May 12, 1964 R. H. HASS 3,132,473

EXHAUST PURIFYING APPARATUS AND METHOD

Filed July 1, 1960

2 Sheets-Sheet 1

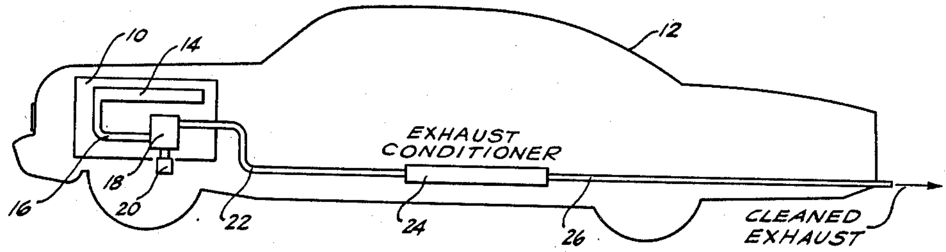

FIG-1

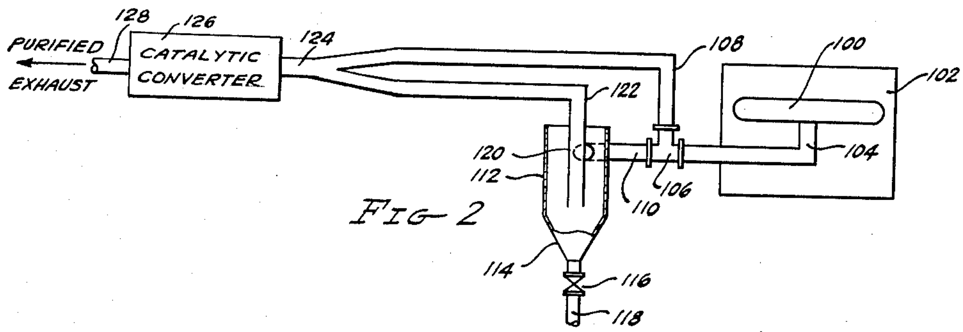

FIG-2

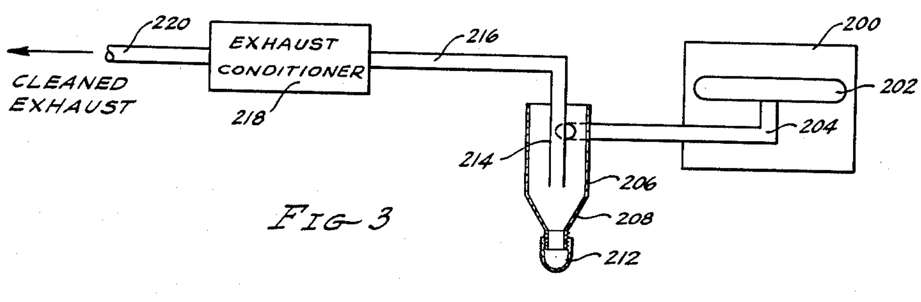

FIG-3

INVENTOR.
ROBERT H. HASS
BY Jack M. Miller
AGENT

May 12, 1964 R. H. HASS 3,132,473

EXHAUST PURIFYING APPARATUS AND METHOD

Filed July 1, 1960 2 Sheets-Sheet 2

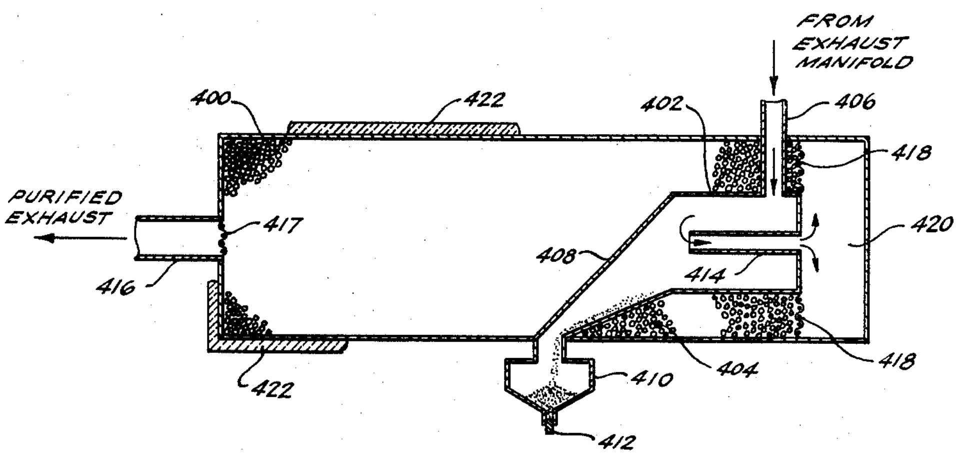

FIG-4

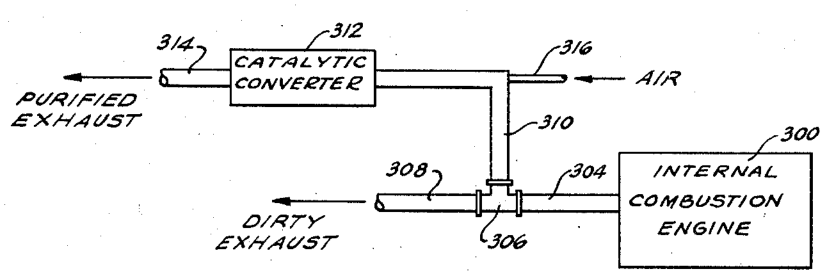

FIG-5

INVENTOR.
ROBERT H. HASS
BY Jack M. Miller
AGENT

United States Patent Office 3,132,473
Patented May 12, 1964

3,132,473

EXHAUST PURIFYING APPARATUS AND METHOD

Robert H. Hass, Fullerton, Calif., assignor to Union Oil Company of California, Los Angeles, Calif., a corporation of California

Filed July 1, 1960, Ser. No. 40,305
4 Claims. (Cl. 60—29)

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 automative 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 of 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 lead, they are gradually coated with an adhesive deposit of lead salts that eventually covers the surface of the catalysts and reduces its effectiveness. These lead salts 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.

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.

We 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 stream, 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 compound particles.

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% 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.

