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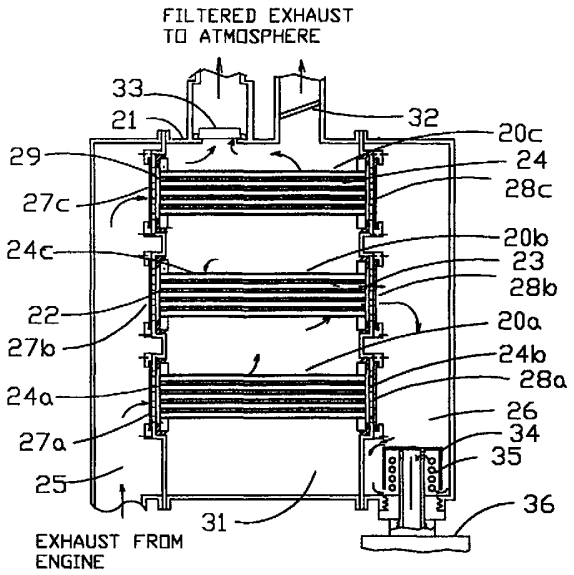
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(54) Title: APPARATUS AND METHOD FOR FILTERING PARTICULATE AND REDUCING NOx EMISSIONS



(57) Abstract: An apparatus and method for filtering particulate from an internal combustion engine by use of monolithic particulate trap systems having porous walls (2c, 24c). The porous walls (2c, 24c) filter the particulate. The filtered particulate on inner surfaces of the porous walls is periodically removed or regenerated via back flow of previously filtered exhaust gas. The back flow is caused by creating a pressure difference across the porous walls. The back flow of the previously filtered exhaust gas is simultaneously or sequentially coupled with high velocity through flow of exhaust gas in the channels. In addition, the particulate trap system can be an adsorber-catalyst particulate trap system for filtering particulate and reducing NOx via an adsorber-catalyst trap systems to achieve the EPA 2007 standards.

WO 03/086580 A1

APPARATUS AND METHOD FOR FILTERING PARTICULATE AND REDUCING NOx EMISSIONS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority of pending US Application 60/372,238, filed 12 April 2002, entitled Particulate Trap and NOx Adsorber-Catalyst Diesel Exhaust Aftertreatment System.

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to the field of diesel or other internal combustion engine exhaust systems, and more specifically, to an apparatus and method for reducing the release of emissions and particulate in the atmosphere, and to an apparatus and method for regenerating exhaust traps by reverse flow of filtered exhaust gas through porous walls of a plurality of tubular passages. The invention also relates to apparatus and method for using adsorption-catalyst technology to reduce NOx emissions when ultra low sulfur fuel becomes available.

DESCRIPTION OF THE RELATED ART

Diesel and other internal combustion engine manufacturers face increasingly stringent Federal and State regulations which limit the particulate and gaseous emissions that can be released into the atmosphere. For example, the Environmental Protection Agency (EPA) emissions regulations for heavy duty diesel trucks for the years 2002 to 2007 limit the particulate emissions to 0.1 g/Hp-Hr and the NOx emissions to 2.0 g/Hp-Hr. The particulate standards can probably be achieved by most modern diesel engines with the addition of a diesel oxidation catalyst in the exhaust system while the NOx standards can probably be achieved by engine related changes such as state of

the art electronically controlled fuel system and exhaust gas recirculation (EGR).

However, in 2007, the EPA emissions regulations for these diesel applications are much more stringent. For example, the particulate emission standards are reduced to 0.01 g/Hp-Hr and the NOx emissions standards are reduced to 0.2 g/Hp-Hr. It is generally agreed that these more restrictive particulate exhaust emissions standards will require high efficiency filtration of the exhaust gas, such as can be attained by monolithic ceramic porus wall flow particulate traps. Achievement of the NOx emission standards for diesel engines may require some type of chemical reduction such as adsorber-catalyst arrangements or selective catalytic reduction (SCR).

To reduce the amount of particulate material being released into the atmosphere, diesel and other internal combustion exhaust gas may be filtered by depth type filters of various materials such as fibrous or metals. The material is usually coated with catalysts and the traps are called diesel oxidation catalysts (DOC). If the temperature of the exhaust is sufficient, this type of trap can effectively reduce gaseous emissions such as hydrocarbons, CO and the like and reduce about 30% of the particulate emissions by burning more of the soluble organic fraction (SOF). However, they are not very efficient in the removal of carbon particles. In addition, the catalysts used are expensive and can generate other undesirable emissions such as sulfates and toxic NO_2. This type of trap is being used to assist engine manufacturers in achieving the less stringent EPA 2002 particulate emissions.

Most of the effort has been directed toward trap systems that use porous, ceramic monolith, that have passages similar to a honeycomb as illustrated in *Frost et al.*, U.S. Patent No. 4,415,344. This type of trap, known generally as the wall flow type, is illustrated in the cross sectional drawing Fig. 1. The honeycomb section monoliths are extruded, relatively

inexpensively and provide a large passage surface area for a given size trap. By plugging exit ends of alternate passages and entrance ends of the remaining passages, the flow of exhaust gas is forced through the porous walls of the passages having the exit ends plugged. A layer of soot and ash accumulates on the inner surfaces of the passages. While these traps remove 95-98% of the particulate from the flow of exhaust gas, pressure drop across the trap builds-up due to the accumulation of the soot and ash. While the soot can be burned periodically by heating all, or a portion, of the exhaust gas, loss of energy occurs and, more seriously, the heat of combustion of the soot leads to cracking and melting of the traps. Complicated catalyst means have been used to lower the ignition temperature of the soot to protect the trap with mixed results. Also, burnout does not prevent long term accumulation and pressure drop due to the build-up of incombustible ash.

Oda et al., U.S. Patent No. 4,483,883, and *Igarashi*, U.S. Patent No. 5,966,928, illustrate a cross-flow, monolithic, ceramic trap coupled with reverse flow of high pressure air to remove the soot and ash without combustion within the particulate trap system. The cross flow type of monolithic trap is illustrated in the cross sectional drawing Fig. 2. The through-flow passages of the cross flow trap are used to direct the dislodged soot and ash to an electrical heater outside the trap, to burn the soot and collect the ash. However, this system results in loss of engine efficiency because of the amount of high pressure air required. In addition, the use of high pressure air requires a rather heavy structure to provide adequate strength and also has led to problems with the reliability of trap seals and valves used to control the reverse flow of air.

Igarashi, U. S. Patent 5,853,438 illustrates cross-flow and wall flow, monolithic, ceramic trap systems that are coupled with reverse flow of high pressure air, as shown in Fig. 3 for a wall flow trap, to remove the soot and

ash without combustion within the particulate traps. The removed soot and ash are directed to an external chamber wherein the soot is burned and the ash is stored. The patent shows means to control the very brief pulses of reverse high pressure air used in either the cross-flow or wall flow trap systems such that the pressure waves and air flow evenly enter the passages at the trap exit faces. In the case of the wall flow trap, the patent indicates that the resultant even pressure distribution in all passages increases the soot and ash removal efficiency from 78% to about 97%. However, these systems use high pressure air pulses that results in an adverse affect on engine fuel consumption and weight.

Yasushi et al., U.S. Patent 5,941,066, and *Yoshimasa et al.*, U.S. Patent 5,930,995, illustrate depth and honeycomb wall flow particulate trap systems respectively in close proximity to the engine. The soot collected by these traps is burned by the heat of the engine exhaust or by electrical heaters located in each trap. By means of special passages and control valves, the engine exhaust pulses are periodically employed to create back flow through the traps to dislodge and remove accumulated ash. However, the high temperatures employed reduce the reliability of the trap.

Bailey et al., U.S. Patent 6,233,926, illustrates various apparatuses and methods to filter particulate from an engine exhaust through the use of ceramic, cross-flow traps similar to the *Oda et. al*, U.S. Patent No. 4,483,883 and *Igarashi*, U.S. Patent No. 5,966,928 previously described. The soot and ash are removed from the engine exhaust by directing it through the through flow passages having porous walls. However, after prolonged periods of filtering, a build-up of soot and ash occurs. To remove the build-up, exhaust gas at a velocity sufficient to erode and dislodge the soot and ash is directed through the through-flow passages. The dislodged or eroded soot and ash are moved to a location outside the trap for combustion of the soot and storage of

the incombustible ash. The exhaust gas from the engine enters the through-flow passages that, during normal filtration, have a suitable valve arrangement to force the exhaust gas to flow through the porous walls to filter out the soot and ash. After filtering, the filtered exhaust gas passes to the atmosphere through clearances surrounding the through-flow passages. The filtered particulate accumulates on the inside of the porous walls and must be periodically removed to prevent excessive pressure drop and back pressure to the engine. The accumulation of soot and ash is removed by periodically passing a flow of exhaust gas through the length of the through-flow passages at a velocity sufficient to erode and dislodge the accumulated soot and ash and moving it out of the trap to be captured. The soot is burnt and the ash collected. All the exhaust gas entering the trap is filtered prior to release into the atmosphere. This is considered to be a very reliable system because the trap is not subjected to high temperatures and pressures during the regeneration process. However, under some engine operating conditions, the erosion and dislodging of the soot and ash build-up may occur at a slower rate than desired. For example, operation at low ambient temperatures or extended low load operation may result in a less than desirable rate of erosion. Under such conditions, the soluble organic fraction (SOF) of the soot may increase or condensation of liquids may occur, either causing an increase in the density of the soot and ash build-up.

Dou, et al., U.S. Patent 6,391,822 B1 and *Ament et al.*, U.S. Patent 6,293,092 B1 illustrate apparatuses and methods of using a metal oxide to adsorb NOx under lean exhaust conditions and platinum or other precious metal catalyst to reduce the NOx when it is released from the metal oxide under rich exhaust conditions. This general approach is considered a very promising method of achieving the very low NOx EPA 2007 standards (0.2 g/hp-hr) when using ultra low sulfur fuel. However, the systems that have

been proposed significantly increase fuel consumption and require changes to the engine.

The present invention is directed to overcoming one or more of the problems set forth above.

BACKGROUND OF THE INVENTION

As noted earlier, most of the effort on high efficiency particulate traps have used monolithic ceramic traps having porous walls through which the exhaust gas passes and is filtered. While these traps remove 95-98% of the particulate, pressure drop across the traps builds up due to the accumulation of soot and ash. While the soot can be burned away by heating all, or a portion, of the exhaust gas, loss of energy occurs and, more seriously, the heat of the combustion of the soot leads to cracking and melting of the traps. In addition, the incombustible ash must be periodically removed by a disruptive and expensive cleaning operation.

In recent years, catalyst coatings have been applied to the wall flow traps to reduce the temperature at which the soot is ignited and to cause the soot to burn more often to reduce the amount of accumulated soot. This approach tends to prevent overheating of the traps during regeneration and reduces engine fuel consumption by igniting the soot all, or most of the time, by the heat of the engine exhaust. This system is called continuous regeneration technology (CRT) and has been used in a number of retrofit applications such as city and school buses. However, these applications must operate at a reasonably high average load factor and the engines must be in a condition that will meet the engine manufacturer's specification. To obtain the most reliable operation, the engines must use very low sulfur fuel to further reduce the light-off temperature of the soot. Finally, these systems are also subject to plugging by incombustible ash.

A more promising approach is to remove the soot and ash by physically removing it from the trap walls and directing the particles to an external chamber where the soot is burned and the ash collected for periodic disposal. As noted earlier, particulate filtration has been accomplished with high efficiency via the use of cross flow monolithic porous wall cross flow traps. When the soot and ash accumulate to unacceptable levels, the traps are regenerated by removing the soot and ash physically by a brief pulse of high pressure air (115 psi), the soot and ash being directed to a small external chamber for burning the soot and storage of the ash. While this system works effectively, the use of high pressure air increases engine fuel consumption and also requires a heavy structure, features that are undesirable for mobile applications.

The subject invention uses monolithic porous wall ceramic traps of either the cross flow or the wall flow type that will collect the soot and ash with an efficiency of 95-98%. The pressure drop across the trap increases as the soot and ash accumulate and the traps must be periodically regenerated. However, in this invention the soot and ash are removed physically by reverse flow of pre-filtered exhaust gas at normally encountered exhaust gas pressures and flow rates and the soot and ash are directed to an external chamber for burning of the soot and storage of the ash. This approach utilizes sequential periods of sustained constant reverse differential pressure that acts equally across the porous walls of all of the passages and throughout their length to dislodge and erode the collected cake of soot and ash and move the particles to the external chamber for burning or storage. Because the engine back pressure is little greater than normal, the system operates without significant increase in engine fuel consumption, the need for low sulfur fuel or increase in weight of the filter structure.

Three-way catalyst technology has been used for a number of years in S.I. automobile engines to reduce NOx emissions to a very low level. This technology uses catalysts of precious metals like platinum, rhodium, etc. to cause reaction between the CO in the exhaust and the NOx to produce N2 and CO_2. However, for this process to work there must be an excess of HC (CO) in the exhaust (a lambda of 0.95 - 1). Because S.I. automotive engines operate at about stoichiometric air/fuel ratios, they can easily be controlled by use of an oxygen sensor to maintain a chemically correct to slightly richer mixture in the exhaust. Thus, the catalyst causes the CO and NOx to react together. This substantially eliminates the NOx from the vehicle.

However, diesel engines (and lean burn S.I. engines) operate with an excess of oxygen in the exhaust at all operating conditions. Reaction of the HC and NOx will not proceed when O_2 is present. To overcome this problem, the adsorption/reduction catalyst process has been identified. The catalyst substrate is coated with a wash coat of BaO along with a catalyst of platinum, rhodium, etc., as shown with a conventional wall flow trap in Fig. 4. The trap with its catalytic coatings is operated within a temperature window of about 250 - 450°C.

During normal diesel lean burn operation, the NOx in the exhaust is adsorbed on the BaO coating by a process called chemisorption. This action is allowed to continue for 1 to 4 minutes. After this time, the BaO coating becomes saturated with NOx stored as $Ba(NO_3)_2$ and additional NOx will begin to pass on through the trap. However, after a time of 1 or 2 minutes, the exhaust gas is temporarily made rich (a lambda of 0.95 to 1) for a few seconds by adding additional fuel to the exhaust stream to react with the free Oxygen. This action almost instantly releases the trapped NO_2 from the BaO coating and the NO_2 is then immediately reacted with the CO through the action of

the adjacent precious metal catalyst sites and exits to the atmosphere as N_2 and CO_2.

This action is capable of reducing NOx exhaust emissions by 90+%. This method is being promoted to be used in conjunction with a wall flow particulate trap. Two phenomena tend to limit the life of the device.

First, much of the sulfur in the fuel will be exhausted as SO_2. This will be further oxidized in the presence of the platinum catalyst to form SO_3 and this reacts with the BaO adsorber coating to form $BaSO_4$. This poisons the trap by soon preventing the adsorption of NO_2. Consequently, the adsorber-catalyst approach is predicated on the use of ultra low sulfur (10ppm) diesel fuel. However, even this small amount of sulfur will gradually poison the trap after several thousand miles. The sulfur-poisoned trap can be regenerated by heating the trap in the presence of hydrocarbons at a temperature of about 700°C for several minutes.

The second phenomena, with a conventional wall flow trap, is gradual plugging with the incombustible ash. After about 50,000 miles the traps must be cleaned by reverse flow, etc., as a maintenance step.

The initial part of the Detail Description/Specification will address the use of the above trap approach that uses reverse flow or reverse flow and through flow for regeneration with either cross flow and wall flow traps. These trap systems will be able to achieve the EPA 2007 particulate standards for both new and retrofit engines without need for a change in current diesel fuels.

The remainder of the Detail Description/Specification will address modifications and additions to the above particulate trap systems to use adsorber-catalyst technology that will permit achievement of the 2007 EPA particulate and the EPA NOx standards when ultra low sulfur becomes available.

SUMMARY OF THE INVENTION

The subject invention uses monolithic porous wall ceramic traps of either the cross flow or the wall flow type that will collect the soot and ash with an efficiency of 95-98%. The pressure drop across the trap increases as the soot and ash accumulate and the traps must be periodically regenerated. However, in this invention the soot and ash are removed physically by reverse flow of pre-filtered exhaust gas at normally encountered exhaust gas pressures and flow rates and the soot and ash are directed to an external chamber for burning of the soot and storage of the ash. The reverse flow of pre-filtered exhaust gas at pressures that will cause little or no additional engine back pressure permits sequential periods of sustained constant reverse differential pressure to dislodge and erode the collected cake of soot and ash without significant increase in engine fuel consumption, the need for low sulfur fuel or a significant increase in weight of the filter structure.

An object of the invention is to provide a trap system to remove engine exhaust particulate that can be automatically regenerated without need for catalysts or complicated sensor systems and in which the soot is burned in a small container and incombustible ash is collected therein for periodic disposal.

Another object of the invention is to provide a reliable and durable trap system that will not require expensive catalysts, can use inexpensive trap materials such as cordierite and will not require any reduction in the sulfur content of current fuels.

Still another object is to provide a reliable and durable particulate trap system that will require substantially no change to the engines and have little or no adverse affect on engine performance.

Yet another object to provide the above characteristics in a system in which the traps and structure do not have to operate at high temperature in either normal engine operation or during regeneration of the traps and which can therefore be located remote from the engine if desired.

Another object is to provide a trap system that can use a multiple of traps or a single, larger trap depending upon the application.

Still another object is to provide a particulate trap system that is well suited to the use of exhaust gas re-circulation for the control of nitrogen oxide emissions.

An aspect of the present invention is to provide an apparatus and method for periodically passing pre-filtered exhaust gas in reverse flow through the porous walls of the through flow passages in a cross flow trap that have an accumulation of soot and ash, either prior to or in conjunction with, high velocity flow of exhaust gas through the through flow passages to enhance the erosion and dislodging of the accumulated soot and ash under certain engine operating conditions and removing it from the trap to be burned outside the trap.

Another aspect of the invention is to provide an apparatus and method for periodically passing pre-filtered exhaust gas in through the porous walls of a wall flow trap monolith in a direction that is reverse to that of normal filtration in order to dislodge and erode the soot and ash layer and carry the dislodged particles out of the passages and into a chamber for separation of the particles of soot and ash wherein the soot is burned and the incombustible ash is stored for periodic disposal prior to permitting the stream of pre-filtered exhaust to escape to the atmosphere.

In another aspect of the invention there is provided an apparatus and method for removing the build-up of soot and ash in low ambient temperatures or during extended low load operation.

In another aspect of the invention there is provided an apparatus and method for removing the build-up of soot and ash by physical or mechanical means under adverse engine operating conditions.

Another aspect of the present invention is to provide an apparatus and method for removing the build-up of soot and ash that is reliable and durable.

Yet another aspect of the present invention is to provide an apparatus and method for removing the build-up of soot and ash using only the flow of exhaust gas at pressures and flow rates commonly encountered in diesel engines.

Still another aspect of the present invention is to provide a compact and quick reacting exhaust flow control valve for providing uniform distribution of the entering exhaust gas across circular, rectangular or other geometric shape trap faces.

Yet another aspect of the present invention is to obtain one or more of the above mentioned aspects when utilizing single traps, preferably large, or multiple traps, preferably small.

Yet another aspect of the present invention is to provide a remote activated relief valve with which to automatically provide a moderate but constant back pressure in the exit chamber of the trap systems to provide the desired reverse flow of pre-filtered exhaust gas.

Still another aspect of the present invention is to provide a fixed or variable venturi tube at the exit of the filtered exhaust to the atmosphere to thereby provide a pressure at its throat that is significantly lower than ambient and to direct the reverse flow during regeneration to the lower pressure throat to thereby increase the total reverse pressure drop across the porous walls of the trap passages and thus enhance the dislodgment and erosion of the soot and ash layer.

Yet another aspect of the present invention is to show how it is well suited to the use of low pressure loop exhaust gas re-circulation and illustrate how it can be used.

Another object of the invention is to provide means for converting the systems utilizing reverse flow or reverse flow and through flow of the subject invention, with minimal change, to particulate trap systems that use the adsorber-catalyst method to achieve the very stringent 2007 EPA NOx standards using ultra low sulfur fuel.

Another object is to provide a substantially steady flow device for controlling the mixture of a small stream of the exhaust at near stoichiometric air fuel ratios in order to provide a rich stream having an excess of CO and/or HC for use in the brief release and reduction of the stored NOx.

Yet another object is to provide a particulate trap and adsorber-catalyst system in which the space velocity of the rich exhaust stream can be varied as desired in order to minimize fuel consumption.

Another object of the invention is to provide particulate traps, adsorber-catalyst systems that provide means to regenerate contamination of the adsorber caused by sulfur and to remove incombustible ash to prevent these from being separate and expensive maintenance operations.

Another aspect of the invention is to use monolithic cross flow or wall flow porous wall particulate traps that have been treated with adsorber - catalyst coatings and to provide means to cause a majority of the normally lean exhaust from the engine to flow through a majority of the traps or discrete portions of a single trap and to provide means to cause a minority of the normally lean exhaust gas from the engine to be enriched by a fuel burner to an approximately stoichiometric mixture and to periodically pass this enriched flow through a minority of the traps or portions of a single trap for a brief period, this brief (1 - 5 seconds) enriched flow being sequentially

changed to pass through different traps or portions of a single trap, in turn, as long as the engine is in normal operation.

Yet another aspect of the invention is to provide a device to split the exhaust flow into a majority exhaust stream and a minority exhaust stream and to use an injector, igniter/burner and oxygen sensor along with suitable controls to maintain in the minority stream a normally steady flow of enriched, approximately stoichiometric mixture rich in CO and/or HC exhaust gas and to direct these two streams to appropriate ducts in the particulate trap system.

Yet another aspect is to provide apparatus in the flow divider/enrichment device to maintain a temperature of 250 - 450°C during normal operation of the engine.

Still another aspect of the invention is to provide means to increase the trap(s) temperatures to approximately 700°C while maintaining the aforementioned minority rich exhaust flow and the majority lean exhaust flow and to provide means to increase the time of the periodic flows of enriched exhaust gas to 3 - 10 minutes in order to regenerate sulfur contamination.

The above aspects are merely illustrative and should not be construed as all-inclusive. The aspects should not be construed as limiting the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference is now made to the drawings which illustrate the best known mode for practicing the steps of the method and apparatus which performs the method; and wherein similar reference characters indicate the same parts throughout the several views.

Fig. 1 is a sectional illustration of a wall flow type of trap monolith.

Fig. 2 is a sectional illustration of a cross flow type of trap monolith.

Fig. 3 is a sectional illustration of a wall flow type trap being regenerated.

Fig. 4 is a cross section of a wall flow trap indicating the BaO wash coat and Pt, etc., catalysts that are used in the adsorber-catalyst method for reducing NOx in diesel engines and lean-burn S.I. engines.

Fig 5 is a cross sectional view of a single cross flow trap that is regenerated by reverse flow of filtered exhaust gas followed by through flow of unfiltered exhaust gas.

Fig. 5a is an end view of the single cross flow trap of Fig. 4 to illustrate the rotary valves used to control the flow of exhaust gas for regeneration.

Fig. 6 is a cross sectional view of a cross flow multi-trap system in which regeneration is accomplished by reverse flow of filtered exhaust gas followed by through flow of unfiltered exhaust.

Fig. 7 is a cross sectional view of single cross flow trap system in which regeneration is accomplished by simultaneous reverse flow of filtered exhaust gas and through flow of unfiltered exhaust gas.

Fig. 7a is an end view of the single cross flow trap system of Fig.6 to illustrate the rotary valve used to control the flow of exhaust gas for regeneration.

Fig. 8 is a cross sectional view of a multi-traps system in which regeneration is accomplished by simultaneous reverse flow of filtered exhaust gas and through flow of unfiltered exhaust gas.

Fig. 9a is a plan view of a moveable part of a perforated plate slide valve.

Fig. 9b is a plan view of a stationary part of a perforated plate slide valve.

Fig. 10 is a plan view of the stationary and moveable parts of the perforated plate slide valve with the parts superimposed to illustrate the "open" position.

Fig. 11 is plan view of the stationary and moveable parts of the perforated plate slide valve with the parts (and holes) slightly misaligned to illustrate the "closed" position.

Fig. 12 is a cross sectional view of a complete perforated plate slide valve shown in the "closed" position.

Fig. 13 is a view of the multi-trap particulate trap system as it might be applied to a tractor of a highway truck.

Fig. 14 is a view of the multi-trap particulate trap system to illustrate how it might look with the use of a low pressure loop exhaust gas re-circulation arrangement.

