PLASMA ACTUATED ELECTRONIC CATALYTIC CONVERTER

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ABSTRACT
An apparatus and method for the breakdown of exhaust gas pollutant molecules into their constituent atoms and then re-assembling those atoms into low energy state non-toxic molecules that are found in the atmosphere naturally is disclosed. A plasma actuated electronic catalytic converter includes an exhaust gas inlet, a first oxidation reaction chamber, a second reduction reaction chamber, an exhaust gas outlet, and an electronics power source. A first reaction chamber includes a plasma discharge electrode and semi-spherical screen that are negatively biased by a direct current source followed by a mixing screen and an anode screen. A second reaction chamber includes a plasma discharge electrode and semi-spherical screen that are positively biased by a direct current source followed by a mixing screen, if needed, a fresh air inlet, and a screen or screens that are negatively biased so as to gradually return electrons to the exhaust gases.
PLASMA ACTUATED ELECTRONIC CATALYTIC CONVERTER

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is a nonprovisional application of U.S. Provisional Patent Application No. 60/901,306 filed on Feb. 15, 2007, currently pending. The disclosure of U.S. Provisional Patent Application No. 60/901,306 is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention
[0003] The present invention relates to a method and apparatus for improving exhaust after-treatment devices for use by diesel and gasoline powered vehicles, generators, heavy equipment, industrial power sources, fuel burners and other sources of airborne pollutants from a wide variety of air pollution sources. Specifically, the invention includes a plasma electronic catalyst assisted molecular reformation of the elements within the exhaust gases into their least toxic and lowest energy molecular states, specifically, N₂, CO₂, and H₂O, all of which occur naturally within the atmosphere.

[0004] 2. Description of the Related Art
[0005] The plethora of exhaust after-treatment systems devoted to reduction of pollution of the air are simply too numerous to specifically reference individually. In the specific case of diesel vehicles there is no system that, at present, is in widespread use that treats the exhaust in a manner that is sufficiently efficient or effective for it to be commercially viable and accepted at this time. The reason for this is that to date no practical solution has been found for the following issues:

[0006] 1. High soot (hydrocarbon particulate) output during engine warm-up that leads to clogging of conventional metallic catalyst type catalytic converters;
[0007] 2. Very high NOₓ output due to the nature of compression ignition used by diesel engines; and
[0008] 3. The sensitivity of the diesel engine to any exhaust restriction leading to increased exhaust back-pressure which seriously degrades performance.

[0009] A number of systems are under development, other than the present invention, attempt to solve this problem but none of them deal with the pollutant output of a diesel engine with a simple elegant integrated solution that does not involve bulky and complicated equipment, significantly degrade performance, and/or increase fuel usage.

[0010] The plasma based emissions control technology now getting the most developmental attention for diesel engines, is based on various non-thermal plasma or simply corona discharge plasma systems (or to a lesser extent fuel reformers which will be discussed later). These systems have shown enough promise to continue to attract research funding, but they have yet to reach commercial viability. The reasons for this system's difficulty in development are:

[0011] 1. Limitations in handling high amounts of hydrocarbon particulates;
[0012] 2. Susceptibility to vibration of the material used to provide a surface area for the corona discharge; and
[0013] 3. The bulk of the apparatus necessary to create enough surface area to treat typical exhaust flow rates.

Although this technology has shown some promise in the laboratory, the above mentioned problems have yet to be given cost effective and market acceptable solutions.

[0014] The other plasma based exhaust treatment technology getting research attention is one that uses the plasma with a conventional filter and/or catalytic converter. A plasma fuel reformer is used to create a reaction between a hydrocarbon of some sort (usually fuel but in a couple of cases alcohol) and either air or exhaust gas to create an intermediate compound (aryl and aldehyde are both mentioned in the prior art) that is then combined with the exhaust gases before they enter either a filter trap or a metallic catalytic type catalytic converter. These systems have been under development for a number of years without reaching the market for the following reasons:

[0015] 1. They require either extra fuel or a totally separate tank of its own special fuel to operate;
[0016] 2. The accompanying plumbing and apparatus is complex and expensive; and
[0017] 3. In many cases there is a filter trap that accumulates solid waste that must be disposed of on a regular basis, which is probably subject to EPA regulations.

[0018] New development activity for technologies of this type has been declining lately probably due to the above stated issues. For these reasons, the need for the present invention is greater now than ever.

[0019] Automotive catalytic converters of the type mandated by federal law for every car sold in America are a great success story in terms of how much they have cleaned up the air we breathe. Despite this, these catalytic converters have several serious limitations. Conventional catalytic converters cannot be used to treat the exhaust of diesel engines for oxides of nitrogen (NOₓ) because of the presence of oxygen in the exhaust.

[0020] For a conventional catalytic converter to break down oxides of nitrogen (NOₓ) in automotive exhaust, the engine is deliberately de-tuned to run rich and produce carbon monoxide (CO), normally considered a pollutant. However, in the presence of a metallic catalyst at operating temperature, the carbon monoxide (CO) completes its combustion by removing the additional oxygen atom each molecule needs from the oxides of nitrogen (NOₓ) in the automotive exhaust. Diesel engines on the other hand are designed to be “over-scavenged” to insure complete removal of exhaust gases at the end of each exhaust cycle. This results inevitably in the presence of free oxygen in the exhaust. With free oxygen available, the carbon monoxide (CO) completes its combustion by using the free oxygen instead of reacting with the oxides of nitrogen (NOₓ) thus defeating one of the primary purposes of the conventional catalytic converter.

[0021] An additional limitation of the conventional catalytic converter is the presence of the “Hydrocarbon Bubble”. The phenomenon that the E.P.A. refers to as the “Hydrocarbon Bubble” is the pollution emitted by a modern gasoline fueled automobile equipped with a conventional catalytic converter during its first ten to twenty minutes of operation. Until the catalytic converter reaches its approximate operating temperature at least 685° F., it does not function. Unfortunately, this also happens to be at the same time that a gasoline fueled spark ignited engine is getting an enriched fuel-air mixture during its warm-up period. The resultant high output of pollution that occurs during engine warm-up is referred to within the industry as the “Hydrocarbon Bubble” and constitutes between 80 to 90% of the total air pollution that the average automobile engine will make in a day. Ironically this usually occurs within the first 10% of its operation for each use.

[0022] Another problem associated with the conventional catalytic converter is its susceptibility to a reduction in efficacy due to fuel contamination. Substances such as lead or sulfur in the fuel “poison” the rare earth metals used in the catalyst material rendering them useless. These contaminant elements pass through the combustion process without hav-
ing their metallic catalyst contaminant qualities affected. The only way to avoid this problem is to avoid the dependence on metallic catalysts.

The effectiveness of the metallic catalyst in a conventional catalytic converter is limited by its surface area. This problem is obviated by the use of a plasma actuated electronic catalyst instead of depending on a metallic catalyst. Since metallic catalysts produce their effect of promoting a chemical reaction by making electrons available for a chemical reaction without otherwise directly participating in the reaction, use of a plasma actuated electronic catalyst completely avoids the surface area issue. If a stronger catalytic effect is needed the output level of the direct current power supply for the present invention can be increased to make a greater number of electrons available. This power level output could be adjusted in response to signals from an engine management computer or from sensors that respond to pollutant levels in the exhaust to be treated, the presence of pollutants in the treated exhaust, or by a variety of other sensor feedback systems.

This same apparatus and method can also be applied to industrial gaseous exhaust systems used by a wide variety of processes and is not limited to just combustion occurring within internal combustion engines.

The prior art for catalytic converters does not disclose any apparatuses that electronically disassemble the pollutant molecules within the exhaust gases into their constituent atoms. Nor does it disclose any apparatuses that then electronically re-assemble these same atoms from the exhaust gas pollutants into innocuous non-toxic molecules normally found in the atmosphere.

SUMMARY OF THE INVENTION

As best understood, the present invention operates by having the exhaust gas stream flow through into a reaction chamber by passing through a plasma discharge device that either adds or subtracts electrons depending upon the type of pollutants to be treated. After this, the electrical charge is evenly distributed and the gases are mixed to promote the desired reaction that either oxidizes or reduces the pollutants as determined by whether electrons were either added or subtracted. After the reaction has taken place and the right conditions are achieved, then the electrical charge in the gases caused by the electrons earlier being added or subtracted are then returned to a balanced condition. Once the exhaust gases reach an electrically neutral charge, the treatment of gases for that set of pollutants meant to be treated by that specific reaction, be it oxidation or reduction, is complete.

More specifically, if both types of reaction chambers are used together, the most practical arrangement is two reaction chambers with the first chamber being a plasma oxidation reaction chamber, and the second chamber being a plasma reduction reaction chamber. The first chamber, a plasma oxidation reaction chamber treats hydrocarbons (C\text{\textsubscript{x}}H\text{\textsubscript{y}}), partially combusted hydrocarbons to include hydrocarbon particulates (C\text{\textsubscript{z}}H\text{\textsubscript{y}}O\text{\textsubscript{z}}), carbon monoxide (CO) and especially aromatic and nitrogenous aromatic hydrocarbon particulates (C\text{\textsubscript{z}}H\text{\textsubscript{y}}N\text{\textsubscript{z}}O\text{\textsubscript{w}}). The second chamber, a plasma reduction reaction chamber, treats ozone (O\text{\textsubscript{3}}), and oxides of nitrogen (NO\text{\textsubscript{x}}).

The plasma oxidation reaction chamber uses a plasma discharge anode device to introduce free electrons into the gas stream. These free electrons act as an electronic catalyst to promote the breakdown and oxidation of the hydrocarbon based pollutants. This action is similar to and an improvement upon metallic catalysts, which work by making electrons available to the chemical reaction that they are assisting. In addition to the electronic catalytic action circumventing the surface area problem of metallic catalysts, there is not an opportunity for soot (hydrocarbon particulates) to build up and clog the apparatus before it is oxidized.

The plasma reduction reaction chamber first uses a plasma discharge cathode device to strip electrons from highly polar, high energy state molecules such as O\text{\textsubscript{2}} and NO\text{\textsubscript{x}}. This stripping of electrons from these oxides causes them to break down into their individual constituent atoms in a positively ionized state. Then the plasma reduction reaction chamber has the gases containing these ionized atoms cooled down to the appropriate lower temperature. With the temperature of the gases reduced, and by having the final series of anodes gradually return the electrons to the atoms, there would not be enough energy available to re-constitute them into ozone (O\text{\textsubscript{3}}) and oxides of nitrogen (NO\text{\textsubscript{x}}). Instead, when the electrons are returned to the atoms from the second set of pollutants, they will come together in their lowest energy state to reform the molecules of N\text{\textsubscript{2}} and O\text{\textsubscript{2}}. Molecular nitrogen (N\text{\textsubscript{2}}) and molecular oxygen (O\text{\textsubscript{2}}) are innocuous compounds normally found in the atmosphere. These last set of anodes also balance out into neutrality the electrical charge of the exhaust gases.

By doing all of this, the present invention can take in complex nitrogenated aromatic hydrocarbon particulates (a carcinogen found in diesel engine exhaust that is responsible for several hundred thousand cancer cases in the USA each year), NO\text{\textsubscript{x}}, CO, and other pollutants, break them down and then reform them into compounds that normally occur in the air we breathe. The benefits of the present invention are complimentary with and in addition to those achieved by all other methods currently in use to reduce the pollutant content of gaseous exhaust outputs.

It is accordingly an object of the present invention to provide an apparatus and method for assuring the immediate and complete breakdown of the pollutants in exhaust gases and their subsequent reformation into innocuous gases that are normally found in the atmosphere.

It is a further object of the present invention to make possible the practical and economically viable retrofitting of existing vehicles, engines, furnaces, and other sources of air pollution with an apparatus and method that provides for the complete treatment of their exhaust gases.

Another object of the present invention when applied to vehicles, engines or other noisy industrial processes is to provide for the combined functions of noise pollution control as well as air pollution control in the same apparatus.

The outer housing of the main body of the Plasma Actuated Electronic Catalytic Converter comprises of an electrically insulated outer casing that contains the reaction chamber(s). In the most complete and effective version of the present invention, the electrically insulated outer casing encloses two reaction chambers. The first one is a plasma oxidation reaction chamber. The exhaust gases are subjected to a plasma discharge as soon as they enter the plasma oxidation reaction chamber. This plasma discharge occurs between a centrally located plasma discharge electrode and a relatively open mesh plasma discharge screen that the exhaust gases flow past and then through. To create this plasma discharge, both the centrally located plasma discharge electrode and the relatively open mesh plasma discharge screen are provided with a multi-frequency high voltage current by a plasma generation circuit.

In order to produce the electronic catalytic action, electrons must be added to the exhaust gases as they pass through the plasma discharge. This is accomplished by hav-
ing the relatively open mesh plasma discharge screen also act as an anode to provide the extra free electrons necessary for oxidation catalysis. For this to happen, the relatively open mesh plasma discharge screen is connected to the negative voltage output of a direct current power source as well as to one of the multi-frequency high voltage outputs of the plasma generation circuit.

Collectively, the structure that subjects the exhaust gases to a plasma discharge and also adds the extra free electrons needed for the electronic catalytic oxidation to take place is referred to as a plasma discharge anode device. This comprises of the plasma generation circuit connected to both the centrally located plasma discharge electrode and the relatively open mesh plasma discharge screen with the relatively open mesh plasma discharge screen also connected to the negative voltage output of the direct current power source. This electrical connection of the relatively open mesh plasma discharge screen to the negative voltage output of the direct current power source is the source of the extra free electrons needed for the electronic catalytic oxidation action to take place.

In order to prevent particulate matter (soot) from causing clogging up of the plasma discharge anode device, there is a constant radius from the tip of the centrally located plasma discharge electrode (or alternative structure) to every point on the surface of the relatively open mesh plasma discharge screen which the gases flow through. By being set up with a constant radius, any particulate matter (soot) that should build up on the relatively open mesh plasma discharge screen would present a shorter distance for the plasma discharge to cross from the centrally located plasma discharge electrode to the part of the screen with the soot. As a result of this, the focus of the discharge would shift to that location on the relatively open mesh plasma discharge screen having the effect of literally blasting that soot into atoms. To enable this screen to handle the process and environment that it is subjected to, it would preferably be made of heavy gage high temperature stainless steel or some other appropriate alternative material. It is also within the spirit and intent of the present invention for the plasma discharge anode device to be comprised of alternative structures for the individual internal components that accomplish the same function.

After the exhaust gases pass through the plasma discharge anode device, they are thoroughly mixed and have the extra free electrons evenly distributed throughout by an electrically isolated gas mixing and charge distribution spiral screen. It is here that the majority of the electronic catalytic reaction takes place. While passing through the electrically isolated gas mixing and charge distribution spiral screen, the extra free electrons will have their electronic catalytic effect on the pollutants in the exhaust by aiding the oxidation process, causing it to take place rapidly and completely. Anything that has not been yet been oxidized will be oxidized by the addition of electrons (oxidation is accomplished through the donation of electrons), thus changing the hydrocarbons (C\textsubscript{1}, C\textsubscript{2}, partially combusted hydrocarbons (C\textsubscript{2}H\textsubscript{4}, CO), carbon monoxide (CO), and hydrocarbon particulates from the exhaust gases into carbon dioxide (CO\textsubscript{2}) and water (H\textsubscript{2}O) however the oxides of nitrogen (NO\textsubscript{x}) will remain unaffected. In addition to free electrons, the other thing needed for this electronic catalytic oxidation to take place is available oxygen from extra air.

When used for treating diesel engine exhaust the extra air needed for the complete treatment of hydrocarbons is already available because diesel engines are "over-scavenged" and run with a lean fuel-to-air ratio. This over-scavenging usually occurs at the end of the exhaust stroke when both the intake and exhaust valves (or ports) are kept open and extra air is sent completely through the combustion chamber into the exhaust manifold in order to insure that as much of the exhaust as possible has been removed (scavenged) from it before the next intake of fresh air into the combustion chamber. Also, diesel engines are always set up so that there is more air than necessary for a stoichiometric mixture of fuel and air in order to insure that the most complete combustion possible can occur under the circumstances.

When used for treating gasoline powered engine exhaust the additional air needed for the complete treatment of hydrocarbons is already available from the air pump or other device already in place for use with the conventional catalytic converter that the present invention would be replacing.

Actually an automotive gasoline engine equipped with the present invention could have its brake specific fuel consumption (BSFC: the ratio of horsepower over time per unit of fuel consumed) significantly improved while still meeting environmental regulations for oxides of nitrogen (NO\textsubscript{x}) content in the exhaust. This is possible because for a conventional catalytic converter to operate, the spark ignited engine must be deliberately de-tuned in order to insure the production of carbon monoxide (CO) in the exhaust. Also the compression ratio of the engine must be limited in order to limit the production of oxides of nitrogen (NO\textsubscript{x}) in the automotive exhaust so that it does not overheat the production of carbon monoxide (CO) produced by de-tuning. This is because the carbon monoxide (CO) is used in the conventional catalytic converter to react with the oxides of nitrogen (NO\textsubscript{x}) to produce molecular nitrogen (N\textsubscript{2}) and carbon dioxide (CO\textsubscript{2}) in the exhaust. In a vehicle equipped with the present invention the engine can be tuned for maximum efficiency instead of being de-tuned. Also since the present invention is more effective in treating the oxides of nitrogen (NO\textsubscript{x}) to begin with, it is possible to raise the compression ratio of the spark ignited engine as well which would further increase the brake specific fuel consumption (BSFC).

When used for other applications such as industrial process exhaust treatment, if the gases are oxygen free it may be necessary to provide for additional air to be introduced to the exhaust before it enters the present invention.

Electronic catalysis is an improvement over the action of metallic catalysts that also work by making electrons available to the chemical reaction in order to facilitate the process they are applied to. The three primary advantages of using an electronic catalyst over a metallic catalyst are:

1. Metallic catalysts do not become active until they reach their operating temperature, before that they do not contribute anything to the reaction unlike an electronic catalyst that operates once the circuit is turned on;

2. The effectiveness of an conventional catalyst is limited by its surface area, whereas with an electronic catalyst the extent of electrons available to assist the chemical reaction can be determined by the amount of current that the designer wishes to use for a given application, or by a sensor feedback system that responds in real time to the operating conditions encountered; and

3. A ceramic substrate that is long, thin and easily clogged with soot, is not needed at all with an electronic catalyst.

With these advantages, electronic catalysis as a process can accomplish many things that have defied treatment by conventional catalytic converters.

In addition to its other functions dealing with electronic catalysis, the electrically isolated gas mixing and
charge distribution spiral screen also contributes to noise control by helping to break up standing waves of acoustic energy. This last feature is especially important for the diesel over-the-road truck market with the functions of exhaust treatment and noise abatement provided for in one retrofitted device. It will only require the space already allocated for the muffler already in place on diesel powered buses and trucks.

Although a spiral screen is specified throughout this section, it is to be understood that it is within the spirit and intent of the invention to utilize alternative screen configurations, or other structures that accomplish the same function.

In the simpler variation of the plasma oxidation reaction chamber, meant to handle lesser loads of hydrocarbon based pollutants, after enough of a distance to insure electrical isolation from the electrically isolated gas mixing and charge distribution spiral screen, the exhaust gases pass through an electron retrieval cathode conical screen. This is connected to the positive voltage output of the direct current power source for recovering the extra free electrons used in the plasma catalytic oxidation reaction. By removing these extra free electrons used for the electronic catalytic reaction it also balances out to neutrality the overall electrical charge of the exhaust gases leaving the plasma oxidation reaction chamber. In the simpler variation of the plasma oxidation reaction chamber, it has the exhaust gases completely exit the apparatus at this point. If the exhaust gases also contain pollutant oxides, such as oxides of nitrogen (NOx) then it enters the next section, a plasma reduction reaction chamber. If however, this is not the case, this is not necessary and the process is complete.

However for the version of the plasma oxidation reaction chamber required to handle greater concentrations of hydrocarbon pollutants, the next thing encountered by the exhaust gases after the electrically isolated gas mixing and charge distribution spiral screen is an electron retrieval cathode spiral screen. This achieves the same functions of electron retrieval and electrical neutrality of the exhaust gases as the electron retrieval cathode conical screen used in the previously discussed variation of the plasma oxidation reaction chamber. The electron retrieval cathode spiral screen is also connected to the positive voltage output of the direct current power source but since it has a number of turns and much more surface area, it contributes to two other functions as well:

1. It helps to cool down the exhaust gases in order to limit the re-formation of NOx; and
2. It also further contributes to noise reduction.

However, at this point in the treatment process, although all of the hydrocarbon based pollutants have been oxidized into carbon dioxide (CO2) and water (H2O), the oxides of nitrogen (NOx) remain unaffected.

In order to avoid wasting energy from the plasma oxidation reaction chamber during its operation, a hydrocarbon pollutant level sensor can be used to monitor the amount of hydrocarbons contained by the incoming exhaust gases. This information will be used to determine more precisely the amount of current needed to thoroughly oxidize the hydrocarbons in the incoming exhaust gases. By providing a control signal to the direct current power source, so that it produces just the appropriate amount of free electrons necessary to oxidize the hydrocarbons present, power waste can be avoided and component life can be extended. This is especially important when the present invention is applied to treating engine exhaust. When the engine first starts up, during its warm-up period it produces much more hydrocarbon based pollutants than it does after it has run long enough to warm-up. During this time, more power would be needed to effectively treat the exhaust gases. After warm-up, the hydrocarbon pollutant level sensor would detect the drop in incoming hydrocarbons and the power output from the direct current power source could be reduced accordingly.

The plasma oxidation reaction chamber can exist as a stand alone device for the treatment of hydrocarbon based pollutants by themselves. If there are not any oxides of nitrogen in need of treatment in the exhaust gases, then the process is complete with just the plasma oxidation reaction chamber by itself as a stand-alone device.

After leaving the plasma oxidation reaction chamber the exhaust gases will enter the plasma reduction reaction chamber which is the second chamber of the device meant to treat both types of pollutants found in diesel engine exhaust for an example. Although there are alternative second reaction chamber configurations they all have in common a plasma discharge cathode device as the first thing encountered by the exhaust gases as they enter the chamber.

The plasma discharge cathode device consists of exactly the same components as the plasma discharge anode device with the only difference being the polarity of its connections to the direct current power source being used for the plasma reduction reaction chamber. For the purpose of clarification, the plasma discharge cathode device is comprised of the plasma generation circuit connected to both the centrally located plasma discharge electrode and the relatively open mesh plasma discharge screen with the relatively open mesh plasma discharge screen also connected to the positive output of the direct current power source for the plasma reduction reaction chamber. There is a constant radius from the tip of the centrally located plasma discharge electrode (or other structure) to every point on the surface of the relatively open mesh plasma discharge screen which the gases flow through. For this screen to handle the process and environment that it is subjected to, it would preferably be made of heavy gage high temperature stainless steel or some other appropriate alternative material.

The function of the plasma reduction reaction chamber is the removal of electrons from the various pollutant oxides, specifically oxides of nitrogen (NOx), to break them down into their individual component atoms. In the field of chemistry the process of reversing oxidation through the removal of electrons is referred to as reduction, hence the name of this portion of the present invention: the plasma reduction reaction chamber. If the exhaust gas flow is only being treated for pollutant oxides such as oxides of nitrogen (NOx) then the plasma reduction reaction chamber can be used as a stand-alone device.

For the treatment of pollutants in the exhaust gases the electrons removed will tend to come off of those molecules that are highly polar in nature and in a high energy state to begin with such as ozone (O3) and oxides of nitrogen (NOx) leaving alone the more stable molecules such as carbon dioxide (CO2) and water (H2O). To avoid breaking down non-pollutant molecules and wasting power from the direct current power source, the extent of electron stripping can be controlled by an oxides of nitrogen pollution level sensor. This sensor is used to detect the presence of oxides of nitrogen (NOx) in the exhaust as it leaves the plasma reduction reaction chamber or to detect the level of oxides of nitrogen (NOx) present in the incoming exhaust gases if the plasma reduction reaction chamber is being used as a stand alone device. This would provide feedback or input to control power output from the direct current power source in order to insure that only enough direct current is supplied to strip electrons from just
the high energy state pollutant oxides without affecting the more stable non-pollutant compounds such as carbon dioxide (CO₂) and water (H₂O).

[0059] The high energy state pollutant molecules have their shared outer valence electrons removed causing them to break apart into their constituent atoms leaving them in an ionized state. To insure that the entire gas stream is treated after passing through the plasma discharge cathode device they will then flow through the electrically isolated gas mixing and charge distribution spiral screen with the following three functions:

[0060] 1. Mixing the exhaust gases and evenly distributing the positive electrical charge;

[0061] 2. As a heat sink to reduce the temperature of the exhaust gases in order to inhibit the re-formation of oxides of nitrogen (NOₓ); and

[0062] 3. To provide for additional noise abatement.

[0063] An option within the present invention includes a cooler fresh air inlet pipe that introduces cooler fresh air into the exhaust gases approximate in the middle of the electrically isolated gas mixing and charge distribution spiral screen to further cool down the gases. This exhaust gas dilution and cooling effect is very important to insure that oxides of nitrogen (NOₓ) are not re-created when the electrons are returned. For application to internal combustion engines, this option is most easily applied if an air pump, turbo-charger, or super-charger is already available as a source of air with the best practice being to have the air pass through an intercooler to cool them down before being introduced into the flow of exhaust gases.

[0064] After the exhaust gases containing ionized atomic nitrogen and ionized atomic oxygen leave the electrically isolated gas mixing and charge distribution spiral screen, they enter the section where the electrons are gradually returned. The electron return function is accomplished by a series of screens, each individual one being either an electron return anode spiral screen, an electron return anode conical screen, or an electron return anode hemispherical screen. There is also the option of using a resistive electron return anode spiral screen for a smoother voltage gradient to do electron return compared to using a series of electron return anode screens.

[0065] The key to avoiding the formation of higher energy pollutant compounds such as oxides of nitrogen (NOₓ) and ozone (O₃) during the electron return phase is having each screen in the series only getting a portion of the return voltage from the relatively open mesh plasma discharge screen of the plasma discharge cathode device. This is done by having each screen that the exhaust gases pass through have progressively less resistance between it and the negative terminal of the direct current power source that has its positive terminal connected to the relatively open mesh plasma discharge screen of the plasma discharge cathode device. In order to insure complete electrical charge neutrality of the exhaust gases exiting the plasma reduction reaction chamber, the final electron return screen that the exhaust gases pass through has no resistance between it and the negative terminal of the direct current power source of the plasma reduction reaction chamber.

[0066] It is may also possible to use a single anode screen if the material that it is made of has sufficient resistance in the material it is constructed from so that there will be a significant voltage drop across the length of the screen. By having the negative output of the direct current power source connected to the end of the end of the screen closest to the exhaust gas exit of the present invention, there will be a voltage gradient across its length. This voltage gradient will result in a smoother gradient of electron return compared to using a series of electron return anode screens.

[0067] Since the exhaust gases have been cooled below the temperature at which oxides of nitrogen (NOₓ) can form and the outer valence electrons are being returned at a controlled and gradual rate, not enough energy is available from the heat of the exhaust gases and the energy released by electrons being returned together for the formation of such compounds as oxides of nitrogen (NOₓ) and ozone (O₃). This ensures that the exhaust exiting the device consists of compounds that already exist within the atmosphere such as molecular nitrogen (N₂), carbon dioxide (CO₂), molecular oxygen (O₂), and water (H₂O) which present no threat to the public health.

[0068] With the integration of pollution and noise control in one device it makes possible the equipping of all of the diesel engine powered vehicles on the road today with the present invention. Since there is so little change to the existing structure of the vehicle, there is no excuse not to retro-fit everything on the road to bring them into compliance with the 2009 diesel engine emission regulations.

[0069] This is especially important since that there are several hundred thousand cases each year of cancer in the United States that have been directly linked to nitrogenated aromatic hydrocarbon particulate emission from diesel trucks and buses. To have a solution that because of its ease of installation can be implemented across the board to include vehicles presently in use is of incredible importance.

[0070] It is within the spirit and intent of the present invention for either the plasmaoxidation reaction chamber or the plasma reduction reaction chamber to be used as an individual stand-alone device or in any of a number of combinations with each other or other apparatus for the treatment of exhaust gases. Whether or not one type of reaction chamber, the other, or both are used and in what combination they are with each other or with other pollution control devices used are dependent on what pollutants are present in the exhaust being treated.

[0071] With the enormous personal heartbreak, societal costs, diverted economic resources, and specifically governmental expenditures in the form of Medi-Care and Medi-Aid costs that threaten to bankrupt our healthcare system, there is enormous pressure to get all of the diesel powered vehicles in the USA to pollute much less. With the present invention, it is not necessary to “grandfather” in older vehicles already on the road. The present invention offers this capability with a minimum of change to the existing design and structure of vehicles already in use at a minimum of expense to the vehicle owner and/or operator.

[0072] The present invention also has the capacity to be up-scaled to provide large scale treatment of industrial process exhaust as well which provides a new and different tool for the control of air pollution.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0073] The above and other objects and features of the present invention will be clearly understood from the following description with respect to the preferred embodiment thereof when considered in conjunction with the accompanying drawings and diagrams, in which:

[0074] FIG. 1 is a cross sectional side view of the entire exhaust after treatment apparatus of the present invention installed in an exhaust pipe.

[0075] FIG. 2A is a cross sectional side view of the plasma oxidation reaction chamber with an electron retrieval conical cathode screen.
FIG. 2B is a cross sectional side view of the plasma oxidization reaction chamber including an exhaust gas cooling and cathode screen. FIG. 3 is a cross sectional side view of the plasma reduction reaction chamber equipped with a set of the electron return anode conical screens. FIG. 4A is a cross sectional side view of the electron return portion of the electron return anode spiral screen equipped with a set of an electron return anode hemispherical screens. FIG. 4B is a cross sectional side view of the electron return portion of the electron return anode spiral screen equipped with a set of the electron return anode spiral screens. FIG. 4C is a cross sectional side view of the electron return portion of the plasma reduction reaction chamber equipped with the electron return anode spiral screen made of resistive material. FIG. 5 is a schematic of the plasma generation circuit in its simplest form.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention will now be described in further detail in connection with illustrative preferred embodiments for improving exhaust after-treatment of industrial processes, furnaces, and internal combustion engines. Special attention will be paid to the problems faced in the treatment of exhaust from diesel engines. There will be presented several different variations of each section of the device within the scope of the present invention.

Referring to FIG. 1, the present invention is shown treating an exhaust output from a diesel engine 101 which enters a plasma oxidization reaction chamber 103 which is enclosed in an electrically insulated outer casing 105. As the gases to be treated flow in the first thing they encounter is a hydrocarbon pollutant level sensor 107 just before they are subjected to the first phase of the treatment process. This process is the ionization and the addition of electrons to the exhaust gases by a plasma discharge anode device 109 which consists of a centrally located plasma discharge electrode 111 and a relatively open mesh plasma discharge screen 113. A plasma generation circuit 115 supplies the centrally located plasma discharge electrode 111 and the relatively open mesh plasma discharge screen 113 with the high voltage multi-frequency electrical current produces a plasma discharge 99 (not shown in FIG. 1) that ionizes the exhaust gases as they flow through the plasma discharge anode device 109. By having the relatively open mesh plasma discharge screen 113 have open mesh design and be at a constant radius from the centrally located plasma discharge electrode 111, the problem from hydrocarbon particulate (soot) build-up causing clogging is avoided. This is because the open mesh design does not significantly restrict flow in the first place and more importantly, when any soot does deposit on the relatively open mesh plasma discharge screen 113, it has a reduced distance between it and the centrally located plasma discharge electrode 111. The result of this reduced distance at the location of the soot build-up is that the plasma discharge 99 (not shown in FIG. 1) will shift its point of focus on the relatively open mesh plasma discharge screen 113 to the soot literally blasting it into atoms thus preventing any clogging from taking place.

The relatively open mesh plasma discharge screen 113 is also connected to a negative output lead 117 of a high voltage direct current power source 119 to provide the extra free electrons to the exhaust gas being treated for the electronic catalytic effect to take place. The high voltage direct current power source 119 is of a type than be obtained “off-the-shelf” from a commercial power supply manufacturer and is well known within the art to include those models with the feature of having their output level controlled by some kind of sensor input.

To avoid wasting power and extend the life of the system components, the needed amount of extra electrons provided for the electronic catalytic action from the high voltage direct current power source 119 is controlled by the hydrocarbon pollutant level sensor 107 which sends its signal through a sensor signal line 108. This system is especially useful when the present invention is applied to internal combustion engines used to power vehicles which produce widely differing amounts of hydrocarbons depending on their operating conditions. Specifically, when an engine is warming up, it produces a very high amount of hydrocarbons and the high voltage direct current power source 119 would have to produce much more current in order to effectively treat the exhaust. Once the engine is warmed up, the amount of hydrocarbons produced decreases dramatically reducing the need for electronic catalytic action which will be sensed by the hydrocarbon pollutant level sensor 107 with the power output of the high voltage direct current power source 119 reduced accordingly.

Since the plasma discharge anode device 109 can not possibly treat all of the exhaust gases exactly evenly or equally, and because time with space in addition to the extra electrons are needed for electronic catalysis to take place, the exhaust gases need to be thoroughly mixed. To do this, after enough spacing to insure electrical isolation between the two components the next thing encountered by the exhaust gases is an electrically isolated gas mixing and charge distribution spiral screen 121. It is to be understood that it is within the spirit of the present invention to employ alternative structures to a spiral screen to accomplish the same function. It is in this part of the plasma oxidization reaction chamber 103 that the hydrocarbon based pollutants are oxidized completely.

The electrons used to achieve the catalytic action are recovered by an electron retrieval cathode conical screen 123 after enough spacing to insure electrical isolation between the two components. This is connected to a positive output lead 125 of the high voltage direct current power source 119 which in the process of picking up the extra electrons also balances out into neutrality the electrical charge of an exhaust flow free of hydrocarbon based pollutants 126 leaving the plasma oxidization reaction chamber 103.

It is within the spirit and intention of the present invention for any of a number of different cathode screen configurations (or other structure to accomplish the same function) to retrieve the extra free electrons added by the plasma discharge anode device 109 inside the plasma oxidization reaction chamber 103.

The exhaust flow free of hydrocarbon based pollutants 126 now enter a plasma reduction reaction chamber 127 that treats the non-hydrocarbon pollutants such as oxides of nitrogen (NOx). The first thing that the exhaust gases encounter is a plasma discharge cathode device 129 that just like the plasma discharge anode device 109, it consists of another set of a centrally located plasma discharge electrode 131 and a relatively open mesh plasma discharge screen 133. Similarly, it too is connected to a plasma generation circuit 135 but the difference is that the plasma discharge cathode device 129 has the relatively open mesh plasma discharge screen 133 connected to a positive output lead 137 of a high voltage direct current power supply 139. The effect of this is to strip electrons from the ionized gases passing through the plasma.
discharge cathode device 129 resulting in a breakdown of high energy state highly polar pollutant oxides such as oxides of nitrogen (NOx).

[0091] To keep the electron stripping process selective, prevent energy waste, and to increase the life of the parts, the amount of power applied to the electron stripping process by the high voltage direct current power supply 139 is controlled by an oxides of nitrogen pollutant level sensor 141 which sends its signal through a sensor signal line 142. This feedback loop will ensure that just enough power was supplied to the plasma reduction reaction chamber 127 by the high voltage direct current power supply 139 to break down the oxides of nitrogen (NOx) in the exhaust without squandering energy or the useful life of component breaking down non-pollutants. Just like the high voltage direct current power source 119 used for the plasma oxidation reaction chamber 103, the high voltage direct current power supply 139 used for the plasma discharge cathode device 129 is of a type that be obtained “off-the-shelf” from a commercial power supply manufacturer and are well known within the art. These can be purchased with the feature of having their output level controlled by some kind of sensor input.

[0092] Since the plasma discharge cathode device 129 can not possibly treat all of the exhaust gases exactly evenly or equally, and because the ionized atoms from the pollutant oxides must be significantly cooled down before the electrons are returned to them in order to avoid re-formation of oxides of nitrogen (NOx), the next thing they go through is an electrically isolated gas mixing and charge distribution spiral screen 143. Between the relatively open mesh plasma discharge screen 133 and the electrically isolated gas mixing and charge distribution spiral screen 143 there is enough of an interval to insure electrical isolation between the two components. It is to be understood that it is within the spirit of the present invention to employ alternative structures to a spiral screen to accomplish the same function. If the electrically isolated gas mixing and charge distribution spiral screen 143 is not sufficient to effectively cool the ionized atoms from the pollutant oxides, it is within the spirit of the invention to include the option of a cooler fresh air inlet pipe 145. This will further cool the exhaust gases by diluting them with cooler fresh air from an outside source (not shown) such as a bleed-off from the turbo-charger, supercharger, or air pump with the air cooled by an intercooler (not shown).

[0093] With the exhaust gases sufficiently cooled down the next step is to re-assemble the atoms from the pollutant oxides into non-toxic innocuous compounds. In order to avoid releasing too much energy at one time in one place leading to oxides of nitrogen (NOx) being created, electron return is done gradually by four individual units of an electron return anode conical screen 147. Each of the electron return anode conical screens 147 gets its supply of electrons ultimately from the high voltage direct current power supply 139 through the negative output lead 149 from the high voltage direct current power supply 139. The rate of electron return is controlled by changing the amount of resistance between each of the electron return anode conical screens 147 and the high voltage direct current power supply 139.

[0094] The electron return anode conical screen 147 closest to the electrically isolated gas mixing and charge distribution spiral screen 143 is connected to a high value current limiting resistor 151. The actual resistance for an operational unit being determined by the specific conditions of the application but for purposes of illustration in this description will be referred to as X ohms. The high value current limiting resistor 151 is in turn connected to the negative output lead 149 coming from the high voltage direct current power supply 139. The electron return anode conical screen 147 that comes next is connected to a medium value current limiting resistor 153 with a resistance of ½ X ohms which is in turn connected to the negative output lead 149 coming from the high voltage direct current power supply 139. The electron return anode conical screen 147 that follows the previous two is connected to a low value current limiting resistor 155 with a resistance of ½ X ohms which is in turn connected to the negative output lead 149 coming from the high voltage direct current power supply 139. Finally, to insure that all of the electrons are returned and that the electrical charge of the gases leaving the present invention is neutral, the electron return anode conical screen 147 that comes at the end of the process is connected directly to the negative output lead 149 coming from the high voltage direct current power supply 139 without any resistor.

[0095] The operative concept employed in this section is the gradual return of electrons. It is within the spirit and intention of the invention to employ any of a number of screen designs, a different number of screens than four, and/or any mixture of screen designs to accomplish the function done by the four of the electron return anode conical screens 147 mounted in the plasma reduction reaction chamber 127 shown in FIG. 1.

[0096] The one last thing that the exhaust gases flow past before they exit the present invention is an oxides of nitrogen pollutant level sensor 141 used to control the power output level from the high voltage direct current power supply 139 as described earlier. At this point, all of the exhaust gases have been treated: the hydrocarbon based pollutants have been subjected to electronic catalysis and thoroughly oxidized into carbon dioxide (CO2) and water (H2O) inside the plasma oxidation reaction chamber 103 and the pollutant oxidants have been molecularly disassembled and then the atoms re-assembled into molecular oxygen (O2) and molecular nitrogen (N2) by the plasma reduction reaction chamber 127. Exiting the present invention is an output flow of treated exhaust gases 157.

[0097] Referring to FIG. 2A, a cut-away close-up view of the plasma oxidation reaction chamber 103 with the plasma discharge 99 shown between the centrally located plasma discharge electrode 111 and the relatively open mesh plasma discharge screen 113. Also shown is an exhaust gas flow free of hydrocarbon based pollutants 126 exiting the plasma oxidation reaction chamber 103 and entering the plasma reduction reaction chamber 127 (not shown). Other than this, FIG. 2A is an exact duplicate of the plasma oxidation reaction chamber 103 portion of the present invention that was described in detail for FIG. 1.

[0098] FIG. 2B is a cut-away close-up view of the plasma oxidation reaction chamber 103 shown with a component variation in place designed to reduce the temperature of the exhaust gases being treated. This function is done by having an electron retrieval cathode spiral screen 159 perform the electron return function with a much greater surface area than the electron retrieval cathode conical screen 123 shown in FIG. 2A. The greater surface area of the electron retrieval cathode spiral screen 159 will have the effect of reducing the temperature of the exhaust gases being treated. Prior to this point in the process, the temperature of the exhaust gases being treated has been raised by the combustion of the hydrocarbons (CnHm), partially combusted hydrocarbons (CnHmOx), carbon monoxide (CO), and hydrocarbon particulates. At the point that the electrons are returned, the temperature is further raised by the electrical discharge between the ionized exhaust gases and the beginning of the electron retrieval cathode spiral screen 159. However, as the exhaust gases travel through the length of the electron retrieval cathode spiral
screen 159, it will absorb heat from the exhaust gases passing through it. This is of great importance if the plasma oxidation reaction chamber 103 is going to be used in conjunction with the plasma reduction reaction chamber 127. The cooler the exhaust gas flow free of hydrocarbon based pollutants 126 is entering the plasma reduction reaction chamber 127, the easier it is to avoid the re-formation of oxides of nitrogen (NOx) in the following reduction process.

[0099] FIG. 3 shows the plasma reduction reaction chamber 127 as either a stand-alone device or as the second reaction chamber of the present invention with the plasma discharge 99 shown between the centrally located plasma discharge electrode 131 and the relatively open mesh plasma discharge screen 133. As described earlier, its function is the treatment of pollutants such as oxides of nitrogen (NOx) and ozone (O3). Its construction and method of operation is exactly the same as that described in the detailed description of FIG. 1 with the only potential difference being the option of placement for the oxides of nitrogen pollutant level sensor 141. Hot ionized gases would be found in the exhaust gas flow free of hydrocarbon based pollutants 126 coming from the plasma oxidation reaction chamber 103. But when the plasma reduction reaction chamber 127 is used as a stand-alone device it is possible to place the oxides of nitrogen pollutant level sensor 141 at the inlet because it would not be confused by hot ionized gases in the exhaust being treated.

[0100] FIG. 4A shows the electron return section of the plasma reduction reaction chamber 127 with an electron return anode hemispherical screen 161 installed in each of the four positions originally occupied by the electron return anode conical screens 147.

[0101] FIG. 4B shows the electron return section of the plasma reduction reaction chamber 127 with an electron return anode spiral screen 163 installed in each of the four positions originally occupied by the electron return anode conical screens 147. The electron return anode spiral screens 163 shown have a greater surface area than either the electron return anode conical screens 147 or the electron return anode hemispherical screen 161 and may be called for if it turns out that more surface area is needed for the gradual, complete, and even return of electrons.

[0102] FIG. 4C shows an electrically resistive material electron return anode spiral screen 165 taking the place of an entire series of electron return screens of the other types. This is done by being made of a resistive material and by having the end of it that is at the very end of the treatment process connected without any resistor to the negative output lead 149 coming from the direct current power supply 129. The placement of the electrical connection establishes a voltage gradient across the length of the electrically resistive material electron return anode spiral screen 165. This voltage gradient has its lowest voltage being at its end closest to the electrically isolated gas mixing and charge distribution spiral screen 143 (shown and described in reference to FIG. 1, and shown in FIG. 3) and its highest voltage right at the end of the treatment process. The purpose of voltage gradient is to affect a gradual return of electrons thus avoiding a concentration of energy release from electron return discharge leading to oxides of nitrogen (NOx) re-forming in the exhaust gases.

[0103] Another option (not shown) for an even more gradual return of electrons is to have a series of the electrically resistive material electron return anode spiral screens 165 connected to the negative output lead 149 coming from the high voltage direct current power supply 129 through a set of resistors such as those used with the electron return anode conical screens 147. In this arrangement, the electrically resistive material electron return anode spiral screens 165 closest to the electrically isolated gas mixing and charge distribution spiral screen 143 is connected to a high value current limiting resistor 151. The actual resistance for an operational unit being determined by the specific conditions of the application, but for purposes of illustration in this description will be referred to as X ohms. The high voltage current limiting resistor 151 is in turn connected to a negative output lead 149 coming from the high voltage direct current power supply 139. The electrically resistive material electron return anode spiral screens 165 that comes next is connected to a medium value current limiting resistor 153 with a resistance of ½ X ohms which is in turn connected to the negative output lead 149 coming from the high voltage direct current power source 139. Finally, to ensure that all of the electrons are returned and that the electrical charge of the gases leaving the present invention is neutral, the electrically resistive material electron return anode spiral screens 165 that comes at the end of the process is connected directly to the negative output lead 149 coming from the high voltage direct current power source 139 without any resistor. Of all of the options presented for electron return described, this one offers the most gradual return capability.

[0104] FIG. 5 shows a schematic used for both the plasma generation circuit 115 connected to the plasma discharge anode device 109 and the plasma generation circuit 135 connected to the plasma discharge cathode device 129 (shown in FIG. 1). This circuit is controlled by a square wave generator 167 through a control signal input line 169 that is connected to the gate of a series of matching power Metal Oxide Surface Field Effect Transistors 171 (henceforth referred to as the power MOSFETs 171). These three power MOSFETs 171 are the switches that when turned on allow current to flow from a direct current power source 173 through a primary winding 175 of a high voltage transformer labeled T1 177. The three power MOSFETs 171 connect the other end of the primary winding 175 to a direct current ground connection 179 through a 0.2 ohm resistor 181. Between the low voltage side of the primary winding 175 and the direct current ground connection 179 are a capacitor of 4700 picofarads 183, another capacitor of 4700 picofarads 185 and a capacitor of 2200 picofarads 187 and a high amperage diode 189. When used in this circuit, the high amperage diode 189 acts as a free wheeling diode.

[0105] A capacitor of 0.047 microfarads 191, a capacitor of 0.1 microfarads 193, and a capacitor of 2200 picofarads 195 are connected across the leads to the primary winding 175. Also attached to the power side of the primary winding 175 connected to the direct current ground connection 179 are a capacitor of 4700 picofarads 197, a capacitor of 2200 picofarads 199, a capacitor of 0.1 microfarads 201, and a capacitor of 1.0 microfarad 203.

[0106] Connected to a secondary winding 205 of the high voltage transformer labeled T1 177 are two plasma discharge circuit output lines 207. These lines are each in turn connected to either the plasma discharge anode device 109 (shown in FIG. 1) or to the plasma discharge cathode device 129 (shown in FIG. 1) depending which reaction chamber the plasma generation circuit 115, 135 is used with. The plasma discharge circuit output line 207 that is connected to the relatively open mesh plasma discharge screen 113, 133 (shown in FIG. 1) is also connected to one of the outputs from the high voltage direct current power source 119, 139 (shown in FIG.
What is claimed is:
1. A plasma oxidation device comprising: an electrically insulated outer casing with a gas flow inlet and a gas flow outlet; a plasma discharge anode device disposed within the outer casing, wherein the plasma discharge anode device includes a first plasma discharge electrode and a second plasma discharge electrode, wherein at least one of the first and second plasma discharge electrodes can donate electrons; a gas mixing and charge distribution mesh being electrically isolated from the outer casing; an electron retrieval cathode mesh; a plasma generation circuit connected to the first and second plasma discharge electrodes; and a direct current power source being operatively connected to the electron retrieval cathode mesh and at least one of the plasma discharge electrodes.
2. A plasma oxidation device according to claim 1, wherein a negative output of the direct current power source is connected to at least one of the plasma discharge electrodes and a positive output of the direct current power source is connected to the electron retrieval cathode mesh.
3. A plasma reduction device comprising: an electrically insulated outer casing with a gas flow inlet and a gas flow outlet; a plasma discharge cathode device disposed within the outer casing, wherein the plasma discharge cathode device includes a first plasma discharge electrode and a second plasma discharge electrode, wherein at least one of the first and second plasma discharge electrodes can remove electrons for a gas; a gas mixing and charge distribution mesh electrically isolated from the outer casing; a plurality of electron return anode meshes; a plasma generation circuit connected to the first and second plasma discharge electrodes; and a direct current power source being operatively connected to at least one of the electron return anode meshes and at least one of the plasma discharge electrodes.
4. A plasma reduction device according to claim 1, wherein a negative output of the direct current power source is connected to the plurality of electron return anode meshes and a positive output of the direct current power source is connected to at least one of the plasma discharge electrodes.

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