Another similar type of centrifugal separator, also operative in my invention, is a mechanical centrifuge wherein the centrifugal force comes not from the motion of the gas alone, but the gas rotation is obtained by means of a fan. The blades of the fan are especially shaped to direct the separated dust into an annular slot leading to a collection hopper while the clean gas continues to the scroll.

The impingement separator, another species of the inertial separator, depends on the inertial deposition of particles as a gas passes through an obstruction. The shape of the obstruction can vary from that of simple baffles to complicated patterns which give maximum impaction efficiency with minimum pressure loss. In baffle chambers, the simplest type of impingement separators, the suspended matter is impacted in the direction of flow while the gas undergoes at least one flow reversal, thus separating the gas from the solid particles. The tortuous flow of the baffle chamber is obtained by zigzag blades or shaped obstacles placed in the gas stream. These devices are particularly suitable for removing particles larger than 20 microns.

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 catalyst comprises a pelleted, e.g., $\frac{1}{32}$-inch to $\frac{1}{4}$-inch, carrier such as activated alumina impregnated with catalytically active metals or metal oxides, such as palladium, platinum, copper oxide, vanadium oxide, chromium oxide, or mixtures thereof. Any suitable oxidation, or reduction, catalyst can be used which is capable of operating over long periods of time at elevated temperatures. 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 lead from exhaust gases prior to contacting the catalyst.

