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(54) EXHAUST GAS PURIFYING APPARATUS

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(57) **ABSTRACT**

The present invention relates to an exhaust gas purifying apparatus comprising; a plasma-assist PM purifying reactor; a detecting device for detecting an amount of PM accumulated in the PM purifying reactor; a power supply for the PM purifying reactor; and a controlling device for controlling the power supply on the basis of signals from the detecting device. The controlling device controls the power supply to start supplying the electric power to the PM purifying reactor, or to increase the amount of electric power which is supplied to the PM purifying reactor, when the amount of accumulated PM detected by the detecting device exceeds a predetermined amount.

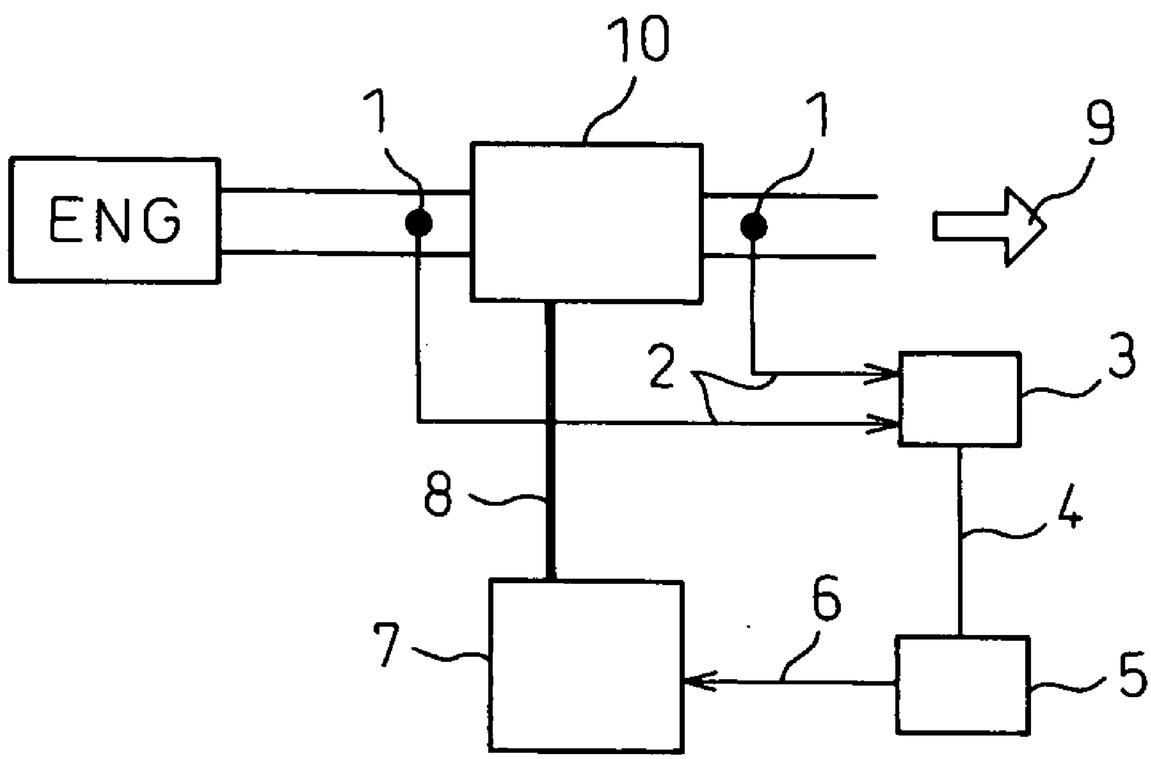


Fig. 1

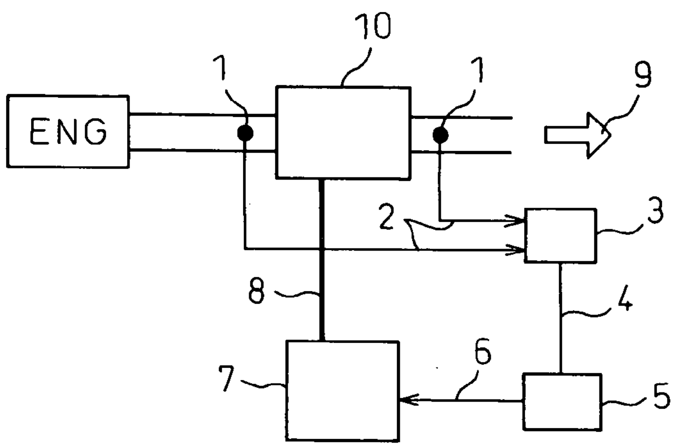

ENG
10
1
1
9
2
3
4
5
6
7
8

Fig. 2

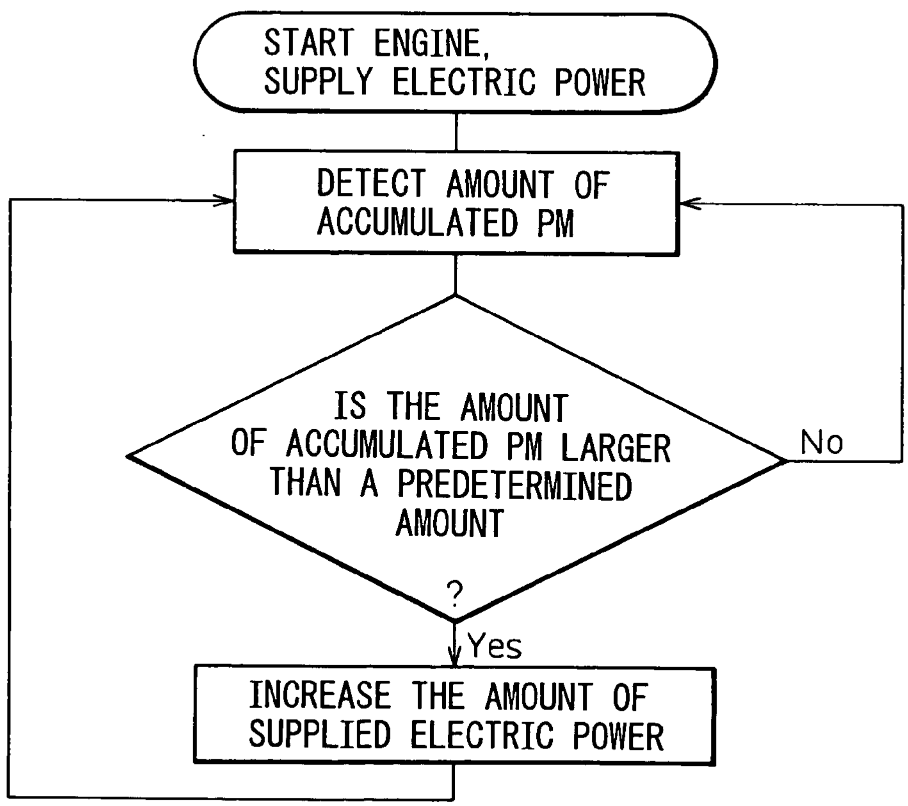

START ENGINE,
SUPPLY ELECTRIC POWER
DETECT AMOUNT OF
ACCUMULATED PM
IS THE AMOUNT
OF ACCUMULATED PM LARGER
THAN A PREDETERMINED
AMOUNT
?
No
Yes
INCREASE THE AMOUNT OF
SUPPLIED ELECTRIC POWER

