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(54) **SELF-REGENERATING PARTICULATE TRAP SYSTEMS FOR EMISSIONS AND METHODS THEREOF**

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(51) **Int. Cl.**
***B01J 19/08*** (2006.01)
***A62D 3/19*** (2007.01)

(52) **U.S. Cl.**
USPC .......... **204/164**; 588/311

(58) **Field of Classification Search**
USPC .......... 204/164; 588/311
See application file for complete search history.

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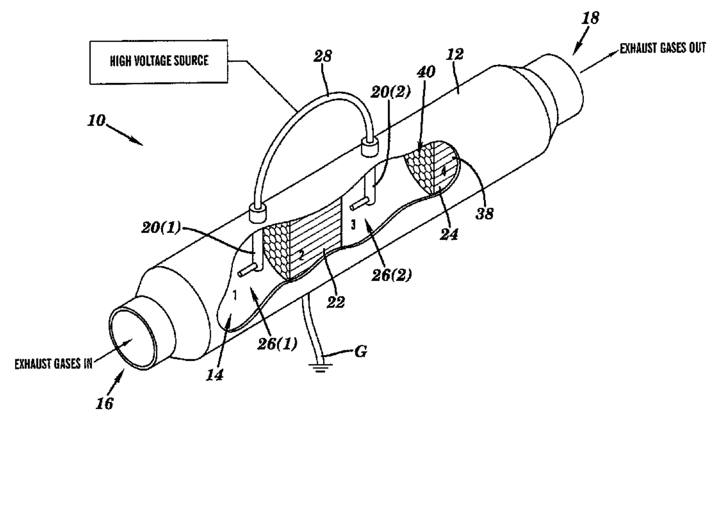
(57) **ABSTRACT**

A method and system for treating emissions includes charging particles in an exhaust stream, producing one or more radicals, and oxidizing at least a portion of the charged particles with at least a portion of the produced radicals. At least a portion of the charged particles in the exhaust stream are then attracted on at least one attraction surface which is one of oppositely charged from the charged particles and grounded. The attracted particles are oxidized with another portion of the one or more produced radicals to self regenerate the at least one attraction surface. Downstream from where the attracted particles are oxidized, at least a portion of one or more first compounds in the exhaust stream are converted to one or more second compounds downstream from the attracting. Additionally, at least a portion of any remaining charged particles are oxidized into one or more gases.

**8 Claims, 6 Drawing Sheets**



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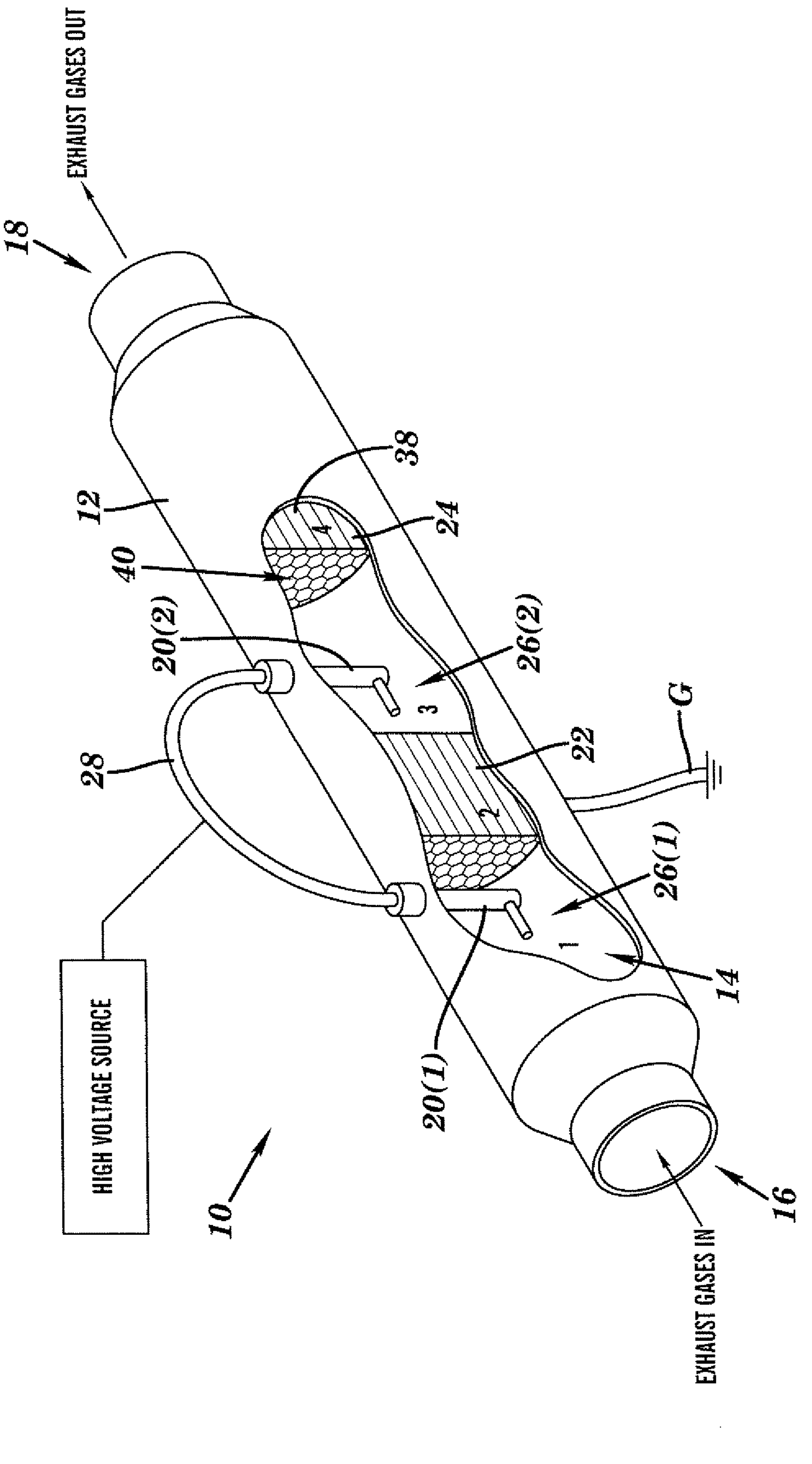
EXHAUST GASES OUT
18
12
38
24
40
4
20(2)
26(2)
3
28
22
G
2
26(1)
1
14
HIGH VOLTAGE SOURCE
20(1)
10
16
EXHAUST GASES IN

