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EXHAUST TREATMENT APPARATUS AND METHOD

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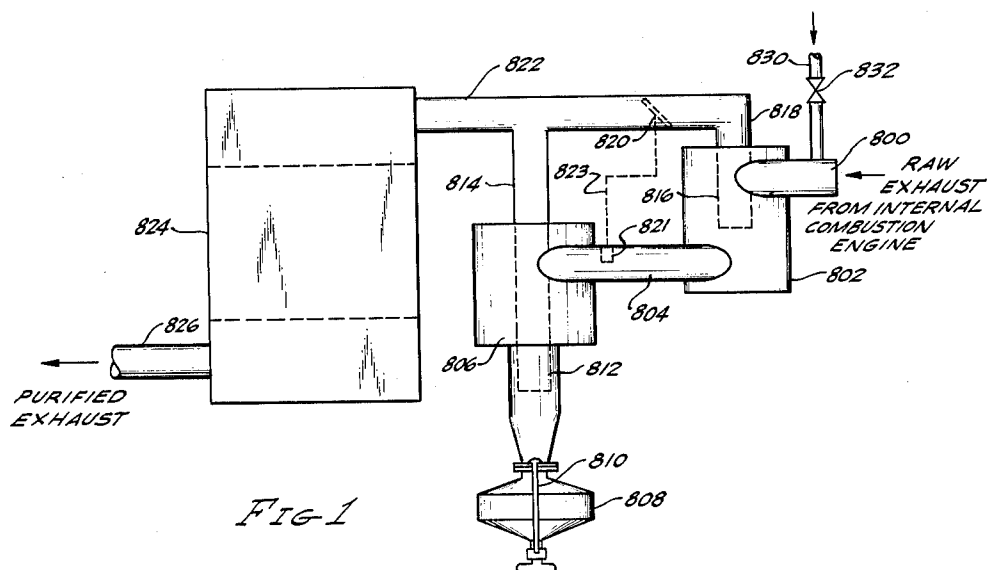


FIG 1

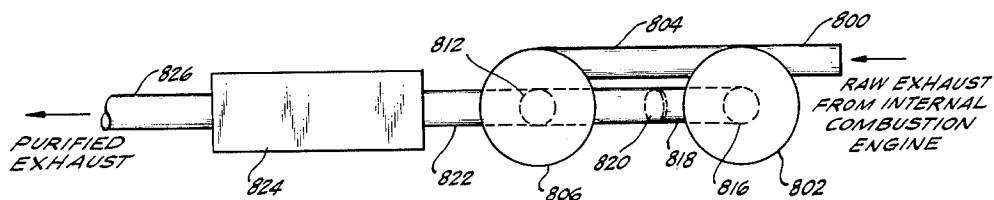


FIG 2

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EXHAUST TREATMENT APPARATUS
AND METHOD

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480,438

8 Claims. (Cl. 60—30)

This application is a division of application Serial No. 129,760 filed August 7, 1961, which in turn is a continuation-in-part of application Serial No. 40,305, filed July 1, 1960, now matured as U.S. Patent No. 3,132,473.

This invention relates to the abatement of air pollution by the control of internal combustion engine emissions, and in particular concerns new and useful improvements in methods and apparatus for removing pollutant materials from the exhaust gases of automotive internal combustion engines burning metal-containing additive fuels.

The existence of noxious and harmful gaseous components, such as carbon monoxide, nitrogen oxides, sulfur oxides and hydrocarbons in the exhaust gases expelled from internal combustion engines powering automotive vehicles is well known. Many systems have been devised in the past in an attempt to remove these pollutants from the exhaust gas, but little attention has been given to eliminating the particulate metal compounds in these automotive exhaust streams which result from the passage of metal-containing gasoline and oil additives through an internal combustion engine. Tetraethyl and tetramethyl lead, used extensively as antiknock additives in most hydrocarbon automotive fuels, produce lead compounds in the exhaust which contribute to air pollution, and which have substantial value if they can be recovered. Tremendous quantities of lead are expelled every day in the combustion of lead-containing fuels, e.g., in the Los Angeles Basin of Southern California alone, in excess of about 30,000 pounds of lead is exhausted from vehicles which burn about 6,000,000 gallons of gasoline every day. The practical elimination of this particular source of contamination has been an unsolved problem over the years.