Fig. 3

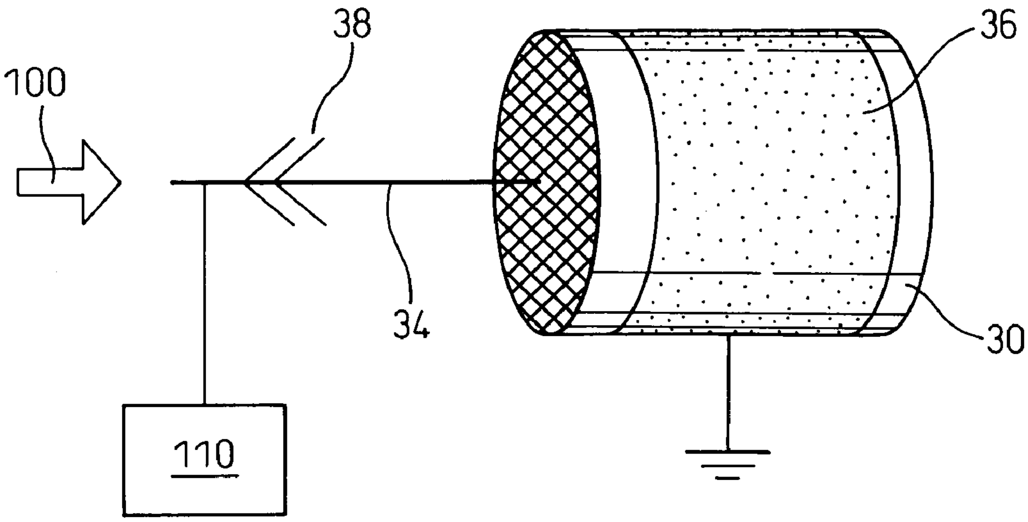


Fig. 4

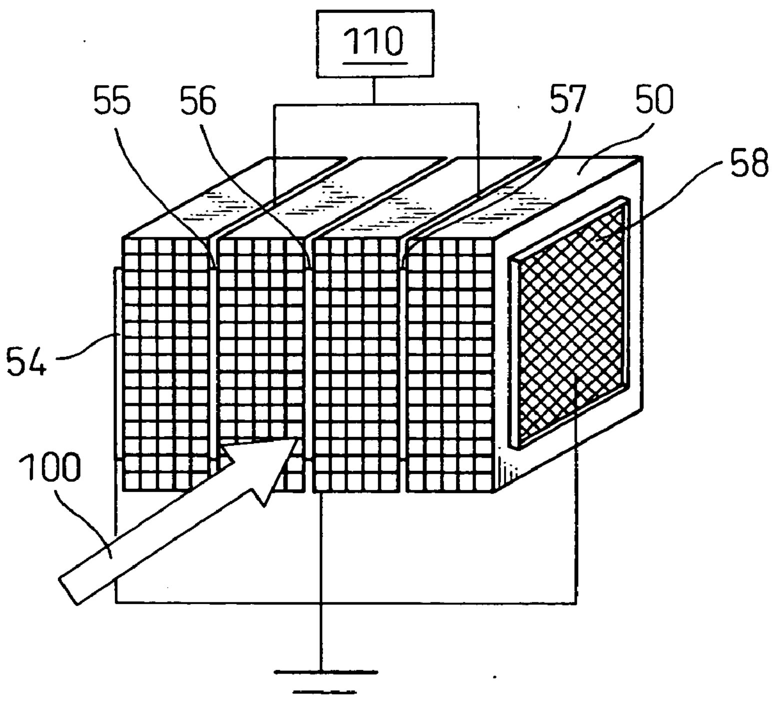


Fig. 5(a)

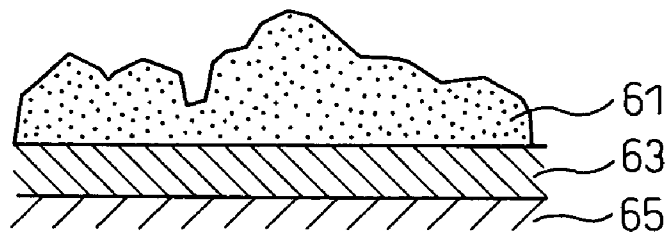
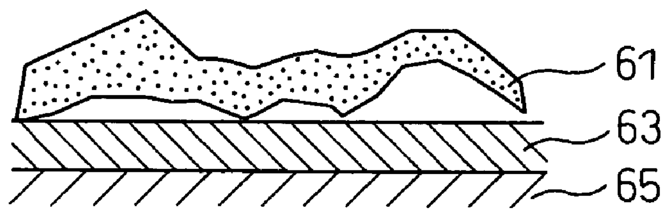


Fig. 5(b)



EXHAUST GAS PURIFYING APPARATUS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an apparatus for purifying an exhaust gas emitted from an internal combustion engine and, in particular, to an apparatus for purifying PM (particulate matter) emitted from a diesel engine.

[0003] 2. Description of Related Art

[0004] Diesel engines are usually used for motor vehicles, and particularly, for large motor vehicles. The diesel engine must now have a decreased emission of nitrogen oxide (NO_x), carbon monooxide (CO) and hydrocarbon (HC) as well as PM. Therefore, it is desired to develop not only the technique which decreases the amount of generated PM by improving engine itself or optimizing combustion condition thereof, etc., but also the technique which purifies the PM in the exhaust gas.

[0005] It is possible to trap the PM in the exhaust gas by the use of a so-called diesel particulate filter (DPF). However, the DPF is plugged by the trapped PM as time goes by and increases the differential pressure across the DPF and this causes a larger load on the engine.

[0006] In the prior art, it is well-known to burn out the trapped PM by heating the DPF with a heater, etc.