My invention will be more readily understood by reference to the accompanying drawings which form a part of this application. FIGURE 1 is a schematic diagram of one of the simplest embodiments of this invention comprising an intertial separator and an exhaust conditioner as incorporated on an automobile. FIGURE 2 is a schematic diagram of the apparatus of this invention illustrating a specific embodiment of an inertial separation device comprising a T separator and a cyclone separator. FIGURE 3 is a schematic diagram of a cyclone separator used in combination with an exhaust conditioner. FIGURE 4 is a schematic diagram of a catalytic converter with an integral intertial separator. FIGURE 5 is a schematic diagram of a T separator used to pretreat the gas feed to a catalytic converter. 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 internal 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 FIGURE 1, the apparatus there shown consists essentially of a particular exhaust gas system for internal combustion engine 10 used to power automotive vehicle 12 by burning metal-containing fuels. The particle laden exhaust gas from internal combustion engine 10, running at normal load is expelled at a temperature of about 1,000–1,600° F. through exhaust manifold 14 into exhaust conduit 16. Exhaust conduit 16 conveys the exhaust gas to inertial separator 18 at a flow quantity between about 6 s.c.f./minute and about 250 s.c.f./minute (s.c.f.=cubic feet at 60° F. and one atmosphere pressure) and at a temperature usually between about 500° F. and about 1,200° F. Inertial separator 18, wherein there is some form of directional flow change of the exhaust gas stream, can be located at any point in the exhaust system after exhaust manifold 14, but for convenience of access is preferably located near internal combustion engine 10 in the engine compartment. Solids particles, comprising primarily the oxides and halides of metals in the fuels, are separated from the exhaust gas stream and collected in solids container 20. Periodically, container 20 is emptied of accumulated metal compound solids. The cleaned exhaust gas stream exits from inertial separator 18 via conduit 22 which conveys the cleaned exhaust gas stream to exhaust conditioner 24. Exhaust conditioner 24 can be a direct flame afterburner, a catalytic converter, a conventional sound attenuating exhaust muffler, or some other type of exhaust conditioner. After treatment in exhaust conditioner 24, the exhaust gas stream is expelled to the atmosphere via tail pipe 26 whose outlet is conventionally, but not necessarily, located at the rear of the vehicle.

Conduits 16, 22 and 26 are usually constructed of $1\frac{1}{2}$ to 2-inch I.D. steel tubing, such as is conventional for exhaust system piping, but any tubing size can be used to give appropriate flow velocities and pressure drops. The overall pressure drop of the exhaust system shown in FIGURE 1 is usually about 2 to about 10 inches of water at cruising speed (about 50 m.p.h.), but can vary from less than one inch of water to more than 15 inches of water with ordinary passenger vehicles. The representation in FIGURE 1 is illustrative of an exhaust system having a single common exhaust line, but it is common in modern internal combustion engines, particularly those with eight cylinders, to have dual exhaust systems conducting the exhaust gases from each side of the engine to separate exhaust gas systems. In such a case, the system as shown in FIGURE 1 would be duplicated for each side with appropriate sizing to accommodate the reduced exhaust gas flow. The method and apparatus of my invention has been successfully applied to engines on vehicles having dual exhaust systems and any number of inertial separators may be integrated into an exhaust system.

A specific embodiment of an inertial separator is shown in FIGURE 2. Exhaust manifold 100 conducts the expelled exhaust gases to exhaust conduit 104 from internal combustion engine 102 which is burning a "leaded" gasoline. Exhaust conduit 104 is connected to T separator 106 wherein the particle laden exhaust gas is separated into a cleaned stream (reduced particulate content) which is exhausted through conduit 108, and a dirty stream (increased particulate content) which is passed to separator 112 through conduit 110. Although conduit 108 is shown as a 90° connection in relation to the straight-through portion of T separator 106, it is to be understood that the axis of conduit 108 can be at any angle removed from the axis of the straight-through portion of the conduit represented by the aligned portions of conduit 104, T separator 106, and conduit 110. Preferably, conduit 108 is at an angle of between about 15° and about 165° from the above-mentioned aligned portions, and usually is a standard piping or tubing T with the branch at 90° to the straight-through portion of the T. The lead compound particles, having a greater inertia than the gaseous components, tend to continue in the original direction of flow while a portion of the gas stream makes a flow direction change and flows up through the 90° branch of T separator 106 into conduit 108 as a cleaned stream of reduced lead content. The dirty stream, containing substantially all of the metal-containing particles (lead compounds) in the exhaust gas entering T separator 106 from exhaust conduit 104, is conducted from T separator 106 to cyclone separator 112 via line 110. In cyclone separator 112 the gas velocity generates a centrifugal force which impacts the lead compound particles against the walls of cyclone separator 112 and the particles settle downwardly into collector 114. Periodically, the metal-containing solids particles are removed from collector 114 via line 118 by opening solids valve 116. The exhaust gas, after undergoing a change of flow direction in cyclone 112, is withdrawn via central gas outlet 120 to conduit 122 which conducts the substantially particle-free gas stream from cyclone separator 112. The cleaned exhaust gas stream in conduit 122 is combined with the cleaned exhaust gas in conduit 108 in manifold 124, and the mixed streams conducted to catalytic converter 126 wherein the pollutants in the exhaust gases are removed and the purified exhaust is discharged from catalytic converter 126 via tail pipe 128.