Tetraethyl lead has been used since 1923 to provide the improved antiknock quality required to keep pace with more efficient engines having high compression ratios. Virtually all automotive gasolines today contain tetraethyl or tetramethyl lead, or both, in concentrations up to about 4 milliliters per gallon (about 0.15 weight percent lead). Commercial antiknock fluids also usually contain ethylene dibromide and ethylene dichloride to scavenge engine combustion chambers by converting lead oxide to lead halides which have greater volatility at engine temperatures and can be expelled. The elimination of lead from engines is thus manifested by the discharge particulate oxides and halides of lead. In fact, substantially all of the particulate matter in auto exhausts, on a weight basis, is composed of lead compounds. For the most part, these compounds do not remain suspended in the atmosphere, but fall upon the highways and accumulate.

Metal compounds in the exhaust stream have posed a further problem in previous attempts to use afterburners and catalytic devices for purifying engine exhausts. The metal compounds, particularly those containing lead, have been found to poison most catalysts seriously, thus rapidly deactivating catalytic converters and making their use costly and impractical. Even where the catalysts are not seriously poisoned by metals such as lead, they are gradually coated with an adhesive deposit of metal salts that eventually covers the surface of the catalysts and reduces its effectiveness. These metal salts, usually lead salts,

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have also been found to interfere with the effective life of sound-attenuating mufflers and direct flame afterburners by adhering to the internals of those devices thus plugging the flow areas and increasing the pressure drop through the entire exhaust system.

It is accordingly an object of this invention to provide an improved method and apparatus for the abatement of atmospheric pollution resulting from the operation of internal combustion engines which burn fuels having metal-containing additives.

Another object is to provide an improved method and apparatus for effectively removing a major portion of the metal compound particles from automotive exhausts, thus preventing the dispersal of these pollutants into the atmosphere and onto the earth's surface.

A further object of this invention is to provide an improved method and apparatus for preventing the poisoning of catalysts used to treat internal combustion engine exhausts by removing a substantial portion of the particulate metallic catalyst poisons from exhaust gas streams, thus substantially prolonging the life of such catalysts.

A still further object of this invention is to provide an improved method and apparatus for substantially eliminating the physical deposition of metallic compound particles within the internals of mufflers and afterburners used in conjunction with internal combustion engines burning metal additive fuels.

An additional object of this invention is to provide an improved method and apparatus for obtaining optimum particle removal by inertial separation with exhaust gas streams from internal combustion engines having widely varying flow quantities.

A still further object of this invention is to provide an improved method and apparatus for enhancing the agglomeration of particulate solids in the exhaust gas streams from internal combustion engines and for decreasing the gas viscosity substantially to optimize the removal of particulate masses from the gas stream.

Another object of this invention is to provide an improved method and apparatus for minimizing the entrainment of collected solids from a collection zone of an inertial separator because of the breathing effect inherent with the widely varying exhaust gas volumes of internal combustion engines.

A further object of this invention is to provide an improved method and apparatus for adding auxiliary combustion air to an exhaust gas stream prior to catalytic conversion.

Other and related objects will be apparent from the detailed description of the invention, and various advantages not specifically referred to herein will be apparent to those skilled in the art on employment of the invention in practice.

I have now found that the foregoing objects and their attendant advantages can be realized with a conventional internal combustion engine, such as is used in the propulsion of motor vehicles, by providing an inertial particle separator which removes the metal-containing particles from the exhaust stream by changing the flow direction of the particle-laden exhaust, thus providing a cleaned exhaust gas stream substantially reduced in metal-containing particles. After removal of a substantial proportion of these metal-containing particulate compounds from the exhaust gas system, the latter can be exhausted to the atmosphere through a conventional muffler, or it can be subsequently passed through a catalytic converter or afterburner with reduced poisoning of the catalyst and substantial elimination of the usual coating and plugging of afterburners with these metal compounds.