[0007] Recently, as a more efficient procedure, it is also proposed to use plasma energy in order to burn out PM which is trapped in the DPF. For example, Japanese Unexamined Patent Publication (JPP) No. 2002-276333 proposes to combine the DPF and a plasma generator, thereby generating NO_2 and active oxygen to promote oxidation of the trapped PM. The document also proposes promoting the oxidation of PM by generating plasma when the DPF is at a low temperature.

[0008] JPP No. 2002-129949 describes combining a catalyst and plasma generator for purifying HC, CO and NO_x, and supplying a requisite minimum amount of electric power to the plasma generator on the basis of a engine speed, a temperature of the catalyst, etc.

[0009] According to these prior arts utilizing plasma, it is possible to effectively oxidize and remove trapped PM even when the DPF has a lower temperature as in the case of starting an engine. However, even though the DPF has a higher temperature, a large amount of PM may be accumulated in the DPF due to the change of combustion conditions in the engine.

[0010] Once such a large amount of PM is accumulated in DPF, the accumulated PM makes the generation of plasma unstable and lowers the PM oxidation ability, and therefore, PM is further accumulated in the DPF. This becomes a vicious cycle.

[0011] A large amount of heat is generated, if the large amount of accumulated PM is burned out at once to remove. The large amount of heat shortens the life of the DPF, and may break the DPF.

[0012] This problem can be partially solved by controlling generation of plasma on the basis of not only the temperature of DPF, but also the engine speed, etc. as described in above JPP'949. However, changes in the combustion conditions in the engine are not always pradictable. Therefore, in some cases, plasma generation controlled on the basis of engine speed, etc. may be not enough in order to properly remove PM.

BRIEF SUMMARY OF THE INVENTION

[0013] An exhaust gas purifying apparatus of the present invention comprises a plasma-assist PM purifying reactor (also referred simply as a "PM purifying reactor"); a detecting device for detecting an amount of PM accumulated in the PM purifying reactor; a power supply for the PM purifying reactor; and a controlling device for controlling the power supply on the basis of signals from the detecting device. The controlling device controls the power supply to start supplying the electric power to the PM purifying reactor, or to increase the amount of electric power which is supplied to the PM purifying reactor, when the amount of accumulated PM detected by the detecting device is above a predetermined amount.

[0014] According to the present invention, the power supply is controlled on the basis of "the amount of accumulated PM" in the PM purifying reactor rather than "the amount of generating PM" which relates to parameters such as engine speed. Therefore, it is possible to avoid the destabilizing of plasma generation and the intensive burning of PM caused by an unexpectedly accumulated large amount of PM. Further, it is, naturally, also possible to save the electric energy needed to remove PM, comparing to supplying a constant amount of energy to the PM purifying reactor.

[0015] In one embodiment of the present exhaust gas purifying apparatus, the detecting device comprises a differential pressure gauge which detects a differential pressure across the PM purifying reactor.

[0016] According to this embodiment, it is possible to determine the pressure loss at the PM purifying reactor on the basis of the differential pressure across it, and then more correctly determine the amount of PM actually accumulated in the PM purifying reactor on the basis of the pressure loss. It is because that the pressure loss at the PM purifying reactor increases with the amount of PM accumulated in the PM purifying reactor.

[0017] In the case that DPF is heated by use of heater, etc. to burn PM in the PM purifying apparatus out, the PM contacting to a catalyst is mainly burned out. Therefore, as shown in **FIG. 5**(*a*), when a large amount of PM **61** is deposited on the catalyst **63** on the substrate **65**, the PM is burned out only near the catalyst **63**, and only SOF (soluble organic fraction) is burned out at a point distant from the catalyst **63**. Therefore, PM **61** may be left in a part away from the catalyst **63** as shown in **FIG. 5**(*b*). In the situation of **FIG. 5**(*b*), the interrelationship between the pressure loss and the amount of PM accumulated in the PM purifying reactor differs from the that in the situation of **FIG. 5**(*a*), and therefore, it is sometimes difficult to accurately determine the amount of PM accumulated in the PM purifying reactor on the basis of the pressure loss at the reactor.

[0018] Contrary to heating the DPF by the use of heater to burn PM out, in the case that PM is burned out by the use of plasma in the PM purifying reactor, the deposited PM is burned out and removed also at the surface layer by the electrons which are emitted from negative-electrode wall of the cell in DPF, etc., and by NO_2 and/or active oxygen which are generated by plasma. Further, an electric current passing through the deposited PM by application of electric voltage leads to the burning out of PM also at a point other than the interface of catalyst and PM.