FIG. 1

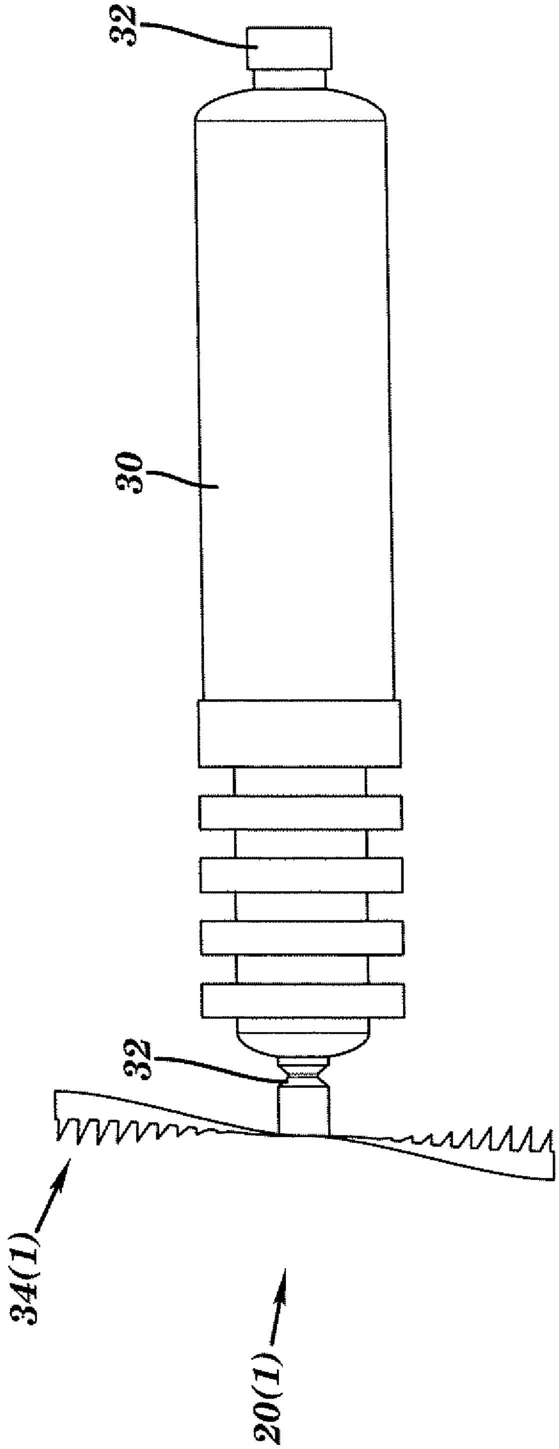


FIG. 2

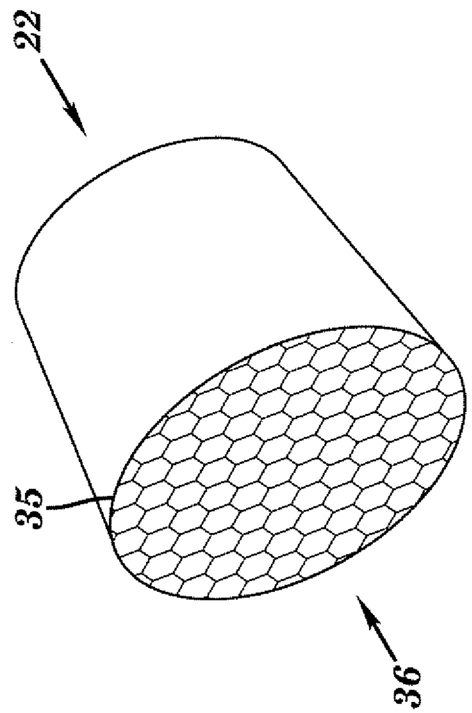


FIG. 4

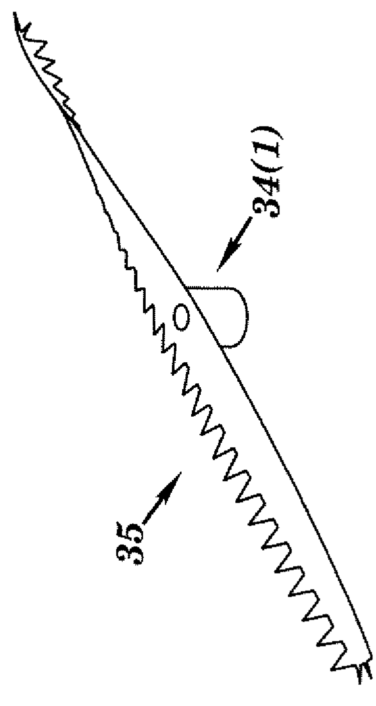


FIG. 3

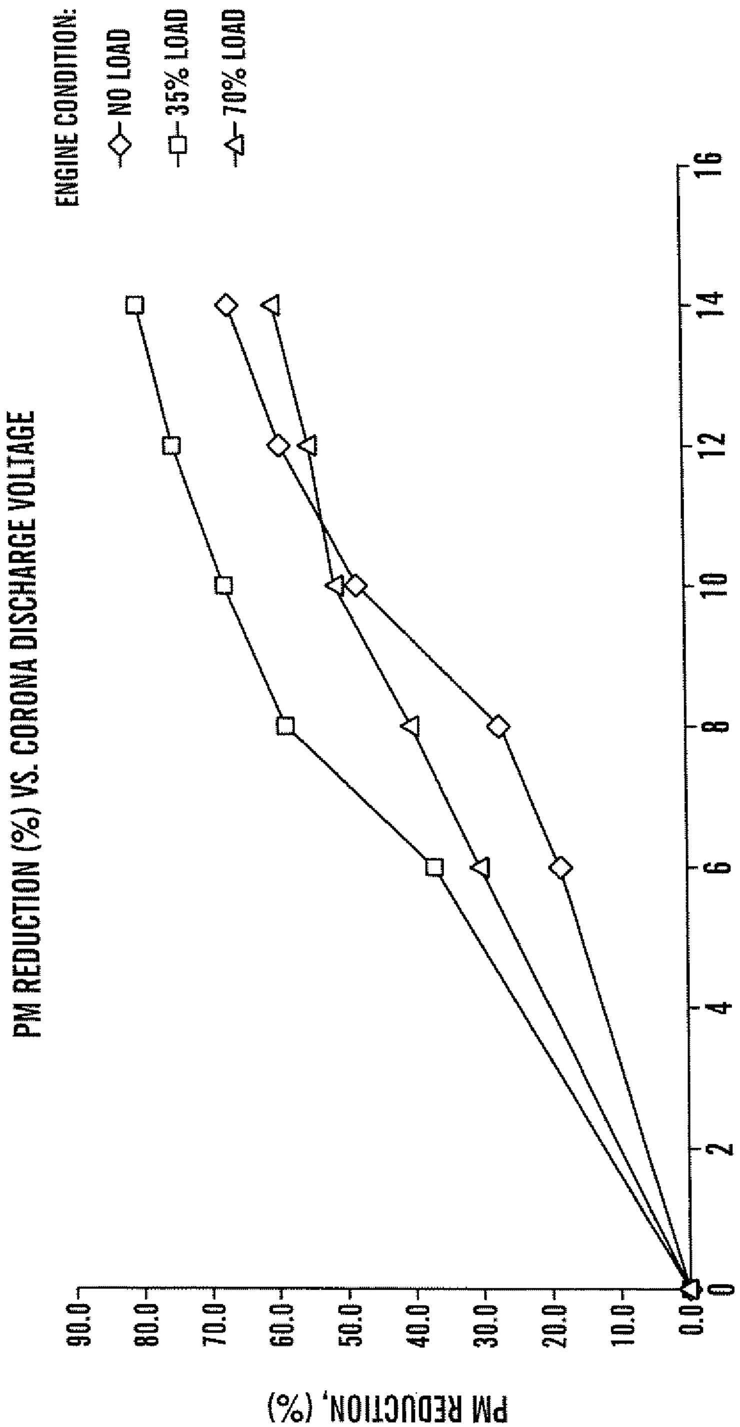
PM REDUCTION (%) VS. CORONA DISCHARGE VOLTAGE
ENGINE CONDITION:
NO LOAD
35% LOAD
70% LOAD
PM REDUCTION, (%)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
2
4
6
8
10
12
14
16
CORONA DISCHARGE VOLTAGE (-kV)