Referring now more particularly to FIGURE 3, the apparatus there shown comprises another embodiment of my exhaust treatment system. The exhaust gases from internal combustion engine 200 are expelled to cyclone separator 206 via exhaust manifold 202 and exhaust conduit 204. The dirty exhaust gas stream is tangentially introduced into cylindrical cyclone vessel 206 wherein by centrifugal action the solid particles are concentrated at the periphery of the vessel where they impact with the vessel walls, lose their momentum, and fall through conical collector 208 at the bottom of the vessel into solids container 212. The metal compound particles are periodically recovered from solids container 212 by unscrewing the threaded portion of container 212 from conical collector 208. Solids container 212 can be attached to the bottom of the cyclone by a threaded fitting as shown, or by a flanged fitting, clamp or other such connecting means. The exhaust gas spirals downwardly between the walls of vessel 206 and central gas exit 214 to the opening in central gas exit 214 located below the tangential cyclone gas inlet. The gas, substantially free of solid particles, then flows into central gas exit 214 which connects directly to exhaust gas conduit 216. The cleaned exhaust gas is then conducted to exhaust conditioner 218 wherein subsequent purification or other treatment takes place. The treated exhaust gas is then expelled to the atmosphere via tail pipe 220.

A further modification of my exhaust gas treatment system is illustrated in FIGURE 4. The cylindrical cyclone separator 402 in this embodiment is integrally mounted within catalytic converter 400 and is surrounded by catalyst bed 404. Thus, there is no heat loss from the inertial separator (cyclone separator 402) and the exhaust gas feed to the catalyst bed is maintained at a high temperature level. A reduction in the length of the connecting conduit between the catalytic converter and the exhaust manifold is often desirable from the standpoint of reducing the heat loss from the exhaust gas before it contacts the catalyst bed. The exhaust gas, containing lead compound particles from an internal combustion engine exhaust manifold, enters the side of converter 400 via line 406 which is directly connected to cyclone separator 402 which is centrally disposed within catalytic converter 400. The gas stream spirals towards the opening in central gass outlet pipe 414 which conducts the essentially particle-free stream into reversal chamber 420. In chamber 420 the cleaned gas makes a 180 degree change in flow direction and enters catalyst bed 404 through catalyst retaining screen 418. The cleaned gas entering catalyst bed 404 passes the length of catalytic converter 400, exiting therefrom through catalyst retaining screen 417 via tail pipe 416. Catalytic converter 400 is preferably surrounded by a layer of thermal insulation 422. Any conventional insulating material can be used such as glass-wool, asbestos, and the like. The exit gas has had the lead particles removed therefrom, and carbon monoxide, hydrocarbons, etc., have been converted to inert harmless compounds such as carbon dioxide and water. The lead compound particles, impacted on the walls of cyclone separator 402 by the swirling action of the gas stream, settle into conical section 408 which funnels into container 410. Container 410 is periodically drained of collected solids by removing plug 412.

The following examples specifically illustrate the practice of my invention.

Exaxmple I

The effectiveness of the device illustrated in FIGURE 2 was demonstrated in a nine-hour experiment wherein internal combustion engine 100 was a one-cylinder four-cycle Lauson engine, Model L–F, with a displacement of 13.5 cubic inches, a compression ratio of 6 to 1, and having about 2.75 horsepower at 1,800 r.p.m. This engine had a gasoline consumption rate of about 359 grams/hour which is equivalent to about 3.06 gallons/day and burned a 99 Research Octane fuel containing 2.93 milliliters of tetraethyl lead (motor mix)/gallon.

Line 104 was a ¾-inch Schedule 40 steel pipe connected directly to the exhaust port on the vertical side of the Lauson engine and ran horizontally into a standard ¾-inch piping T which constituted T separator 106. Line 108, a ¾-inch Schedule 40 steel pipe, was connected vertically in a fluid-tight manner to the branch connection of T separator 106, and conducted the cleaned exhaust gas to an atmospheric exhaust vent. Horizontal line 110, a ¾-inch Schedule 40 steel nipple, was threaded at one end into T separator 106 and was connected at the other end to the inlet of cyclone separator 112. Line 122, a ¾-inch Schedule 40 steel pipe connected to the cleaned gas outlet of cyclone 112, conducted the exhaust gas from the apparatus to an atmospheric exhaust vent.