[**0019**] Therefore, contrary to heating the DPF by the use of heater to burn PM out, the burning out of the PM by the use of plasma makes it easier to determine the amount of accumulated PM on the basis of the a differential pressure across the PM purifying reactor.

[**0020**] In one embodiment of the present invention, the PM purifying reactor comprises electrodes and an insulative honeycomb structure having a number of cell passages.

[**0021**] According to this embodiment, the PM in the exhaust gas passing through the cell passages of the honeycomb structure is deposited onto the sidewalls of the cell passages of the honeycomb structure, and is burned out thereon.

[**0022**] In this embodiment, the electrodes may make an electric field which is non-parallel, particularly at the angle of at least 45 or 60 degrees, more particularly substantially perpendicular, to the direction of the cell passages of the honeycomb structure.

[**0023**] Further, the electrodes may comprise a center electrode and an outer electrode surrounding the center electrode, and the honeycomb structure may be positioned between the center and the outer electrodes.

[**0024**] Alternatively, the reactor may have two or more honeycomb structures having opposite outer surfaces, and the electrodes may comprise two or more pairs of plate electrodes respectively placed on the opposite outer surfaces of the two or more honeycomb structures, and the sets of the honeycomb structure and the pair of plate electrodes may be aligned in parallel to each other. In this case, the plate electrode between the honeycomb structures may be shared among the adjacent sets.

[**0025**] In these cases, the electrodes generate an electric field which is non-parallel with the direction of the cell passages. Therefore, the Coulomb force between the PM and the electric field improves trapping of the PM. Further, in this situation, the PM deposited in the honeycomb structure is burned with the use of not only thermal energy of an exhaust gas but also the plasma and an electrical current that passes through the deposited PM rather than the insulative honeycomb structure.

[**0026**] These and other objects, features and advantages of the present invention will become apparent to a person with ordinary skilled in the art upon studying the following detailed description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0027**] **FIG. 1** shows a block diagram of one embodiment of the present apparatus.

[**0028**] **FIG. 2** shows a flow chart describing a way to control the electric power supply of the present apparatus.

[**0029**] **FIG. 3** shows a perspective view of an plasma assist plasma purifying reactor which can be used for the present exhaust gas purifying apparatus.

[**0030**] **FIG. 4** shows a perspective view of another plasma assist plasma purifying reactor which can be used for the present exhaust gas purifying apparatus.

[**0031**] FIGS. **5**(*a*) and (*b*) respectively show a schematic diagram of the shape of the PM accumulated in the DPF before and after being burned by heating the DPF.

DETAILED DESCRIPTION OF THE INVENTION

[**0032**] The present invention is described using embodiments and drawings which are not intended to limit the scope of the present invention shown in the claims.

[**0033**] **FIG. 1** schematically shows the exhaust gas purifying apparatus of the present invention. In this **FIG. 1**, an exhaust gas from the engine (ENG) passes through the plasma assist PM purifying reactor **10** and any other exhaust gas purifying device (not shown) such as NO_x. storage-reduction catalyst downstream of the plasma assist PM purifying apparatus **10** to the atmosphere in the direction of arrow **9**.

[**0034**] In this exhaust gas purifying apparatus, PM purifying reactor **10** is located downstream of the engine. The detecting device for detecting an amount of PM accumulated in the PM purifying reactor comprises the pressure gauges **1** ahead of and behind the reactor **10**, the signal line **2** and the calculating device **3**, and is connected to the controlling device **5** via the signal line **4**. The calculating device **3** may, naturally, be an ECU (Engine Control Unit). The power controlling device **5** is connected to the power supply **7** via the signal line **6**, and the power supply **7** is connected to the PM purifying reactor **10** via the power line **8**.

[**0035**] The power-supply controlling device **5** controls the power supply **7** on the basis of the amount of PM accumulated in the PM purifying reactor **10**, the amount being determined using the detecting device **1**, **2**, **3**. In this case, when the amount of accumulated PM, which is detected by the detecting device **1**, **2**, **3**, exceeds a predetermined amount, the controlling device **5** controls the power supply **7** via controlling line **6** such that the power supply **7** commences to supply the electric power or increases the amount of electric power supplied to the PM purifying reactor **10**.