*FIG. 5*

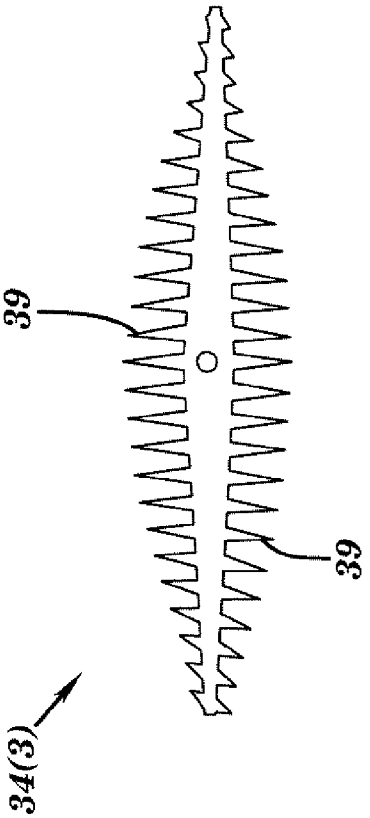


FIG. 6B

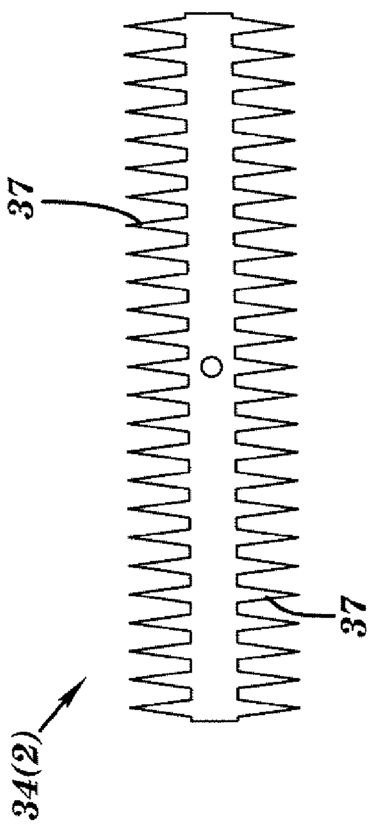


FIG. 6A

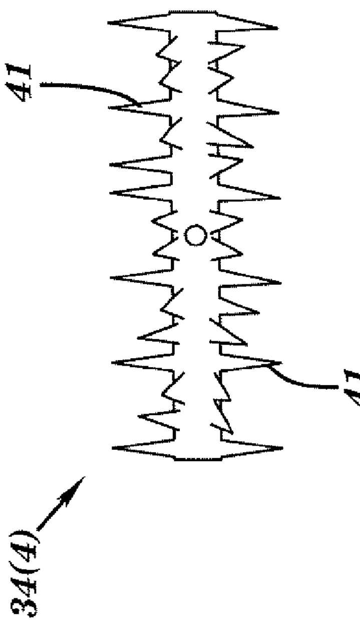


FIG. 6C

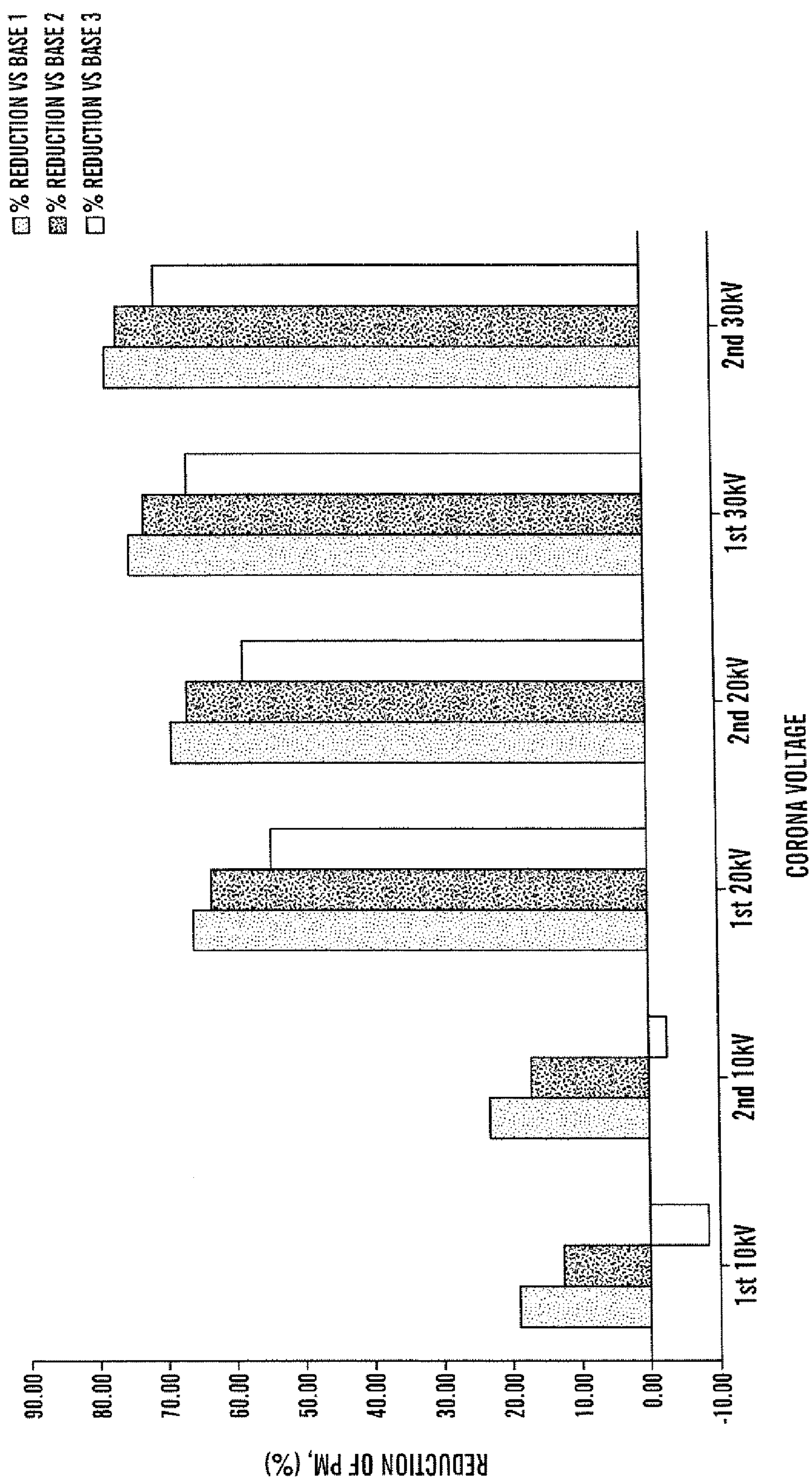
% REDUCTION VS BASE 1
% REDUCTION VS BASE 2
% REDUCTION VS BASE 3
REDUCTION OF PM, (%)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
1st 10kV
2nd 10kV
1st 20kV
2nd 20kV
1st 30kV
2nd 30kV
CORONA VOLTAGE

*FIG. 7*

# SELF-REGENERATING PARTICULATE TRAP SYSTEMS FOR EMISSIONS AND METHODS THEREOF

This application is a divisional of U.S. patent application Ser. No. 11/480,059, filed Jun. 30, 2006, which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/696,978, filed Jul. 6, 2005, which is hereby incorporated by reference in its entirety.

## FIELD OF THE INVENTION

The present invention generally relates to emissions treatment systems and methods thereof and, more particularly, to a self regenerating particulate trap system for one or more emissions and methods thereof.

## BACKGROUND

There is a growing demand for energy usage in the United States, primarily due to increasing economic activity. This increasing demand for energy is being met by pursuing increased power generation. Unfortunately, this increase in power generation is resulting in the generation of over 160, 000 tons of particulate emissions per year in the United States polluting the air.