Cyclone separator 112 was an Aerotec dust collector (Aerotec Corp., Greenwich, Conn.) with an inlet manifold surrounding two tangential gas entries, 180° apart, opening into a main precipitating cylinder about ¾-inch in diameter. The central gas outlet tube 120 was ⅜-inch in diameter with its inlet located below the level of the tangential gas entries. The flow capacity of this cyclone separator was determined to be about 50 cubic feet/hour at 60° F. and one atmosphere pressure with a pressure drop across the cyclone of about 4 inches of water.

The total exhaust rate, determined by connecting a wet test meter directly to the exhaust port of the Lauson engine, recorded 1.0 cubic foot/30 seconds, equivalent to about 120 s.c.f./hour. The exhaust gas flow through the cyclone during the nine-hour run determined by passing the entire flow from line 122 through a wet test meter, averaged 51.6 s.c.f./hour from two determinations: one of 49.7 s.c.f./hour (0.25 cubic feet/18.1 seconds) and a second of 53.4 s.c.f./hour. By difference, the flow through line 108 was ascertained to be about 68.4 s.c.f./hour.

The exhaust gas streams were isokinetically sampled by withdrawing a representative gas sample during the experiment and analyzing for lead. Each exhaust gas sample was drawn through a condensate trap in an ice bath, then through a Type AA Millipore filter having a pore size of 0.80 micron, and finally through a wet test meter to determine the sample volume. The particulate matter collected in the Millipore filter and the contents of the condensate trap were each dissolved in a nitric acid solution. These nitric acid solutions of the collected particulate matter were then separately analyzed for lead content by polarograph. The following table gives the lead analysis of the feed and product gas streams flowing through the apparatus as determined by the above procedure:

	Wet Test Meter Pressure, in. of Hg vacuum	Measured Sample Volume, ft.^{3}	Corrected Sample Volume, s.c.f.	Lead Found, milligrams		
				Filter	Trap	Total
Raw Exhaust (line 104)	2.0	2.4	2.24	2.0	1.7	3.7
By-Pass (line 108)	2.0	20.0	18.70	3.5	2.1	5.6
Cyclone Outlet (line 122)	2.0	20.1	18.75	4.8	1.9	6.7

Thus, to summarize this experiment, the lead content of the raw exhaust gas in exhaust conduit **104** averaged 165 milligrams of lead/100 s.c.f. and was introduced into T separator **106** at a temperature of about 700° F., and a linear flow velocity of about 20 feet/second. After undergoing a flow direction change in T separator **106**, about 57 percent by volume of the total exhaust gas stream from conduit **104** was withdrawn via conduit **108** at a temperature of about 700° F. and a velocity of about 11 feet/second. The gas stream in conduit **108** averaged 30 milligrams of lead/100 s.c.f., or only about 18 percent by weight of that present in the raw exhaust gas. The gas entering cyclone **112** from conduit **110** had a velocity of about 9 feet/second at a temperature of about 700° F. The clean gas leaving cyclone **112** via line **122** contained an average of about 36 milligrams of lead/100 s.c.f., or only about 22 percent by weight of that present in the raw exhaust gas. At the end of the nine-hour run, 1.4728 grams of particulate solids removed from collector **114** (cyclone separator **112** was not entirely cleansed of solids) was analyzed for lead and found to contain about 61.5 percent by weight lead. A determination of particle size, made on a representative sample of these solids by photomicrograph (100×), revealed about 64 percent by number of particles 5.4 microns and smaller. Thus, T separator **106** and cyclone **112** effected a lead removal efficiency of approximately 80 percent.