This invention is particularly concerned with the use of an apparatus which depends primarily on the separation of suspended matter from the gas stream by changing

the flow direction of the gas. Of these devices, conventionally called inertial separators, the most common are cyclones and baffle chambers. The cyclone separator, one of the most widely used of gas cleaning devices, generally consists of a main precipitating cylinder with a tangential gas inlet, an inverted cone attached to the base for the collection of particulate matter, and a central gas outlet. The main precipitating cylinder can have a diameter from less than one inch to several feet, depending on the efficiency desired and the amount of gas which must be handled. In a conventional cyclone, the gas enters tangentially either from a horizontal duct or through directing vanes, then spirals downwardly through the annular space between the main precipitating cylinder and the central outlet tube into a cylindrical or conical chamber, turns upward and forms an inner spiral of gas which leaves through the central outlet tube. The solids particles impact on the walls of the separator, lose their momentum, and fall to the bottom of the conical chamber of the cyclone where they are periodically removed. Cyclones are particularly effective, i.e., above about 90 percent efficiency, in removing particles or agglomerates 5 microns and larger. However, cyclones can remove much smaller particles, even 1 micron size and below. The conventional cyclone design has become standard and tables of detailed dimensions are available from many sources.

A particular feature of my invention is the protection of exhaust conditioning devices by pretreatment of the exhaust stream with inertial separators. These exhaust conditioners are usually either mufflers (sound attenuators) or devices for removing gaseous contaminants from the exhaust stream. Since the gaseous contaminants of automobile exhaust gases are for the most part unburned or partially burned hydrocarbons, one of the most effective methods of reducing these contaminants lies in completing the combustion initiated in the engine, thereby converting these contaminants into carbon dioxide and water. This is the principle of "afterburners" which are of two main types: the catalytic converter and the direct flame afterburner. The principal difference between the catalytic converter and the direct flame afterburner is that, with a catalyst present, considerably lower temperatures suffice to oxidize the combustible contaminant material.

In a catalytic converter, exhaust gases, usually with sufficient added air for complete oxidation of the contaminants, are brought into intimate contact with a catalytic material. A sufficiently high temperature must be maintained to insure a continuous and complete oxidation of the contaminants to carbon dioxide and water. With both the catalytic converter and the direct flame afterburner, provisions are normally necessary for a controlled air supply. Although the invention is not limited to the use of any particular catalyst, a typical preferred oxidation catalyst comprises small pellets, e.g., $\frac{1}{32}$ -inch to $\frac{1}{4}$ -inch, of an activated oxide carrier such as activated alumina, silica, beryllia, thoria, magnesia, zirconia or mixtures thereof impregnated with catalytically active metals or the metal oxides, or mixtures thereof, of metals such as copper, molybdenum, tungsten, nickel, cobalt, vanadium, chromium, manganese, titanium, tantalum, and iron.

One of the more common types of oxidation catalyst comprises noble metals which include platinum, palladium, gold, silver, iridium, rhodium, ruthenium, osmium, etc. These noble metals, when used as catalysts, are often generally associated with a refractory metal oxide and particularly an oxide of a metal in the left-hand column of Groups III and IV of the Periodic Table including particularly the oxides of aluminum, titanium, zirconium, hafnium, thorium, etc. Sometimes two or more metal oxides can be included in the catalyst and in other cases activating components can also be included in the catalysts. These activating components generally

are acidic and include halogens, particularly chloride and fluorine, other mineral acids, organic acids, and the like, the acid component or components usually being associated with the metal oxide and/or metal in the combined state. In general, the oxidation catalyst is usually present in an amount from about 2 to about 30 percent, based on an overall weight of the catalyst and its support.

Suitable reduction catalysts for use in catalytic converters, either alone or in combination with oxidation catalysts, include active metals of Group VIII of the Periodic Table and/or their oxides supported on activated alumina, e.g., nickel, copper, and the noble metals. A catalytic reduction zone usually precedes a catalytic oxidation zone in a two-stage series catalytic treatment of exhaust gas streams, but the catalysts in both catalytic zones can be the same with only a difference in reaction conditions. Any suitable oxidation or reduction catalyst can be used which is capable of operating over long periods of time at elevated temperatures, e.g., temperatures of 600° F. to 1,300° F. are common. However, the successful catalysts are all somewhat susceptible to metal poisoning or deactivation from lead, manganese, boron and the like. Although some catalysts appear to have a certain degree of lead tolerance, maximum catalyst life and efficiency can be attained only by the removal of metal poisons such as lead from exhaust gases prior to contacting the catalyst.

My invention will be more readily understood by reference to the accompanying drawing which forms a part of this application.

FIGURE 1 is a schematic diagram of the dual-cyclone separator of this invention with pressure control means for controlling the flow to the second-stage cyclone and having air introduction into the raw exhaust gas stream prior to entry into the dual-cyclone separators. The cyclone separators are shown in plan view, mounted with their longitudinal axis horizontal, in combination with a rectangular catalytic converter.

FIGURE 2 is a side view of the device of FIGURE 1. It is to be understood that although the metal-containing particle removal method and apparatus of this invention is particularly applicable to the internal combustion engines used in automotive vehicles, it is also broadly useful for other combustion engines such as those used in stationary installations, airplanes, and the like which use metal-containing fuels and oils.

Referring now more particularly to FIGURES 1 and 2, the apparatus there shown comprises a preferred embodiment of my exhaust gas treatment system. Raw exhaust gases from an internal combustion engine (not shown) are conducted to first cyclonic separator 802 via conduit 800. Exhaust gases enter first cyclonic separator 802 through a tangential entry and a cleaned exhaust gas is removed via central exit conduit 816 to cleaned exhaust conduit 818 at a rate controlled by butterfly control valve 820 which is responsive to pressure change in conduit 804 via mechanical linkage 823 connected to pressure responsive element 821.

The cleaned exhaust gas stream in conduit 818 is regulated by butterfly control valve 820 which is used to maintain a substantially constant volume of dirty exhaust gas flowing through conduit 804 (therefore constant pressure drop), thus assuring substantially optimum operation of cyclonic separator 806. Control valve 820 can be controlled hydraulically or mechanically, or by other suitable means to open or close with fluctuations in pressure or flow quantity in line 804. Mechanical biasing of valve 820 can also be done with a spring, or other suitable means responsive to changes in exhaust gas volume or pressure through conduit 804. A typical device for automatically regulating the flow of a gaseous fluid by means of the intake manifold pressure is illustrated in U.S. Patent No. 2,880,079. With a substantially constant pressure drop across cyclonic operator 806, the design of cyclone 806 can be set at an optimum for particle removal

from the exhaust of a particular engine. Thus, as the exhaust gas flow in line 806 decreases, the pressure decreases and pressure responsive element 821 reacts via mechanical linkage 823 and butterfly control valve 820 closes to maintain a substantially constant flow to cyclonic separator 806. As the exhaust gas flow in line 804 increases, the pressure increases and valve 820 opens sufficiently to maintain a substantially constant exhaust gas flow to cyclonic separator 806.

Valve 820 can also be operated by a conventional spring mechanism or by a diaphragm or piston positioner, either of which can be motivated by the manifold vacuum, a pressure drop in the exhaust system, or back-pressure on an engine exhaust. Alternatively, valve 820 can be controlled hydraulically or electrically by an analog signal equated to exhaust velocity, pressure drop, back-pressure, or the like. For example, as the volume of raw exhaust gas is increased passing through conduit 800, butterfly control valve 820 is opened to maintain a substantially constant pressure drop across cyclonic separator 806, and as the raw exhaust gas passing through conduit 800 is decreased, valve 820 is closed to maintain a substantially constant pressure drop across the flow through cyclonic separator 806. Thus, at very low exhaust gas flow volumes through conduit 800, valve 820 is completely closed and the entire gas stream passes through cyclonic separator 802 and exits therefrom via dirty exhaust gas conduit 804 to cyclonic separator 806. At high exhaust volumes through conduit 800, butterfly control valve 820 is in the horizontal position (completely open) thus permitting the maximum flow through conduit 818 and thus still maintaining a substantially constant pressure drop across cyclonic separator 806. The exhaust gas passing butterfly control valve 820 is conducted into cleaned exhaust gas manifold 822. The dirty exhaust gas stream from cyclonic separator 802 is removed from the collecting bottom of cyclonic separator 802 via a tangential outlet to cyclonic separator 806 via dirty exhaust gas conduit 804. The dirty exhaust gas from cyclonic separator 802 is passed into cyclonic separator 806 through a tangential entry and particles are separated therefrom by cyclonic action. A cleaned exhaust gas stream is removed from second cyclonic separator 806 via central exhaust gas exit 812 to cleaned exhaust gas conduit 814. Exhaust gas conduit 814 opens into cleaned exhaust gas manifold 822. Particulate solids removed from the exhaust gas stream in cyclonic separator 806 are collected in solids particle collector 808 which is removably attached to the base of second cyclonic separator 806 by means of clamp 810. Exhaust gas from cleaned exhaust gas manifold 822 is conducted into catalytic converter 824, containing a pelleted alumina impregnated with 10 weight percent manganese dioxide wherein the cleaned exhaust gas is catalytically reacted at about 730° F. for the removal of obnoxious and harmful components, producing as an effluent a purified cleaned exhaust gas which is removed from catalytic converter 824 via tail pipe 826.

Since cyclonic separators operate more efficiently at lower gas temperatures, advantage can be taken of the cooling effect from mixing auxiliary air with the raw exhaust gas prior to entry into the cyclone, particularly where such air is required for reaction in a catalytic converter located subsequent to a cyclone. In addition to the advantage of the lower viscosity which is inherent with the lower temperature gas streams resulting from the mixing of auxiliary air with the raw exhaust, a further advantage to adding cooling air relates to the greater agglomerating characteristics of the solids at lower temperatures. The solid metal particles in the cooler exhaust entering cyclone separators 802 and 806 agglomerate more readily, thus giving the solids a greater tendency to separate in the cyclone because of greater particle mass.

The auxiliary air, necessary for the combustion of hy-

drocarbons, carbon monoxide, and other obnoxious components in a catalytic converter such as catalytic converter 824, can be added at several locations. In FIGURE 1, auxiliary air is added to the raw exhaust in conduit 800 via conduit 830 at a rate controlled by valve 832 to take advantage of the cooling and agglomerating effect which can be gained by mixing raw exhaust gases with the auxiliary air. This auxiliary air can be supplied to air conduit 830 by a conventional venturi aspirator or by a pump, or other means. A preferable system comprises a variable flow pump controlled proportionally with engine speed to provide the desired exhaust gas-air ratio. A portion of the required air can also be added to exhaust gas manifold 822 if desired.

A dual cyclonic separator, as illustrated in FIGURES 1 and 2, is particularly advantageous since the efficiency of cyclonic separator 806 is increased by regulating its pressure drop near an optimum value. Also, because of the throttling valve feature of butterfly control valve 820, this apparatus improves engine efficiency by reducing the back-pressure to the engine at the higher exhaust velocities where normally this is a serious problem. When used in conjunction with a catalytic exhaust converter such as catalytic converter 824, dual cyclonic separators 802 and 806 constitute an apparatus of minimum size to separate and collect particulate matter such as lead particles with a maximum of efficiency which greatly extends the life and improves the performance of the catalytic converter.

Any metal-containing particle can be removed by the method and apparatus of the invention. For example, if a gasoline additive contains other metals, such as boron, manganese, phosphorus and the like, then the oxides, halides, and similar compounds of these metals are removed from the exhaust stream by the inertial separator. Although the major portion of the metallic solids in the exhaust gas is derived from metal-containing fuel additives such as lead and manganese, a portion of the metal also comes from the metal additives used in compounding lubricating oils. Lubricating oil is constantly being burned in the combustion chamber of an internal combustion engine, and the combustion products, including some metal compounds, are exhausted with the fuel combustion products. Some of the metals commonly found in lubricating oils, such as phosphorus, zinc, boron potassium, and the like, are known catalyst poisons and their removal from the exhaust stream is advantageous for the same reasons previously discussed with respect to lead. Another source of metal compound particles in the exhaust gas stream is the corrosion which takes place within the engine interior and exhaust manifold. This corrosion produces iron oxides and salts as well as oxides and salts of alloying elements, all of which are advantageously removed from exhaust gases prior to catalytic treatment.

A cyclonic separator installed on the exhaust outlet of an internal combustion engine behaves like an orifice and exhibits a pressure drop which increases with the square of the gas velocity. This pressure drop is the so-called back-pressure on the engine combustion chamber. Cyclones operate more efficiently at higher pressure drops, but any added back-pressure on the engine exhaust outlet results in a power loss. Consequently, the ultimate cyclone design in my invention is a compromise between engine performance and cyclone efficiency. As a design basis, the cyclone pressure drop is usually set at a value no greater than that of a standard muffler. The normal pressure drop in the conventional exhaust systems of automotive vehicles is in the range of 2 to 10 inches of water. Cyclones are least efficient at low speeds and idle and most efficient at high speeds and during acceleration. However, these characteristics are not necessarily disadvantageous since it is during periods of high power output that most of the lead is exhausted from internal combustion engines.

The apparatus of this invention can be installed in any

combination of number and sizes desired to obtain a particular pressure drop. Thus, series dual cyclones can be installed in parallel to provide any desired particle separation efficiency and pressure drop. If it is desired to take a greater pressure drop in the exhaust gas system than the conventional 2 to 10 inches of water, then some type of flow booster such as a fan, pump, aspirator or the like can be incorporated into the exhaust system to provide the necessary energy to overcome the additional pressure drop through the exhaust system.

Various other changes and modifications of this invention are apparent from the description of this invention and further modifications will be obvious to those skilled in the art. Such modifications and changes are intended to be included within the scope of this invention as defined by the following claims.

I claim:

1. A method of treating particle-laden internal combustion engine exhaust gas, which comprises:

adding air to the exhaust gas discharged from said engine to produce an exhaust gas mixture of reduced temperature;

causing said exhaust gas mixture to flow in a circular path in a first cyclone separation zone wherein said exhaust gas mixture is separated into a first cleaned exhaust gas mixture of reduced particle content and a first particle-rich exhaust gas mixture of increased particle content;

withdrawing said first cleaned exhaust gas mixture from said first cyclone separation zone;

withdrawing said first particle-rich exhaust gas mixture from said first cyclone separation zone;

causing said first particle-rich exhaust gas mixture to flow in a circular path in a second cyclone separation zone whereby solid particles are separated from said exhaust gas mixture by inertia to produce a second cleaned exhaust gas mixture of reduced particle content;

withdrawing said second cleaned exhaust gas mixture from said second cyclone separation zone;

passing said first cleaned exhaust gas mixture and said second cleaned exhaust gas mixture to an exhaust gas conditioner in which the noxious components of said exhaust gases are removed; and

discharging conditioned exhaust gas from said exhaust gas conditioner.

2. The method defined in claim 1 including the additional step of maintaining the pressure drop across said second separation zone at a value not to exceed a predetermined maximum by controlling the amount of said first cleaned exhaust gas withdrawn from said first cyclone separation zone.

3. The method defined in claim 1 including the additional step of accumulating the separated solid particles in a solids collecting zone.

4. The method defined in claim 3 including the additional step of periodically removing accumulated solid particles from said solids collecting zone.

5. A method of treating particle-laden internal combustion engine exhaust gas, which comprises:

adding air to the exhaust gas discharged from said engine to produce an exhaust gas mixture of reduced temperature;

introducing said exhaust gas mixture tangentially into a first cyclone separation zone so that said exhaust gas mixture is caused to flow in a circular path through said separation zone thereby causing the separation of said exhaust gas mixture into a first cleaned exhaust gas mixture of reduced particle content and a first particle-rich exhaust gas mixture of increased particle content;

withdrawing said first cleaned exhaust gas mixture from the axis of said circular flow path of said first cyclone separation zone;

withdrawing said first particle-rich exhaust gas mixture

tangentially from the periphery of the circular flow path of said first cyclone separation zone;

introducing said first particle-rich exhaust gas mixture tangentially into a second cyclone separation zone so that said exhaust gas mixture is caused to flow in a circular path through said separation zone whereby solid particles are separated from said exhaust gas mixture by inertia to produce a second cleaned exhaust gas mixture of reduced particle content;

withdrawing said second cleaned exhaust gas mixture from the axis of said circular flow path of said second cyclone separation zone;

controlling the volume of said first cleaned exhaust gas mixture withdrawn so as to maintain the pressure at the inlet of said second cyclone separator at a value not exceeding a predetermined maximum;

accumulating said separated solid particles in a solids collecting zone removed from said circular flow path; passing said first cleaned exhaust gas mixture and said second cleaned exhaust gas mixture to an exhaust gas conditioner in which the noxious components of said exhaust gases are removed; and

discharging conditioned exhaust gas from said exhaust gas conditioner.

6. An apparatus for the treatment of particle-laden internal combustion engine exhaust gas, which comprises:

a first cyclone separator;

an exhaust gas conduit communicating with said first cyclone separator for transporting raw exhaust gas from said engine to said first cyclone separator;

means for adding air to said raw exhaust gas discharged from said engine prior to introduction of said gas into said first cyclone separator;

a first cleaned exhaust gas conduit communicating with said first cyclone separator;

a second cyclone separator;

means for withdrawing a particle-rich exhaust gas stream from said first cyclone separator and transporting said withdrawn gas to said second cyclone separator;

a second cleaned exhaust gas conduit communicating with said second cyclone separator;

means for conditioning said first and said second cleaned exhaust gases communicating with said first and said second cleaned exhaust gas conduits;

means for discharging a conditioned exhaust gas from said exhaust gas conditioning means.

7. The apparatus defined in claim 6 additionally including valve means in said first cleaned exhaust gas conduit responsive to the pressure at the inlet of said second cyclone separator, said valve opening as said pressure is increased and closing as said pressure is decreased.

8. An apparatus for the treatment of particle-laden internal combustion engine exhaust gas, which comprises:

a first cyclone separator defining a confined circular flow path and having a tangential raw exhaust gas inlet, a tangential particle-rich gas outlet at the periphery of said circular flow path and a clean exhaust gas outlet at the axis of said circular flow path;

an exhaust gas conduit for transporting raw exhaust gas from said engine to said first cyclone separator communicating with said inlet of said first cyclone separator;

a first clean exhaust gas conduit communicating with said clean exhaust gas outlet of said first cyclone separator;

a second cyclone separator defining a confined circular flow path and having a tangential exhaust gas inlet at the periphery of said circular flow path and a clean exhaust gas outlet at the axis of said circular flow path;

means in communication with said tangential particle-rich gas outlet of said first cyclone separator for withdrawing a particle-rich exhaust gas therefrom

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and transporting said gas to the inlet of said second cyclone separator;

means in communication with said second cyclone separator for accumulating separated solid particles removed in said second cyclone separator;

a second clean exhaust gas conduit communicating with said clean exhaust gas outlet of said second cyclone separator;

valve means in said first clean exhaust gas conduit responsive to the pressure at the inlet of said second cyclone separator, said valve opening as said pressure is increased and closing as said pressure is decreased; means for conditioning said first and said second cleaned

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exhaust gases communicating with said first and said second cleaned exhaust gas conduits; and means for discharging a conditioned exhaust gas from said exhaust gas conditioning means.

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