Without significant new controls and treatments of emissions, millions of individuals will continue to breathe air polluted by these particulate emissions. Additionally, these emissions will continue to cause damage to environment in the form of acid rain and smog. Significant reductions in emissions of nitrogen oxides (NOx), particulate matter, non-methane hydrocarbons, carbon monoxide, sulfur dioxide, and other toxins would result in substantial benefits to both the public health and the environment.

At the present time a device that is robust, efficient, durable, packagable, and maintenance-free is not available for elimination of particulate matter. For diesel engines in particular, several devices have been designed to combat the problem of particulate emissions. Most of these devices use different filtration technologies with either thermal regeneration capabilities or manually replaceable filtration media. The problem with these filtration devices is that they quickly clog and increase the exhaust backpressure thus negatively affecting efficiency and performance. In addition thermal regeneration requires vast amounts of energy and produces very high temperatures.

As discussed below, other technologies available for separating particulate matter from a gas stream have been investigated. For example, non-thermal plasma-assisted catalytic reduction of exhaust gases using a corona discharge have been studied and reported in the literature. J. A. Ekchian, E. N. Balles, D. L. Christeller, J. S. Cowart, and W. D. Fuller, "Use of Non-Thermal Plasma Generated by a Corona Discharge Device to Improve the Efficiency of Three-Way Catalyst", which is herein incorporated by reference in its entirety, disclosed testing on the use of a corona discharge device for the reduction of HC, CO, and NOx in tailpipe emissions in conjunction with a three-way automotive catalyst and reported significant improvements.

Additionally, M. B. Penetrante, R. M. Brusasco, B. T. Merritt, W. J. Pitz and G. E. Wogtlin, "Feasibility of Plasma Aftertreatment for Simultaneous Control of NOx and Particulates". SAE Paper 1999-01-3637 (1999)", which is herein incorporated by reference in its entirety, disclosed a study on the feasibility of plasma after treatment of NOx and particulates. This study reported that although $NO_2$ can be used to



non-thermally oxidize the carbon fraction of particulates, this does not provide a high level of reduction of NOx since it also leads to conversion of NO to $NO_2$.

Further, Suzanne E. Thomas, Anthony R. Martin, David Raybone, James T. Shawcross, Ka Lok Ng, Phil Beech, and J. Christopher Whitehead, "Non-Thermal Plasma After Treatment of Particulates-Theoretical Limits and Impact on Reactor Design", SAE Paper 2000-01-1926 (2000), which is herein incorporated by reference in its entirety, disclosed work that was carried out using non-thermal plasma by introducing packing material into the plasma region to increase the residence time for the oxidation of particulate matter in the treatment of diesel exhaust. This reference showed that a non-thermal plasma reactor designed in this manner could be effective in the oxidation of particulate matter at low temperatures. This reference also reported that a two-stage plasma system might be needed to convert NO, produced during the process, back to $NO_2$ upstream of a catalytic treatment. This reference indicated that the plasma in combination with a catalyst would be required to take care of aldehydes and CO.

Unfortunately, each of the technologies still has one or more limitations which prevent it from providing a robust, efficient, durable, packagable, and maintenance-free, particulate trap system and method.

## SUMMARY

A method for treating emissions in accordance with embodiments of the present invention includes charging particles in an exhaust stream, producing one or more radicals, oxidizing at least a portion of the charged particles with at least a portion of the produced radicals. At least a portion of the charged particles in the exhaust stream are attracted on at least one attraction surface which is one of oppositely charged from the charged particles and grounded. The attracted particles are oxidized with another portion of the one or more produced radicals to self regenerate the at least one attraction surface.

A system for treating emissions in accordance with other embodiments of the present invention includes a housing with a passage having at least one inlet and at least one outlet, at least one charging system, and at least one attraction system. The charging system charges particles in an exhaust stream in the passage, produces one or more radicals, and oxidizes at least a portion of the charged particles with at least a portion of the produced radicals. The attraction system attracts at least a portion of the charged particles in the exhaust stream on at least one attraction surface which is one of oppositely charged from the charged particles and grounded in the passage downstream from the charging system. The attracted particles on the at least one attraction surface are oxidized with another portion of the one or more produced radicals to self regenerate the attraction surface.

A method for making a system for treating emissions in accordance with other embodiments of the present invention includes providing a housing with a passage having at least one inlet and at least one outlet, providing at least one charging system, and providing at least one attraction system in the passage downstream from the charging system. The charging system charges particles in the passage, produces one or more radicals in an exhaust stream, and oxidizes at least a portion of the charged particles with at least a portion of the produced radicals. The attraction system attracts at least a portion of the charged particles in the exhaust stream on at least one attraction surface which is one of oppositely charged from the charged particles and grounded. The attracted particles on the

at least one attraction surface are oxidized with another portion of the one or more produced radicals to self regenerate the attraction surface.

A corona discharge device in accordance with embodiments of the present invention includes at least one conductive member and a plurality of teeth along at least one edge of the at least one conductive member. At least one electrical connector is coupled to the at least one conductive member.

A method for making a corona discharge device in accordance with other embodiments of the present invention includes providing at least one conductive member and forming a plurality of teeth along at least one edge of the at least one conductive member. At least one electrical connector is coupled to the at least one conductive member.

A method of making corona discharge in accordance with other embodiments of the present invention includes providing at least one conductive member with a plurality of teeth along at least one edge and coupling the at least one conductive member to at least one power source. A voltage from the power source is applied to the at least one conductive member to generate an ionization discharge.