Example II

In this experiment, the T separator, previously described in relation to FIGURE 2, was used as a lead removal pretreater for a catalytic converter. The apparatus used is illustrated in FIGURE 5 and included the identical Lauson engine described in Example I, shown as internal combustion engine **300**, burning the same fuel at the same rate as in Example I. Line **304**, a ¾-inch Schedule 40 steel pipe connected to the exhaust port in the vertical side of engine **300**, ran horizontally into T separator **306**. The latter took the form of a ¾-inch pipe T and had a ¾-inch flexible conduit **308** connected to it in a straight-through flow direction from line **304**. Conduit **308** conveyed the dirty exhaust gas stream to an atmospheric exhaust vent. Line **310**, a ¼-inch stainless steel pipe vertically connected to the branch connection at the top of T separator **306** by means of a suitable bushing, conducted the cleaned exhaust gas to catalytic converter **312**. Auxiliary combustion air was injected from line **316** into the exhaust gas stream in line **310** in order to supply sufficient oxygen for complete combustion in catalytic converter **312**. About 70.1 grams of a platinum-containing catalyst (0.6 weight percent platinum) on a gamma alumina carrier (⅛-inch pellets) was held in a 5.25 inch long fixed-bed in catalytic converter tube **312**. The catalyst bed volume was thus about 75 milliliters. During the 371 hour run period the average hourly gas space velocity (volume of gas per hour per volume of catalyst) was about 7,000 at an average conversion temperature of about 800° F. Line **314**, a ¼-inch Schedule 40 steel pipe, conducted the purified exhaust gas to an atmospheric exhaust vent. The flow rate of the purified gas exhausted from line **314** was determined periodically by wet test meter, and averaged about 0.1 cubic foot/19.5 seconds (18.5 s.c.f./hour). This gas included an air flow (by wet test meter) of 0.1 cubic foot/61 seconds (6 s.c.f./hour). The gas flow through line **310** was then found by difference (disregarding changes in volume in catalytic converter **312** due to combustion) to be about 12.5 s.c.f./hour. Therefore, the gas velocity in line **304** was about 20 feet/second at an average temperature of about 700° F. as it entered T separator **306**; the gas velocity in line **310** was about 14 feet/second at about 700° F.; and the gas velocity in line **308** was about 18 feet/second at about 700° F. Thus, with a total exhaust volume of 120 s.c.f./hour containing about 165 milligrams of lead/100 s.c.f., it would be expected that in 371 hours operation a total of 7.65 grams of lead would be deposited on the catalyst and/or would be contained in the effluent from line **314**. However, the purified exhaust gas stream from line **314** was substantially lead-free and the catalyst was found to contain only 136.9 milligrams of lead. This indicated a lead separation efficiency of about 98 percent for T separator **306**. The dirty exhaust gas expelled from line **308**, thus contained in excess of 99 percent of the lead exhausted from engine **300**.

Ordinarily, the platinum-containing catalyst referred to above has an active life of less than 100 hours (activity drops to substantially zero) when operated to treat raw exhaust gas under the conversion conditions set forth above. However, after 371 hours operation (equivalent to 13,000 miles of vehicle travel), in the system of FIGURE 5, the catalyst was found to still have sufficient activity to burn most of the pollutants present in the exhaust. The following table gives the catalyst conversion activity throughout this experiment in terms of percent conversion (burned to carbon dioxide and water) of pollutants as determined by infrared spectrophotometric analysis of the purified exhaust.

Hrs.	Equiv. Mileage	Exhaust Gas Temperature, ° F.		Percent Conversion of Exhaust Pollutants				
		Entering Converter	Leaving Converter	C_3+ Hydrocarbons	CO	CH_4	C_2H_4	C_2H_2
42	1,470	510	1,180	100	100	100	100	100
138	4,830	525	1,367	100	100	100	100	100
371	13,000	579	1,159	95	100	80	100	100

This example is thus indicative of the high separation efficiency of the T form of inertial separator when used in my invention, and shows a minimum of a seventy-fold extension of catalyst life which can be expected when pretreating the exhaust gas feed to a catalytic converter by inertial separation of the lead compound particles.

Example III

This example is illustrative of the use of the apparatus of FIGURE 3 when utilized in combination with a conventional automobile having an eight-cylinder internal combustion engine. Engine **200** has a compression ratio of about 10.2 to 1; a 352 cubic inch displacement; a brake horsepower of about 300; and usually consumes about one gallon of gasoline per 14 miles of travel to produce an exhaust gas quantity of about 6 s.c.f./minute at idle, about 250 s.c.f./minute at maximum acceleration, and about 49 s.c.f./minute at a normal road speed of 50 m.p.h.