Fig. 15 is a cross sectional view of a multi-trap wall flow trap system having a remote controlled relief valve to increase the pressure in the filtered exhaust gas exit channel to provide pressure across the trap in the reverse direction.

Fig. 16 is a cross sectional view of a cylindrical perforated plate slide valve used with a wall flow trap system to control the normal flow of exhaust gas for filtration and for periodic reverse flow of filtered exhaust gas for regeneration.

Fig. 17 is a cross sectional view of a two-position poppet valve used as an alternative means to control the normal flow of exhaust gas for filtration and for periodic reverse flow of filtered exhaust gas for regeneration.

Fig. 18 is a cross sectional view of a device for separating the soot and ash particles from the regeneration reverse flow of filtered exhaust gas, and igniting the soot and storing the incombustible ash prior to allowing the flow stream to enter the atmosphere.

Fig. 18a is a cross sectional view of a device for separating the soot and ash particles from the regeneration reverse flow of filtered exhaust gas, and igniting the soot and storing the incombustible ash prior to allowing the flow stream to enter the atmosphere, taken along line a-a.

Fig. 19 is a cross sectional view of a remote controlled relief valve for maintaining a desired pressure in the filtered exhaust duct.

Fig. 20 is a cross section of a remote activated relief valve/venturi arrangement for maintaining an increased pressure on the exit of each trap and for providing reduced pressure at the inlet of each trap and thereby increasing the reverse flow pressure drop across the trap.

Fig. 21 is a cross sectional view of a multi-trap wall flow trap system having a remote controlled relief valve/venturi valve to increase the pressure at the normal exit of the trap while, at the same time, reducing the pressure at the entrance to the trap to provide a greater reverse pressure drop across the trap but without increasing back pressure on the engine and means to modify the exhaust flow to permit heating of the traps t o effect soot burn-out if required under certain conditions..

Fig. 22 is a view of how a particulate trap system consisting of wall flow traps and low pressure loop EGR might look like on a highway truck.

Fig. 23 is a view of how a particulate trap system consisting of wall flow traps that uses a relief valve/venturi to enhance regeneration and a low pressure loop system for reduction of nitrogen oxide emissions might look like when mounted on a highway truck.

Fig. 24 is a cross sectional view of a single wall flow trap system.

Fig. 24a is a cross sectional view of the single wall flow trap system according to Fig. 24 taken along line a-a.

Fig. 25 is a schematic of an auxiliary heater that can be used to heat the small flow exhaust stream of any of the systems of the invention to burn away any remaining soot.

Fig. 26 is a schematic illustration of an exhaust divider and enrichment device used to enrich a smaller flow of the exhaust gas to stoichiometric mixture as part of a the adsorber-catalyst particulate trap and NOx reducer systems of the invention.

Fig. 27 is a cross sectional illustration of a cross flow multi-trap version of the adsorber-catalyst particulate trap and NOx reducer system.

Fig. 28a is a cross sectional illustration of a cross flow single trap version of the adsorber-catalyst particulate trap and NOx reducer system.

Fig. 28b is a cross sectional illustration of the faceplate having an aperture therein of the cross flow single trap version of the adsorber-catalyst particulate trap and NOx reducer system according to Fig. 28a.

Fig. 29 is a cross sectional illustration of a wall flow multi-trap version of the adsorber-catalyst particulate trap and NOx reducer system.

Fig. 30 is a cross sectional illustration of a wall flow single trap version of the adsorber-catalyst particulate trap and NOx reducer system.

Fig. 30a is a cross sectional illustration of the wall flow single trap version of the adsorber-catalyst particulate trap and NOx reducer system according to Fig. 30a taken along line a-a.

DETAILED DESCRIPTION

The current invention relates to a particulate trap system that uses either cross flow or wall flow traps and has means for accomplishing reverse flow of the exhaust gas as well as through flow of the exhaust gas to dislodge, erode and remove the soot and ash build-up at temperatures below the ignition point of soot and at pressures and flow rates normally encountered in internal

combustion engines, thereby resulting in minimal adverse effects on engine performance. The particulate trap system accomplishes the regeneration or removal of the soot and ash build-up by reverse flow or a combination of reverse flow and through flow to dislodge and erode the soot and ash build-up through a physical or mechanical mechanism, without the addition of heat to burn the soot. The invention eliminates the need for high temperatures and/or the use of expensive catalysts. The ignition of the soot and subsequent combustion of the ash take place in a separate, small and robust chamber. An advantage of lower temperature is the elimination of melting or cracking of the particulate trap system, thereby increasing the reliability and life of the particulate trap system, and permitting the particulate trap system to be constructed of low cost cordierite. Additional advantages include elimination of the cost of a heater, the associated energy requirements, and the freedom to locate the particulate trap system remote from the engine, such as in an exhaust stack.. The invention also includes means to employ, with minimal modification, adsorber-catalyst technology to permit diesel engines to achieve the EPA 2007 Nox emissions standards when ultra
low sulfur fuel becomes available.

Fig. 5 illustrates a cross-flow trap 1 having a plurality of tubular passages 2. In this embodiment, the cross-flow trap 1 is a single, cylindrical-shaped monolithic cross-flow trap. The plurality of tubular passages 2 have porous walls 2c. The plurality of tubular passages 2 and the cross-flow trap 1 have an inlet end 1a and an outlet end 1b. The plurality of tubular passages 2 have clearances 3 between outside diameters of the plurality of tubular passages 2. The porous walls 2c of the plurality of tubular passages 2 permit the filtered exhaust gas to pass out of the cross-flow trap 1, enter an exit chamber 4 and then pass to the atmosphere through a by-pass valve 5 or a relief valve 6. A rotary valve 7 is located in close proximity to the inlet end

1a of the cross-flow trap 1 and periodically blocks the entry of exhaust gas into the plurality of tubular passages 2 from an inlet chamber 8. In the preferred embodiment, the rotary valve 7 continually rotates and has a strut 7a, preferably a single strut, that moves in proximity to the face of the cross-flow trap 1 to briefly block the entrance to some of the plurality of tubular passages 2a, as the rotary valve 7 rotates. As the rotary valve 7 rotates a complete revolution, all of the plurality of tubular passages 2 will at one time or another have been blocked. A second rotary valve 9 is located proximate to the outlet end 1b of the cross-flow trap 1 and blocks the outlet end 2b of some of the plurality of tubular passages 2 for substantially all of its rotation. The second rotary valve 9 continuously rotates at the same speed as that of the rotary valve 7. The rotation of the rotary valve 7 and second rotary valve 9 is synchronized. The second rotary valve 9 has an aperture 9a that briefly unblocks the outlet end 2b of each of the plurality of the tubular passages 2, in turn, to permit exhaust gas to exit from the plurality of tubular passages 2. As explained hereinafter, the blocking by the strut 7a of the inlet end 2a of the plurality of tubular passages 2 and the unblocking of the outlet ends 1b of the plurality of tubular passages 2 by the aperture 9a operate in a phased relationship as illustrated in Fig. 5a. In normal operation the periodic flow that exits from each of the plurality of tubular passages 2 contains eroded or dislodged soot and ash that are directed to a separation chamber 10. The soot and ash settle in the separation chamber 10 and out of the flow of the exhaust gas, wherein the soot is ignited and burned by an igniter coil 11 and the incombustible ash settles in the separation chamber 10. The incombustible ash is removed via a cap 12 and discarded. A secondary filter 13 removes the particulate from the unfiltered exhaust gas that flows into the separation chamber 10 prior to exiting through a passage 15, a three-way valve 14 and a second passage 17 to the atmosphere. The size of the secondary filter 13 is

selected as a function of the maximum flow that is expected to enter the separation chamber 10 while maintaining a maximum pressure in the separation chamber 10 that is near ambient. The three-way valve 14 is used to periodically block the passage 15 and introduce a brief pulse of high pressure air from a third passage 18 to remove any soot or ash layer accumulating on the secondary filter 13.

In operation during normal filtering mode, the exhaust gas from the engine enters the inlet chamber 8, and then enters the plurality of tubular passages 2 that are not blocked by the strut 7a. The exhaust gas entering the plurality of tubular passages 2 either exits into the separation chamber 10 or is blocked by the second rotary valve 9 and therefore must pass through the porous walls 2c of the plurality of tubular passages 2. There are a plurality of tubular passages 2 at any one moment that are not blocked or plugged by the strut 7a and the second rotary valve 9, respectively, as shown in Fig. 5a and explained hereinafter. Hence, the exhaust gas entering the plurality of tubular passages 2 exits into the separation chamber 10 via an opening 9a. The exhaust gas passing through the porous walls 2c because the outlet ends 2b of the plurality of tubular passages 2 are blocked by the second rotary valve 9 is filtered and will then pass through the clearances 3 between the plurality of tubular passages 2 into the exit chamber 4 and then through the open by-pass valve 5 into the atmosphere. The soot and ash filtered via the porous walls 2c of the cross-flow trap 1 will result in the build-up of soot and ash on the porous walls 2c of the plurality of tubular passages 2. As the rotary valve 7 and the second rotary valve 9 rotate, a small amount of exhaust gas will pass through the plurality of tubular passages 2 during a brief phase period in which both the inlet ends 2a and outlet ends 2b of the plurality of tubular passages 2 are open. This small amount of flow through passages that are

open at both ends, is in effect, regeneration flow and may keep the trap system functioning with acceptable backpressure for long periods of time.

However, soot and ash may eventually build-up on the porous walls 2c of the plurality of tubular passages 2 during the filtration process and increase the pressure drop across the walls to a level that will result in excessive backpressure on the engine causing deterioration in engine performance. When a point is reached, as determined by an engine parameter, such as backpressure, the engine control will automatically initiate the regeneration mode.

When the cross-flow trap 1 enters the regeneration mode, the control system (not shown) will close the by-pass valve 5 and the continuing flow of filtered exhaust gas will cause pressure to build-up in the exit chamber 4 until it reaches a pressure that will open the relief valve 6 prior to exiting into the atmosphere. In the preferred embodiment, the relief valve 6 is set at a moderately increased pressure, such as 30 in. wg. The pressure in the inlet chamber 8 will increase from approximately 15 in. wg. to 45 in. wg. The elevated pressure in the exit chamber 4 will be maintained during the regeneration period that will include at least one complete revolution of the rotary valve 7 and the second rotary valve 9. In addition, to the increased pressure in the exit chamber 4, the filtered exhaust gas in the exit chamber 4 will reverse flow through the plurality of tubular passages 2. The reverse flow will blow out most of the soot and ash build-up.

Referring now to Fig. 5a, the process for removing the soot and ash from each of the plurality of the tubular passages 2 is as follows. At any one time, there are four conditions. First, some of the plurality of tubular passages 2 are neither blocked nor plugged by the rotary valve 7 or the second rotary valve 9. Second, some of the plurality of tubular passages 2 are blocked by the rotary valve 7 but not plugged by the second rotary valve 9. Third, some

of the plurality of tubular passages 2 are not blocked by the rotary valve 7 but are plugged by the second rotary valve 9. Fourth, some of the plurality of tubular passages 2 are both blocked and plugged by the rotary valve 7 and the second rotary valve 9, respectively. As the rotary valve 7 and the second rotary valve 9 rotate, the inlet end 2a of some of the plurality of tubular passages 2 will be blocked by the strut 7a. A short time later, the slit 9a in the second rotary valve 9 will open the outlet end 2b of these plurality of tubular passages 2. This action will result in a strong flow of previously filtered exhaust gas back through the porous walls 2c of the plurality of tubular passages 2 and then through the plurality of tubular passages 2 itself and exit into the separation chamber 10. The relatively high reverse pressure, preferably 30 in. wg, difference across the porous walls 2c and the soot and ash build-up will serve to break off or dislodge the soot or ash and carry most of the particles out of the plurality of tubular passages 2 and into the separation chamber 10.

After the reverse flow action has continued for a predetermined length of time, the rotary valve 7 and the second rotary valve 9 move such that the strut 7a uncovers the inlet end 2a of the plurality of tubular passages 2 previously covered permitting exhaust gas to pass completely through the plurality of tubular passages 2 from the inlet chamber 8. The higher differential pressure, approximately 45 in. w.g, between the inlet chamber 8 and the separation chamber 10 will result in a very high velocity, in excess of 100 fps to flow through the plurality of tubular passages 2 further removing soot and ash and effectively eroding and dislodging any soot and ash layer that was not previously removed. Following a predetermined period of through flow, the second rotary valve 9 will close the outlet end 2b of the plurality of tubular passages 2, returning the cross-flow trap 1 to the porous wall filtration flow process. The above described action will be repeated for

each of the plurality of tubular passages 2, in turn, until the rotary valve 7 and the second rotary valve 9 have made at least one full revolution and all of the plurality of tubular passages 2 have been regenerated. While the regeneration takes place, the majority of the plurality of tubular passages 2 will continue filtering the exhaust gas released from the engine. Although the engine back pressure during the regeneration period will be slightly greater than would normally be desired, it will have minimal adverse affect on engine performance.

In the preferred embodiment, following the regeneration period determined by elapsed time because the rotary valve 7 and the second rotary valve 9 will be electrically driven at constant speed, the control system (not shown) will automatically open the by-pass valve 5, allowing the filtered exhaust gas to exit from the exit chamber 4, returning the cross-flow trap 1 to normal filtering mode. In alternative embodiments, the regeneration period can be determined by other factors, such as pressure.

The dislodged and removed soot and ash from the plurality of tubular passages 2 is passed into the separation chamber 10. In the separation chamber 10, the soot and ash will settle and drop to the bottom, wherein the soot is ignited and burned by the igniter coil 11 and the incombustible ash is collected for removal through the cap 12. The exhaust gas that contains particulate in the form of smoke will be filtered by the secondary filter 13 prior to the exhaust gas being released into the atmosphere through the passage 15, the three-way valve 14 and the second passage 17. The three-way valve 14 and the third passage 18 are used to periodically provide a small stream of high pressure air in reverse flow through the secondary filter 13 to dislodge any excessive collection of soot and ash and aid in its settling toward the igniter coil 11.

Fig. 6 illustrates a second embodiment of the present invention that utilizes a plurality of monolithic cross-flow traps 20a, 20b, 20c that are mounted in a structure 21. The plurality of cross-flow traps 20a, 20b, 20c can be manufactured to various sizes and number, depending upon the application, and the plurality of cross-flow traps 20a, 20b, 20c can be of any shape, such as circular or rectangular in cross section. The plurality of cross-flow traps 20a, 20b, 20c have entrance ends 22 and exit ends 23. The number of the plurality of cross-flow traps 20a, 20b, 20c can be increased or decreased. The plurality of cross-flow traps 20a, 20b, 20c have a plurality of tubular passages 24 having porous walls 24c through which exhaust gas is passed for filtering. The plurality of tubular passages 24 have an entrance end 24a and an exit end 24b. The structure 21 has an inlet chamber 25 and a separation chamber 26. The plurality of cross-flow traps 20a, 20b, 20c have clearances 29 between the outside diameters of the plurality of tubular passages 24 to permit the filtered exhaust gas to exit the plurality of cross-flow traps 20a, 20b, 20c. The plurality of cross-flow traps 20a, 20b, 20c are mounted in the structure 21 using sealing material, such as INTERAM®, at each end to prevent any leakage of unfiltered exhaust gas from the inlet chamber 25 or the separation chamber 26 from passing into an exit chamber 31 without first having to pass through the porous walls 24c. INTERAM® is the federally registered trademark of the Minnesota Mining and Manufacturing Company, located at 3M Center, St. Paul, Minnesota. After the filtered exhaust gas exits the plurality of cross-flow traps 20a, 20b, 20c, it passes up the exit chamber 31 and then through either a by-pass valve 32 or a relief valve 33.

The plurality of cross-flow traps 20a, 20b, 20c have a plurality of inlet valves 27a, 27b, 27c and a plurality of outlet valves 28a, 28b, 28c. The plurality of inlet valves 27a, 27b, 27c are located at the entrance ends 22 of

through the open by-pass valve 32. Soot and ash will eventually build-up in the plurality of tubular passages 24, resulting in an excessive pressure drop across the plurality of cross-flow traps 20a, 20b, 20c causing an excessive back pressure that would adversely effect engine performance. At this point, it is desirable to regenerate the plurality of cross-flow traps 20a, 20b, 20c to remove the build-up of soot and ash.

When an engine parameter, such as back pressure, is monitored and reaches a pre-designated level, the engine control system will initiate the regeneration mode. A trap control system (not shown) controls the regeneration process. The regeneration process results in the by-pass valve 32 being closed, which blocks escape of the filtered exhaust gas from the exit chamber 31, causing the pressure to rise thereby opening the relief valve 33. In the preferred embodiment, the relief valve 33 is set at 30 in. wg. This pressure is maintained in the exit chamber 31 throughout regeneration process. Depending upon the engine operating conditions and the degree of plugging of the plurality of cross-flow traps, the pressure in the inlet chamber 25 will rise to approximately 45 in. wg. The control system also energizes an electrically heated element 34 to a temperature greater than 550°C, which is the ignition temperature of the soot. After a brief period, the control system electrically or pneumatically closes one of the plurality of inlet valves 27a, 27b, 27c. For example, one of the plurality of inlet valves 27b closes, preventing exhaust gas from entering one of the plurality of cross-flow traps 20b. One of the plurality of outlet valves 28b is then quickly opened permitting exhaust gas to flow from the plurality of tubular passages 24 of one of the plurality of cross-flow traps 20b into the separation chamber 30. This reduces the pressure in the plurality of tubular passages 24 to the same level of pressure as in the separation chamber 30, which is close to ambient. This results in a strong back flow of previously filtered exhaust gas from the

exit chamber 31 that is at a pressure of 30 in. wg. through the porous walls 24c of the plurality of tubular passages 24 thereby blowing out the soot and ash build-up on the inner surface of the porous walls 24c of the one of the plurality of cross-flow traps 20b. Because filtered exhaust gas at 30 in. wg is continuously supplied by the plurality of the cross-flow traps 20a, 20c that are not being regenerated, the reverse flow will continue as long as one of the plurality of inlet valves 27b is kept closed and one of the plurality of outlet valves 28b is kept open. After a predetermined time period, one of the plurality of inlet valves 27b will open. Because one of the plurality of outlet valves 28b is still open, a very high velocity flow of exhaust gas will pass through the plurality of tubular passages 24 of the one of the plurality of cross-flow traps 20b due to the 45 in. wg that exists in the inlet chamber 25 and the very low pressure, near 0 in. wg,, that exists at the exit end 24b to the separation chamber 30. This high velocity will quickly blow out any soot and ash that were dislodged by the reverse flow and erode and dislodge additional soot and ash build-up, including the soot and ash on the porous walls 24c that was partially separated or partially dislodged by the reverse flow. During this high velocity through flow, reverse flow will continue through the porous walls 24c of the plurality of tubular passages 24 near their exit ends 24b. However, pipe flow pressure losses will cause a pressure inside the plurality of tubular passages 24 near the entrance ends 24a that will exceed the 30 in. wg pressure in the exit chamber 31.

After this flow continues for a predetermined time, one of the plurality of outlet valves 28b will close and the plurality of cross-flow trap 20b will return to its normal forward flow filtering. Immediately following this action, either of the plurality of cross-flow traps 20a or 20c, such as 20c, will undergo regeneration as was described for the plurality of cross-flow trap 20b. This process will continue until each of the plurality of cross-flow traps 20a, 20b,

20c has been regenerated in a predetermined sequence. The plurality of inlet valves 27a, 27b, 27c and the plurality of outlet valves 28a, 28b, 28c sequentially open and close as described with respect to the plurality of cross-flow trap 20b. After regeneration, the trap control system will return the trap system to the normal filtration mode by again opening the by-pass valve 32, reducing the pressure in the exit chamber 31 to substantially ambient pressure. This will, in turn, result in the pressure in the inlet chamber 25 dropping to less than 15 in. wg because the plurality of cross-flow traps 20 will have been cleaned of the soot and ash build-up. This reduces the engine back pressure and improves engine performance until regeneration is again required. Although the regeneration period of approximately twenty minutes will reduce engine performance because of the slightly increased back pressure, the level of pressure is still quite moderate and the effect on engine performance is not very great. Also, during the normal filtration mode, the electrically heated element 35 may be automatically turned off to save energy because it is only used during the regeneration mode.

In the preferred embodiment, the closing of the inlet valves 27a, 27b, 27c, and opening of the plurality of outlet valves 28a, 28b, 28c, opening of the inlet valve 27a, 27b, 27c and finally closing the plurality of outlet valves 28a, 28b, 28c, are arranged to be carried out in just a few seconds of total elapsed time. While this sequence may be repeated several times, the total period the exhaust gas flows during these bursts is minimal. Consequently, the average mass flow rate of the exhaust gas with the dislodged soot and ash is low. Thus, it becomes possible to pass the flow of this exhaust gas through the electrically heated element 35 and heat it to the ignition temperature with a relatively small amount of energy input of approximately 1500 watts.

In another embodiment, the separation of the soot and ash from the exhaust gas, the burning of the soot and the collecting of the ash may use

elements similar to those of Fig.5, wherein these elements (not shown) include, but are not limited to, a separation chamber, an igniter coil, a cap, a secondary filter, a three-way valve, a passage, a second passage, and a third passage. During regeneration mode, the dislodged and removed soot and ash from the plurality of tubular passages 24 is passed into the separation chamber. In the separation chamber, the soot and ash will settle and drop to the bottom, wherein the soot is ignited and burned by the igniter coil and the incombustible ash is collected for removal through the cap. The exhaust gas that contains particulate in the form of smoke will be filtered by the secondary filter prior to the exhaust gas being released into the atmosphere through the passage, the three-way valve and the second passage. The three-way valve 14 (Fig. 5) and the third passage 18 (Fig. 5) are used to periodically provide a small stream of high pressure air in reverse flow through the secondary filter to dislodge any excessive collection of soot and ash and aid in its settling toward the igniter coil.

As the flow of exhaust gas containing the soot and ash passes through and is heated to the ignition temperature of the soot by the electrically heated element 35, the soot burns and only the exhaust gas with some smoke content and the ash exits. Fig. 6 illustrates the electrically heated element 35 having a shield 34 surrounding it which forces the flow of the exhaust smoke with the soot and ash to move in close proximity to the electrically heated element 35, assuring that the soot completely burns while passing through this area. The flow of exhaust gas continues to the secondary filter and storage chamber 30 as illustrated. The secondary filter and storage chamber 36 removes the particulate from the smoke from the flow of exhaust gas and also catches and stores the incombustible ash.

An alternative method of regenerating the trap system very similar to that of Fig. 5 includes only partially closing one of the plurality of inlet valves

27 by using stops (not shown). This restricts the flow of exhaust gas passing through the plurality of tubular passages 24 thereby resulting in velocity that is sufficient to erode and dislodge the soot and carry out any dislodged particles but low enough to assure that a reverse flow will pass into the plurality of passages 24 through the porous walls 24c through out the entire length of the plurality of tubular passages 24. This is accomplished because the pressure drop through the plurality of tubular passages 24, due to pipe loss, is reasonable at the lower flow velocities. This combined through flow and reverse flow through the porous walls 24c enhances the erosion and dislodging of the soot and ash build-up. The flow of exhaust gas is controlled in short bursts by opening and closing of the corresponding of the plurality of outlet valves 28b to reduce mass flow rate as previously discussed.

Fig. 7 and 7a illustrates a single trap system that is very similar to that of Fig. 5 except that it has only one rotary valve and is therefore somewhat simpler. For this reason, all of the numbers of the remaining parts are the same as those used in Fig. 5. The major difference is that the cross flow trap through flow passages 2 are only blocked at their exit ends 2b until they are briefly opened by slot 9a as rotor 9 rotates. The passages 2 are always open to admit exhaust gas at their entrance ends 2a. All other parts remain the same as the system of Fig. 5 in both design and function.

In operation, exhaust from the engine enters chamber 8 and passes into the entrance ends 2a of all of the trap passages. In those passages 2 that are blocked at their exit ends 2b, the exhaust gas cannot escape and must pass through the porous walls 2c where the particulate is removed and from which it passes through the clearance 3 between the tubular passages 2 and thence into chamber 4. During normal operation the exhaust in chamber 4 passes through the open by-pass valve 5. The resistance to exhaust gas flow through the porous walls 2c will result in pressure drop across the trap between its

entrance end 1a and its exit end 1b that will gradually increase to about 15 in. wg. as the filtered soot and ash collect. In normal operation, exhaust gas that enters the passages 2 in which their exit ends 2b are open will blow through the passages into chamber 10 in which the pressure is only a few in. wg. The aforementioned pressure drop results in an exhaust flow velocity through the passages 2 of about 40 - 50 feet per second. Because the rotary valve 9 is continuously rotated, each passage will be subjected to this moderate through flow velocity during normal operation and this may remove some of the soot and ash accumulation.