The present invention provides systems and methods for elimination of particulate matter that are robust, efficient, durable, packagable, and maintenance-free. With the present invention, air quality is improved through significant annual reductions of particulate emissions providing benefits to public health and the environment. By using non-thermal plasma, the present invention is very efficient in terms of power consumption when compared to other prior particle separation and trapping technologies. Additionally, by self oxidizing carbon particulates the present invention is able to self regenerate the catalyzed electrostatic surface. Further, the present invention provides a treatment system which has a lower weigh, and lower system pressure drop than prior units.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partial perspective and partial broken away view of a emissions treatment system in accordance with embodiments of the present invention;

FIG. **2** is a perspective view of a corona discharge electrode device in the emissions treatment system shown in FIG. **1**;

FIG. **3** is a side, perspective view of the corona probe for the corona discharge electrode device shown in FIG. **2**;

FIG. **4** is a perspective view of a section of a catalyzed electrostatic system in the emission system shown in FIG. **1**;

FIG. **5** is graph of experimental test results of particulate matter reduction versus corona discharge voltage;

FIGS. **6**A-**6**C are top, perspective view of other embodiments of corona probes for the corona discharge electrode device; and

FIG. **7** is a diagram of test results of particulate matter reduction.

## DETAILED DESCRIPTION

An emissions treatment system **10** in accordance with embodiments of the present invention is illustrated in FIGS. **1**-**4**. The emissions treatment system **10** includes a housing **12** with a passage **14** having an inlet **16** and outlet **18**, corona discharge electrode devices **20**(**1**)-**20**(**2**), a catalyzed electrostatic system **22**, and a catalyst system **24**, although the emissions treatment system **10** can comprise other numbers and types of components in other configurations. The present invention provides a number of advantages including providing systems and methods for elimination of particulate matter which are robust, efficient, durable, packagable, and maintenance-free.



Referring to FIG. **1**, the housing **12** defines the passage **14** which extends between the inlet **16** and the outlet **18**, although the housing **12** could have other shapes and configurations with other numbers of passages with other numbers of inlets and outlets. The housing **12** has chambers **26**(**1**) and **26**(**2**) in passage **14** on opposing sides of the catalyzed electrostatic system **22**, although the housing **12** could have other numbers and types of chambers in passage **14** in other configurations.

Referring to FIGS. **1**-**3**, the corona discharge electrode device **20**(**1**) is located in the first chamber **26**(**1**) in the passage **14** adjacent the inlet **16**, although other numbers and types of devices for charging particulate matter and in other locations could be used. The corona discharge electrode device **20**(**1**) provides a corona discharge that is used to charge particles in an exhaust stream passing through a chamber **26**(**1**) in the passage **14** in housing **12**, such as soot in diesel exhaust.

The corona discharge electrode device **20**(**1**) includes a ceramic base **30**, a conductive rod **32**, and a probe **34**(**1**), although the corona discharge electrode device **20**(**1**) could be comprised of other types and numbers of elements in other configurations. The base **30** is formed around and insulates the rod **32** and has a threaded end which is used to secure the base **30** in an opening in the housing **12** so the probe **34**(**1**) is disposed in the passage **14**, although other types of bases made of other materials and secured to the housing in other manners can be used and other types of conductors can be used for rod **32**. In these embodiments, the probe **34**(**1**) has an elongated, rectangular shape with teeth **35** that have sharp peaks along three sides and a smooth edge along the remaining side and the probe has a twisted configuration, although the probe **34**(**1**) could have other numbers and type of teeth along other numbers of edges and could have other shapes in other configurations. Additionally, in this embodiment the probe **34**(**1**) is made of brass, although other types of materials could be used.

By way of example only, other embodiments of probes **34**(**2**)-**34**(**4**) which could be used with one or both of the corona discharge electrode devices **20**(**1**) and **20**(**2**) are illustrated in FIGS. **6**A-**6**C. In this embodiment, the probe **34**(**2**) has an elongated shape with a plurality of teeth **37** on opposing elongated sides, although the probe **34**(**2**) could have other shapes and configurations. Each of the teeth **37** have: a sawtooth shape; substantially the same overall size; a spacing between each of the teeth **37** which is substantially the same; and a direction in which each of the teeth **37** on the same elongated side extend in substantially the same direction, although the probe **34**(**2**) could have other types and numbers of teeth, with other spacing and direction, and with other shapes and configurations on other numbers of sides.

In this embodiment, the probe **34**(**3**) has an elongated shape with a plurality of teeth **39** on opposing elongated sides and with an overall twisted configuration, although the probe **34**(**3**) could have other shapes and configurations. Each of the teeth **39** have: a sawtooth shape; an overall size for each of the teeth **39** which tapers down from a center towards each of the ends of the probe **34**(**3**); a spacing between each of the teeth **39** which is substantially the same; and a direction in which each of the teeth **39** on the same elongated side extend in substantially the same direction, although the probe **34**(**3**) could have other types and numbers of teeth, with other spacing and direction, and with other shapes and configurations on other numbers of sides.

In this embodiment, the probe **34(4)** has an elongated shape with a plurality of teeth **41** on opposing elongated sides, although the probe **34(3)** could have other shapes and configurations. Each of the teeth **41** have: a sawtooth shape; substantially the same overall size; a spacing between each of the teeth **41** which is substantially the same; and a direction in which each of the teeth **41** on the same elongated side extend varies between the teeth **41**, although the probe **34(4)** could have other types and numbers of teeth, with other spacing and direction, and with other shapes and configurations on other numbers of sides

The different shapes, configurations, sizes and directions for the teeth on the probes **34(1)-34(4)** improve the corona discharge from the corona discharge electrode devices **20(1)** and **20(2)**. Unlike prior single pole, mesh type, or plate electrodes which serve a limited area of exhaust gas flow, the use of corona discharge electrode devices **20(1)** and **20(2)** with one of these probes **34(1)-34(4)** leads to the formation of wide rectangular ionization field which covers a wide area of the passage **14** in housing **12**.