[**0036**] In this case, the detecting device comprising the pressure gauges **1**, the signal line **2** and the calculating device **3** is used as a detecting device for detecting an amount of PM accumulated in plasma assist PM purifying reactor **10**. However, any other device can be used in order to detect an amount of PM accumulated in the PM purifying reactor. Therefore, it is also possible to determine the amount of accumulated PM on the basis of the changes of electric resistance, weight, degree of blackening, or concentration of NO_2 or O_2 in exhaust gas having passed through the reactor (the concentration of NO_2 and O_2 are reduced when the amount of accumulated PM is increased, because they are consumed in the burning of the PM).

[**0037**] **FIG. 2** shows the one embodiment of use of the present exhaust gas purifying apparatus of **FIG. 1**. As shown in **FIG. 2**, when the engine starts to run, the PM purifying reactor is powered, and the exhaust gas from the engine is passed through the plasma assist PM purifying reactor **10**, whereby the PM in the exhaust gas is trapped by the reactor

10. After that, if the detecting device **1**, **2**, **3** detects that a predetermined amount of PM is accumulated in the PM purifying reactor **10**, the controlling device **5** controls the power supply **7** in order to increase an amount of electric power supplied to the PM purifying reactor **10** for a predetermined duration or until the amount of PM detected by the detecting device become less than a predetermined amount. If the detecting device **1**, **2**, **3** detects that the accumulated PM in the PM purifying reactor **10** is less than the predetermined amount, the controlling device **5** controls the power supply **7** in order to keep the amount of electric power supplied to the PM purifying reactor **10** stable, and then the detecting device **1**, **2**, **3** check the amount of accumulated PM again.

[**0038**] Although the electric power supply starts with the operation of the engine, it is also possible to control the power supply **7** by the use of the controlling device in order not to supply electric power normally, and to commence supplying electric power only when the amount of accumulate PM exceeds a predetermined amount. Further, it is also possible to control the power supply on the basis of the condition of the engine as described in JPP'949, i.e. on the basis of the amount of generating PM, in addition to the amount of accumulated PM as in the present invention. According to this, it is possible to normally control the power supply on the basis of the condition of the engine, and to control the power supply according to the present invention only when an amount of accumulated PM exceeds a predetermined amount.

[**0039**] The plasma assist PM purifying reactor which can be used for the present exhaust gas purifying apparatus may be ones that generate plasma therein and the plasma promotes combustion of PM. Therefore, the plasma assist PM purifying reactor may be ones described in above JPP'333 and JPP'949.

[**0040**] Further, the plasma assist PM purifying reactor may be ones seen in **FIG. 3** which shows perspective views thereof.

[**0041**] In **FIG. 3, 10** indicates a straight-flow type insulative honeycomb structure having a number of cell passages, **14** indicates a center electrode, **16** indicates an outer electrode, **18** indicates needle electrodes on the center electrode **14**, and **110** indicates a power supply. The insulative honeycomb structure **10** is positioned between the center **14** and the outer **16** electrodes such that these electrodes are electrically insulated. An exhaust gas containing PM flows from the left side to the right side of the **FIG. 3** as indicated by an arrow **100**, and passes through the cell passages of the honeycomb structure **10** surrounded by the outer electrode **16**.

[**0042**] In the use of the PM purifying reactor shown in **FIG. 1**, the electric power supply **110** applies a voltage between the center electrode **14** and the outer electrode **16** to generate a radial electric field in the honeycomb structure **10**.

[**0043**] The components of the PM purifying reactor shown in **FIG. 3** are described below in more detail.

[**0044**] The insulative honeycomb structure **10** may be made of a ceramic material, e.g. cordierite. The honeycomb structure may be a straight-flow type (i.e. a honeycomb structure of which cell passages are substantially not plugged) or wall-flow type (i.e. a honeycomb structure of which cell passages are alternatively plugged, a so-called "Diesel Particulate Filter (DPF)"). According to this embodiment, the straight-flow type honeycomb structure is preferable for gas-flow resistance, and can achieve a sufficient PM trapping. Further, the wall-flow type honeycomb structure is preferable for producing a PM path, and then burning the trapped PM by the electric current therethrough. The insulative honeycomb structure may be sufficiently more insulative than PM in order to make sure that more electric current passes through the deposited PM than through the honeycomb structure to burn out the PM. The honeycomb structure may carry a catalyst such as NO_x purifying catalyst.