It is expected that under most engine operating conditions, soot and ash will continue to build up on the inner surfaces of the porous walls 2c of the passages 2. This will increase the pressure drop across the trap module and increase the pressure in chamber and 8 and thus increase engine backpressure with adverse affect on engine performance. It should be noted that the increased pressure across the trap will also increase the velocity of the exhaust gas through the passages 2 when their exits 2b are uncovered by slot 9a. This increased velocity will erode and dislodge much more of the soot/ash layer and remove it to the separation chamber 10 for combustion and storage. Thus, the system is to a large extent self regulating in the event of control failure and the like. However, it will probably be desirable to limit the increase in trap pressure drop to 15 to 20 in. wg. during most normal operation in order to have little or no adverse affect on engine performance. Increases above that will require that the trap system enter a regeneration mode.

When the control system determines that trap regeneration is necessary, based on backpressure or some other engine parameter, the by-pass valve 5 will close thus blocking the exiting filtered exhaust until the pressure in chamber 10 increases to the setting of the relief valve 6 such as 30 in. wg.

At this point the filtered exhaust will flow through the relief valve and the pressure in chamber 10 will remain at a substantially constant 30 in. wg. Under these conditions, the pressure in inlet chamber 8 will be about 45 in. wg. Consequently, when the slot 9a uncovers the exit ends 2b of the slots, engine exhaust gas will flow through the affected passages 2 at a velocity greater than 100 feet per second. This will erode and dislodge much of the soot/ash accumulation within the passages. In addition, there will also be a large flow of previously filtered exhaust gas back through the porous walls 2c of the passages 2 over much of their length. As mentioned in connection with the system of Fig. 5, because of flow friction in the passages 2, there will be a reverse flow through the walls only along about half to two thirds of their length from the exit end. However, there will be a very high reverse flow toward the exit ends where the accumulated soot/ash cake is said to be the thickest. The strong reverse flow will either dislodge or break up the soot layer and make it more amenable to removal by the high velocity through flow exhaust gas. As in the case of the system of Fig. 5, the soot/ash particles blown out of the trap and the smoke contained in the through flow exhaust gas will be prevented from escaping to the atmosphere by the secondary filter 13 and the soot will be burned and the ash stored in chamber 10. Following the regeneration period that will involve at least one complete revolution of rotary valve 9, the by pass valve 5 will again be opened. This will return the pressure in chamber 4 to substantially zero for normal operation.

Fig. 8 illustrates a multi-trap particulate trap system that is similar to the system shown in Fig. 6 except that it uses only one valve per trap and also incorporates a different type of secondary filter. Again, because of the similarity of design and operation, drawing numbers used are the same as were used in Fig. 6 except for the parts or components that are different. The

major difference is that the system has no valves at the entrance to the traps and therefore the entrance to the passages 24 is never blocked. This simplifies the system because a second set of valves and their actuators is not required. The exit end of the passages 24b are blocked by valves 28a, 28b and 28c until one of these valves is briefly opened during the regeneration process. The other principal difference between this system and the one shown in Fig. 6, is a different type of secondary filter and associated soot igniter and ash canister. The secondary filter consists of a refractory fabric 37 that is capable of removing 90-95% of the soot from exhaust smoke and which is located across the structure at the exit of the traps. This is backed up by a convoluted porous or perforated metal plate 38. Chamber 36 is connected at the lower end to the igniter/storage chamber 41 that contains the soot igniter 41a. Chamber 39 is located behind the porous metal plate 38 to receive the filtered exhaust gas leaving the secondary filter 37 and porous plate 38 and conduct it to the atmosphere by means of duct 40.

In normal operation, exhaust from the engine enters chamber 25 and thence into passages 24. Because these passages are usually blocked by valves 28a, 28b and 28c, the exhaust gas must pass through the porous walls 24c of passages 24 whereby the particulate is removed. The filtered exhaust gas then passes through the clearance 29 between the passages 24 and then through open by-pass valve 32 to the atmosphere. During normal operation, valves 28a, 28b and 28c will each open sequentially for a brief period. Because the pressure in chamber 25 with clean traps will be 10 to 15 in. wg. , there will be a brief moderate velocity (20- 40 ft. per sec.) through flow in passages 24 because the secondary filter will be designed to limit the pressure in chamber 36 to no more than 2-4 in. wg. This through flow may result in some of the soot/ash cake being dislodged or eroded and it will pass into the separation chamber 36 to eventually be burned/stored. Another

reason for sequentially actuating the valves 28 is to exercise them to prevent them from sticking.

As operation continues, the filtered soot and ash will buildup a layer on the inside of the porous walls 24c which will result in the pressure drop across the trap rising from say 10 in. wg. to perhaps 15 - 20 in. wg. As this pressure increases, it will increase the engine backpressure and there will be some point at which regeneration will be desirable. However, it should be noted that if no steps are taken the resultant eventual large pressure drop across the trap will rise to 40 - 50 in. wg. or even greater. This will cause exhaust gas to flow at very high velocity (>100 ft./sec.) through the trap passages and this will dislodge and erode the soot/ash layer at a much greater rate and will probably result in an equilibrium in which the soot/ash layer is removed at the same rate at which it is deposited. However, this may result in greater than desired engine fuel consumption because of the higher engine backpressure, making periodic brief but effective regeneration of the trap preferable.

When the control system indicates that regeneration is required, based on sensed engine backpressure or other parameters, the control first closes the by-pass valve 32. This blocks the passage of filtered exhaust gas to the atmosphere and causes the pressure in chamber 31 to increase until it opens relief valve 33 which is preferably set at 30 in. wg. This pressure in chamber 31 will exist around the periphery of all of tubes 24. When, say, valve 28b is then opened in its normal sequence as described above, filtered exhaust gas will flow in reverse through the porous walls 24c along the trap length from one third to two thirds of the distance from the tube exits 22b. The reverse flow will be maximum near the exit of each tube 24 and will then flow through the tubes 24 to exit into chamber 36. There will also be a simultaneous very high velocity (>100 ft. per sec.) flow of raw engine exhaust

gas from chamber 25 entering tubes 24 at their entrance end 24a passing through the length of the tube and exiting into chamber 36. This very high velocity will result from the high pressure (45 in. wg.) in chamber 25 caused by the pressure drop across the porous walls of 15 in. wg. added to the 30 in. wg. backpressure caused by the relief valve. This very high velocity through flow of engine exhaust gas will dislodge and erode any soot/ash cake abetted by the reverse flow of filtered exhaust gas back through the soot/ash cake. The through flow will very effectively carry dislodged soot/ash particles out of the trap where some will fall by gravity to the igniter/storage chamber 41 and some will be caught by the fabric secondary filter material 37 along with the smoke that was contained in the raw exhaust gas. Following a brief opening of valve 28b to regenerate trap 20b, the valve 28b will close. This action will be followed a short time later by valve 28c opening to cause the same regeneration action in trap 20c. This sequential action will continue until all of the traps have been regenerated. At this time by-pass valve 32 will again open, dropping the pressure in chamber 31 to substantially ambient and normal operation will then continue with clean traps until regeneration is again required.

As operation continues, a layer of soot/ash will build up on fabric filter 37. However, the collected cake will be more or less continuously broken off by the impinging velocity of the exhaust gases leaving the traps which may erode the layer. In addition, the stagnation pressure due to the impinging flow as each valve 28 opens will cause the fabric to flex in a manner similar to bag house technology and this will mechanically crack and break off the soot/ash cake. In order to prevent fabric filter durability problems due to the flexing action, the convolutions in the perforated back-up plate 38 will be designed to limit flexing to no more than is required to break and remove the soot/ash cake.

The soot/ash particles that fall in chamber 36 will enter the igniter/storage container contact the very hot (>550°C) igniter coils whereby the soot will be ignited and burned. The incombustible ash will pass on through the igniter coils and be stored in the igniter/storage container for periodic disposal.

Figs. 9a, 9b, 10, 11 and 12 illustrate the perforated plate slide valves that are shown in the preceding multi-trap systems of Fig. 6 and Fig.8; however, other suitable valves, such as poppet valves, can be used. The perforated plate slide valves have advantages, especially for valves used in the particulate trap systems in which the pressures are very low and in which a small amount of leakage can be tolerated. Advantages include flexibility of adapting to different cross sectional shapes of the trap, such as round, rectangular, etc., while maintaining a uniform distribution of the fluid to the trap regardless of the degree of opening. In addition, the stroke is very short and the inertia is minimal permitting very fast actuation by electrical solenoid or pneumatics. Finally the valves are very compact and should be relatively inexpensive.

Referring initially to Fig 9a and 9b, the perforated plate slide valve has a moveable perforated plate 44 and a stationary perforated plate 43, each containing an identical hole, slot or other aperture pattern. In the preferred embodiment, a series of approximately 0.25 inch diameter holes are spaced apart substantially as illustrated. The stationary perforated plate 43 may be part of the trap structure material. The moveable perforated plate 44 is a relatively thin and accurately guided plate having a suitable member 44a to attach it to an actuation device, not shown. A plurality of accurate stops (not shown) in conjunction with a guidance device (not shown) are used to assure that the moveable perforated plate 44 and the stationary perforated plate 43 are accurately aligned. The moveable perforated plate 44 and the stationary

perforated plate 43 are constructed of a refractory material and are in close proximity to each other for satisfactory sealing.

Fig. 10 illustrates the moveable perforated plate 44 and the stationary perforated plate 43 assembled together with the holes aligned with each other in the "open" position. This provides at least a 25% open area in the face of the perforated plate slide valve that is satisfactory for controlling flow to the particulate traps at minimal pressure loss.

Fig.11 illustrates the moveable perforated plate 44 and the stationary perforated plate 43 assembled together with the holes out of alignment in the "closed" position. The distance plate 44 moves from the open position to the closed position is approximately 0.3 inch.

Fig. 12 is a cross sectional view of the preferred design of the perforated plate valve for use with the aforementioned multi-trap particulate trap systems. The trap 48 is shown sealed in bulkhead 49 by a layer of Interam 49a. The stationary perforated plate 43 is manufactured as part of trap structure bulkhead 49 as shown, the perforated hole pattern probably being stamped in during the manufacture of the bulkhead 49. Moveable perforated plate 44 has a matching hole pattern to that of stationary perforated member 43, and is coupled by an appropriate member (not shown) to an actuator (also not shown). The moveable perforated plate 44 has an integral formed section 44b to provide a reliable and durable guide with bolted-on guide member 47. The moveable perforated plate is bent in a shallow arc (in the plane of the paper of Fig. 12) following its stamped forming and its high temperature grade material is then heat treated. During assembly, the guide member, with the moveable perforated plate in place, is bolted against the bulkhead 49. This action forces the arc of the heat treated plate into a flat configuration and this spring action effects a tight fit between the two plates, assuring a good seal when the valve is in its "closed" position.

Fig. 13 illustrates how the particulate trap system of Fig. 8 might look like when mounted on the tractor of a highway truck. In this design, cross flow traps of the type manufactured by Asahi Glass Company of Japan are used. The nine trap modules (4"x5.6"x8") used would provide particulate control for a truck of about 300 hp. The traps can be located remote from the engine because no attempt is made to keep the traps hot in normal operation and they do not have to be heated for regeneration. As can be seen, the actuators for the perforated slide valves (as shown) can be located on the external surface of the trap structure and consequently operate cool. Because of the cool location, the short 0.3in. stroke and low force required and the simple on-off valve function, it is expected that the valves actuators can use direct electromagnetic control.

Fig. 14 illustrates how the particulate trap system of Fig. 8 coupled with low pressure loop (LPL) exhaust gas re-circulation EGR might look when mounted on a tractor of a highway truck. Low pressure loop EGR is considered to be well matched with this type of particulate control system with no sulfur reduction from current (2002) diesel fuel because of its excellent filtration efficiency, cool operating temperature, and lack of catalysts which can generate sulfates that can damage the engine. The cool location minimizes the amount of cooling that might be required prior to admitting the filtered re-circulated exhaust into the engine ahead of the turbocharger. The drawing shows the relief valve as a symbol; the design of this remote controlled component will be further discussed later.

Fig. 15 is a cross section of a multi-trap system that uses wall flow traps that are regenerated by reverse flow of pre-filtered exhaust gas. The wall flow traps 50, are contained in cylindrical tubes 50a, as assemblies 51a and 51b that have a layer of Interam (not shown) between the tubes 50a, and traps 50 to provide a seal and to hold the traps in place. The trap assemblies

51a and 51b are mounted in a structure that is shown generally as 52. Each trap assembly with its contained trap is slid into bulkhead 53, passed through the circumferential seal 54a in bulkhead 54, and thence intothe bulkhead 55. The tube is then bolted to bulkhead 53, an "O" ring of Interam 56, is placed over the head of the tube, and the valve actuator/cover plate 57 is bolted in place. As can be seen, the bulkheads form separate channels 58 and 59 in the volume surrounding the trap assemblies 51a and 51b. Exhaust from the engine enters channel 59, passes around the trap assemblies 51a and 51b and is either permitted to pass through the traps, as shown in the case of trap assembly 51b, or is blocked from entering the traps as shown for trap assembly 51a. Channel 58, registers with the left end of the trap assemblies and is also connected with the centrifugal separator 66, which is used to remove and burn the dislodged soot and store the incombustible ash. Channel 58, is either open to permit flow to either exit or enter the traps, as shown in the case of 51a, or to block this flow as shown for the trap assembly 51b.

The above action is carried our by the cylindrical slide valves, shown generally at 60. A valve 60 consists of a pattern of small holes 62, (apprx. 0.25 in. dia.) arranged about a portion of the periphery of the tubes 50a., and a matching set of holes arranged about the periphery of an axially moveable cylinder 61, closely fitted within tubes 50a. As can be seen in the drawing, in the trap assembly 51a the moveable and stationary holes adjacent to channel 58, are aligned and thus can permit flow, while those adjacent to duct 59, are out of alignment and thus will not permit flow to take place. However, in the trap assembly 51b, the inner cylinder 61 of the valve has been moved axially to the left about 0.3 in. by the actuator 57. This results in the holes adjacent to duct 58, being out of alignment and are thus open to permit flow to occur. The outside diameter of the inner perforated cylinder 61, is made slightly larger than the inside diameter of the outer stationary tube

50a and the cylinder 61, and includes a longitudinal slit 63, in the cylinder wall. This permits the cylinder 61, to be squeezed slightly to permit installation in stationary tube 50a and , upon release, will result in a small outward pressure, due to the spring rate of the cylinder, to prevent leakage in the vicinity of the holes. The inner cylinder 61 will be made of a high temperature material to retain its physical properties in the hot environment. The actuators 57, move the inner cylinders by means of the tee shaped member 64, in which ends of the tee are loosely slipped into additional holes in the inner cylinders 61, prior to their installation in the stationary cylinders 50a.

Referring to Fig. 15, in normal engine operation the exhaust gas flow from the engine will enter channel 59, and then will enter all of the traps because the slide valves will all be positioned as shown in the case of trap assembly 51b. After passing through the aligned holes, the exhaust will enter into the small chamber formed within the slide valves 60, and then flow into the wall flow traps to be filtered. The filtered exhaust gas from all of the traps will then pass through the open relief valve, shown generally at 69, and thence to the atmosphere. The removed particulate matter will build up in a layer or cake on the inside of the trap entrance passages and this will result in an increase in trap pressure drop that will increase the engine back pressure and adversely affect engine performance. Consequently, after a few hours of normal operation the traps must be regenerated to remove the accumulated cake of soot and ash.

When the electronic engine control (EEC) senses exhaust backpressure or other parameters t hat indicate regeneration is required, the remote controlled pressure relief valve 69, in the exhaust channel 68, is activated to

restrict any filtered exhaust gas from leaving duct 68, until its pressure has increased to approximately 30 in. w.g. This increased pressure is equally distributed in the clean exit channels of all of the traps and throughout the entire length of each channel. After a brief period, the EEC will cause one of the valve actuators 57, to move the slide valve 60 to the position as it is shown in trap assembly 51a. This action will block further engine exhaust from entering this trap and, at the same time, open the normal entrance of this trap to channel 58. Because channel 58 is at, or below, ambient pressure, a very significant reverse pressure differential will exist across the porous walls of the wall flow trap channels throughout their length. It is emphasized that this very significant reverse pressure drop will remain constant during the regeneration period. This is because the other traps in the system will continue to filter and supply clean exhaust into channel 68, which must exit through the pressure relief valve. This constant reverse pressure will break off and dislodge the accumulated soot/ash cake and will also result in a strong reverse flow of pre-filtered exhaust gas through the porous trap walls. This flow will further erode any remaining soot/ash cake and carry the dislodged particles out through channel 58 and thence into the centrifugal separator 66, in which the soot will be burned by high temperature electrical heater coils 67, and the incombustible ash stored for periodic disposal. It is emphasized that the reverse flow used to remove the soot and ash cake and carry the particles to the centrifugal separator consists of pre-filtered clean exhaust gas, except for an insignificant amount of raw exhaust that is trapped in the valves at the time of their actuation. Thus, most of the soot and ash particles will be removed from clean exhaust gas by the centrifugal separator and burned or stored.

Because there is only a moderate increase in pressure in Channel 68, and thus in engine backpressure, during the regeneration period, this reverse

flow clean-out of a trap can be maintained for several minutes without significant adverse affect on engine performance. After this reverse flow clean-out has been completed, the EEC will proceed to return this valve to its original position as in the case of 51b and the EEC will move the valve of the next trap to the position as illustrated by 51a. This sequential action will continue until all traps have been regenerated. At this time all valves will be returned to the position as shown for 51b to permit all traps to again begin filtering the engine exhaust and the relief valve 69, will again move to a fully open position, thus returning engine exhaust pressure back to normal.

Fig. 16 illustrates an enlarged cross sectional view of the cylindrical perforated plate slide valves. These were described earlier as used in flat plate form for simple on –off control of flow. The cylindrical form is used, as mentioned in regard to Fig. 15, to provide a three-way type of valve. Numbers used in Fig. 16 are the same as used in Fig. 15 for functionally similar parts. The tube 50a is used to contain the trap 50a and is also a functional part of the cylindrical perforated valve as will be explained. The trap assemblies 51 are slid into the structure through bulkhead 53. The tube 50a is then pushed through the internal seal ring 54a located in bulkhead 54 and then finally is pushed into the aperture in bulkhead 55. The tube 50a contains the perforations or holes (apprx. 0.250 in. dia.) and is the stationary part of the slide valve. The inner, moveable cylinder 61 is made of thinner (apprx. 0.030 in. thick) refractory metal such as stainless steel and is formed into a partial cylinder that is slightly larger in diameter than the inside diameter of tube 50a and has a small gap 61a. The tube 51 and inner cylinder 61 would probably be manufactured by stamping flat prior to rolling into cylinders, at which time the small perforations or holes would be stamped. The hole pattern is such that with the inner cylinder in one axial position, the holes in the two cylinders at the left (as shown) line up exactly with each

other and are "open" while the holes in the two cylinders at the right (as shown) are misaligned. and are thus "closed". Actuation of the valve inner cylinder to move it to the left stop (in the drawing) will change the "open" holes to "closed" holes and vice versa. The inner cylinder 61 is sprung to a slightly smaller diameter with a device like a piston ring compressor and then it is slid into the larger tube 50a and then a pin (not shown) is placed in the outside tube in a hole made in the original stamping operation to locate and keep the two cylinders in correct positions with each other. When the inner cylinder 61 is being prepared to be pushed into place, actuation member 64 is loosely slipped into the punched orifices shown and moves in with the inner cylinder, along with the actuator mechanism 57. It is assumed that a suitable material can be found for the inner cylinder to be able to retain much of its springlike properties when located in the heated exhaust. An alternative is the addition of Belleville springs made of a material like Hastelloy X to provide a nearly constant pressure between the inner and outer cylinders to assure good sealing. The method of operation of the cylindrical perforated slide valves was described in regard to Fig. 15.

Fig. 17 is an alternative means of controlling the flow as required for the particulate trap system shown in Fig. 15. Again, the part numbers used in Fig. 15 will be used for this device for functionally similar parts. Tube 50a contains a wall flow particulate trap 50 with the space between them sealed with Interam (not shown). The trap assembly 51 is slid in through bulkhead 53, then through bulkhead 90 whose sole function is to maintain lateral position of the left end (in the drawing) of the trap assembly 51 by means of the stamped fingers and slots in bulkhead 90. Bulkhead 91 contains an inner ring seal 91a through which tee shaped (in cross section) poppet valve 94 is slid. The seal at the outside surface of the poppet valve 94 effects a seal to prevent any exhaust gas from passing from chamber 58 to 54 when the valve

is seated in either direction. The poppet valve contains large perforations 95 to permit flow of exhaust to pass freely between chambers 59 and 58 within the confines the outer cylinder.

During normal filtration, the exhaust gas from the engine passes through channel 59 and thence around each of the particulate traps. Flow from this channel then passes through the slots in bulkhead 90 and then through the opened poppet valve 94 and enters the trap 50 as indicated by the arrows. The exhaust gas then passes through the trap wherein it is filtered before entering the exit duct as it leaves the trap.

During regeneration of the trap, the poppet valve 94 moves to the right (in the drawing) about 0.7 inches and seats against the trap can 50a. This action prevents any further exhaust gas from passing from channel 59 into the valve chamber. The valve action also unseats the poppet valve 94 from the valve actuator structure and permits exhaust gas from the exit duct to flow in reverse through the trap 50 into the valve chamber, through the apertures 94a and then out through the opened valve and into channel 58. This reverse flow dislodges and erodes the soot/ash cake on the trap inner surfaces and carries them through channel 58 to the separation chamber (not show) wherein the soot is burned and the incombustible ash is stored for periodic disposal.

Fig. 18 illustrates the separator and igniter/storage device used to remove the soot/ash particles from the reverse flow stream of pre-filtered exhaust gas by which the soot/ash was removed from the trap(s) during regeneration. The reverse flow pre-filtered exhaust gas is itself clean and free of exhaust smoke. However, the particles must be separated from this stream and the soot ignited and burned and the incombustible ash stored before the stream can be discharged to the atmosphere. While a simple centrifugal separator as shown with the system in Fig. 15 may suffice, a somewhat more extensive device may be required. Pre-filtered with its

content of dislodged soot/ash particles enters the separator from duct 103 off-set as shown in view A-A such that the gas spins at a high rate of rotation within casing 102. This rotational motion will tend to move the particles, which have relatively high mass, out toward the periphery of casing 102. As the spinning flow stream moves down in casing 102, the particles will be caught by small louvers 104 and directed into the annular volume 110 between the casing 102 and the ash storage canister 105. These particles fall down by gravity abetted by a small flow of exhaust through orifice 109. Upon contacting the high temperature (>550°C) igniter coils 111, the soot is ignited and burned and the incombustible ash continues to fall down and be deposited in the ash storage canister 105 for periodic disposal. The majority of the pre-filtered exhaust gas, devoid of most of the particles passes into the exit duct 112 after passing through a final refractory fabric filter 108. The final filter will probably not be required but can be optionally included to assure that no particles are emitted to the atmosphere. Alternatively, a separate larger secondary filter of any suitable design can be used for this latter purpose. It would be expected that the soot igniter coils would require about 200 watts of energy when energized to ignite the soot.

Fig. 19 is a drawing of a remote controlled straight relief valve. Referring to the drawing, the filtered exhaust passes up from channel 68 (Fig. 15) and enters the duct 115 in the relief valve body 166. It then passes butterfly valve 117 that is open during normal trap filtering, and then passes on to the atmosphere as indicated. When the EEC detects that regeneration is required, three-way valve 118 is opened to the position shown. This permits air from the air brake reservoir to flow through pipe 119 and thence into the actuator cylinder 120 and builds up a pressure in end 120a of the cylinder until it reaches the 30in. wg. setting of the small relief valve 124. This forces piston121 to move to the left and, through a suitable linkage, rotate the

butterfly valve toward the closed position. The speed at which this occurs is controlled by the small choked orifice 122 in the air supply line. As the butterfly valve begins to close, pressure will build up in passage 115 and channel 68 (Fig. 15). As this pressure builds up, exhaust gas will flow through the tube and damping orifice 123 and build up an opposing pressure in end 120b of the cylinder. When the pressure in 120b equals the 30 in.wg. pressure in 120a maintained by the small relief valve 124, the buttterfly valve will stop closing with 30 in. wg. pressure existing in passage 115, as desired. If the engine speed decreases, the pressure in passage 115 will decrease, air will flow out of 120b and the constant small flow of air into 120a will cause the piston to move the butterfly toward closed until once again the pressure in passage 115 just balances the 30 in.W.G. pressure in 120a. If engine speed increases, a similar but opposite action will occur. When it is desired to deactivate the relief valve assembly 116, the EEC will rotate the three-way valve to close off the air supply and dump the air contained in the system, thus letting the air pressure in passage 115 and the force of the small spring 125 to rotate the butterfly valve to the fully open position at which setting there is little no pressure in channel 68 (Fig. 15).

