BACKGROUND OF THE INVENTION

[0002] This invention relates to the regeneration of exhaust aftertreatment devices and more particularly to spatially selective regeneration of aftertreatment units.

[0003] U.S. pending application Ser. No. 10/868,333 discloses spatial control of hydrogen-rich gas for improving the regeneration of devices that clean engine exhaust. This application considered particular aftertreatment devices—diesel particulate filters (DPF) and NOx traps.

[0004] As taught in that application, the use of spatially selective regeneration of aftertreatment units offers advantages in relation to a decreased fuel penalty, increased options for regeneration (oxidation/reducing environments, temperature control), regeneration at reduced loading, increased reliability from decreased temperatures during regeneration, decreased temperature gradients, and in some cases, reduced thermal stress. In addition, the use of spatially selective regeneration can reduce catalyst cost by allowing the use of a one-leg rather than a two-leg system with an exhaust valve. High catalyst cost is a key issue in developing commercially attractive NOx trap systems.

[0005] There is therefore a need for optimization of a device that can be used to direct the hydrogen-rich gas to a particular region of the device for regeneration, and has the ability to selectively direct the hydrogen-rich gas to different sections of the aftertreatment device. It is also desirable to have a novel means for determination of end-of-regeneration conditions.

SUMMARY OF THE INVENTION

[0006] In one aspect, the invention is a regeneration system including an exhaust aftertreatment unit fitted to the exhaust of an internal combustion engine and a fuel reformer providing hydrogen-rich gas to the aftertreatment unit to spatially non-uniformly regenerate the aftertreatment unit. In a preferred embodiment, the aftertreatment unit is segmented into sections that undergo independent regeneration. It is preferred that engine exhaust be prevented from flowing in the region being regenerated by arranging the hydrogen-rich gas to flow in a direction opposite to that of the exhaust flow. Appropriate aftertreatment devices for regeneration according to the invention includes diesel particulate filters and NOx traps. An SCR/lean NOx trap device is another device useful for cleaning exhaust, and included in aftertreatment devices that can benefit from the present invention.

[0007] In a preferred embodiment, a hydrogen-rich gas switchbox controls the flow of hydrogen-rich gas using appropriate valves and plumbing to regenerate a desired section of an aftertreatment unit. Suitable valves include butterfly valves, poppet valves and sleeve valves. An electromagnetic actuator may be used to control the valves. In yet another preferred embodiment, at least one regeneration sensor is located upstream from the exhaust system to monitor either reformate compounds or regeneration compounds. A suitable fuel reformer is a plasmatron fuel reformer.

BRIEF DESCRIPTION OF THE DRAWING

[0008] FIGS. 1a and 1b are cross-sectional views of an embodiment of the regeneration system disclosed herein.

[0009] FIG. 2 is a cross-sectional view of a schematic of an embodiment of a hydrogen-rich gas switchbox for the selection of flow through multiple outlets to direct hydrogen-rich gas to specific sections of the aftertreatment unit.

[0010] FIG. 3 is a schematic illustration of an embodiment of the system disclosed herein using a fuel reformer, a hydrogen-rich gas switchbox and an aftertreatment unit.

[0011] FIGS. 4a and 4b are perspective and cross-sectional views, respectively, of a hydrogen-rich gas box illustrating the use of a flat sleeve valve.

[0012] FIG. 5 is a cross-sectional schematic illustration of an embodiment of the invention using a sensor to monitor end-of-regeneration conditions upstream from the aftertreatment unit.

[0013] FIG. 6 is a cross-sectional view of an embodiment of the invention including a sensor downstream from the aftertreatment unit for monitoring end-of-regeneration conditions.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0014] During regeneration of NOx traps, it is desirable to minimize the flow of exhaust through the section being regenerated. Minimization of the exhaust flow is important to reduce additional reductant that would be wasted by eliminating free oxygen present in the exhaust flow before any reduction of the nitrogen oxides on the catalyst can begin. A fuel penalty can be severely impacted by the presence of even small levels of exhaust (which contain free oxygen) in a NOx trap region being regenerated.

[0015] With reference first to FIG. 1a, an aftertreatment unit 10 includes a plurality of subsections as shown. The aftertreatment unit 10 may be a diesel particulate filter or an NOx trap. During normal operation as shown in FIG. 1a, exhaust gas flows through the individual subsections. When it is time to regenerate the aftertreatment unit 10, reformate including a hydrogen-rich gas is introduced through a pipe 12 into a first subsection 13 for regeneration. The reformate flows in the opposite direction of an exhaust gas thereby excluding substantially all of the exhaust gas from the subsection 13 under regeneration. Each of the remaining subsections can be regenerated in turn.

[0016] For regeneration of NOx traps, it is important to eliminate as much free oxygen as possible. Co-flow (wherein hydrogen-rich gas flows in the same direction as the exhaust) will introduce oxygen into the stream. Counterflow in which hydrogen-rich gas is introduced downstream from the unit in the opposite direction to the exhaust flow prevents the entrainment of exhaust gas in the segment of the aftertreatment section being regenerated as shown in FIG. 1b. Counterflow decreases the fuel penalty for the regeneration of NOx traps since hydrogen-rich gas is not wasted on free oxygen in the exhaust flow.

[0017] With reference now to FIG. 2, a hydrogen switchbox 14 receives hydrogen-rich gas from a fuel reformer 16 that is preferably a plasmatron fuel reformer. Valves 18, 20 and 22 control the flow of hydrogen-rich gas through feed lines 24,
The valves 18, 20 and 22 may be of a butterfly configuration, or they can be poppet valves or sleeve valves. It is noted that any number of valves and feed lines may be provided. The three valves in FIG. 2 are merely exemplary. Butterfly valves have the advantage of low cost. A sleeve valve allows for a single moving unit with one or more openings that when moved, redirects the flow of hydrogen-rich gas to the appropriate feed lines or pipes. Sleeve valves minimize the number of moving parts but have a single control. Sleeve valves require substantial motions of the moving part of the valve.

FIG. 3 is another schematic illustration showing the hydrogen-rich gas switchbox 14 receiving hydrogen-rich gas from the reformer 16 and selectively introducing hydrogen-rich gas into the aftertreatment unit 10 in a direction opposed to the exhaust gas flow. In order to minimize pressure fluctuations in the reformer 16, it is preferred to switch the flow between different pipes in a manner in which two or more of the valves are open during the switching as illustrated in FIGS. 4a and 4b. Valve overlap (wherein more than one valve is open) minimizes high-speed flows across narrow (near-closed or near-open) valves, that could result in deposits or increased heat transfer through regions with high turbulence because of the high flow speeds. Therefore, the requirement of fast acting, but soft valve landing required for engine valves is not needed, and valve motion control is not needed to minimize noise or vibration. Simple pressurized air or vacuum actuated valves can be used and are attractive for cost minimization of the hydrogen-rich gas switchbox 14.

As shown in FIGS. 4a and 4b, sleeve valves 30 can be a flat plate 32 with axial pipes, or it can be a cylindrical shell with a radial pipe activated with angular motion. In the case of the sleeve valve, overlap is achieved by proper sizing of a pipe opening 34 and the moving element opening. It should be recognized that there can be more than one opening in the plate.

In either case, a valve does not require large forces to either actuate or close. Spring loaded valves, in the case of butterfly or poppet valves, are sufficient. Since valve actuation does not have to be particularly fast, the valves can be actuated by vacuum or pressurized air as a means of decreasing the cost of the hydrogen-rich gas switchbox 14.

In contrast to valves in an exhaust system in a two-leg configuration that need to be very tight (having little leakage), it is not required that the valves in the switchbox 14 be very tight. If there is some leakage, the effect is a linear drop in efficiency, with minimal effect on any fuel penalty. This situation is in sharp contrast to a valve in an exhaust system in which a small leakage may require substantial amounts of hydrogen-rich gas to combust the free oxygen, much larger than the amount of hydrogen-rich gas required to regenerate a catalyst in the aftertreatment unit 10.

As the duty cycle of each valve is relatively small (at most, if the reformer is on all the time, the duty cycle is the inverse of the number of valves), the temperature of the valves can be maintained sufficiently low to minimize the temperature requirements of the unit. The use of low temperature valves is useful for cost minimization of the hydrogen switchbox 14. However, there can be times, for example, during desulfation cycles in which the temperature of the valves can be high. However, the number of desulfation cycles is typically much smaller than that of trap regeneration.

It may be desirable to decrease the temperature of the reformate before introduction into the aftertreatment unit. A heat exchanger can be introduced between the reformer and the aftertreatment unit. One advantage of the decreased temperature is that thermal stresses in the aftertreatment unit during regeneration can be decreased. The heat exchanger can be gas-to-air, gas-to-exhaust, or gas-to-liquid. The heat exchanger can be incorporated into the reformer, the hydrogen switch box or placed in-between the reformer and the hydrogen rich box.

In another embodiment, the reformer can operate over a wide range of oxygen-to-carbon ratios. Partial oxidation is defined when the oxygen atoms' flow rate in the air to the reformer is the same as that of the carbon atoms' flow rate in the fuel to the reformer. Full combustion is defined as when the fuel is fully combusted with no excess oxygen (stoichiometric combustion). In the case when the reformer operates with high oxygen-to-carbon ratios, the hydrogen yield is decreased but the reformer is at higher temperatures, which may be advantageous for some applications. On the other hand, operating at oxygen-to-carbon ratios below partial oxidation may generate lower temperatures, at the expense of hydrogen flow rate. Operation with some oxygen in the reformer for the generation of some oxygen is however desired. The reformer may use the engine exhaust, which for diesel engines or lean burn gasoline engines has free oxygen, as well as air, as the fuel oxidizer.