The hydrocarbon fuel burned in engine **200** has a Research Octane of about 99, contains about 3 milliliters of tetraethyl lead per gallon (about 0.113 weight percent lead in the fuel), and contains small amounts of ethylene dibromide and ethylene dichloride as scavengers. Conduit **204**, having an inside diameter of about 2 inches, conducts the exhaust gas at an average temperature of about 900° F., to cyclone **206** which has an inlet gas manifold surrounding dual tangential gas entries 180° apart opening into a main precipitating cylinder about 3 inches in diameter and having a central gas outlet tube about 2 inches in diameter with its inlet located below the level of the tangential gas entries. This cyclone has a pressure drop of about 2 inches of water at a 50 m.p.h. cruising speed (49 s.c.f./minute of exhaust) when the exhaust gas leaving the cyclone has a temperature of about 700° F.

Conduit **216** has an inside diameter of two inches and connects the central gas outlet **214** of cyclone **206** to exhaust conditioner **218** which is a catalytic converter containing about 25 pounds of a vanadium pentoxide catalyst (10 percent vanadium pentoxide). The hourly gas space velocity within catalytic converter **218** averages about 7,400 at cruising speed (50 m.p.h.) with an average conversion temperature of about 800° F.

The purified effluent from tail pipe **220** is essentially lead-free throughout the life of the vehicle and contains only trace amounts of the harmful, noxious unburned hydrocarbon components normally found in untreated exhaust gas streams. When 1,800 gallons of fuel is consumed in about 700 hours of operation in traveling 25,000 normal driving miles, the catalyst activity at the end of the 700 hours of operation is approximately 75 percent of the original activity. At this rate of deactivation the catalyst would be completely deactivated at the end of about 2,800 hours of operation (100,000 miles). A typical lead balance around the exhaust gas system and the internal combustion engine after 700 hours operation reveals the following:

	Lbs.
Lead in gasoline to engine **200**	12.3
Lead in exhaust gas from manifold **202**	9.2
Lead collected in container **212**	8.5
Lead on catalyst in converter **218**	0.7
Lead in exhaust gas to atmosphere	Nil

When the identical run conditions are duplicated except that conduit **204** is connected directly to catalytic converter **218**, and cyclone **206** is hence by-passed, the vanadium pentoxide catalyst is lead poisoned and almost completely deactivated (about 10 percent of original activity) within about 280 hours (10,000 miles). This example is thus illustrative of extending the catalyst life of a catalytic converter by about tenfold with a cyclone separator pretreatment.

Example IV

This example, with the same apparatus and operating conditions as described in Example III except that exhaust conditioner **218** is a direct flame afterburner instead of a catalytic converter, illustrates the use of inertial separators to protect afterburners, mufflers, and the like. After 200 hours of operation (7,000 miles), the internal flow surfaces of the afterburner are clean and without deposits. This contrasts with the condition of the same afterburner when operating on the exhaust gas directly from exhaust conduit **204**, wherein after about 200 hours of operation, the afterburner flow surfaces are heavily coated with lead compounds which adhere tightly to the flow surfaces and which plug the burner internals. Thus, increased effectiveness and a prolonged life can be expected of any exhaust conditioner used subsequent to the inertial separators of this invention.

The exhaust treatment apparatus of this invention is rugged by virtue of its simplicity, but should any maintenance or repair work be required, this can easily be accomplished since conventional parts, fittings and equipment are, for the most part, used to construct the exhaust flow system.

Although the invention described herein has as a principal purpose the removal of lead particles from the exhaust stream, it has been found that the inertial separator is also valuable in protecting catalytic devices from detrimental slugs of liquid hydrocarbon, water, etc., which occasionally are expelled through the exhaust manifold because of engine malfunction and the like. Thus, any such liquid separated from the exhaust stream is gradually vaporized in the collection zone of the inertial separator and returned to the exhaust stream as a gaseous component.

While the foregoing specific examples have been described with particular reference to the removal of solid lead compounds from exhaust gases, it is to be understood that 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.