Fig. 20 shows a cross section of the combined relief valve/venturi. The object of this design is to increase the reverse pressure drop that can be imposed across the trap for a given engine back pressure. With a simple relief valve, we can, for example, impose a 30 in. wg. back pressure in channel 68 (Fig. 15). If we assume a 15 in.wg. pressure drop across the trap walls at the time of regeneration, we will then have an engine backpressure of 45 in.wg. which is within the engine manufacturers recommended limit. However, if we place a venturi in the exhaust stack with this same 30 in.wg pressure drop as it flows to ambient pressure, we can obtain a vacuum at the venturi throat of about 20 to 60 in.wg. Because this will be in series with the 30 in.wg back

pressure we will have, neglecting pipe flow losses, a reverse pressure across the trap walls of 50 to 90 in.wg. Thus, we will have greatly increased the aggressiveness of the reverse flow cleaning process or, if not required, we can achieve the same reverse flow with less back pressure on the engine.

Referring to Fig. 20, the filtered exhaust passes up from channel 68 (Fig. 15) and into the main passage 145 of body 146. The flow then is split by valve member 147, and thence passes up through the annular channel 148 and then out to the atmosphere, as indicated. As the flow splits and enters the annular channel, in which the minimum cross sectional area is much less than that of passage 145, the velocity is greatly increased and consequently the static pressure is significantly reduced. This low pressure is connected by annular slots 149, to passage 150 and this, in turn, is connected to the outlet of the centrifugal separator and thence to channel 58 and the trap passages.

It will be noted that the valve member comprises a piston which tends to be pushed upward by the very light, low rate parking spring 151. The valve will be forced in the down direction by pressure in the cavity 152 above the piston. When activated, air at a constant 30 in.wg. will be imposed in the cavity 152 and this will push the piston down and decreasing the cross sectional area of the annular passage 148 and therefore increasing the pressure in passage 145 and channel 68 (Fig. 14). When the pressure in passage 145 reaches 30 in.wg., the force downward by the activation air pressure will be just balanced by the equal 30 in.wg. pressure and the desired reverse pressure in channel 68 will be achieved. Also, the high velocity in the annular channel 148 will create a low pressure (vacuum) in the passage 150, as previously discussed, which will be used to enhance the reverse pressure across the trap walls.

When the engine speed and/or load increase, the increased flow through annular passage 148 will increase the pressure in passage 145 and this

will push piston/valve 147 up against the constant activation pressure. Reduced engine speed and/or load will have a reverse affect. When regeneration is complete, the activation pressure is dropped to zero by the EEC and the gas pressure and the force of the return spring will move the piston/valve up to remain against its stop and the pressure in channel 68 (Fig. 15) will drop to substantially ambient.

Fig. 21 is similar to the configuration shown in Fig. 15 that was discussed earlier except that it employs a venturi in conjunction with the relief valve to obtain greater reverse differential pressure and it also uses a 3-way valve to modify the exhaust flow to permit heating of a small portion of the exhaust gas to assist regeneration as will be discussed later in more detail. Because most of the elements are the same as in Fig. 15, only the parts pertinent to the discussion will be identified.

The relief valve/venturi, which was described in the discussion of Fig. 20, is shown at the exit of the filtered exhaust channel 68, and connected by channel 153, to the outlet of the separator. As described in the discussion of Fig. 20, the relief valve/venturi will provide the desired increased pressure in chamber 68 of say 30 in. w.g. while the increased velocity at the throat 148, of the venturi will reduce the pressure at this point to 20 - 60 in. w.g. below ambient (vacuum). The increased pressure in channel 68 coupled with the reduced pressure in duct 153 results in a significantly greater reverse pressure drop of 50-90 in. w.g. across the trap wall during regeneration. The venturi principle can also be applied to the cross flow trap systems but it is felt to be more useful applied to the wall flow configurations because of the absence of any high velocity through flow in this type of trap.

The three-way valve 65 is arranged to normally admit the smaller of two streams of engine exhaust into channel 58 or, upon actuation for trap regeneration, connect the channel 58 with the soot/ash separator 66 and

internal igniter coil 67. The major portion of the exhaust enters channel 59 and then after passing through the perforated valves as shown in 51b, enters all of the traps except one. Filtered exhaust, after passing through the traps, passes up channel 68 and then through the relief valve/venturi assembly, shown generally at 70, which, upon demand by the electronic engine control (EEC) can be actuated to create a pressure in channel 68, and thus in all of the clean exit passages of all of the traps, of about 30 in. w.g. along with a negative pressure (vacuum) in the separator chamber 67, as discussed above and in conjunction with Fig. 20.

In normal operation the exhaust flow from the engine will, after passing through a suitable divider, continue on to pass through 3-way valve 65 and thence enter channel 58. Depending upon the number of traps used, this flow may be from perhaps 1/4 to 1/15 of the total exhaust flow. The remaining exhaust flow may be 3/4 to 14/15 of the total flow and will this will enter channel 59 through the large exhaust flow entrance. At the trap, the small exhaust stream will enter channel 58, pass through the open perforated valve in trap assembly 51a, thence through the trap and then exit into channel 68 as filtered exhaust. The large exhaust stream will enter the channel 59, from which it will enter all of the other trap assemblies in which the perforated valves are positioned as in trap assembly 51b. These traps will also filter the exhaust passing through them and these flow streams will also enter channel 68, where they will combine with the small exhaust flow emanating from trap assembly 51a. The combined stream of exhaust, now filtered, will pass through the relief valve/venturi 70 , which is fully open to permit flow to pass through with no retained pressure in channel 68. This operation will continue with 90 - 97% of the soot/ash being removed from the exhaust, with little or no adverse affect on engine performance and without any need for low sulfur fuel. However, after extended operation of a number

of hours, the soot/ash will build up as a cake on the inside surfaces of the trap passage walls and this will ultimately increase trap pressure drop until the engine exhaust back pressure increases to a level of 15 – 30 in. w.g. , and regeneration is required to remove the collected layer of soot/ash.

When the electronic engine control (EEC) senses exhaust backpressure or other parameters and these indicate that regeneration is required, the relief valve 70 is activated to restrict any filtered exhaust from leaving channel 68 until its pressure has increased to about 30 in. w.g. As stated previously, this increases the pressure in all of the trap exit or clean passages. Following this action, the EEC will cause the three-way valve 65 to move to its position shown "dashed" and this will stop all further flow toward the trap system in the small flow pipe and this flow will then begin to enter channel 59 along with the large stream of exhaust gas. At the same time, channel 58 will be opened permitting the exhaust gas in channel 58 to flow to the centrifugal separator and thence through duct 153 to the relief valve/venturi in this configuration.

Each time a cylindrical perforated slide valve opens to connect a trap with channel 58, which is now at or near ambient pressure, there will be a strong reverse flow from channel 68, back through the trap walls during which time the flow will dislodge and erode the soot and ash cake. The flow will then carry the particles of dislodged particulate out through channel 58 and thence into the centrifugal separator. As mentioned in the discussion of Fig. 15, the reverse pressure drop will be sustained as long as the perforated slide valve keeps the trap open to channel 58. This is because the large exhaust flow stream will continue to pass through the traps and enter channel 68 and then exit through the relief valve which will keep the pressure constant at the selected setting under all engine operating speeds and loads. It is

believed that this strong sustained reverse flow will remove all, or substantially all, of the soot and ash.

It is stressed that the reverse flow that is used to dislodge the soot and ash has been previously filtered and will contain no smoke except a very small amount that resides in the trap at the time the perforated valve is actuated. This clean stream, with its entrained, relatively large soot/ash particles, is carried out in channel 58 and will pass tangentially into the centrifugal separator 66. This action will force the relatively large particles of soot/ash to the outside where the soot will be burned by igniter 67 and the ash will remain in storage. The center flow will move up and through the pipe and thence, if found necessary, to a secondary filter. It will then be delivered to the combined relief valve/venturi assembly which will be at a vacuum of about 20 to 50 in. w.g. as a result of the venturi action.

The above action will continue, with each trap being reverse flow cleaned, in turn, until all of the traps have been cleaned. Following this, the relief valve/venturi will be deactivated thus dropping the pressure in channel 68 to substantially ambient. Valve 65 will then be actuated to again close off the flow path to the centrifugal separator and open the flow of the small flow stream into channel 58 once again. During all normal operation, the cylindrical slide valves will continue to actuate thus connecting each of the traps to channel 58 for a brief period in turn. This periodic movement will keep the valves and actuators from becoming stuck or otherwise put out of order due to prolonged residence in one position.

Fig. 22 illustrates an installation of the wall flow trap system of Fig.15 as it might be installed on the tractor of a highway truck.. In this design, five wall flow traps (5.66"dia.x 12" long) traps are used, along with a duct and control for low pressure loop EGR. The use of the larger (5.66" dia. X 12" long) traps minimizes the number of trap assemblies and associated trap

control valves required for a given engine horsepower. Characteristics, such as high efficiency particulate removal, low trap temperature and the absence of catalysts that may generate sulfates make these trap systems attractive for the use of this simpler and more efficient EGR approach.

Fig. 23 illustrates an installation of the wall flow trap system of Fig. 21 as it might be installed on the tractor of a highway truck. In this design, nine wall flow traps (5.66"x 6" long) are used, along with a relief valve/venturi connected to the separator, soot igniter and ash cannister. It also uses low pressure loop EGR. Although the operation of the designs shown in Fig. 22 and Fig. 23 are essentially the same, the smaller traps used in this design permit a reduced structure cross section that may be attractive for some applications.

Fig. 24 shows a cross section of a single trap system that uses a wall flow trap that is regenerated by reverse flow of filtered exhaust gas. In this arrangement, the trap 160 is mounted and sealed in the trap system structure 161. A rotary valve/duct member 162 is turned at about one revolution per each half hour and is rotated by drive member 163. The duct part of the rotary member defines a pie shape at the point where it touches the face of the trap module as shown at 164 in section A-A. The tubular end 165 of the rotary member duct is symmetrical about the trap centerline and is rotated in bulkhead 166 and sealed against axial leakage by seal 166a. The circular chamber 167 at the exit of the trap passages connects with the passage leading to the type of relief valve employed.

In operation, the largest part of the exhaust passes into the trap passage labeled large flow stream. Also a smaller portion of the exhaust flow is passed in to valve assembly 168 and thence through passage 169 to enter the cylindrical portion 165 of the rotary member 162.

In normal trapping operation, the large flow enters the passage in the trap that is so labeled, passes into volume 170 and from this volume enters the open ends of the majority (5/6 to 19/20 of the total) of the trap entrance passages that are not covered by the rotating pie shaped duct. The small exhaust flow enters valve 168, passes through passage 169 and then through the rotating duct 165 and into the trap entrance passages encompassed by the pie shaped duct 164. It should be noted that spoke members 171 are used to maintain the integrity of the rotary member and play no other role. The shape of the contact between the rotary member and the trap is shown by the approximately 0.25 inch wide contacting members 172. As the trap continues to operate, the flow entering the trap passages passes through the porous walls of the channels and then exits through the clean or exit channels to then pass into channel 167 and thence through the open relief valve to the atmosphere.

When the trap system control senses that regeneration is required, the relief valve assembly 173 is activated, thus causing a constant pressure of 30 in. wg. to occur in the filtered exhaust in channel 167 and also in the clean exit passages of the trap. Shortly after this pressure rises and stabilizes, three-way valve 108 is actuated to the right and seats thus shutting off all of the small flow to the trap passage 169. By this same action, channel 169 is opened to much lower pressure and this causes the 30 in. wg. pressure in channel 167 to flow back through the porous walls of the passages encompassed by duct/trap contact 164. This dislodges and erodes the soot/ash cake and carries it out through valve 162 to be disposed of as discussed for the multi-trap system. Again, because exhaust is continually flowing into channel 167, the reverse pressure will be constant at 30 in. wg. as long as the relief valve is activated because filtered exhaust is continuously flowing from the much more numerous passages through which the entire exhaust gas flow is passing. Each of the passages will experience this high pressure reverse

flow as long as they are encompassed within the contact pie shape 164. Though not shown, it will be understood that the previously described venturi could be used to increase the reverse flow pressure and then enhance regeneration.

While we believe that the trap systems shown in Fig. 15 and Fig. 24 will effectively remove substantially all of the soot/ash cake in the passages, there may be some conditions such as very cold ambient where heat may need to be added to more completely burn out the soot. Fig. 25 shows the placement of an electrical heater 181 in the small flow passage that can be used to heat the small flow of exhaust gas to above the ignition temperature of the soot. This would only be used following reverse flow regeneration of the particulate trap system to insure that most of the soot/ash deposits were removed from the trap to prevent trap damage caused by combustion of the soot in the trap. The control system would initiate the reverse flow regeneration phase and then, if engine back pressure or other engine parameters indicated that additional trap cleaning were necessary, the control would return the three-way valve to the "normal" position and energize the heater for at least one complete cycle. Because of the small flow rate, this can be accomplished with a relatively small heater and minimal expenditure of energy. Thermocouple 180 is used to sense the temperature and to reduce or shut off the electrical energy when the necessary small flow temperature is reached. A small burner could be used as an alternative to the electric heater.

Figs. 26 - 30 cover the changes necessary to modify the aforementioned reverse flow embodiments that are fundamentally very efficient particulate trap systems into the advanced adsorber-catalyst particulate trap systems that will be required to achieve the very stringent 2007 EPA standards using ultra low sulfur fuel (10ppm). An important advantage of the forgoing particulate trap systems is that substantially the

same trap structure, trap control valves, exhaust relief valves, etc. will be used for the adsorber-catalyst systems. The principal difference will be the application of the wash coats of BaO and Pt. etc. catalysts to the inner surfaces of the trap channels, use of insulation to keep the traps hot and use of a divider enrichment device to split the exhaust into two streams. One of these streams will be of large flow (5/6-19/20 of total exhaust flow rate) of normal (lean) exhaust and the other a much smaller flow (1/6 -1/20 of the total exhaust flow rate) and this stream will be enriched by burning fuel at stoichiometric conditions to provide an excess of CO and/or HC. The normal (lean) stream and the enriched stoichiometric streams are required for the adsober-catalyst process as will be described.

In this patent, all values are to be considered as approximate and the values may vary some in an actual adsorption/reduction particulate trap system as a result of test experience.

Exhaust Gas Divider and Treatment Apparatus

One purpose of the gas stream divider shown in Fig. 26, is to divide the engine exhaust into two streams prior to these being directed to the respective entry passages in the adsorber-catalyst particulate trap(s). One of these streams has flow rate of about 1/6 to 1/20 of the engine exhaust mass flow rate at a given normal engine operating condition, is enriched with hydrocarbon (HC) and is termed the "rich exhaust" stream. The other stream contains the remainder of the engine exhaust mass flow rate (5/6 to 19/20) which remains unchanged in its content and is termed the "normal exhaust" stream. These two streams pass through appropriate pipes until they enter the respective labeled passage-ways in either the multi-trap or single-trap adsorber-catalyst particulate trap structure, with which it is used.

The relative flow rates and temperature of these two exhaust streams can be varied by the control system as required to achieve best NOx reduction with a minimum usage of added fuel, to periodically remove collected ash and to periodically remove sulfur contamination of the adsorber and/or catalyst coatings.

In operation, exhaust gas from the engine enters duct 203 as noted on the drawing. If the temperature of the larger normal exhaust stream at the point where it enters the trap structure after passing through duct 203, as indicated by thermocouple 212, is between 100 and 450°C, the temperature control valve 202 will remain fully open and the flow will continue unaffected down the duct 203. If the temperature is above 450°C, valve 202 will be partially closed by the EEC and some flow will be diverted to the exhaust-to-air or exhaust-to-coolant heat exchanger 201. This action will reduce the temperature of the normal exhaust stream at the point where it enters the trap structure. This closed loop control action will continue until the control valve stabilizes wherein the amount of flow passing through the cooler is just sufficient to keep the temperature at thermocouple 212 at just about 450°C. If the temperature at the normal exhaust entry into the trap structure is below about 80°C, and if the heat exchanger is of the exhaust-to-coolant type, valve 202 will closed by the EEC to divert exhaust gas through the heat exchanger to be heated by the coolant temperature. This action would only be used to speed heat-up of the exhaust gas flows after cold start or at perhaps extended idle.

After passing the temperature control valve 202, the engine exhaust gas is divided, as shown, with the bulk of the flow passing on down duct 203 as the normal exhaust stream. The smaller rich exhaust stream passes into the rich exhaust duct 205. The ratio of the normal stream flow rate to the rich stream flow rate during most operating conditions (through flow - all valves

open) will be inherently controlled. This is because the area of the trap porous walls exposed to the rich flow and that exposed to the normal flow will be designed to be about the same ratio as that of the desired flow rates of the respective gas streams. This, coupled with the fact that the pressure difference across the trap walls will be about the same for each of the two exhaust gas streams, will inherently assure the desired relative flow rates for the two streams under most normal engine operating conditions.

The rich exhaust stream will pass rich stream control valve 211, which will be fully open. It will then pass the injector 206 which will inject a fine spray of diesel fuel into the stream which will be ignited by igniter 207 and then the burning flow of gas will pass through the flame holder/mixer section 208. This action will result in nearly complete combustion of a well mixed flow of fuel and air. This flow will eventually enter the "rich exhaust" passage in the trap structure. At or near this point will be located an oxygen sensor 209 and a thermocouple 210. The oxygen sensor 209 will detect any oxygen in the gas stream. If free oxygen exists, the oxygen sensor and a closed loop control will cause the injector 206 to increase the quantity of fuel injected until equilibrium exists with no oxygen sensed indicating a stoichiometric mixture (a lambda of 0.95-1.0) has been attained. If there is no oxygen sensed, the closed loop control will gradually decrease the amount of fuel injected until free oxygen is just detected.

The thermocouple 210 will determine whether the rich stream temperature is between 250 and 450°C. If the temperature is greater than 450°C, the valve 211 will close slightly, thus reducing the rate of flow of the exhaust entering the rich duct 205. This action will tend to cause the rich stream to become richer and this will be sensed by the oxygen sensor which will reduce the amount of fuel injected. Reducing the fuel rate will reduce the energy released and along with heat losses will reduce the temperature of the

rich stream. This action will continue until equilibrium is achieved. If the temperature is below 250°C, valve 211 will remain fully open and valve 204 will close slightly and thus direct more exhaust into the rich stream in duct 205. This will cause the stream to become leaner resulting in the oxygen sensor and control increasing the amount of fuel injected by injector 206 and this action will continue until equilibrium exists when the temperature at thermocouple 210 reaches 250°C as a result of the greater energy released by the combustor.

Cross Flow Multi-trap Adsorber-Catalyst Configuration

Fig. 27 is a cross section of a cross flow multi-trap adsorber-catalyst system. This drawing shows four traps 220a, 220b, 220c and 220d but and actual system might have 6 to 15 individual cross flow traps in which the passages have porous walls through which the exhaust gas will pass to be filtered. The inner surface of the tubular passages will be coated with BaO and with more conventional precious metal catalysts such as Pt, Rh, Pd, etc. These catalysts will provide adsorption of the NOx while the platinum etc., coatings will cause reduction of the NOx by CO, as previously described.

The above listed traps are mounted in structure 221 and the ends of each are sealed by a high temperature sealant such as Interam as shown at 221a. The entry of rich exhaust gas into the trap modules is controlled by open-close slide valves 222a, 222b, 222c and 222d located at the left end of the traps having the same designation letters. Entry of normal exhaust gas into the right end of the traps is controlled by similar open-close slide valves 223a, 223b, 223c, and 223d that are located at the right end of the traps having the same designation letters. The chamber 224 surrounding the trap modules leads to the exit of the filtered exhaust to the atmosphere. No

exhaust gas can get into chamber 224 and thence to the atmosphere without first passing through the porous walls of the cross flow passages.

Selecting a given moment in usual operation, normal exhaust at a temperature in the range of 250-450°C will arrive from the divider/treatment apparatus and enter chamber 225 and from there enter open valves 223a, 223c and 223d (at a given moment) but no flow will enter the trap through valve 223b which is closed. Similarly, rich exhaust from the divider/treatment device will enter chamber 229 and from there enter trap 220b through the open valve 222b but will be blocked from entering traps 220a, 220c and 220d because valves 222a, 222c and 222d are closed. This action results in the NOx in the normal exhaust stream, which is lean, being adsorbed and stored in the BaO coating in the traps 220a, 220c and 220d while the rest of the exhaust gas passes on through the trap into chamber 224 and thence to the atmosphere. At the same moment, the rich exhaust at a similar temperature is entering trap 220b as noted above. This exhaust stream which is rich in hydrocarbons releases the stored NOx from the BaO layer and this is almost instantly reduced by the CO as a result of the Pt, Rh, etc. catalytic coating, resulting in the formation of N2, CO_2 etc. and then the cleaned exhaust gas passes through the porous wall into chamber 224 and thence to the atmosphere.

After a few seconds of this operation, the valve 222b will close and valve 223b will open. Also, at the same instant valve 222c will open and valve 223c will close. These valve actuations will result in the rich exhaust stream now entering trap 220c releasing and reducing its stored NOx while trap 220b in turn accepts lean normal exhaust and stores the NOx contained therein.

The above actions continue all the while that the engine is operating with each trap, in turn, receiving lean exhaust and storing its contained NOx and, in turn, receiving the rich exhaust stream for a few seconds to release and

reduce the NOx that was stored therein. The temperature of the exhaust gas streams and of the traps 220 are maintained at the correct temperature for effective operation by the previously described action of the divider/treatment device ahead of the traps.

Although the soot particulate will be substantially continuously burned and thus removed from the trap with the adsorption/reduction system, incombustible ash will remain in the trap and increase engine backpressure unless removed. In our system the EEC will sense engine operating conditions along with backpressure to determine if the ash build-up needs removal. If so, the control will first cause valve 204 in Fig.26 to partially close to cause the pressure in rich exhaust duct 205 to exceed that in normal exhaust duct 203 by 10 to 40 in. W.G. Referring to Fig. 27, this pressure difference will, of course, also exist between chamber 229 and 225. The control will also direct all of the valves 223 to remain open while the valves 222 each open, in turn, through one full sequence as explained previously. This action will result in a strong flow (50 - 150fps) of rich gas to pass through each trap, in turn, thus blowing our the accumulated ash. Because this sequence will require only a short time, it may be allowable to also shut off the injected fuel during this process. The ash particles blown out will be carried by inertia and enter the louvers in plate 226. Upon reaching the relatively quiescent chamber 227, the ash will settle by gravity into the ash canister 228. Following this ash removal sequence, the system will return to normal operation mode, discussed previously.

If the fuel contains any sulfur, it will eventually collect in the BaO coating and destroy its effectiveness to store NOx as discussed earlier. Also, as discussed earlier, this contamination can be removed by heating the trap to 700°C in the presence of HC. The need to regenerate the trap of sulfur can be determined by miles or hours of operation or perhaps other sensing means.

When sulfur removal is required, the control system will slow the time required to go through a complete sequence of the trap valve events from the normal operation time value of 1 to 2 minutes to perhaps a total time of 1 to 1 1/2 hours. Referring to Fig.26, the control will also change the interaction between the thermocouple 212 and valve 202 to limit the temperature entering duct 203 to 700°C, rather than 450°C as exists during normal operation. The temperature of the flow of rich exhaust gas will be sensed by thermocouple 210 and if below 700°C the control will open valve 211 fully. If the temperature is still lower than 700 deg C, the control will partially close valve 204 to direct additional exhaust gas into duct 205. This will result in increased fuel being injected by injector 206 to keep the mixture stoichiometric and thus additional heat will be supplied to the rich exhaust passage at the trap until eventually the temperature will reach equilibrium at 700°C. The high 700°C temperature of the trap passages coupled with the longer period that it is sustained will result in the sulfur contamination being released as H_2S and released to the atmosphere.