[**0045**] A voltage applied between the electrodes may usually be more than 5 kV, preferably more than 10 kV. The pulse period of the applied voltage is preferably less than 10 ms (milli-second), more preferably less than 1 ms. A direct current (DC) voltage, alternating current (AC) voltage, a voltage having a periodic waveform, etc. may be applied between the electrodes. Preferably, a DC pulse voltage is applied since it can generate a stable corona electric discharge. The applied voltage, pulse width and pulse period of the DC pulse voltage may be optionally determined as long as it generates a corona electric discharge. Preferably, the applied voltage and pulse period are respectively a high voltage and short period in order to generate a corona electric discharge, though those parameters may be restricted by the design of the apparatus, an economical interest, etc.

[**0046**] In **FIG. 4, 50** indicates a straight-flow type insulative honeycomb structure having a number of cell passages, **54** to **58** indicate mesh plate electrodes, **110** indicates an electric power supply. Among the plate electrodes **54** to **58**, the plate electrodes **55** and **57** are connected to the electric power supply **110**, and the plate electrodes **54**, **56** and **58** are grounded. Each of the plate electrodes **54** to **58** is electrically insulated with adjacent ones by the insulative honeycomb structure **50** therebetween. An exhaust gas containing PM passes through the cell passages of the insulative honeycomb structures **50** sandwiched between the plate electrodes **54** to **58**, as shown in an arrow **100**.

[**0047**] In the use of the PM purifying reactor shown in **FIG. 4**, the electric power supply **110** applies a voltage between the plate electrodes **54**, **56** and **58**, and the adjacent electrodes **55** and **57** to generate an electric field in the honeycomb structure **50**. In any case, the electric field crosses the cell passages of the honeycomb structure **50** through which an exhaust gas flows. The electric field forces the PM in the exhaust gas to be deposited onto the sidewall of the cell passages of the honeycomb structure **50** by the Coulomb force in order to improve a trapping of the PM.

[**0048**] Regarding the components of the reactor of **FIG. 4**, refer to the description for the reactor of **FIG. 3**.

[**0049**] In the following examples, the effects of the PM purifying reactors are disclosed. These reactors can be used for the present exhaust gas purifying apparatus and are as disclosed in **FIGS. 3 and 4**.

EXAMPLE 1

[**0050**] A PM purifying reactor was provided as shown in **FIG. 3**. That is, in this reactor, around the circumference surface of a straight-flow type cordierite honeycomb structure (diameter: 30 mm and length: 50 mm, cell density: 200 cells/square inch, porosity: 65%, and average pore size: 25 μm (micro meters)), a stainless steel mesh (width: 40 mm, SUS 304, 300 mesh) was surrounded to be an outer electrode. On the center axis of the honeycomb structure, a center electrode (bar electrode) having needle electrodes was fixed.

EXAMPLE 2

[0051] The exhaust gas purifying apparatus of this example was the same as that of the example 1, except that a wall-flow type cordierite honeycomb structure (cell density: 300 cells/square inch, porosity: 65%, and average pore size: 25 μm) was used in place of the straight-flow type cordierite honeycomb of the example 1.

[0052] Performance Evaluation: PM trapping

[0053] Each of the reactors of the examples 1 and 2 was surrounded by an alumina mat and inserted in a quartz tube having an inner diameter of 37 mm (milli-meters). The center electrode was electrically connected to an electric power supply, and the outer electrode was grounded. To the exhaust gas purifying apparatus, a part of the exhaust gas (100 L/minute) from a direct-injection system diesel engine having a displacement volume of 2400 cc was pumped, and a voltage of 4 kV (input electric power of about 3 W) was applied. The contents of the PM in the exhaust gas were determined at the upstream and downstream of the apparatus by the use of an ELPI (Electric Low Pressure Impactor). A PM purifying rate was determined from the difference between the contents of the PM at the upstream and downstream of the apparatus. The higher this value is, the better the performance of the reactor is. In all cases, the engine was idling (at 700 rpm).

[0054] Performance Evaluation: PM Oxidization

[0055] After sufficiently depositing PM in the honeycomb structures of the examples 1 and 2, the honeycomb structures were dried for 24 hours at the temperature of 120° C. in a dryer, and then weighed. The obtained weight is an initial weight. The each reactor was inserted in the quartz tube as stated above (atmosphere: air), and the center electrode was power at 15 kV for 15 minutes. The resulted honeycomb structure was dried for 24 hours at the temperature of 120° C., and then weighed. The obtained weight is an after-treatment weight. The PM oxidation (combustion) amount is obtained from the difference between the initial weight and the after-treatment weight. The PM oxidation energy was calculated by dividing the PM oxidation amount by the input energy (voltage×electric current×time) from the electric power supply. The lower this value is, the better the PM oxidation performance is. The input energy required for oxidizing PM by mere heating is about 290 kJ/g.