The normal pressure drop in the conventional exhaust systems of automotive vehicles is in the range of 2 to 10 inches of water. This pressure drop is the so-called backpressure on the engine combustion chamber. The apparatus of this invention, and in particular the inertial separators, can be installed in any combination of number and sizes desired to obtain a particular pressure drop. Thus, cyclones, T separators, and the like can be installed in series or 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 and 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 separating metal compound particles from an exhaust gas of an internal combustion engine burning a metal-containing fuel which comprises:

passing said exhaust gas from said internal combustion engine into a main exhaust conduit having a straight section;

allowing a first gas stream to flow from an intermediate location in the length of said straight section of said main exhaust conduit into a bypass conduit in such manner that said first stream of gas leaves said main exhaust conduit at an angle from the longitudinal axis of said main exhaust conduit thereby disengaging metal compound particles by inertia from said first gas stream of said exhaust gas and effecting a concentration of metal compound particles in the remaining gases flowing in said straight section of said main exhaust conduit past said bypass conduit;

abruptly changing the direction of flow of said remaining gases in a confined separation zone whereby metal compound particles are disengaged therefrom by inertia;

collecting said disengaged metal compound particles in a collection zone away from the redirected flow of exhaust gases;

removing from said separation zone a second cleaned exhaust gas stream with a substantially reduced metal compound particle content relative to that of said remaining gases entering said confined separation zone;

combining said first gas stream and said second cleaned exhaust gas stream; and

passing said combined first and second cleaned exhaust gas streams through a catalytic converter to purify said combined cleaned exhaust gas streams.

2. In combination with an internal combustion engine:

a cyclone separator;

primary conduit means for delivering engine exhaust gases from said engine to said cyclone separator, said primary conduit means having a straight conduit section;

solid particle connecting means communicating with the lower end of said cyclone separator and adapted to receive by gravity flow solid particles separated from the engine exhaust gas in said cyclone separator;

means for removing collected solid particles from said collecting means;

a catalytic contacting vessel having a gas inlet and containing a fixed-bed of a solid conversion catalyst;

a bypass conduit opening at one end into an intermediate location in the length of said straight conduit section of said primary conduit means at an angle of between about 15° and 165° from the longitudinal axis of said primary conduit, said bypass conduit communicating at its other end with the gas inlet end of said catalytic contacting vessel; means for passing cleaned gas from said cyclone separator to said gas inlet of said catalytic contacting vessel and through said bed of catalyst; and means for discharging cleaned converted gas from said catalytic contacting vessel to the atmosphere.

3. A device for conditioning exhaust gas containing lead and incompletely burned fuel components produced by an internal combustion engine, comprising:

a closed vessel provided with exhaust gas inlet means and conditioned gas outlet means adjacent its opposite ends respectively;

a cyclone separator positioned within said vessel and adapted to receive exhaust gas introduced into said vessel via said inlet means;

solid particle collecting means positioned at the lower end of said cyclone separator and adapted to receive by gravity flow solid particles separated from exhaust gas introduced into said cyclone separator; and

means for removing collected solid particles from said collecting means to a point exterior of said vessel, said vessel walls forming enlarged conduit means surrounding and spaced apart from said cyclone separator, said enlarged conduit means containing a gas permeable catalyst and transmitting exhaust gas from the outlet of said cyclone separator to said conditioned gas outlet means.

4. A device as defined in claim 3 including:

primary conduit means for delivering engine exhaust gases from said engine to said exhaust gas inlet means of said vessel, said primary conduit means having a straight conduit section; and

a bypass conduit opening at one end into an intermediate location in the length of said straight conduit section of said primary conduit means at an angle of between about 15° and about 165° from the longitudinal axis of said primary conduit, said bypass conduit communicating at its other end with said outlet of said cyclone separator.

References Cited in the file of this patent

UNITED STATES PATENTS

485,915	Duckham	Nov. 8, 1892
1,522,111	Franck-Philipson	Jan. 6, 1925
1,867,325	Neville	July 12, 1932
2,488,563	Sills	Nov. 22, 1949
2,880,079	Cornelius	Mar. 31, 1959
2,942,687	Kollander	June 28, 1960
3,056,662	Ridgway	Oct. 2, 1962

FOREIGN PATENTS

324,201	Italy	Jan. 24, 1935

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,132,473 May 12, 1964

Robert H. Hass

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

In the grant (only), line 1, for "Robert H. Haas" read -- Robert H. Hass --; column 11, line 25, for "connecting" read -- collecting --.

Signed and sealed this 7th day of December 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents