SYSTEM AND METHOD FOR USING NONTHERMAL PLASMA REACTORS

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ABSTRACT
In one embodiment, the process for treating a gas stream, comprises: introducing a gas stream to a plasma reactor, maintaining a reactor temperature of the plasma reactor at greater than or equal to about 70°C, and reducing the concentration of a gas stream component in the plasma reactor to produce a treated gas stream.
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CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/424,857, filed on Nov. 8, 2002, the teachings of which are incorporated herein by reference in their entirety.

BACKGROUND OF INVENTION

[0002] Ozonators (devices capable of producing ozone) have been employed to remove odors (e.g., smoke), etc. from enclosed environments (e.g., a room). Use of these devices, however, requires a great deal of time. The device is set up with a timer, once the room is deserted, the timer starts the ozonator. Then, after completion, it takes several hours for the ozone to dissipate.

[0003] In order to properly operate, the ozonator needs to be cooled, and the use of catalysts are required to remove other contaminants, and a dispersing mechanism is required to disperse the ozone produced.

[0004] A plasma reactor typically comprises a chamber through which there is a constant flow of gas at a pressure reduced to less than atmospheric pressure, e.g., about 1 millibar (i.e., 10\(^{-6}\) newton per square meter (N/m\(^2\))) is typically employed. When the gas at the reduced pressure is subjected to a radio frequency (RF) potential of up to about 150 watts at, for example, up to about 14 megahertz (MHz), the gas is partially ionized, forming a plasma, and produces a glow discharge.

[0005] A non-thermal plasma reactor with parallel plate technology designed for in-situ operation at about average atmospheric pressure in the typical conditions found in an exhaust system of an internal combustion engine can be used to reduce the amount of nitrogen oxides (NO\(_x\)) and unburned hydrocarbons in the exhaust gas, but does not reduce ozone concentration. In order to meet stricter emissions standards, a need exists for a method of controlling or reducing ozone formed in the exhaust gas stream before the ozone exits the exhaust system.

[0006] There remains a need for a cost effective, quick, system and method for removal of contaminants from gas streams.

SUMMARY OF INVENTION

[0007] Disclosed herein are a system and a process for using a treatment system. In one embodiment, process for treating a gas stream, comprises: introducing a gas stream to a plasma reactor, maintaining a reactor temperature of the plasma reactor at greater than or equal to about 700 \(^\circ\) C., and reducing the concentration of a gas stream component in the plasma reactor to produce a treated gas stream.

[0008] One embodiment of a vehicle exhaust system, comprises: an engine, an exhaust conduit in fluid communication with the engine, configured to direct a gas stream from the engine out of the vehicle, a plasma reactor disposed downstream from the engine and in fluid communication with the exhaust conduit, a power source in electrical communication with the plasma reactor; and a controller disposed in operable communication with the power source and with a temperature sensor, wherein the temperature sensor is disposed in thermal communication with the exhaust conduit.

[0009] The above described and other features are exemplified by the following figures and detailed description.

BRIEF DESCRIPTION OF DRAWING

[0010] Referring now to the figure, which is an exemplary embodiment, and wherein the like elements are numbered alike:

[0011] FIG. 1 is a schematic diagram illustrating an exhaust treatment system comprising a non-thermal plasma reactor configured to operate according to an example of the disclosed system and method.

DETAILED DESCRIPTION

[0012] Disclosed herein is a system and method for efficiently and effectively removing contaminants from a gas stream, an enclosed environment (e.g., building, room, vehicle cabin, submarine, airplane, aerospace vehicle, and the like), in situ. That is, without requiring evacuation of the area, and without the need for additional and dispersing mechanisms. The system comprises a plasma reactor (e.g., a non-thermal plasma reactor), a temperature sensor (e.g., a thermistor) disposed downstream of the plasma reactor, a power source in electrical communication with the plasma reactor, and a controller in operable communication with the temperature sensor and the power source. It is the system utilized to remove contaminants from an exhaust stream on a vehicle (e.g., a low temperature exhaust gas temperature of about 50 \(^\circ\) C. to about 150 \(^\circ\) C.) diesel engine exhaust stream), the system may further comprise an engine in fluid communication with the plasma reactor such that engine exhaust can be passed through the plasma reactor, and an optional exhaust emission control device disposed downstream of the plasma reactor. For use in an enclosed environment, the plasma reactor is disposed in fluid communication with the environment (e.g., with the room, cabin, etc.) such that the air in that environment can be circulated through the plasma reactor (e.g., using a pump, fan, or the like).

[0013] In operation, the plasma reactor is preferably first brought up to temperature prior to the introduction of gas. Therefore, without initiating a flow of gas through the plasma reactor, sufficient power is supplied to the reactor to heat the reactor to a desired temperature. Determination of when the reactor attains the desired temperature can be determined based upon the size of the reactor and the amount of power supplied. For example, the time to attain the desired temperature can be determined experimentally. The reactor can then be heated for a selected time at a selected power to attain the desired temperature. Once the desired temperature (i.e., sufficient temperature to oxidize components in the gas while decomposing ozone) has been attained, a flow of gas can be initiated through the reactor.

[0014] Treated gas exiting the reactor can be monitored for temperature. The controller, based upon the temperature sensor reading of the treated gas temperature, the flow rate of the treated gas and the energy delivered to the plasma reactor, can control the power supply to maintain the reactor
temperature at the desired temperature level (e.g., typically greater than or equal to about 70°C). Preferably, the reactor temperature is controlled to be about 80°C to about 300°C. Within this range, the reactor temperature is preferably greater than or equal to about 125°C, with greater than or equal to about 150°C more preferred. Also preferred within this range, is a reactor temperature of less than or equal to about 275°C, with less than or equal to about 250°C more preferred. The higher temperatures are preferred for system simplicity and to enable greater leeway in the reactor temperature variability specifications. (At the higher temperatures, the desired oxidations occur as well as the decomposing of the ozone.)

To attain the desired reactor temperature, pulsing of the electrical signal (e.g., preferably an alternating current (AC)) may be employed. By “pulsing” the electrical signal to the plasma reactor, the energy density of the electrical signal can be delivered at the optimum frequency while the corona discharge remains uniform across the plasma reactor. For purposes of this discussion, the frequency of the alternating current from the electrical power source is referred to as the carrier frequency. The modulation frequency or duty cycle is then defined as the time in which the alternating current signal is applied to the plasma reactor. For instance, if the alternating current signal is applied (or “on”) only 10% of the time over a given period, this is a 10% duty cycle. Using this “pulsing” approach, the energy density going into the gas can be separated from the energy going into the reactor plates and can be controlled using the carrier frequency, the modulation frequency and the amplitude of the electrical signal. Limiting the size of the carrier frequency to a single 360 degree period and using the modulation frequency as the primary energy modulation method provides the optimal energy transfer to the gas. Therefore, a series of single period pulses may be applied at varying intervals. Since the number of pulses applied in a given interval is known as the density of pulses, this pulsing technique may be referred to as pulse density modulation (“PDM”).

The carrier frequency, modulation frequency, and voltage are interrelated variables in determining the energy delivered to the reactor. When there is a desire to heat the reactor (as opposed to maintain a temperature), the carrier frequency can be greater than or equal to about 10 kiloHertz (kHz), with about 13 kHz to about 20 kHz employed in many applications. The modulation frequency can be greater than or equal to about 10 Hertz (Hz), with about 500 Hertz to about 15 kHz employed in many applications. The voltage can be greater than or equal to about 500 volts (V), with about 1,000 volts to about 20 kilovolts (kV) employed in many applications.

In contrast, where it is desirable to maintain the reactor temperature while continuing to oxidize components of the gas, a short power pulse can be employed. Basically, the pulse is in the order of nanoseconds (ns), with less than or equal to about 100 ns. Generally sufficient to maintain the desired reactions without increasing the temperature of the reactor. Under these conditions the modulation frequency can be about 1 Hz to about 1 MHz, with about 500 kHz to about 10 kHz preferred. The voltage can be about 100 volts to about 100 kV, with about 2 kV volts to about 20 kV preferred. The current can be about 100 milli-amperes (mA) to about 10 kA, with about 1 A to about 1 kA preferred.

When the reactor is at the desired temperature and the flow of gas through the reactor has commenced, a chemical reaction occurs within the plasma reactor, reducing the concentration of at least one gas component (e.g., nitrogen oxides, hydrocarbons, nitrogen, oxygen, water, carbon monoxide, ozone, hydrogen sulfides, and/or soot). For example, the contaminants in the gas are converted to nitrogen, carbon dioxide, water, sulfur dioxide.
employed downstream of the plasma reactor. An example of a temperature sensor is a thermistor. The temperature sensor(s) are in communication with the controller and are capable of determining the treated gas temperature of the exhaust stream. This information is transmitted to the controller that uses the information to control the power to the plasma reactor 12, and thereby control the temperature thereof (e.g., the temperature of the reactive elements to about 80°C. to about 300°C.).

[0025] The controller can be a computer or controller capable of implementing the method described herein. The disclosed method can be embodied in the form of computer or controller implemented processes and apparatuses for practicing those processes. It can also be embodied in the form of computer program code containing instructions embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, or any other computer-readable storage medium, wherein, when the computer program code is loaded into and executed by a computer or controller, the computer becomes an apparatus for practicing the method. The method may also be embodied in the form of computer program code or signal, for example, whether stored in a storage medium, loaded into and/or executed by a computer or controller, or transmitted over some transmission medium, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus for practicing the method. When implemented on a general-purpose microprocessor, the computer program code segments configure the microprocessor to create specific logic circuits.

[0026] The controller is in operable communication with a power source 18 that is in electrical communication with the plasma reactor 12. The power source can be any available source of power for the given application. Some possible power sources include batteries, capacitors, generators, fuel cells, grid power, and the like. The controller should be sized and designed to provide the desired amount of power to the plasma reactor to maintain the surface of the reactive elements within the desired temperature range and to attain the desired plasma discharge in the reactor.

[0027] Referring now to FIG. 1 that illustrates a vehicle use of the present system and method. In FIG. 1, the exhaust treatment system 10 comprises a non-thermal plasma reactor 12 interconnected between an optional catalytic converter 14 (or another exhaust emission treatment device such as a NOx adsorber, particulate filter, and/or sulfur oxides (SOx) trap, and the like) and an internal combustion engine 16; down stream from the engine. Optionally, an exhaust component sensor 24 (e.g., a NOx sensor, hydrocarbon sensor, or the like) upstream of the plasma reactor and an exhaust component sensor 26 downstream of the plasma reactor may be provided. An electric power source 18 provides an electrical signal to the non-thermal plasma reactor 12.

[0028] In operable communication with the electric power source 18 may be a controller 20 that can be used to modulate the power to the reactor. During operation, the electrical signal is preferably pulsed by the controller 20, e.g., as is taught in U.S. Pat. No. 6,423,190 B2, to achieve a uniform barrier discharge in the plasma reactor 12. The desired amount of energy provided to the plasma reactor 12 is determined based upon the temperature of the exhaust stream provided by the temperature sensor 28 along with other factors. Optionally, the temperature sensor 28 and/or the NOx sensor 26 may be disposed downstream of an optional exhaust emission treatment device 14.

[0029] During operation, exhaust gas from the engine enters the plasma reactor 12 where the concentration of at least one emission component is reduced (e.g., the concentration of NOx). Before entering and/or subsequent to exiting the plasma reactor 12, the composition of the exhaust stream can be determined.

[0030] From the plasma reactor 12, the exhaust stream may be passed through an optional exhaust emission treatment device. The exhaust emission treatment device can be employed throughout the operation of the system or merely during startup to prevent breakthrough emissions. Optionally, an exhaust emission treatment device can be disposed upstream of the plasma reactor 12, to reduce emissions throughout the process and/or for startup control of the emissions. Possible exhaust emission treatment devices include catalytic converters, evaporative emissions devices, scrubbing devices (e.g., hydrocarbon, sulfur, and the like), particulate filters/ traps, adsorbers/absorbers, plasma reactors, and the like, as well as combinations comprising at least one of the foregoing devices.

[0031] The disclosed system and method for reducing emissions in a gas stream reduces undesirable emissions components (e.g., oxidizable contaminants) to a total of less than or equal about 10 ppm each, by controlling the temperature of the plasma reactor, and optionally even eliminating gas treatment devices (e.g., catalyst and the like). This system does not need to be isolated when operated in the area to be decontaminated (e.g., removal of smoke odor), but can be employed anytime. It can also be employed for multiple contaminant removal and destruction of airborne pathogens.

[0032] While the invention has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the spirit of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A process for treating a gas stream, comprising:
   introducing a gas stream to a plasma reactor;
   maintaining a reactor temperature of the plasma reactor at greater than or equal to about 70°C.; and
   reducing the concentration of a gas stream component in the plasma reactor to produce a treated gas stream.

2. The process of claim 1, wherein the temperature of the plasma reactor is maintained at a temperature of about 80°C. to about 300°C.

3. The process of claim 1, further comprising sensing a reacted gas stream temperature; and
pulsing an electric signal to the plasma reactor based upon the sensed temperature.

4. The process of claim 1, further comprising introducing an electric signal to the plasma reactor prior to introducing the gas stream.

5. The process of claim 1, further comprising controlling the reactor temperature by pulsing an electric signal to the plasma reactor from a power source.

6. The process of claim 5, wherein the electric signal has a modulation frequency of about 1 Hz to about 1 MHz.

7. The process of claim 6, wherein the electric signal has a modulation frequency of about 500 Hz to about 10 kHz.

8. The process of claim 5, wherein the electric signal has a pulse duration of less than or equal to about 100 nsec.

9. The process of claim 8, wherein the electric signal does not increases the reactor temperature.

10. The process of claim 1, further comprising directing gas from within a vehicle to the plasma reactor.

11. The process of claim 1, further comprising directing gas from within a building to the plasma reactor.

12. The process of claim 1, further comprising directing gas from within a submarine to the plasma reactor.

13. The process of claim 1, further comprising directing gas from with an airplane or aerospace vehicle to the plasma reactor.

14. The process of claim 1, wherein the concentration of the gas stream component is reduced to less than or equal to 10 ppm.

15. An vehicle exhaust system, comprising:

   an engine;

   an exhaust conduit in fluid communication with the engine, configured to direct a gas stream from the engine out of the vehicle;

   a plasma reactor disposed downstream from the engine and in fluid communication with the exhaust conduit;

   a power source in electrical communication with the plasma reactor; and

   a controller disposed in operable communication with the power source and with a temperature sensor, wherein the temperature sensor is disposed in thermal communication with the exhaust conduit downstream from the plasma reactor.