TABLE 1

	PM trapping		
	with electric field (%)	without electric field (%)	PM oxidation energy (kJ/g)
Ex. 1 (straight-flow)	11	69	65
Ex. 2 (wall-flow)	45	68	67

[0056] The PM trapping performances in Table 1 show that the electric field in the honeycomb structure improves the PM trapping, and that the straight-flow type and wall-flow type honeycomb structures achieve the similar PM trapping results on being provided with the electric power. The PM oxidizing performances in Table 1 show that the electric current reduces the required PM oxidation energy relative to mere heating.

EXAMPLE 3

[0057] A PM purifying reactor was provided as shown in **FIG. 4**. That is, straight-flow type cordierite honeycomb structures in rectangular parallelepiped form (cell density: 200 cells/square inch, porosity: 65%, average pore size: 25 am, height: 15 cells, width: 5 cells, and length: 50 mm) are sandwiched with stainless steel mesh electrodes (SUS 304, height of 24 mm, length of 45 mm, and 300 or 30 mesh).

[0058] In the experiment, the exhaust gas passes through the reactors in a direction indicated by an arrow **100** in **FIG. 4**. The mesh electrodes are alternatively connected to an electric power supply and to the ground. The electrodes connected to the electric power supply are anodes, and the grounded electrodes are cathodes.

[0059] Performance Evaluation: PM Trapping

[0060] A PM trapping rate was determined as in examples 1 and 2, except that the reactor of the example 3 was surrounded by an alumina mat and inserted in an acrylic tube having a profile of 34×48 mm, and that a DC electric power of 4 kV and about 3 W was applied to the electrodes.

[0061] Performance Evaluation: PM Oxidization

[0062] The PM oxidation energy is determined as in Examples 1 and 2 except that the honeycomb structures of example 3 was inserted in the acrylic tube as stated above (atmosphere: air), and powered at 10 kV for 20 minutes.

TABLE 2

	PM trapping		
	with electric field (%)	without electric field (%)	PM oxidation energy (kJ/g)
Ex. 3	19	67	70

[0063] The PM trapping performances in Table 2 show that the electric field in the honeycomb structure improves the PM trapping. The PM oxidizing performances in Table 2 show that the electric current reduces the required PM oxidation energy relative to mere heating.

[0064] Although the present invention has been fully described by way of the example with reference to the accompanying drawings, it should be understood that various changes and modifications will be apparent to those skilled in the art. Therefore, such changes and modifications can be made within the scope of the present invention as hereinafter defined.

1. An exhaust gas purifying apparatus comprising;

a plasma-assist PM purifying reactor;

a detecting device for detecting an amount of PM accumulated in said PM purifying reactor;

a power supply for said PM purifying reactor; and

a controlling device for controlling said power supply on the basis of signals from said detecting device,

said controlling device controls said power supply to start supplying the electric power to said PM purifying reactor, or to increase the amount of electric power which is supplied to said PM purifying reactor, when the amount of accumulated PM detected by said detecting device exceeds a predetermined amount.

2. The exhaust gas purifying apparatus according to claim 1, wherein the detecting device comprises a differential pressure gauge which detects a differential pressure across the PM purifying reactor.

3. The exhaust gas purifying apparatus according to claim 1, wherein said PM purifying reactor comprises electrodes and an insulative honeycomb structure having a number of cell passages.

4. The exhaust gas purifying apparatus according to claim 3, wherein the electrodes generate an electric field which is not parallel to the direction of the cell passages of said honeycomb structure.

5. The exhaust gas purifying apparatus according to claim 4, wherein the electrodes comprises a center electrode and an outer electrode surrounding the center electrode, and the honeycomb structure is positioned between the center and the outer electrodes.

6. The exhaust gas purifying apparatus according to claim 4, wherein said honeycomb structure has opposite outer surfaces, and said electrodes comprise a pair of plate electrodes respectively placed on the opposite outer surfaces of said honeycomb structure, and sets of said honeycomb structure and said pair of plate electrodes are aligned in parallel to each other.

* * * * *