In still another embodiment, the conditions in the region of the NOx trap can be sufficiently rich that ammonia is generated in the region being regenerated. The ammonia thus produced is then used in the other regions that are not being directly regenerated by the hydrogen rich gas. This embodiment is allowed because of the counterflow direction of the of hydrogen rich gas with respect to the direction of the exhaust flow. In this embodiment, the catalyst formulation optimized for lean NOx should be closer to the exhaust, and the catalyst formulation optimized for an SCR catalyst should be closer to the engine side. In this manner, the hydrogen rich gas travels over the lean NOx catalyst before it reaches the SCR catalyst. Under some conditions it would be preferred that the amount of hydrogen rich gas be adjusted so that little hydrogen rich gas survives past the lean NOx catalyst.

High temperature of the reformate results in substantial gas speeds at the end of the pipe that carries the reformate to an NOx trap. High speed is needed in order to provide the effect of a gas-dynamic valve, wherein the reverse flowing reformate excludes exhaust from the section being regenerated thereby eliminating any free oxygen. The reformate reverse flow has enough momentum to stop the exhaust flow.

It is preferred to provide sensors to determine when the regeneration has been completed. As shown in FIGS. 5 and 6, a sensor 40 can be placed in one of two places, either upstream from the aftertreatment unit 10 (on the side of the aftertreatment device 10 that is closest to an engine as shown in FIG. 5) or it can be placed downstream from the aftertreatment unit 10 on the same side of the aftertreatment unit wherein the hydrogen-rich gas is introduced as shown in FIG. 6. The sensor 40 can be a chemical sensor for sensing one or more of the compounds from the reformer 16 (hydrogen, CO) or for sensing one or more of the compounds resulting from the regeneration process.

It is recognized that modifications and variations of the invention disclosed herein will be apparent to those of
ordinary skill in the art and it is intended that all such modifications and variations be included within the scope of the appended claims.

What is claimed is:
1) Regeneration system comprising:
an exhaust aftertreatment unit fitted to the exhaust of an internal combustion engine; and
a fuel reformer providing hydrogen-rich gas to the aftertreatment unit so as to obtain spatially selective regeneration of the aftertreatment unit; and
including a hydrogen-rich gas switchbox having associated valves and plumbing for controlling the flow of hydrogen-rich gas, wherein the valves in the switchbox are used to direct the flow of hydrogen-rich gas to the appropriate plumbing to regenerate the associated section of the aftertreatment unit.

2) Regeneration system comprising:
an exhaust aftertreatment unit fitted to the exhaust of an internal combustion engine; and
a fuel reformer providing hydrogen-rich gas to the aftertreatment unit so as to obtain spatially selective regeneration of the aftertreatment unit wherein the engine exhaust is prevented from flowing in the region being regenerated by the hydrogen-rich gas flowing in an opposite direction to the exhaust flow.

3) The regeneration system of claims 1 or 2 wherein the aftertreatment unit is segmented in sections that undergo independent regeneration.

4) The system of claims 1 or 2 wherein the aftertreatment device is a NOx trap.

5) The system of claims 1 or 2 wherein the aftertreatment device is a diesel particulate filter.

6) The system of claim 2 further including a hydrogen-rich gas switchbox having associated valves and plumbing for controlling the flow of hydrogen-rich gas, wherein the valves in the switchbox are used to direct the flow of hydrogen-rich gas to the appropriate plumbing to regenerate the associated section of the aftertreatment unit.

7) The system of claim 6 wherein the valves are butterfly valves.

8) The system of claim 6 wherein the valves are poppet valves.

9) The system of claims 7 or 8 wherein the valves are actuated by either vacuum or compressed air.

10) The system of claim 6 wherein the valves are sleeve valves.

11) The system of claim 10 wherein the sleeve valve is made of flat surfaces, the moving part having one or more openings.

12) The system of claim 11 wherein the sleeve valve surfaces are cylindrical shells with the moving part having one or more openings.

13) The system of claim 11 wherein the moving part is driven by an electromagnetic actuator.

14) The system of claim 5 wherein, during switching, there are two or more partially or fully open valves.

15) The system of claims 1 or 2 further including at least one regeneration sensor located upstream from the exhaust system, the sensor or sensors monitoring the reformatte compounds or regeneration compounds.

16) The system of claims 1 or 2 wherein the fuel reformer operates over a wide range of oxygen-to-carbon ratios, from below partial oxidation to below full combustion.

17) The system of claims 1 or 2 wherein there is a heat exchanger downstream from the reformer but upstream from the aftertreatment unit.

18) The system of claim 4 wherein there is ammonia generated in the region that is being regenerated by the hydrogen rich gas, the ammonia re-entering other regions of the NOx trap that are not being regenerated by the hydrogen rich gas.

19) The system of claims 1 or 2 wherein a lean NOx catalyst and an SCR catalyst are both used and where the SCR catalyst is closer to the engine, so that the hydrogen rich gas passes over the lean NOx catalyst before it reaches the SCR catalyst.

20) The system of claims 1 or 2 wherein the fuel reformer is a plasmatron fuel reformer.

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