Referring to FIG. **1**, the corona discharge electrode device **20(2)** is identical to the corona discharge electrode device **20(1)** illustrated and described with reference to FIGS. **1-3**, except as described herein. The corona discharge electrode device **20(2)** is located in the second chamber **26(2)** in the passage **14** between the catalyzed electrostatic system **22** and the catalyst system **24**, although other numbers and types of discharge devices could be used. The corona discharge electrode device **20(2)** provides a corona discharge in the chamber **26(2)** in the passage **14** downstream from the catalyzed electrostatic system **22**. The corona discharge is used to convert compounds in the exhaust stream, such as NO, to other compounds, such as $NO_2$, which can be treated by the catalyst system **24**.

A high voltage power source **28** is coupled to the corona discharge electrode devices **20(1)** and **20(2)** and supplies power at a very high voltage between about 5 kV and 70 kV at a very low current between about 0.01 mA and 7 mA, although the power supply **28** can supply power at other voltages and currents to the corona discharge electrode device **20(1)**. One of the advantages of the present invention is that the system **10** works effectively with the corona discharge electrode devices **20(1)** and **20(2)** generating non-thermal plasma which requires less power and thus is more energy efficient.

Referring to FIGS. **1** and **4**, the catalyzed electrostatic system **22** comprises a substrate core **35** which has a plurality of passages **36** that extend through, although the catalyzed electrostatic system **22** can comprise other types and numbers of components in other configurations and other types and numbers of attraction systems could be used. In this embodiment, the substrate core **35** is made of a metal with a silver coating in the passages **36**, although the catalyzed electrostatic system **22** can comprise other types and numbers of components in other configurations and the substrate core and the coatings can be made of other types of materials. The catalyzed electrostatic system **22** is located in and fills the space in the passage **14** between the chambers **26(1)** and **26(2)** which are fluidly connected together by the passages **36**, although other configurations could be used. The conductive surfaces of the catalyzed electrostatic system **22** are coupled to ground, although other types of electrically connections could be used, such as coupling the conductive surfaces of the catalyzed electrostatic system **22** to a device with an opposite charge from the charge on the particles.

The catalyzed electrostatic system **22** uses an electrostatic principal to deflect and attract charged soot particles in the exhaust stream to a surface of one of the passages **36** in the substrate core **35**, although other manners for attracting the particles on other types of surfaces can be used. Additionally, the catalyzed electrostatic system **22** provides space for the conversion of soot and other particulate materials captured on the catalyzed electrostatic system **22** through oxidation so the catalyzed electrostatic system **22** can self regenerate.

Referring to FIG. **1**, the catalyst system **24** includes a catalyst substrate **38** with a plurality of passages **40** and is made of a ceramic material, although the catalyst system **24** can comprise other types and numbers of components in other configurations and can be constructed with other types of materials. The catalyst system **24** is located in and fills the space of the passage **14** between the chamber **26(2)** and the outlet **18** which are fluidly coupled together, although other configurations could be used. The catalyst system **24** is used to reduce or eliminate tailpipe emissions such as CO, HC and NOx with one or more reactions with catalysts in the catalyst system **24** in manners well known to those of ordinary skill in the art.

A method of reducing emissions in accordance with embodiments of the present invention will now be described with reference to FIGS. **1-4**. An exhaust stream, such as diesel soot, is introduced through the inlet **16** into the chamber **26(1)** in the passage **14**, although other types of fluids could be introduced for treatment. Meanwhile, power supply **28** is engaged to supply power to the corona discharge electrode devices **20(1)** and **20(2)** in manners well known to those of ordinary skill in the art. In these embodiments, the power supplied to corona discharge electrode devices **20(1)** and **20(2)** is at very high voltage between about 5 kV and 70 kV with a very low current between about 0.01 mA and 7 mA, although the power can be supplied at other voltages and currents.

The high voltage applied to the corona discharge electrode device **20(1)** charges carbon particles in the exhaust stream with ions repelled by the corona discharge in chamber **26(1)**, although other manners for charging the particulate matter in chamber **26(1)** can be used. The shape and configuration of the probe **34(1)** on the corona discharge electrode device **20(1)** leads to the formation of an ionization field which covers a substantial portion of the chamber **26(1)**. The corona discharge in the chamber **26(1)** also excites the gas atoms to produce highly reactive O, OH, and $NO_2$ radicals. These highly reactive radicals oxidize at least a portion of the soot particles passing through chamber **26(1)** into gases, such as $N_2$, CO, $CO_2$ and $H_2O$ by way of example only.

Next, the charged particles in the exhaust stream in chamber **26(1)** are directed downstream into the passages **36** in the substrate core **35** of catalyzed electrostatic system **22**, although the charge particles could be directed to other types of attraction systems. The charge particles in the exhaust stream migrate to and are attracted on the conductive surfaces in the passages **36** in the substrate core **35** which are coupled to ground G, although the conductive surfaces could be coupled in other manners, such as to a device which provides an opposite charge from the charge on the charge particles. By way of example only, particle migration velocities of 0.01 to 4 ft/sec are common.

Meanwhile, the radicals, such as O, OH, and $NO_2$, generated in the chamber **26(1)** are also directed downstream into the passages **36** in the substrate core **35** in catalyzed electrostatic system **22**. The radicals, such as O, OH, and $NO_2$, also oxidize at least a portion of the particles attracted on the conductive surfaces in the passages **36** in the substrate core **35** to self regenerate the catalyzed electrostatic system **22**. These highly reactive radicals oxidize the attracted particles into gases, such as $N_2$, CO, $CO_2$ and $H_2O$, while again self regenerating the catalyzed electrostatic surface.

Next, the high voltage applied to the corona discharge electrode device **20**(**2**) generates a corona discharge in chamber **26**(**2**), although other manners for generating a corona discharge or other plasma can be used. The shape and configuration of the probe **34**(**1**) on the corona discharge electrode device **20**(**2**) helps to lead to the formation of the ionization field which covers a substantial portion of the chamber **26**(**2**). The corona discharge in chamber **26**(**2**) converts any residual compounds, such as NO, in the exhaust stream from the catalyzed electrostatic system **22** into other compounds, such as $NO_2$, which can be treated by the catalyst system **24**, although other manners for preparing the exhaust stream in chamber **26**(**2**) for further treatment can also be used. Yet another function occurring in chamber **26**(**2**) with the ionization is the oxidization of at least a portion of any remaining soot particles into gases, such as $N_2$, CO, $CO_2$ and $H_2O$

Next, the exhaust stream is provided into the passages **40** in the catalyst substrate **38** for the catalyst system **24** to reduce or eliminate tailpipe emissions, such as CO, HC and NOx, with one or more reactions with catalysts in the catalyst system **24** in manners well known to those of ordinary skill in the art. The treated exhaust stream is then output via the outlet **18** in the housing **12**, although other treatments could be applied and the exhaust could be outlet in other manners.

By way of example only, sample result from a diesel generator equipped with the system **10** is shown in FIG. **5**. As illustrated, the system **10** providing a particulate matter reduction between about 37% and 80% depending upon the engine load and the level of power supplied by the power supply **28** to the corona discharge electrode devices **20**(**1**) and **20**(**2**). These results prove the feasibility of using non-thermal plasma with the system **10** as a viable method to reduce soot in a diesel generator and diesel engine exhaust. Additionally, by way of example only, the results from a diesel pick up truck equipped with the system **10** are also illustrated in the table shown in FIG. **7**.

The present invention has a number of applications, including as a component of an emissions treatment system for automotive applications, such as off-road vehicles, distributed power systems, stationary power systems and mining systems. Other applications for the present invention, by way of example only, include removal of tar in biomass conversion and in stack gas applications.

Accordingly, the present invention provides a particulate trap system which is effective in reducing emissions, is durable, and is self-regenerating. Since the present invention works with non-thermal plasma, it is very efficient in terms of power consumption when compared to prior particle separation and trapping technologies. Another advantage of the present invention is the simplicity and effectiveness of the design of the corona probe. Yet another advantage of the present invention is the absence of precious metal such as Platinum for conversion of NO to $NO_2$. Yet a further advantage of the present invention is that the low temperature (>=100° C.) operation of the system **10** makes it very suitable for use in vehicles and systems, such as school busses, refuse trucks, construction equipment, on and off road vehicles, and generators by way of example only.

Having thus described the basic concept of the invention, it will be rather apparent to those skilled in the art that the foregoing detailed disclosure is intended to be presented by way of example only, and is not limiting. Various alterations, improvements, and modifications will occur and are intended to those skilled in the art, though not expressly stated herein. These alterations, improvements, and modifications are intended to be suggested hereby, and are within the spirit and scope of the invention. Additionally, the recited order of processing elements or sequences, or the use of numbers, letters, or other designations therefore, is not intended to limit the claimed processes to any order except as may be specified in the claims. Accordingly, the invention is limited only by the following claims and equivalents thereto.

What is claimed is:

**1**. A method for treating emissions, the method comprising:

charging carbon particles in an exhaust stream in a housing with a passage having an inlet and an outlet by a first corona discharge in a first chamber which generates a non-thermal plasma that charges the carbon particles with ions from the first corona discharge;

producing one or more radicals by exciting gas atoms in the exhaust stream by the first corona discharge;

oxidizing a portion of the charged carbon particles with a portion of the produced radicals to remove a portion of the carbon particles in the exhaust stream;

attracting a portion of the charged carbon particles in the exhaust stream on a flow-through maintenance-free attraction system comprising a substrate core having a plurality of individual passages that extend therethrough and which fills a space in the housing passage that electrostatically attracts a portion of the charged carbon particles on a catalyzed attraction surface oppositely charged from the charged carbon particles and grounded; and

oxidizing the attracted particles with another portion of the one or more produced radicals to self regenerate the at least one attraction surface.

**2**. The method as set forth in claim **1** wherein the produced one or more radicals comprises at least one of O, OH, and $NO_2$.

**3**. The method as set forth in claim **1** wherein the portion of removed carbon particles are removed from the exhaust stream by the first corona discharge device by being oxidized into gases comprising at least one of $N_2$, CO, $CO_2$,and $H_2O$.

**4**. The method as set forth in claim **1** wherein the attracted particles on the attraction surface are oxidized into gases comprising at least one of $N_2$, CO, $CO_2$ and $H_2O$ to self regenerate the attraction surface.

**5**. The method as set forth in claim **1** further comprising:

generating a second corona discharge in a second chamber which generates a non-thermal plasma that oxidizes a portion of the charged carbon particles with ions from the second corona discharge and converts residual compounds from the first chamber into other compounds which can be treated by a catalyst system; and catalyzing the other compounds in a flow-through catalyst system comprising a substrate having a plurality of individual passages that extend therethrough and which fills a space of the housing passage between the second chamber and the outlet to reduce or eliminate emissions from the exhaust stream.

**6**. The method as set forth in claim **5** wherein the portion of charged carbon particles are removed from the exhaust stream by the second corona discharge device by being oxidized into gases comprising at least one of $N_2$, CO, $CO_2$, and $H_2O$.

**7**. The method as set forth in claim **5** wherein the other catalyzed compounds reduced or eliminated from the exhaust stream are emissions comprising at least one of CO, HC, and $NO_x$.

**8**. The method as set forth in claim **5** wherein the second corona discharge converts the residual compounds from the first corona discharge into other compounds by converting at least a portion of nitrogen oxide in the exhaust stream to nitrogen dioxide.

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