Cross Flow Single-trap Adsorber-Catalyst Configuration

Fig. 28 shows in longitudinal and transverse cross section the cross flow single-trap arrangement of the adsorber/reducer system. The larger single cross flow trap 240 is mounted in the structure 241 and the ends are sealed by high temperature sealant Interam. Rotary valves 242 and 243 are rotated at the same speed and in fixed angular relationship to each other. Rotation speed under normal operation is 1 to 2 rpm and it is driven by synchronized drive gears 242b and 243b. The rotary valves are sealably fitted against the respective machined faces of the trap 240. Rotary valve 242 contains a narrow slit (about 3 to 60 degrees wide) to admit 1/20 to 1/6 of the total exhaust flow into the trap passages. Rotary valve 243 contains a strut

243a about (2 to 40 degrees wide) that is sealably fitted against the trap face. The rich exhaust stream after being received from the divider/treatment system in Fig. 26, is directed into the chamber 244. The normal exhaust stream when received tangentially enters chamber 245, as shown.

In operation, the normal exhaust stream after entering chamber 245 and spins as the flow moves to the center and enters most of the passages of the trap (19/20 to 5/6 of the total trap passages). This lean normal flow then passes through the porous walls of the passages wherein the NOx is adsorbed by the BaO layer. The rich exhaust flow enters the fewer number of trap passages (1/20 to 1/6 of the total trap passages) wherein this rich flow releases the stored NOx from the BaO coating and the released NOx is then reacted almost instantly with the CO to form N2 and CO_2. The stream, now cleaned of NOx, passes on through the porous walls and to the atmosphere. Other control functions, such as maintenance of correct temperatures, etc., are substantially the same as in the case of the multi-trap system.

The soot is burned by the elevated temperatures and aided by the presence of the precious metal catalyst as previously described for the multi-trap system. However, again, accumulated noncombustible ash must be periodically removed to prevent excessive increase in engine backpressure. Again, this is accomplished automatically by the control unit upon sensing that ash contamination is excessive. The valve 204 in Fig. 26 is partially closed to raise the pressure in trap system 244 to a pressure level that is about 10 to 20 in. W.G. greater than the pressure in chamber 245. This results in a flow of rich gas completely through the trap from the slit 42a, through the trap passages and exiting into chamber 245. It is emphasized that when the slit first uncovers a passage, the exit end is closed and the rich gas must pass through the porous walls whereby the NOx release and reduction occur. However, a little before the slit closes the passages, the strut, which is

narrower than the slit, will have uncovered the exit of some of the passages. This brief underlap period is illustrated by the small space between the trailing edge of the strut 243aa and the trailing edge of the slit 242aa and permits rich exhaust to flow at high velocity (50 - 100 fps) to erode, dislodge and remove the ash deposits. The ash particles are mixed in with the swirling normal exhaust in chamber 245, whereby the centrifugal force created by the swirl forces them to the periphery of chamber 245 and these are then caught by the louvers 46a and deposited in the ash canister 246.

The process for removing the sulfur contamination from the single-trap system is very similar to that used for the multi-trap system. However, increasing the time for a complete sequence from 1 to 2 minutes to 1 to 1 1/2 hour is accomplished by reducing the speed of the rotary valve drive to 1/60 of normal speed. All other functions are substantially the same.

Wall Flow Multi-Trap Adsorber-Catalyst System

Fig. 29 is a cross section of a wall flow multi-trap adsorber-catalyst configuration. The traps 250 are the same as used with the reverse flow regeneration systems except the passages are coated with a BaO wash coat and a Pt., Rh, etc. precious metal catalyst as indicated at 270. Another difference between the adsorber-catalyst configurations compared with the reverse flow regenerated configurations is that it will be necessary to apply insulation (not shown) on the inner surfaces of the trap system passages to reduce heat loss. This is especially important in the case of the multi-trap configurations. The rich and normal exhaust streams from the divider/treatment device in Fig. 26 are directed to the entrance passages that are so labeled in Fig. 29.

At a given point in time during normal engine operation, all but one of the cylindrical perforated slide valve members 261 are in the position shown

for trap 251b, thus permitting normal (lean) exhaust gas to enter all of the traps from channel 269, except one. Because the exhaust temperature is within a window of about 250-450°C, the NOx in this flow is adsorbed in the BaO coating on the traps as it passes through the porous walls. This results in the rich stream first releasing the stored NOx from the BaO as primarily NO_2 and this, because of the presence of the Pt, Rh, etc. catalyst, immediately reacts with Fig. 29 is a cross section of a wall flow multi-trap adsorber-catalyst configuration. The traps 250 are the same as used with the reverse flow regeneration systems except the passages are coated with a BaO wash coat and a Pt., Rh, etc. precious metal catalyst as indicated at 270. Another difference between the adsorber-catalyst configurations compared with the reverse flow regenerated configurations is that it will be necessary to apply insulation (not shown) on the inner surfaces of the trap system passages to reduce heat loss. This is especially important in the case of the multi-trap configurations. The rich and normal exhaust streams from the divider/treatment device in Fig. 9 are directed to the entrance passages that are so labeled in Fig. 29.

At a given point in time during normal engine operation, all but one of the cylindrical perforated slide valve members 261 are in the position shown for trap 251b, thus permitting normal (lean) exhaust gas to enter all of the traps from channel 269, except one. Because the exhaust temperature is within a window of about 250-450°C, the NOx in this flow is adsorbed in the BaO coating on the traps as it passes through the porous walls. This results in the rich stream first releasing the stored NOx from the BaO as primarily NO_2 and this, because of the presence of the Pt, Rh, etc. catalyst, immediately reacts with the CO to form N2 and CO_2. The stream, now cleaned of NOx, passes on through the porous walls and to the atmosphere. Other control functions, such as maintenance of correct temperatures, etc., are substantially

the same as in the case of the multi-trap system. The above described conditions last for 1-4 seconds and after this time the slide valve 261 is actuated for trap 251a, thus shutting off further in-flow of rich exhaust gas and permitting normal exhaust gas to flow through trap 251a. At the same instant, the slide valve for trap 251b is actuated and this opens channel 258 to permit rich exhaust gas to enter trap 251b. This flow of rich exhaust gas releases the stored NOx from the BaO coating as primarily NO_2 which, assisted by the precious metal catalyst, is immediately converted by the CO in the rich exhaust stream to N_2 and CO_2 and passes to the atmosphere.

The above described events are repeated for each of the traps, in turn. The total cycle time must not exceed four minutes, preferably less, and the period of rich exhaust gas flow is about one to four seconds. The selected actual timing of the events will depend upon the number of traps used for a particular engine application and empirical results. For example, it may be desirable to reduce the flow rate of the rich exhaust stream by partially closing valve 211 in the flow divider/treatment device of Fig. 26. The reduced space velocity in trap 251a (as shown) may permit extending the release/reduction process time and provide more efficient use of the rich exhaust gas. The system lends itself to many control strategies that can be effected by the EEC.

Although the soot collected in the traps is substantially continuously burned in this adsorber-catalyst system by the temperature of the exhaust gas coupled with the Pt, Rh, etc. catalyst, incombustible ash will collect and must be periodically removed to prevent excessive back pressure on the engine. When the EEC senses a significant increase in engine backpressure, the relief valve 267 is activated, thus increasing the pressure in channel 268 to 30 in.W.G. This action is followed by simultaneously changing the position of three-way valve 265 to shut off the flow of rich gas to channel 258 while

simultaneously opening channel 258 to the separator or a secondary filter/canister which are substantially at ambient pressure. The injector 206 in Fig. 26 would also be shut off during this action. The 30 in.W.G. pressure in channel 258 will thus result in a strong reverse flow by through the trap walls which will dislodge and carry the ash particles out of the trap system to a separator and/or a canister and secondary filter to be stored and periodically removed during normal vehicle maintenance.

As mentioned earlier, if there is any sulfur in the fuel the BaO will eventually become contaminated by sulfur. This progressively destroys the capability of the BaO coating to adsorb NOx and it will pass on out to the atmosphere. The sulfur contamination can be regenerated by heating the trap to about 700°C in a rich stream containing HC and CO for several minutes.

Referring to Fig. 26, when sulfur contamination is sensed by some parameter or scheduled such as by time coupled with fuel sulfur content, the EEC changes the interaction between the thermocouple 212 and the exhaust to air or exhaust to coolant heat exchanger by-pass valve 202 to provide cooling of the exhaust only if it is above 700°C instead of the 450°C in normal operation. At the same time, the control also changes the interaction between thermocouple 212 and control valve 204. If the temperature of the thermocouple 210 is below 700°C, valve 204 will close slightly to cause a greater percentage of the engine exhaust to pass through rich duct 205. In order to maintain the desired stoichiometric mixture, the injector 206 will, through its closed loop control with oxygen sensor 209, increase the amount of fuel injected. This will increase the energy, and thus, the temperature of the rich exhaust stream as it approaches the trap system until at least 700°C is achieved. The EEC will also increase the time of the aforementioned events by a factor of about sixty. Thus, the hot (700°C) rich stream will pass through a contaminated trap for 1 to 4 minutes and thus provide time for each trap to

have the sulfur contaminated trap completely regenerated. The valves 261 will be actuated as required to sequentially regenerate each of the traps, in turn, until all have been treated. The EEC will then return the system back to normal operation mode.

Wall Flow Single Trap Adsorber-Catalyst Configuration

The changes to the single trap adsorber-catalyst configuration, shown in Fig. 30, are the same as those described for the multi-trap configuration except that the valve functions are carried out by a rotary valve instead of the plurality of cylindrical perforated slide valves. The interaction with the divider/treatment device in Fig. 26 is the same, as are the methods for periodic removal of ash. The general method of removing the sulfur contamination is the same except that the speed of rotation of the rotary valve is slowed by the EEC from 1-4 rpm to about 1 or 2 rph to provide a much longer time of exposure of the trap passages to the hot (700°C) rich exhaust gas stream. The BaO and Pt, Rh, etc. coatings are also, of course, applied to the single trap as shown at 314.

While preferred embodiments of the invention have herein been illustrated and described, this has been done by way of illustration and not limitation, and the invention should not be limited except as required by the scope of the appended claims.

What is claimed is:

1. A particulate trap system for an internal combustion engine, comprising:

at least one particulate trap module positioned to accept engine exhaust gas including a plurality of passages having porous walls for receiving the exhaust gas, wherein the porous walls filter particulate from the exhaust gas; and

means for periodically reversing a portion of the filtered exhaust gas back through the porous walls in reverse flow at sufficient pressure drop and resultant flow velocity to dislodge and erode any build-up of soot and ash from the porous walls.

2. The particulate trap system according to claim 1, wherein the at least one particulate trap module is at least one monolithic cross flow trap module having a plurality of through flow passages.

3. The particulate trap system according to claim 1, wherein the at least one monolithic particulate trap module is at least one wall flow trap module.

4. The particulate trap system according to claim 2, further including:

an entrance chamber for receiving the exhaust gas from the engine and operatively connected to a first side of the at least one particulate trap module;

a separation chamber operatively attached to a second side of the at least one particulate trap module and for receiving some of the exhaust gas from the at least one particulate trap module; and

an exit chamber for receiving the filtered exhaust gas passing through the porous walls of the at least one particulate trap.

5. The particulate trap system according to claim 4, further including:

means for creating a pressure difference between the separation chamber and the exit chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

6. The particulate trap system according to claim 5, wherein the means for creating the pressure difference between the separation chamber and the exit chamber is a pressure relief valve operatively mounted to the exit chamber for creating pressure build-up in the exit chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls.

7. The particulate trap system according to claim 5, wherein the means for creating the pressure difference between the separation chamber and the exit chamber is a venturi operatively mounted to the exit chamber and operatively connected to the separation chamber, wherein the venturi increases pressure in the exit chamber and reduces the pressure in the

separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls.

8. The particulate trap system according to claim 5, wherein the means for creating the pressure difference between the separation chamber and the exit chamber is a pressure relief valve operatively mounted to the exit chamber valve for creating pressure build-up in the exit chamber, and a venturi operatively mounted to the exit chamber and operatively connected to the separation chamber, wherein the venturi increases pressure in the exit chamber and reduces the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls.

9. The particulate trap system according to claim 8, wherein the at least one valve precluding exhaust gas from entering the at least one particulate trap module from the entrance chamber allows exhaust gas to enter and flow through the through flow passages to blow out the removed soot and ash and to erode any additional soot and ash.

10. The particulate trap system according to claim 9, further including:

an igniter for burning the soot; and

a chamber for storing the ash.

11. The particulate trap system according to claim 5, further including:

a plurality of valves wherein at least one valve precludes exhaust gas from entering the at least one particulate trap module from the entrance chamber and at least one valve of the same particulate trap module allows exhaust gas to flow from the through passages to the separation chamber for periodically allowing the filtered exhaust gas from the exit chamber to flow back through the porous walls of the through flow passages to blow out the build-up of soot and ash on inner surfaces of the porous walls;

wherein the remaining valves allow exhaust gas to enter the remaining particulate trap modules from the entrance chamber and preclude the exhaust gas from exiting the remaining particulate trap modules to the separation chamber, thereby causing the exhaust gas to be filtered through the porous walls; and

wherein each of the particulate trap modules is sequentially precluded from receiving exhaust gas from the entrance chamber via one of the valves and at least one valve of the same particulate trap module allows exhaust gas to flow from the through passages to the separation chamber to sequentially allow filtered exhaust gas from the exit chamber to flow back through the porous walls of the through flow passages to blow out the build-up of soot and ash on the inner surfaces of the porous walls.

12. The particulate trap system according to claim 11, wherein the at least one particulate trap module being precluded from receiving exhaust gas from the entrance chamber is allowed to receive exhaust gas through flow via the opening of the at least one valve to remove the blown out soot and ash.

13. The particulate trap system according to claim 11, further including:

an igniter for burning the soot; and

a chamber for storing the ash.

14. The particulate trap system according to claim 5, further including:

a pressure relief valve operatively mounted to the exit chamber and for creating pressure build-up in the exit chamber prior to the filtered exhaust gas exiting to the atmosphere;

a plurality of valves precluding exhaust gas from exiting the particulate trap modules into the separation chamber;

wherein at least one valve allows exhaust gas to enter the separation chamber from the at least one particulate trap module in response to a pre-established engine operating condition, thereby allowing the filtered exhaust gas from the exit chamber to flow back through the through flow passages of said at least one particulate trap module to blow out the build-up of soot and ash on the inner surfaces of the porous walls;

wherein the remaining valves preclude the exhaust gas from exiting the remaining particulate trap modules to the separation chamber in response to the pre-established engine operating condition, thereby filtering the exhaust gas through the porous walls;

wherein the particulate trap module receiving the filtered exhaust gas via back flow simultaneously receives a high velocity of exhaust gas through flow from the entrance chamber to the separation chamber to erode and blow out the soot and ash; and

wherein each of the particulate trap modules is sequentially allowed to pass exhaust gas to the separation chamber from the entrance chamber, thereby sequentially allowing filtered exhaust gas from the exit chamber to flow back through the porous walls of the through flow passages to blow out

the build-up of soot and ash on the inner surfaces of the porous walls of each of the at least one particulate trap modules in sequence.

15. The particulate trap system according to claim 11, wherein the plurality of valves are perforated slide valves, each of the perforated slide valves include a stationary perforated plate and a moveable perforated plate, wherein the stationary and the moveable perforated plates have apertures therein;

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are in alignment to allow exhaust gas to pass; and

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are not in alignment to preclude exhaust gas from passing.

16. The particulate trap system according to claim 14, wherein the plurality of valves are perforated slide valves, each of the perforated slide valves include a stationary perforated plate and a moveable perforated plate, wherein the stationary and the moveable perforated plates have apertures therein;

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are in alignment to allow exhaust gas to pass; and

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are not in alignment to preclude exhaust gas from passing.

17. The particulate trap system according to claim 11, wherein the plurality of valves are poppet valves;

means for moving the poppet valves away from the particulate trap modules to allow exhaust gas to pass into the through flow passages; and

means for moving the poppet valves toward the particulate trap modules to preclude exhaust gas from passing into the through flow passages.

18. The particulate trap system according to claim 14, wherein the plurality of valves are poppet valves;

means for moving the poppet valves away from the particulate trap modules to allow exhaust gas to pass into the through flow passages; and

means for moving the poppet valves toward the particulate trap modules to preclude exhaust gas from passing into the through flow passages.

19. The particulate trap system according to claim 5, further including:

a first rotary valve having a strut;

means for rotating the strut of the rotary valve around a single particulate trap module between the entrance chamber and the through flow passages for precluding exhaust gas from passing from the entrance chamber to some of the through flow passages;

a second rotary valve having an aperture and face plate and rotatably mounted to the single particulate trap module between the through flow passages and the separation chamber, wherein exhaust gas is allowed to flow through the aperture to the separation chamber and precluded via the face plate from flowing from the through flow passages to the separation chamber;

means for synchronizing the rotation of the first rotary valve and the second rotary valve;

wherein the through flow passages receiving exhaust gas from the entrance chamber that are plugged by the face plate of the second rotary valve filter the exhaust gas through the porous walls;

wherein the though flow passages being blocked by the strut of the first rotary valve and plugged by the face plate of the second rotary valve;

wherein the through flow passages are blocked by the strut and open to the separation chamber via the aperture receive a back flow of filtered exhaust gas through the porous walls from the exit chamber to blow out the build-up of soot and ash on the inner surfaces of the porous walls;

wherein some of the exhaust gas that passes through the through flow passages at a velocity sufficient to erode and dislodge ash and soot build-up from the entrance chamber and into the separation chamber via the aperture is filtered via a secondary filter;

wherein when the means for creating a pressure difference between the separation chamber and the exit chamber in response to the pre-established engine operating condition is started and the pressure in the exit chamber will be greater than the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the through flow passages of the porous walls open via the aperture to the separation chamber to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls; and

wherein each of the through flow passages are sequentially precluded from receiving exhaust gas from the entrance chamber via the strut of the first rotary valve and allowed to pass exhaust gas to the separation chamber when the separation chamber via the aperture filtered exhaust gas from the exit chamber flows back through the porous walls of through flow passages to

blow out the build-up of soot and ash on the inner surfaces of the porous walls.

20. The particulate trap system according to claim 5, further including:

a sole rotary valve having an aperture and face plate and rotatably mounted to a single particulate trap module between the through flow passages and the separation chamber, wherein exhaust gas is allowed to flow through the aperture to the separation chamber and precluded from flowing from the through flow passages to the separation chamber via the face plate;

means for rotating the sole rotary valve;

wherein the exhaust gas entering the through flow passages plugged by the face plate is filtered through the porous walls;

wherein when the means for creating a pressure difference between the separation chamber and the exit chamber in response to the pre-established engine operating condition is started and the pressure in the exit chamber will be greater than the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the through flow passages of the porous walls open via the aperture to the separation chamber to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls while simultaneously receiving a high velocity of exhaust gas through flow from the entrance chamber to the separation chamber to erode and blow out the soot and ash; and

wherein the exhaust gas entering the through flow passages and exiting into the separation chamber via the aperture is filtered through a secondary filter.

21. The particulate trap system according to claim 5, further including:

a secondary filter operatively connected to the separation chamber for filtering exhaust gas in the separation chamber before release into the atmosphere; and

a remote energized three-way rotary valve operatively connected to the separation chamber and operatively connected to a high pressure source for supplying a burst of high pressure air to the secondary filter in reverse flow to dislodge any build-up of soot and ash on the secondary filter in response to the pre-established engine operating condition.

22. The particulate trap system according to claim 21 wherein the secondary filter is porous ceramic.

23. The particulate trap system according to claim 5, further including:

a refractory fabric secondary filter having a convoluted perforated metal support plate operatively positioned to receive the exhaust gas exiting the through flow passages to the separation chamber and for filtering the exhaust gas in the separation chamber before release into the atmosphere, wherein the convoluted perforated support metal plate limits the flexing of the refractory fabric secondary filter and allows some flexing to break up accumulated soot and ash; and

an exit passage operatively connected subsequent to the secondary filter of the separation chamber for directing the filtered exhaust gas passing though the secondary filter to the atmosphere.

24. The particulate trap system according to claim 3, further including:

a first small flow entrance chamber for receiving some of the exhaust gas from the engine and operatively connected to one of the at least one particulate trap module;

a first large flow entrance chamber for receiving the remainder of exhaust gas from the engine and operatively connected to the remaining at least one particulate trap module;

plurality of moveable cylindrical slide valves, each valve including an inner perforated cylinder having apertures to allow exhaust gas to pass when aligned with tube apertures in outer tubes and to preclude exhaust gas from flowing through the apertures and the tube apertures when not aligned;

an exit chamber operatively attached to the at least one particulate trap module and for receiving the filtered exhaust gas from the at least one particulate trap module and releasing the filtered exhaust gas into the atmosphere;

a second small flow entrance chamber for receiving the exhaust gas passing from the first small flow entrance chamber through the cylindrical slide valves, wherein the exhaust gas is filtered through the porous walls of the wall flow passages and directed to the exit chamber;

a second large flow entrance chamber for receiving the exhaust gas from the first large flow entrance chamber through the cylindrical slide valves, wherein the exhaust gas is filtered through the porous walls of the wall flow passages and directed to the exit chamber; and

a separation chamber operatively connected to the first small flow chamber for receiving a back flow of filtered exhaust gas.

25. The particulate trap system according to claim 24, further including:

a three-way valve operatively mounted to the first small flow entrance chamber;

wherein the three-way valve blocks the exhaust gas entering the first small flow entrance chamber and simultaneously opens a connection between the first small entrance chamber and the separation chamber, and thereby causing the exhaust gas to enter the first large flow entrance chamber in response to a pre-established engine operating condition, thereby creating the pressure difference between the exit chamber and the second small flow entrance chamber, wherein the pressure in the exit chamber is greater than the pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls into the secondary filter for filtering of the dislodged and blown out soot and ash; and

wherein the apertures of one of the cylindrical valves is adjusted out of alignment with the tube apertures of one of the outside tubes between the first small flow entrance chamber and the second small flow entrance chamber to preclude exhaust gas from passing to one of the particulate trap modules in response to the pre-established engine operating condition.

26. The particulate trap system according to claim 24, further including:

means for creating a pressure difference between the exit chamber and the second small flow entrance chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the second small flow entrance chamber, thereby forcing

the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls back through the first small flow entrance chamber.

27. The particulate trap system according to claim 26, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve operatively mounted to the exit chamber and for creating pressure build-up in the exit chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

28. The particulate trap system according to claim 26, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a venturi operatively mounted to the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and creates a suction in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

29. The particulate trap system according to claim 26, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a venturi operatively mounted to the exit chamber and operatively connected to the secondary filter, wherein the venturi increases pressure in the exit chamber and creates a suction in the

second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

30. The particulate trap system according to claim 26, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve operatively mounted to the exit chamber and for creating a pressure build-up in the second small flow entrance chamber, and a venturi operatively mounted to the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and creates a suction in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

31. The particulate trap system according to claim 25, wherein the apertures of one of the cylindrical valves is aligned with the tube apertures of one of the tubes between the first small flow entrance chamber and the second small flow entrance chamber to allow exhaust gas to pass to one of the particulate trap modules for filtering through the porous walls, and the apertures of the remaining cylindrical valves are aligned with the tube apertures of the remaining tubes between the first large flow entrance chamber and the second large flow entrance chamber to allow exhaust gas to pass to the remaining particulate trap modules for filtering through the porous walls, and wherein the exhaust gas passes from the particulate trap modules into the exit chamber for release into the atmosphere.

32. The particulate trap system according to claim 31, further including:

means for sequentially dislodging and blowing out the build-up of soot and ash for each of the at least one particulate traps in response to the pre-established engine operating condition.

33. The particulate trap system according to claim 3, further including:

a first small flow entrance chamber for receiving some of the exhaust gas from the engine and operatively connected to one of the at least one particulate trap module;

a first large flow entrance chamber for receiving the remainder of exhaust gas from the engine and operatively connected to the remaining at least one particulate trap module;

a plurality of poppet valves, each valve having a first position and a second position, wherein in the first position exhaust gas is allowed to pass from the first large entrance chamber to the through the porous walls for filtering to the exit chamber, and wherein in the second position filtered exhaust gas from the exit chamber is forced back through the porous walls to the first small flow chamber to dislodge and blow out ash and soot build-up on the inner surfaces of the porous walls;

an exit chamber operatively attached to the at least one particulate trap module and for receiving the filtered exhaust gas from the at least one particulate trap module and releasing the filtered exhaust gas into the atmosphere;

a separation chamber operatively connected to the first small flow chamber for receiving a back flow of filtered exhaust gas.

34. The particulate trap system according to claim 33, further including:

means for actuating the poppet valve from the first position to the second position and from the second position to the first position, wherein one of the poppet valves is moved into the second position for receiving filtered exhaust gas back flow through the porous walls from the exit chamber; and

means for sequentially dislodging and blowing out the build-up of soot and ash for each of the at least one particulate trap modules in response to the pre-established engine operating condition, wherein one of the at least one particulate trap modules receives the back flow of exhaust gas from the exit chamber.

35. The particulate trap system according to claim 34, further including:

means for creating a pressure difference between the exit chamber and the second small flow entrance chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls back through the first small flow entrance chamber.

36. The particulate trap system according to claim 34, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve operatively mounted to the exit chamber and for creating pressure build-up in the exit chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and

ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

37. The particulate trap system according to claim 34, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a venturi operatively mounted to the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and creates a suction in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

38. The particulate trap system according to claim 34, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve operatively mounted to the exit chamber and for creating a pressure build-up in the second small flow entrance chamber, and a venturi operatively mounted to the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and reduces pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

39. A particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system, comprising:

at least one particulate trap module to accept engine exhaust gas including a plurality of passages having porous walls for filtering exhaust gas,

the porous walls having inner surfaces coated with precious metal catalysts and NOx adsorber material;

means for passing a majority of lean exhaust gas through the porous walls of a majority of the plurality of passages, the porous walls removing particulate and oxidizing the particulate via the precious metal catalysts at an acceptable temperature range;

means for converting NOx to NO_2 in the plurality of passages via the precious metal catalyst at the acceptable temperature range;

means for storing the NO_2 in the NOx adsorber material at the acceptable temperature range; and

means for adding fuel to a minority flow of the exhaust gas to convert it to a rich mixture and for passing the minority flow of exhaust gas through a minority of the plurality of passages, thereby causing the rich mixture of exhaust gas flow to release the stored NO_2 for reduction by CO in the rich mixture flow of exhaust gas in the presence of precious metal catalyst at the acceptable temperature range forming CO_2 and N_2.

40. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, wherein the at least one particulate trap module is an at least one cross flow particulate trap module having a plurality of through flow passages having the porous walls, the porous walls having inner surfaces coated with precious metal catalysts and NOx adsorber material;

a first, normal lean exhaust gas entrance chamber that registers with a first end of the through flow passages;

a second, rich exhaust entrance chamber that registers with a second end of the through flow passages;

a third, exit chamber that surrounds the porous walls of the through flow passages for collecting the filtered exhaust gas and directing it to the atmosphere;

at least one first valve having a first position for admitting a majority of the normal lean exhaust gas from the first normal lean exhaust chamber into the first end of the through flow passages for a majority of the time, and a second position for blocking a minority of the normal lean exhaust gas from the first normal lean exhaust chamber into the first end of the through flow passages having porous walls for a majority of time;

at least one second valve having a first position for admitting a minority of rich exhaust gas from the second rich exhaust chamber into the second end of the through flow passages for a minority of time, and a second position for blocking a majority of rich exhaust gas from the second rich exhaust chamber into the second end of the through flow passages for a minority of time;

means for controlling the at least one first valve to allow lean exhaust gas to enter the first end of the majority of passages, while the at least one second valve precludes the rich exhaust gas from entering second end of the majority of passages;

second means for controlling the at least one second valve to allow rich exhaust gas into the second ends of the minority of passages, while the at least one first valve precludes the normal lean exhaust gas from entering the first ends of the minority of the passages; and

means for actuating the at least one first valve and the at least one second valve to sequentially change the passages receiving the normal lean exhaust gas and the rich exhaust gas flow.

41. The particulate trap system having the NOx reduction system according to claim 40, wherein the minority of the flow is $1/6^{th}$ to $1/20^{th}$ and the majority of the flow is 5/6 to $19/20^{th}$ of the total exhaust flow from the engine.

42. The particulate trap system having the NOx reduction system according to claim 39, further including:

an exhaust gas treatment device upstream of the particulate trap system;

wherein the exhaust gas stream from the engine is cooled if a maximum temperature is exceeded;

a first duct to direct the majority of the exhaust gas flow to the particulate trap system to be admitted to the passages as normal lean exhaust;

a second duct to direct the minority of the exhaust gas flow to an enrichment device, wherein a control valve undergoing conditions controls the flow rate of the minority of exhaust gas flow;

a fuel injector to inject fuel into the minority exhaust flow stream;

an igniter and associated burner to provide combustion of the injected fuel;

an oxygen sensor downstream of the fuel injector and the burner and control system and closed loop injector control to assure the mixture burned is at a slightly rich mixture;

a second control system and a temperature sensor to monitor and control the temperature of the minority exhaust gas stream, by controlling the flow rate of the minority exhaust gas stream and through the amount of fuel injected to maintain the slightly rich condition; and

a third duct to direct the enriched minority exhaust flow to the passages as rich exhaust gas to the particulate trap system.

43. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, wherein the at least one particulate trap module is a wall flow particulate trap module having a plurality of passages having porous walls, wherein the opposite ends of alternate passages are plugged to force exhaust gas entering the passages at one end of the trap module to pass through the porous walls and then pass out through exit ends of the alternate passages at the other end of the trap module, said porous wall passages at entrance ends of the wall flow particulate trap module having coated of precious metal catalysts and a coating of NOx adsorber material;

a first channel for directing a majority flow of lean exhaust gas from the engine to the vicinity of the wall flow particulate trap;

a second channel for directing a minority flow of rich exhaust gas from the engine to the vicinity of the wall flow particulate trap;

a third channel for collecting the filtered and purified exhaust from the trap and releasing it to the atmosphere;

a three-way valve having a first position for connecting the entrance end of the wall flow particulate trap to the first channel to admit normal lean exhaust gas, and a second position for or to the second channel connecting the entrance end of the wall flow particulate trap to the first channel to admit rich exhaust gas; and

means for actuating the three-way valve to sequentially change the passages receiving the normal lean exhaust gas and the rich exhaust gas flow.

44. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 43, wherein the plurality of valves are perforated slide valves, each of the perforated slide valves include a stationary perforated plate and a

moveable perforated plate, wherein the stationary and the moveable perforated plates have apertures therein;

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are in alignment to allow exhaust gas to pass; and

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are not in alignment to preclude exhaust gas from passing.

45. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 43, wherein the plurality of valves are poppet valves;

means for moving the poppet valves away from the particulate trap modules to allow exhaust gas to pass into the through flow passages; and

means for moving the poppet valves toward the particulate trap modules to preclude exhaust gas from passing into the through flow passages.

46. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, wherein the acceptable temperature range is from 250 to 450°C.

47. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, further including means for regulating the temperature between 250 and 450°C.

48. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, further including:

a cooler for cooling the flow of exhaust gas cooler when the temperature exceeds 450°C by actuating a cooling valve for forcing a portion of the exhaust gas through the cooler; and

a flow valve for redirecting a greater portion of the exhaust gas to the rich exhaust gas flow chamber, thereby causing the injector to increase the fuel being injected to maintain the rich exhaust gas flow increasing the energy supplied to the at least one particulate trap module when the temperature is below 250°C.

49. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 42, further including:

means for periodically removing incombustible ash from the at least one cross flow particulate trap module in response to a pre-established engine operating condition;

wherein the means for periodically removing incombustible ash includes a flow valve for redirecting a greater portion of the exhaust gas to the rich exhaust gas flow chamber, thereby increasing the pressure significantly higher than in the lean exhaust gas chamber;

valves, wherein in one of the at least one particulate trap modules, the valves are open to the rich exhaust gas flow and the lean exhaust gas flow, thereby allowing a high velocity through flow to remove the ash;

means for separating and storing the ash; and

means for sequentially changing the at least one cross flow particulate trap module receiving the through flow until all of the at least one cross flow particulate traps receive the through flow.

50. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 49, wherein the means for separating and storing ash is an external chamber.

51. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 50, wherein the fuel injector is turned off during the removal of ash.

52. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 43, further including:

means for periodically removing incombustible ash from the at least one wall flow particulate trap module in response to a pre-established engine operating condition;

means for creating a pressure difference between the exit chamber and the second small flow entrance chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls back through the first small flow entrance chamber;

a second three-way valve having a first position for normal operations and a second position for precluding flow to the rich exhaust chamber while

simultaneously opening the rich exhaust gas chamber to an ash separator and storage container; and

means for sequentially changing the at least one wall flow particulate trap module receiving the through flow until all of the at least one wall flow particulate traps receive the reverse flow.

53. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 52, further including:

an external chamber for storing the incombustible ash from the at least one cross particulate trap module.

54. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 53, further including a secondary filter at the ash separator and storage container.

55. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 53, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve operatively mounted to the exit chamber and for creating pressure build-up in the exit chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

56. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 53, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a venturi operatively mounted to the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and creates a suction in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

57. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 52, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve operatively mounted to the exit chamber and for creating a pressure build-up in the second small flow entrance chamber, and a venturi operatively mounted to the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and reduces pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

58. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, further including:

means for determining when the particulate trap module having adsorber-catalyst is contaminated with sulfur;

means for regenerating and decontaminating the particulate trap system by maintaining it at substantially 700°C via a cool valve to cool the exhaust gas stream and a flow valve to direct a greater portion of the exhaust gas into the rich flow stream, thereby increasing the injected fuel while maintaining a stoichiometric mixture;

means for passing the rich mixture through each of the particulate trap module at an increased duration than from normal operations; and

wherein sulfur contamination in the presence of catalyst and hydrocarbons converts sulfur contamination to H_2S and H_2S is released to the atmosphere.

59. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, further including:

means to periodically reduce the flow of the rich mixture through the passages for NO removal with minimum fuel expended under various engine operating conditions.

60. A method for reducing nitrogen oxide (NOx) in a particulate trap system used with an internal combustion engine, the steps comprising:

accepting exhaust gas to at least one particulate trap module including a plurality of passages having porous walls;

passing a majority of lean exhaust gas through a majority of the plurality of passages having the porous walls,

filtering and removing particulate from the exhaust gas through the porous walls having an inner surfaces coated with precious metal catalysts and NOx adsorber material;

oxidizing the particulate via the precious metal catalysts at an acceptable temperature range;

converting NOx to NO_2 in the plurality of passages via the precious metal catalyst;

storing the NO_2 in the NOx adsorber material;

adding fuel to a minority flow of the exhaust gas to convert it to a rich mixture; and

passing the minority flow of exhaust gas through a minority of the plurality of passages, thereby causing the rich mixture of exhaust gas flow to release stored NO_2 for reduction by CO in the rich mixture flow of exhaust gas in the presence of precious metal catalyst at the acceptable temperature range forming CO_2 and N_2.

61. The method for reducing nitrogen oxide (NOx) in a cross flow particulate trap system used with an internal combustion engine according to claim 39, further including the steps of:

aligning a first, normal lean exhaust gas entrance chamber with a first end of the through flow passages;

aligning a second, rich exhaust entrance chamber with a second end of the through flow passages;

filtering exhaust gas through the porous walls of the through flow passages;

collecting the filtered exhaust gas in a third, exit chamber;

directing the exhaust gas from the third, exit chamber to the atmosphere;

admitting a majority of the normal lean exhaust gas from the first normal lean exhaust chamber into the first end of the through flow passages for a period of time, and blocking a minority of the normal lean exhaust gas

from the first normal lean exhaust chamber into the first end of the through flow passages for a majority of the time;

admitting a minority rich exhaust gas from the second rich exhaust chamber into the second end of the through flow passages for a period of time;

blocking a majority of rich exhaust gas from the second rich exhaust chamber into the second end of said through flow passages for a minority of the time;

controlling the at least one first valve to allow normal lean exhaust gas to enter the first end of the majority of passages having porous walls, while precluding the rich exhaust gas from entering second end of the majority of passages;

allowing rich exhaust gas into the second ends of the minority of passages, while precluding the normal lean exhaust gas from entering the first ends of the minority of the passages; and

sequentially changing the passages receiving the normal lean exhaust gas and the rich exhaust gas flow.

62. The method for reducing nitrogen oxide (NOx) in a particulate trap system used with an internal combustion engine according to claim 39, further including the steps of:

treating the entering exhaust gas upstream of the particulate trap system;

cooling the exhaust gas stream when a maximum temperature is exceeded;

directing the majority of the exhaust gas flow to the particulate trap system to be admitted to the passages as normal lean exhaust;

directing and controlling the minority of the exhaust gas flow to an enrichment device;

injecting fuel into the minority exhaust flow stream;

igniting the injected fuel;

sensing the oxygen level downstream of the fuel injector;

monitoring and controlling at a stoichiometric to slightly rich mixture;

monitoring and controlling the temperature of the minority exhaust gas stream via the amount of fuel injected; and

directing the enriched minority exhaust flow to the passages as rich exhaust gas to the particulate trap system.

63. The method for reducing nitrogen oxide (NOx) in a particulate trap system having the at least one wall flow particulate trap used with an internal combustion engine according to claim 39, further including the steps of:

forcing exhaust gas through the porous walls coated with precious metal catalysts and NOx adsorber material of the wall flow particulate trap module;

directing a majority flow of lean exhaust gas from the engine to the vicinity of the at least one wall flow particulate trap module;

directing a minority flow of exhaust gas to the vicinity of the at least one wall flow particulate trap module;

collecting the filtered and purified exhaust gas from the at least one wall flow particulate trap module and releasing it to the atmosphere;

connecting the entrance end of the at least one wall flow particulate trap module to the first channel to admit lean exhaust gas;

connecting the entrance end of the at least one wall flow particulate trap module to the first channel to admit rich exhaust gas; and

sequentially changing the passages receiving the lean exhaust gas and the rich exhaust gas flow.

64. A method for filtering and regenerating particulate trap system for an internal combustion engine, comprising:

positioning an at least one particulate trap module to accept engine exhaust gas, wherein the at least one particulate trap module has a plurality of passages having porous walls for receiving the exhaust gas;

filtering the exhaust gas via the porous walls; and

periodically reversing a portion of the filtered exhaust gas back through the porous walls in reverse flow at sufficient pressure drop and resultant flow velocity to dislodge and erode any build-up of soot and ash from the porous walls.

65. The method for filtering and regenerating particulate trap system for an internal combustion engine according to claim 64, further including the steps of:

creating a pressure difference between the separation chamber and the exit chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

66. A method for filtering and regenerating a particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system, comprising:

accepting engine exhaust gas via an at least one particulate trap module having a plurality of passages having porous walls for filtering exhaust gas, wherein the passages have porous walls with inner surfaces coated with precious metal catalysts and NOx adsorber material;

passing a majority of lean exhaust gas through the porous walls of a majority of the plurality of passages;

removing the particulate via the porous walls and oxidizing the particulate via the precious metal catalysts at an acceptable temperature range;

converting NOx to NO_2 in the plurality of passages via the precious metal catalyst at an acceptable temperature range;

storing the NO_2 in the NOx adsorber material at the acceptable temperature range; and

adding fuel to a minority flow of the exhaust gas to convert it to a rich mixture and for passing the minority flow of exhaust gas through a minority of the plurality of passages, thereby causing the rich mixture of exhaust gas flow to release the stored NO_2 for reduction by CO in the rich mixture flow of exhaust gas in the presence of precious metal catalyst at the acceptable temperature range forming CO_2 and N_2.

AMENDED CLAIMS

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What is claimed is:

1. A particulate trap system for an internal combustion engine, comprising:

at least one particulate trap module positioned to accept engine exhaust gas including a plurality of passages having porous walls for receiving the exhaust gas, wherein the porous walls filter particulate from the exhaust gas; and

reversing means for periodically reversing a portion of the filtered exhaust gas back through the porous walls in reverse flow at a substantially constant pressure drop, resultant flow velocity, and duration sufficient to dislodge and erode any build-up of soot and ash from the porous walls.

2. The particulate trap system according to claim 1, wherein the at least one particulate trap module is at least one monolithic cross flow trap module having a plurality of through flow passages.

3. The particulate trap system according to claim 1, wherein the at least one particulate trap module is at least one wall flow trap module.

4. The particulate trap system according to claim 2, further including:

an entrance chamber for receiving the exhaust gas from the engine and operatively connected to a first side of the at least one particulate trap module;

a separation chamber operatively attached to a second side of the at least one particulate trap module and for receiving some of the exhaust gas from the at least one particulate trap module; and

an exit chamber for receiving the filtered exhaust gas passing through the porous walls of the at least one particulate trap.

5. The particulate trap system according to claim 4, further including:

means for creating a pressure difference between the separation chamber and the exit chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

6. The particulate trap system according to claim 5, wherein the means for creating the pressure difference between the separation chamber and the exit chamber is a pressure relief valve associated with the exit chamber for creating pressure build-up in the exit chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls.

7. The particulate trap system according to claim 5, wherein the means for creating the pressure difference between the separation chamber and the exit chamber is a venturi associated with the exit chamber and operatively connected to the separation chamber, wherein the venturi increases pressure in the exit chamber and reduces the pressure in the

separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls.

8. The particulate trap system according to claim 5, wherein the means for creating the pressure difference between the separation chamber and the exit chamber is a pressure relief valve associated with the exit chamber valve for creating pressure build-up in the exit chamber, and a venturi associated with the exit chamber and operatively connected to the separation chamber, wherein the venturi increases pressure in the exit chamber and reduces the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls.

9. The particulate trap system according to claim 5, further including at least one exit valve to selectively allow exhaust gas to flow through the through flow passages to blow out the removed soot and ash and to erode any additional soot and ash.

10. The particulate trap system according to claim 9, further including:

an igniter for burning the soot; and

a chamber for storing the ash.

11. The particulate trap system according to claim 5, further including:

a plurality of valves wherein at least one valve precludes exhaust gas from entering the at least one particulate trap module from the entrance chamber and at least one valve of the same particulate trap module allows exhaust gas to flow from the through passages to the separation chamber for periodically allowing the filtered exhaust gas from the exit chamber to flow back through the porous walls of the through flow passages to blow out the build-up of soot and ash on inner surfaces of the porous walls;

wherein the remaining valves allow exhaust gas to enter the remaining particulate trap modules from the entrance chamber and preclude the exhaust gas from exiting the remaining particulate trap modules to the separation chamber, thereby causing the exhaust gas to be filtered through the porous walls; and

wherein each of the particulate trap modules is sequentially precluded from receiving exhaust gas from the entrance chamber via one of the valves and at least one valve of the same particulate trap module allows exhaust gas to flow from the through passages to the separation chamber to sequentially allow filtered exhaust gas from the exit chamber to flow back through the porous walls of the through flow passages to blow out the build-up of soot and ash on the inner surfaces of the porous walls.

12. The particulate trap system according to claim 11, wherein the at least one particulate trap module being precluded from receiving exhaust gas from the entrance chamber is allowed to receive exhaust gas through flow via the opening of the at least one valve to remove the blown out soot and ash.

13. The particulate trap system according to claim 11, further including:

an igniter for burning the soot; and

a chamber for storing the ash.

14. The particulate trap system according to claim 5, further including:

a pressure relief valve operatively mounted to the exit chamber and for creating pressure build-up in the exit chamber prior to the filtered exhaust gas exiting to the atmosphere;

a plurality of valves precluding exhaust gas from exiting the particulate trap modules into the separation chamber;

wherein at least one valve allows exhaust gas to enter the separation chamber from the at least one particulate trap module in response to a pre-established engine operating condition, thereby allowing the filtered exhaust gas from the exit chamber to flow back through the through flow passages of said at least one particulate trap module to blow out the build-up of soot and ash on the inner surfaces of the porous walls;

wherein the remaining valves preclude the exhaust gas from exiting the remaining particulate trap modules to the separation chamber in response to the pre-established engine operating condition, thereby filtering the exhaust gas through the porous walls;

wherein the particulate trap module receiving the filtered exhaust gas via back flow simultaneously receives a high velocity of exhaust gas through flow from the entrance chamber to the separation chamber to erode and blow out the soot and ash; and

wherein each of the particulate trap modules is sequentially allowed to pass exhaust gas to the separation chamber from the entrance chamber, thereby sequentially allowing filtered exhaust gas from the exit chamber to flow back through the porous walls of the through flow passages to blow out

the build-up of soot and ash on the inner surfaces of the porous walls of each of the at least one particulate trap modules in sequence.

15. The particulate trap system according to claim 11, wherein the plurality of valves are perforated slide valves, each of the perforated slide valves include a stationary perforated plate and a moveable perforated plate, wherein the stationary and the moveable perforated plates have apertures therein;

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are in alignment to allow exhaust gas to pass; and

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are not in alignment to preclude exhaust gas from passing.

16. The particulate trap system according to claim 14, wherein the plurality of valves are perforated slide valves, each of the perforated slide valves include a stationary perforated plate and a moveable perforated plate, wherein the stationary and the moveable perforated plates have apertures therein;

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are in alignment to allow exhaust gas to pass; and

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are not in alignment to preclude exhaust gas from passing.

17. The particulate trap system according to claim 11, wherein the plurality of valves are poppet valves;

means for moving the poppet valves away from the particulate trap modules to allow exhaust gas to pass into the through flow passages; and

means for moving the poppet valves toward the particulate trap modules to preclude exhaust gas from passing into the through flow passages.

18. The particulate trap system according to claim 14, wherein the plurality of valves are poppet valves;

means for moving the poppet valves away from the particulate trap modules to allow exhaust gas to pass into the through flow passages; and

means for moving the poppet valves toward the particulate trap modules to preclude exhaust gas from passing into the through flow passages.

19. The particulate trap system according to claim 5, further including:

a first rotary valve having a strut;

means for rotating the strut of the rotary valve around a single particulate trap module between the entrance chamber and the through flow passages for precluding exhaust gas from passing from the entrance chamber to some of the through flow passages;

a second rotary valve having an aperture and face plate and rotatably mounted to the single particulate trap module between the through flow passages and the separation chamber, wherein exhaust gas is allowed to flow through the aperture to the separation chamber and precluded via the face plate from flowing from the through flow passages to the separation chamber;

means for synchronizing the rotation of the first rotary valve and the second rotary valve;

wherein the through flow passages receiving exhaust gas from the entrance chamber that are plugged by the face plate of the second rotary valve filter the exhaust gas through the porous walls;

wherein the though flow passages being blocked by the strut of the first rotary valve and plugged by the face plate of the second rotary valve;

wherein the through flow passages are blocked by the strut and open to the separation chamber via the aperture receive a back flow of filtered exhaust gas through the porous walls from the exit chamber to blow out the build-up of soot and ash on the inner surfaces of the porous walls;

wherein some of the exhaust gas that passes through the through flow passages at a velocity sufficient to erode and dislodge ash and soot build-up from the entrance chamber and into the separation chamber via the aperture is filtered via a secondary filter;

wherein when the means for creating a pressure difference between the separation chamber and the exit chamber in response to the pre-established engine operating condition is started and the pressure in the exit chamber will be greater than the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the through flow passages of the porous walls open via the aperture to the separation chamber to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls; and

wherein each of the through flow passages are sequentially precluded from receiving exhaust gas from the entrance chamber via the strut of the first rotary valve and allowed to pass exhaust gas to the separation chamber when the separation chamber via the aperture filtered exhaust gas from the exit chamber flows back through the porous walls of through flow passages to

blow out the build-up of soot and ash on the inner surfaces of the porous walls.

20. The particulate trap system according to claim 5, further including:

a sole rotary valve having an aperture and face plate and rotatably mounted to a single particulate trap module between the through flow passages and the separation chamber, wherein exhaust gas is allowed to flow through the aperture to the separation chamber and precluded from flowing from the through flow passages to the separation chamber via the face plate;

means for rotating the sole rotary valve;

wherein the exhaust gas entering the through flow passages plugged by the face plate is filtered through the porous walls;

wherein when the means for creating a pressure difference between the separation chamber and the exit chamber in response to the pre-established engine operating condition is started and the pressure in the exit chamber will be greater than the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the through flow passages of the porous walls open via the aperture to the separation chamber to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls while simultaneously receiving a high velocity of exhaust gas through flow from the entrance chamber to the separation chamber to erode and blow out the soot and ash; and

wherein the exhaust gas entering the through flow passages and exiting into the separation chamber via the aperture is filtered through a secondary filter.

21. The particulate trap system according to claim 5, further including:

a secondary filter operatively connected to the separation chamber for filtering exhaust gas in the separation chamber before release into the atmosphere; and

a remote energized three-way rotary valve operatively connected to the separation chamber and operatively connected to a high pressure source for supplying a burst of high pressure air to the secondary filter in reverse flow to dislodge any build-up of soot and ash on the secondary filter in response to the pre-established engine operating condition.

22. The particulate trap system according to claim 21 wherein the secondary filter is porous ceramic.

23. The particulate trap system according to claim 5, further including:

a refractory fabric secondary filter having a convoluted perforated metal support plate operatively positioned to receive the exhaust gas exiting the through flow passages to the separation chamber and for filtering the exhaust gas in the separation chamber before release into the atmosphere, wherein the convoluted perforated support metal plate limits the flexing of the refractory fabric secondary filter and allows some flexing to break up accumulated soot and ash; and

an exit passage operatively connected subsequent to the secondary filter of the separation chamber for directing the filtered exhaust gas passing though the secondary filter to the atmosphere.

24. The particulate trap system according to claim 3, further including:

a first small flow entrance chamber for receiving some of the exhaust gas from the engine and operatively connected to one of the at least one particulate trap module;

a first large flow entrance chamber for receiving the remainder of exhaust gas from the engine and operatively connected to the remaining at least one particulate trap module;

plurality of moveable cylindrical slide valves, each valve including an inner perforated cylinder having apertures to allow exhaust gas to pass when aligned with tube apertures in outer tubes and to preclude exhaust gas from flowing through the apertures and the tube apertures when not aligned;

an exit chamber operatively attached to the at least one particulate trap module and for receiving the filtered exhaust gas from the at least one particulate trap module and releasing the filtered exhaust gas into the atmosphere;

a second small flow entrance chamber for receiving the exhaust gas passing from the first small flow entrance chamber through the cylindrical slide valves, wherein the exhaust gas is filtered through the porous walls of the wall flow passages and directed to the exit chamber;

a second large flow entrance chamber for receiving the exhaust gas from the first large flow entrance chamber through the cylindrical slide valves, wherein the exhaust gas is filtered through the porous walls of the wall flow passages and directed to the exit chamber; and

a separation chamber operatively connected to the first small flow chamber for receiving a back flow of filtered exhaust gas.

25. The particulate trap system according to claim 24, further including:

a three-way valve operatively mounted to the first small flow entrance chamber;

wherein the three-way valve blocks the exhaust gas entering the first small flow entrance chamber and simultaneously opens a connection between the first small entrance chamber and the separation chamber, and thereby causing the exhaust gas to enter the first large flow entrance chamber in response to a pre-established engine operating condition, thereby creating the pressure difference between the exit chamber and the second small flow entrance chamber, wherein the pressure in the exit chamber is greater than the pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls into the secondary filter for filtering of the dislodged and blown out soot and ash; and

wherein the apertures of one of the cylindrical valves is adjusted out of alignment with the tube apertures of one of the outside tubes between the first small flow entrance chamber and the second small flow entrance chamber to preclude exhaust gas from passing to one of the particulate trap modules in response to the pre-established engine operating condition.

26. The particulate trap system according to claim 24, further including:

means for creating a pressure difference between the exit chamber and the second small flow entrance chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater

the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls back through the first small flow entrance chamber.

27. The particulate trap system according to claim 26, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve associated with the exit chamber and for creating pressure build-up in the exit chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

28. The particulate trap system according to claim 26, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a venturi associated with the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and creates a suction in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

29. The particulate trap system according to claim 26, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a venturi associated with the exit chamber and operatively connected to the secondary filter, wherein the venturi increases pressure in the exit chamber and creates a suction in the

second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

30. The particulate trap system according to claim 26, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve associated with the exit chamber and for creating a pressure build-up in the second small flow entrance chamber, and a venturi associated with the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and creates a suction in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

31. The particulate trap system according to claim 25, wherein the apertures of one of the cylindrical valves is aligned with the tube apertures of one of the tubes between the first small flow entrance chamber and the second small flow entrance chamber to allow exhaust gas to pass to one of the particulate trap modules for filtering through the porous walls, and the apertures of the remaining cylindrical valves are aligned with the tube apertures of the remaining tubes between the first large flow entrance chamber and the second large flow entrance chamber to allow exhaust gas to pass to the remaining particulate trap modules for filtering through the porous walls, and wherein the exhaust gas passes from the particulate trap modules into the exit chamber for release into the atmosphere.

32. The particulate trap system according to claim 31, further including:

means for sequentially dislodging and blowing out the build-up of soot and ash for each of the at least one particulate traps in response to the pre-established engine operating condition.

33. The particulate trap system according to claim 3, further including:

a first small flow entrance chamber for receiving some of the exhaust gas from the engine and operatively connected to one of the at least one particulate trap module;

a first large flow entrance chamber for receiving the remainder of exhaust gas from the engine and operatively connected to the remaining at least one particulate trap module;

a plurality of poppet valves, each valve having a first position and a second position, wherein in the first position exhaust gas is allowed to pass from the first large entrance chamber to the through the porous walls for filtering to the exit chamber, and wherein in the second position filtered exhaust gas from the exit chamber is forced back through the porous walls to the first small flow chamber to dislodge and blow out ash and soot build-up on the inner surfaces of the porous walls;

an exit chamber operatively attached to the at least one particulate trap module and for receiving the filtered exhaust gas from the at least one particulate trap module and releasing the filtered exhaust gas into the atmosphere;

a separation chamber operatively connected to the first small flow chamber for receiving a back flow of filtered exhaust gas.

34. The particulate trap system according to claim 33, further including:

means for actuating the poppet valve from the first position to the second position and from the second position to the first position, wherein one of the poppet valves is moved into the second position for receiving filtered exhaust gas back flow through the porous walls from the exit chamber; and

means for sequentially dislodging and blowing out the build-up of soot and ash for each of the at least one particulate trap modules in response to the pre-established engine operating condition, wherein one of the at least one particulate trap modules receives the back flow of exhaust gas from the exit chamber.

35. The particulate trap system according to claim 34, further including:

means for creating a pressure difference between the exit chamber and the second small flow entrance chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls back through the first small flow entrance chamber.

36. The particulate trap system according to claim 35, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve associated with the exit chamber and for creating pressure build-up in the exit chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and

ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

37. The particulate trap system according to claim 35, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a venturi associated with the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and creates a suction in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

38. The particulate trap system according to claim 35, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve associated with the exit chamber and for creating a pressure build-up in the second small flow entrance chamber, and a venturi associated with the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and reduces pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

39. A particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system, comprising:

at least one particulate trap module to accept engine exhaust gas including a plurality of passages having porous walls for filtering exhaust gas,

the porous walls having inner surfaces coated with precious metal catalysts and NOx adsorber material;

means for passing a majority of lean exhaust gas through the porous walls of a majority of the plurality of passages, the porous walls removing particulate and oxidizing the particulate via the precious metal catalysts at an acceptable temperature range;

means for converting NOx to NO_2 in the plurality of passages via the precious metal catalyst at the acceptable temperature range;

means for storing the NO_2 in the NOx adsorber material at the acceptable temperature range; and

means for adding fuel to a minority flow of the exhaust gas to convert it to a rich mixture and for passing the minority flow of exhaust gas through a minority of the plurality of passages, thereby causing the rich mixture of exhaust gas flow to release the stored NO_2 for reduction by CO in the rich mixture flow of exhaust gas in the presence of precious metal catalyst at the acceptable temperature range forming CO_2 and N_2.

40. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, wherein the at least one particulate trap module is an at least one cross flow particulate trap module having a plurality of through flow passages having the porous walls, the porous walls having inner surfaces coated with precious metal catalysts and NOx adsorber material;

a first, normal lean exhaust gas entrance chamber that registers with a first end of the through flow passages;

a second, rich exhaust entrance chamber that registers with a second end of the through flow passages;

a third, exit chamber that surrounds the porous walls of the through flow passages for collecting the filtered exhaust gas and directing it to the atmosphere;

at least one first valve having a first position for admitting a majority of the normal lean exhaust gas from the first normal lean exhaust chamber into the first end of the through flow passages for a majority of the time, and a second position for blocking a minority of the normal lean exhaust gas from the first normal lean exhaust chamber into the first end of the through flow passages having porous walls for a majority of time;

at least one second valve having a first position for admitting a minority of rich exhaust gas from the second rich exhaust chamber into the second end of the through flow passages for a minority of time, and a second position for blocking a majority of rich exhaust gas from the second rich exhaust chamber into the second end of the through flow passages for a minority of time;

means for controlling the at least one first valve to allow lean exhaust gas to enter the first end of the majority of passages, while the at least one second valve precludes the rich exhaust gas from entering second end of the majority of passages;

second means for controlling the at least one second valve to allow rich exhaust gas into the second ends of the minority of passages, while the at least one first valve precludes the normal lean exhaust gas from entering the first ends of the minority of the passages; and

means for actuating the at least one first valve and the at least one second valve to sequentially change the passages receiving the normal lean exhaust gas and the rich exhaust gas flow.

41. The particulate trap system having the NOx reduction system according to claim 40, wherein the minority of the flow is $1/6^{th}$ to $1/20^{th}$ and the majority of the flow is 5/6 to $19/20^{th}$ of the total exhaust flow from the engine.

42. The particulate trap system having the NOx reduction system according to claim 39, further including:

an exhaust gas treatment device upstream of the particulate trap system;

wherein the exhaust gas stream from the engine is cooled if a maximum temperature is exceeded;

a first duct to direct the majority of the exhaust gas flow to the particulate trap system to be admitted to the passages as normal lean exhaust;

a second duct to direct the minority of the exhaust gas flow to an enrichment device, wherein a control valve undergoing conditions controls the flow rate of the minority of exhaust gas flow;

a fuel injector to inject fuel into the minority exhaust flow stream;

an igniter and associated burner to provide combustion of the injected fuel;

an oxygen sensor downstream of the fuel injector and the burner and control system and closed loop injector control to assure the mixture burned is at a slightly rich mixture;

a second control system and a temperature sensor to monitor and control the temperature of the minority exhaust gas stream, by controlling the flow rate of the minority exhaust gas stream and through the amount of fuel injected to maintain the slightly rich condition; and

a third duct to direct the enriched minority exhaust flow to the passages as rich exhaust gas to the particulate trap system.

43. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, wherein the at least one particulate trap module is a wall flow particulate trap module having a plurality of passages having porous walls, wherein the opposite ends of alternate passages are plugged to force exhaust gas entering the passages at one end of the trap module to pass through the porous walls and then pass out through exit ends of the alternate passages at the other end of the trap module, said porous wall passages at entrance ends of the wall flow particulate trap module having coated of precious metal catalysts and a coating of NOx adsorber material;

a first channel for directing a majority flow of lean exhaust gas from the engine to the vicinity of the wall flow particulate trap;

a second channel for directing a minority flow of rich exhaust gas from the engine to the vicinity of the wall flow particulate trap;

a third channel for collecting the filtered and purified exhaust from the trap and releasing it to the atmosphere;

a three-way valve having a first position for connecting the entrance end of the wall flow particulate trap to the first channel to admit normal lean exhaust gas, and a second position for or to the second channel connecting the entrance end of the wall flow particulate trap to the first channel to admit rich exhaust gas; and

means for actuating the three-way valve to sequentially change the passages receiving the normal lean exhaust gas and the rich exhaust gas flow.

44. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to

moveable perforated plate, wherein the stationary and the moveable perforated plates have apertures therein;

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are in alignment to allow exhaust gas to pass; and

means for moving the moveable perforated plate over the stationary perforated plate so that the apertures are not in alignment to preclude exhaust gas from passing.

45. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 43, wherein the plurality of valves are poppet valves;

means for moving the poppet valves away from the particulate trap modules to allow exhaust gas to pass into the through flow passages; and

means for moving the poppet valves toward the particulate trap modules to preclude exhaust gas from passing into the through flow passages.

46. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, wherein the acceptable temperature range is from 250 to 450°C.

47. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, further including means for regulating the temperature between 250 and 450°C.

48. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, further including:

a cooler for cooling the flow of exhaust gas cooler when the temperature exceeds 450°C by actuating a cooling valve for forcing a portion of the exhaust gas through the cooler; and

a flow valve for redirecting a greater portion of the exhaust gas to the rich exhaust gas flow chamber, thereby causing the injector to increase the fuel being injected to maintain the rich exhaust gas flow increasing the energy supplied to the at least one particulate trap module when the temperature is below 250°C.

49. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 42, further including:

means for periodically removing incombustible ash from the at least one cross flow particulate trap module in response to a pre-established engine operating condition;

wherein the means for periodically removing incombustible ash includes a flow valve for redirecting a greater portion of the exhaust gas to the rich exhaust gas flow chamber, thereby increasing the pressure significantly higher than in the lean exhaust gas chamber;

valves, wherein in one of the at least one particulate trap modules, the valves are open to the rich exhaust gas flow and the lean exhaust gas flow, thereby allowing a high velocity through flow to remove the ash;

means for separating and storing the ash; and

means for sequentially changing the at least one cross flow particulate trap module receiving the through flow until all of the at least one cross flow particulate traps receive the through flow.

50. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 49, wherein the means for separating and storing ash is an external chamber.

51. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 50, wherein the fuel injector is turned off during the removal of ash.

52. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 43, further including:

means for periodically removing incombustible ash from the at least one wall flow particulate trap module in response to a pre-established engine operating condition;

means for creating a pressure difference between the exit chamber and the second small flow entrance chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls back through the first small flow entrance chamber;

simultaneously opening the rich exhaust gas chamber to an ash separator and storage container; and

means for sequentially changing the at least one wall flow particulate trap module receiving the through flow until all of the at least one wall flow particulate traps receive the reverse flow.

53. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 52, further including:

an external chamber for storing the incombustible ash from the at least one cross particulate trap module.

54. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 53, further including a secondary filter at the ash separator and storage container.

55. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 53, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve operatively mounted to the exit chamber and for creating pressure build-up in the exit chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

56. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 53, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a venturi operatively mounted to the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and creates a suction in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on the inner surfaces of the porous walls back through the first small flow entrance chamber.

57. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 52, wherein the means for creating the pressure difference between the exit chamber and the second small flow entrance chamber is a pressure relief valve operatively mounted to the exit chamber and for creating a pressure build-up in the second small flow entrance chamber, and a venturi operatively mounted to the exit chamber and operatively connected to the second small flow entrance chamber, wherein the venturi increases pressure in the exit chamber and reduces pressure in the second small flow entrance chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

58. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to

means for determining when the particulate trap module having adsorber-catalyst is contaminated with sulfur;

means for regenerating and decontaminating the particulate trap system by maintaining it at substantially 700°C via a cool valve to cool the exhaust gas stream and a flow valve to direct a greater portion of the exhaust gas into the rich flow stream, thereby increasing the injected fuel while maintaining a stoichiometric mixture;

means for passing the rich mixture through each of the particulate trap module at an increased duration than from normal operations; and

wherein sulfur contamination in the presence of catalyst and hydrocarbons converts sulfur contamination to H_2S and H_2S is released to the atmosphere.

59. The particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system according to claim 39, further including:

means to periodically reduce the flow of the rich mixture through the passages for NO removal with minimum fuel expended under various engine operating conditions.

60. A method for reducing nitrogen oxide (NOx) in a particulate trap system used with an internal combustion engine, the steps comprising:

accepting exhaust gas to at least one particulate trap module including a plurality of passages having porous walls;

passing a majority of lean exhaust gas through a majority of the plurality of passages having the porous walls,

filtering and removing particulate from the exhaust gas through the

oxidizing the particulate via the precious metal catalysts at an acceptable temperature range;

converting NOx to NO_2 in the plurality of passages via the precious metal catalyst;

storing the NO_2 in the NOx adsorber material;

adding fuel to a minority flow of the exhaust gas to convert it to a rich mixture; and

passing the minority flow of exhaust gas through a minority of the plurality of passages, thereby causing the rich mixture of exhaust gas flow to release stored NO_2 for reduction by CO in the rich mixture flow of exhaust gas in the presence of precious metal catalyst at the acceptable temperature range forming CO_2 and N_2.

61. The method for reducing nitrogen oxide (NOx) in a cross flow particulate trap system used with an internal combustion engine according to claim 60, further including the steps of:

aligning a first, normal lean exhaust gas entrance chamber with a first end of the through flow passages;

aligning a second, rich exhaust entrance chamber with a second end of the through flow passages;

filtering exhaust gas through the porous walls of the through flow passages;

collecting the filtered exhaust gas in a third, exit chamber;

directing the exhaust gas from the third, exit chamber to the atmosphere;

admitting a majority of the normal lean exhaust gas from the first normal lean exhaust chamber into the first end of the through flow passages

from the first normal lean exhaust chamber into the first end of the through flow passages for a majority of the time;

admitting a minority of rich exhaust gas from the second rich exhaust chamber into the second end of the through flow passages for a period of time;

blocking a majority of rich exhaust gas from the second rich exhaust chamber into the second end of said through flow passages for a minority of the time;

controlling the at least one first valve to allow normal lean exhaust gas to enter the first end of the majority of passages having porous walls, while precluding the rich exhaust gas from entering second end of the majority of passages;

allowing rich exhaust gas into the second ends of the minority of passages, while precluding the normal lean exhaust gas from entering the first ends of the minority of the passages; and

sequentially changing the passages receiving the normal lean exhaust gas and the rich exhaust gas flow.

62. The method for reducing nitrogen oxide (NOx) in a particulate trap system used with an internal combustion engine according to claim 60, further including the steps of:

treating the entering exhaust gas upstream of the particulate trap system;

cooling the exhaust gas stream when a maximum temperature is exceeded;

directing the majority of the exhaust gas flow to the particulate trap system to be admitted to the passages as normal lean exhaust;

injecting fuel into the minority exhaust flow stream;

igniting the injected fuel;

sensing the oxygen level downstream of the fuel injector;

monitoring and controlling at a stoichiometric to slightly rich mixture;

monitoring and controlling the temperature of the minority exhaust gas stream via the amount of fuel injected; and

directing the enriched minority exhaust flow to the passages as rich exhaust gas to the particulate trap system.

63. The method for reducing nitrogen oxide (NOx) in a particulate trap system having the at least one wall flow particulate trap used with an internal combustion engine according to claim 60, further including the steps of:

forcing exhaust gas through the porous walls coated with precious metal catalysts and NOx adsorber material of the wall flow particulate trap module;

directing a majority flow of lean exhaust gas from the engine to the vicinity of the at least one wall flow particulate trap module;

directing a minority flow of exhaust gas to the vicinity of the at least one wall flow particulate trap module;

collecting the filtered and purified exhaust gas from the at least one wall flow particulate trap module and releasing it to the atmosphere;

connecting the entrance end of the at least one wall flow particulate trap module to the first channel to admit lean exhaust gas;

connecting the entrance end of the at least one wall flow particulate trap module to the first channel to admit rich exhaust gas; and

64. A method for filtering and regenerating particulate trap system for an internal combustion engine, comprising:

positioning an at least one particulate trap module to accept engine exhaust gas, wherein the at least one particulate trap module has a plurality of passages having porous walls for receiving the exhaust gas;

filtering the exhaust gas via the porous walls; and

periodically reversing a portion of the filtered exhaust gas back through the porous walls in reverse flow at a substantially constant pressure drop, resultant flow and duration sufficient to dislodge and erode any build-up of soot and ash from the porous walls.

65. The method for filtering and regenerating particulate trap system for an internal combustion engine according to claim 64, further including the steps of:

creating a pressure difference between the separation chamber and the exit chamber in response to a pre-established engine operating condition, wherein the pressure in the exit chamber is greater than the pressure in the separation chamber, thereby forcing the filtered exhaust gas from the exit chamber back through the porous walls to dislodge and blow out the build-up of soot and ash on inner surfaces of the porous walls.

66. A method for filtering and regenerating a particulate trap system for an internal combustion engine having a nitrogen oxide (NOx) reduction aftertreatment system, comprising:

accepting engine exhaust gas via an at least one particulate trap module having a plurality of passages having porous walls for filtering exhaust gas, wherein the passages have porous walls with inner surfaces coated with precious metal catalysts and NOx adsorber material;

passing a majority of lean exhaust gas through the porous walls of a majority of the plurality of passages;

removing the particulate via the porous walls and oxidizing the particulate via the precious metal catalysts at an acceptable temperature range;

converting NOx to NO_2 in the plurality of passages via the precious metal catalyst at an acceptable temperature range;

storing the NO_2 in the NOx adsorber material at the acceptable temperature range; and

adding fuel to a minority flow of the exhaust gas to convert it to a rich mixture and for passing the minority flow of exhaust gas through a minority of the plurality of passages, thereby causing the rich mixture of exhaust gas flow to release the stored NO_2 for reduction by CO in the rich mixture flow of exhaust gas in the presence of precious metal catalyst at the acceptable temperature range forming CO_2 and N_2.

67. The particulate trap system according to claim 3, further including:

rotary valve means for preventing exhaust gas entry into a minority of the passages and for connecting an entrance of the minority of the passages to a separation chamber, wherein the rotary valve rotates to sequentially cause reverse flow through the porous walls of each of the minority of the passages while permitting normal flow to continue through the porous walls of a majority of the trap passages.

68. The particulate trap system according to claim 39, wherein the means for passing a majority of lean exhaust gas through the porous of a majority of the plurality of passages includes rotary valve means for preventing exhaust gas entry into a minority of the passages and for connecting an entrance of the minority of the passages to a separation chamber, wherein the rotary valve rotates to sequentially cause reverse flow through the porous walls of each of the minority of the passages while permitting normal flow to continue through the porous walls of a majority of the trap passages.

PRIOR ART

WALL FLOW TRAP

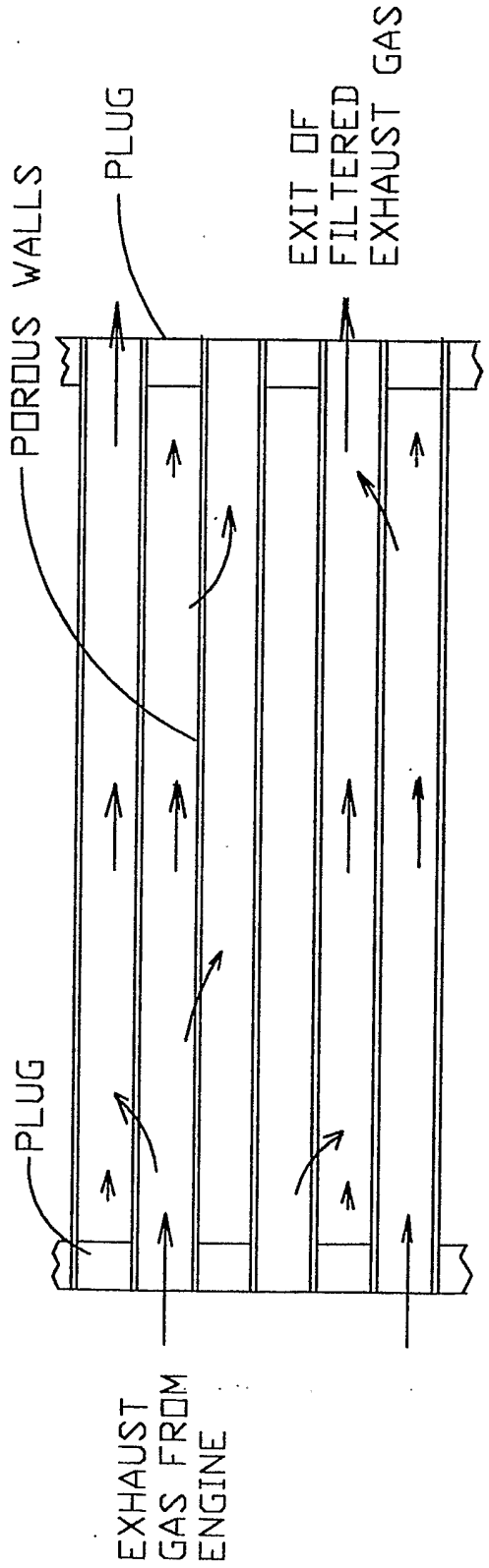


FIG. 1

PRIOR ART

CROSS FLOW TRAP

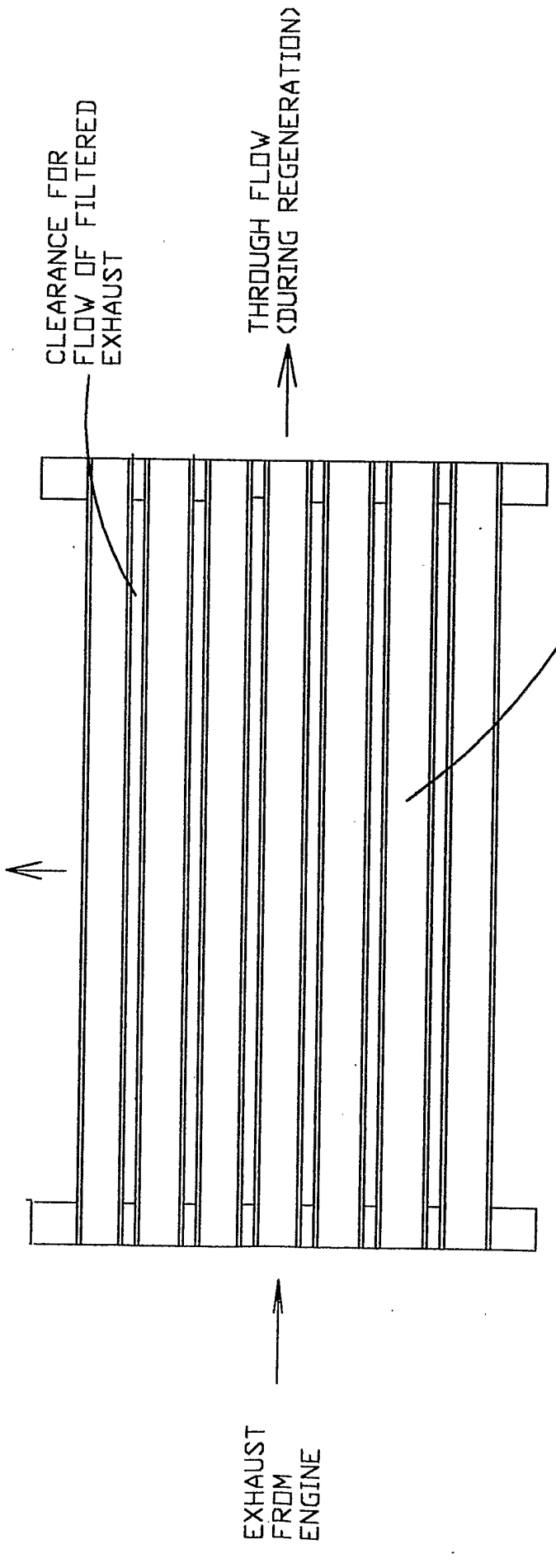


FIG. 2

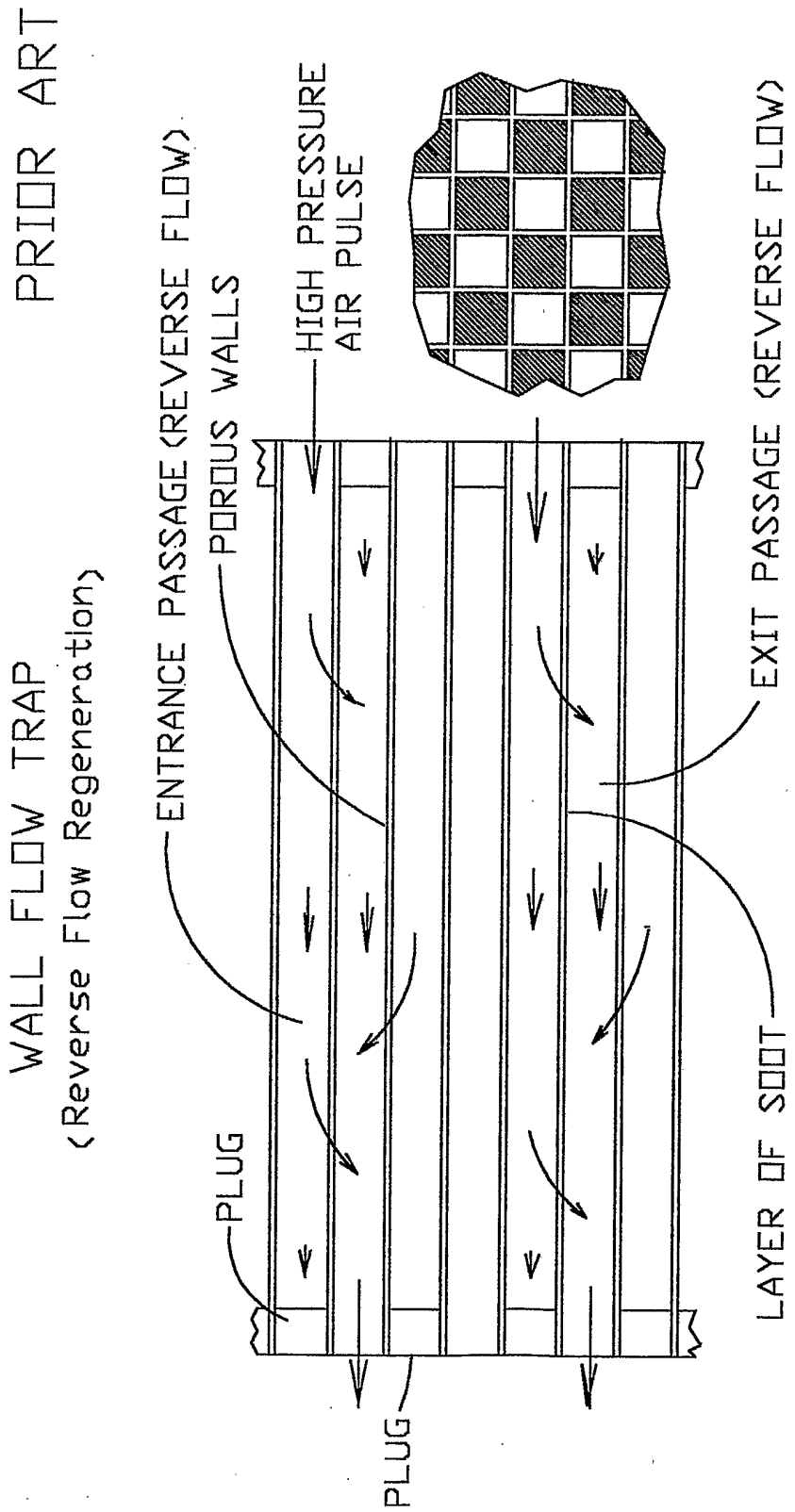

PRIOR ART
WALL FLOW TRAP
(Reverse Flow Regeneration)
ENTRANCE PASSAGE (REVERSE FLOW)
POROUS WALLS
HIGH PRESSURE
AIR PULSE
EXIT PASSAGE (REVERSE FLOW)
PLUG
PLUG
LAYER OF SOOT

FIG. 3

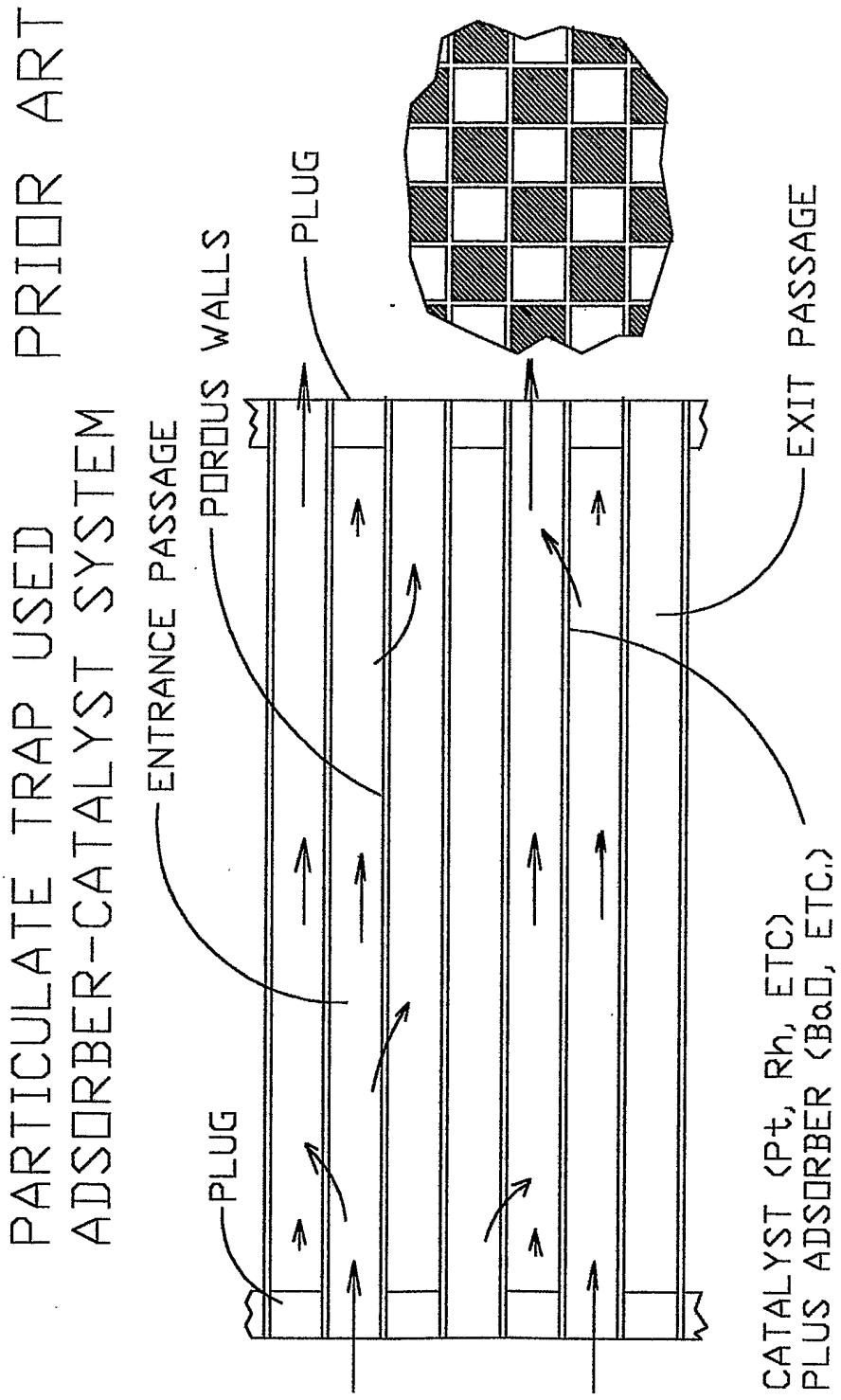

PARTICULATE TRAP USED PRIOR ART
ADSORBER-CATALYST SYSTEM
ENTRANCE PASSAGE
POROUS WALLS
PLUG
PLUG
EXIT PASSAGE
CATALYST (Pt, Rh, ETC)
PLUS ADSORBER (BaO, ETC.)
COATINGS.

FIG. 4

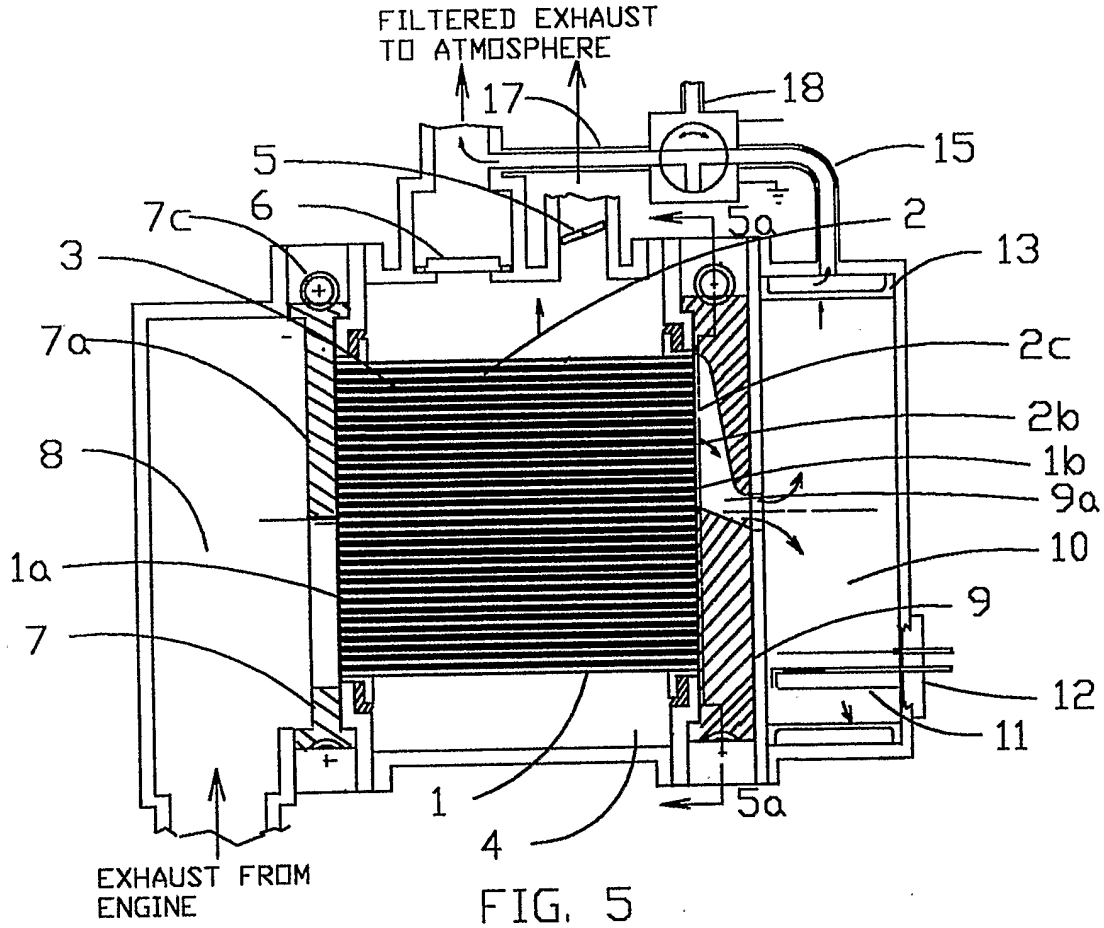

FILTERED EXHAUST
TO ATMOSPHERE
17
18
15
5
6
7c
5a
2
3
13
7a
2c
2b
8
1b
9a
10
1a
9
7
12
11
1
5a
4
EXHAUST FROM
ENGINE

FIG. 5

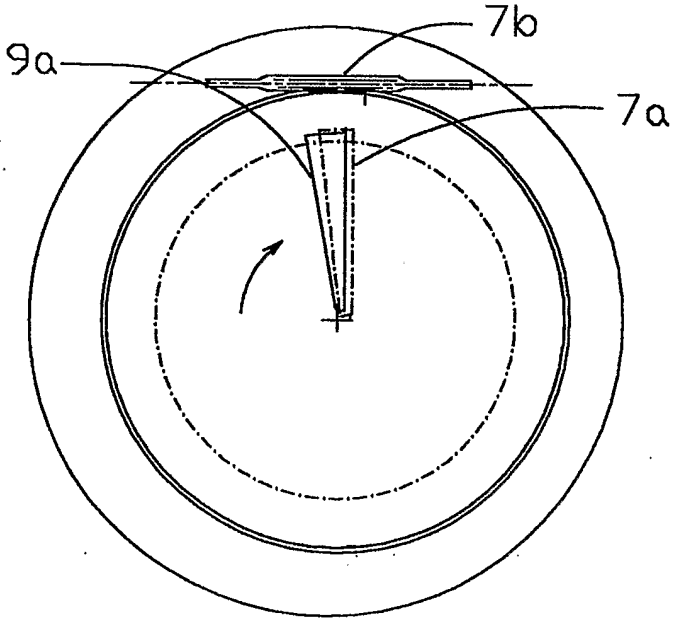

7b
9a
7a

FIG. 5A

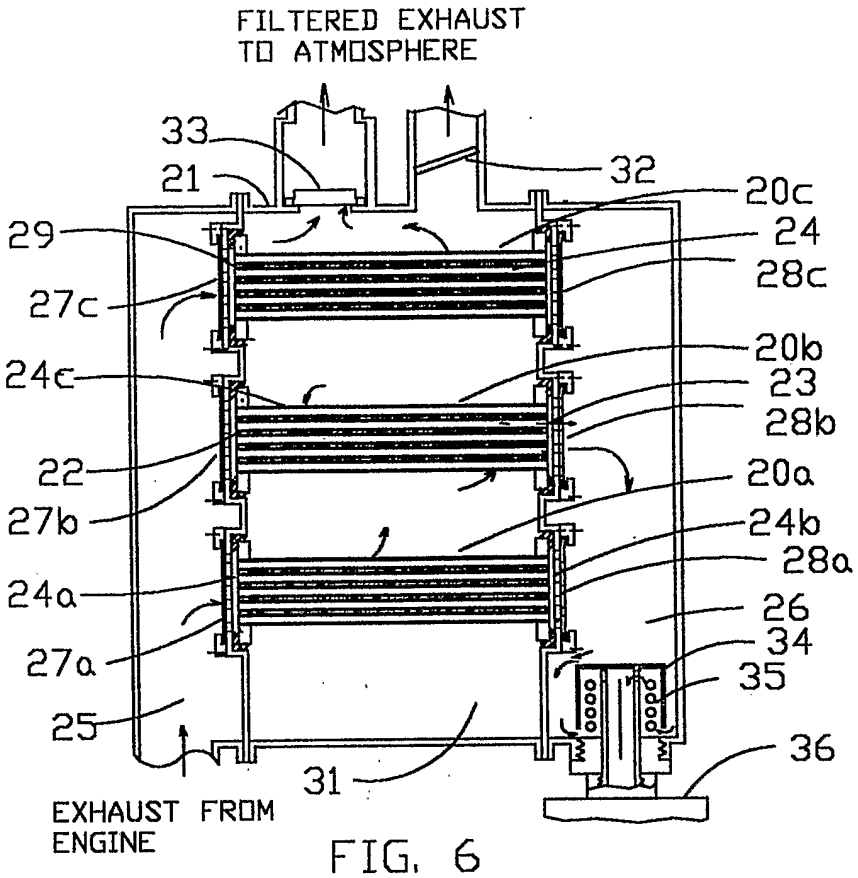

FILTERED EXHAUST
TO ATMOSPHERE
33
21
32
20c
24
28c
29
27c
20b
24c
23
28b
22
20a
27b
24b
28a
24a
26
34
27a
35
25
36
31
EXHAUST FROM
ENGINE

FIG. 6

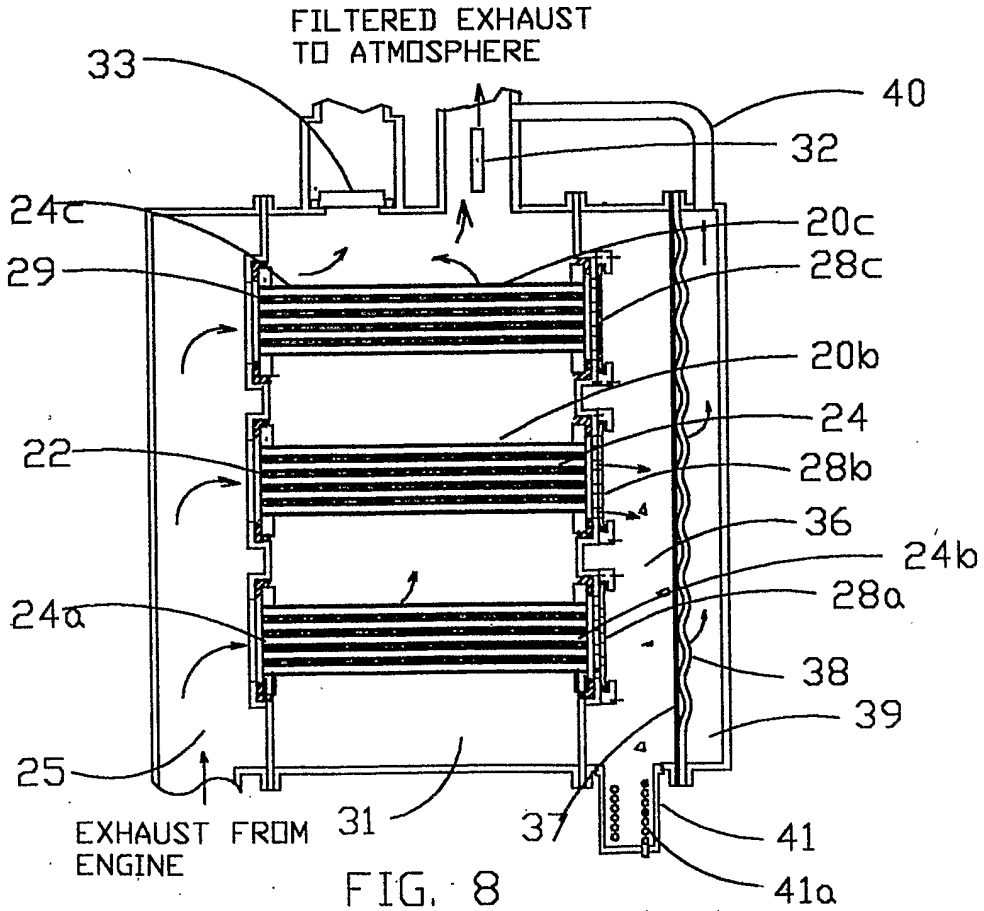

FILTERED EXHAUST
TO ATMOSPHERE
33
40
32
24c
20c
29
28c
20b
24
22
28b
36
24b
24a
28a
38
39
25
31
37
41
EXHAUST FROM
ENGINE
41a

FIG. 8

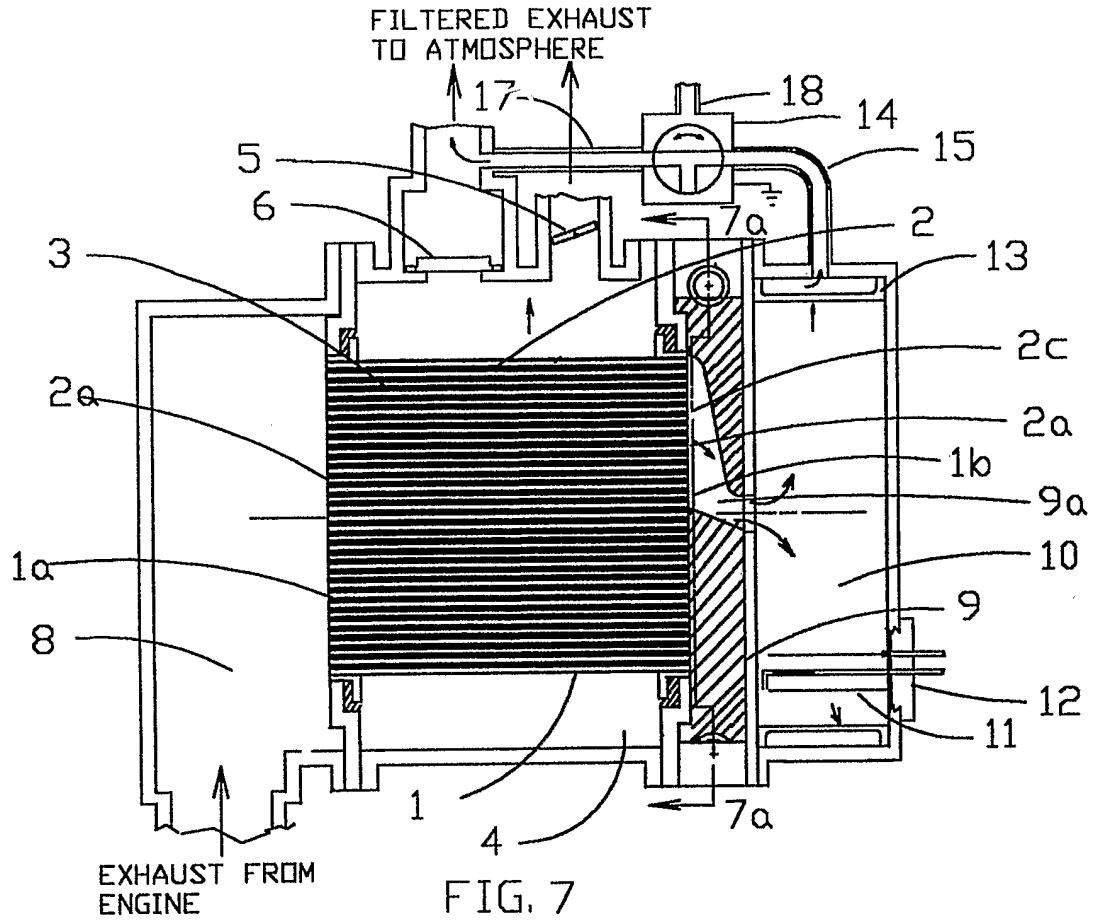

FILTERED EXHAUST
TO ATMOSPHERE
17
18
14
15
5
6
7a
2
13
3
2c
2a
2a
1b
9a
1a
10
8
9
12
11
1
4
7a
EXHAUST FROM
ENGINE

FIG. 7

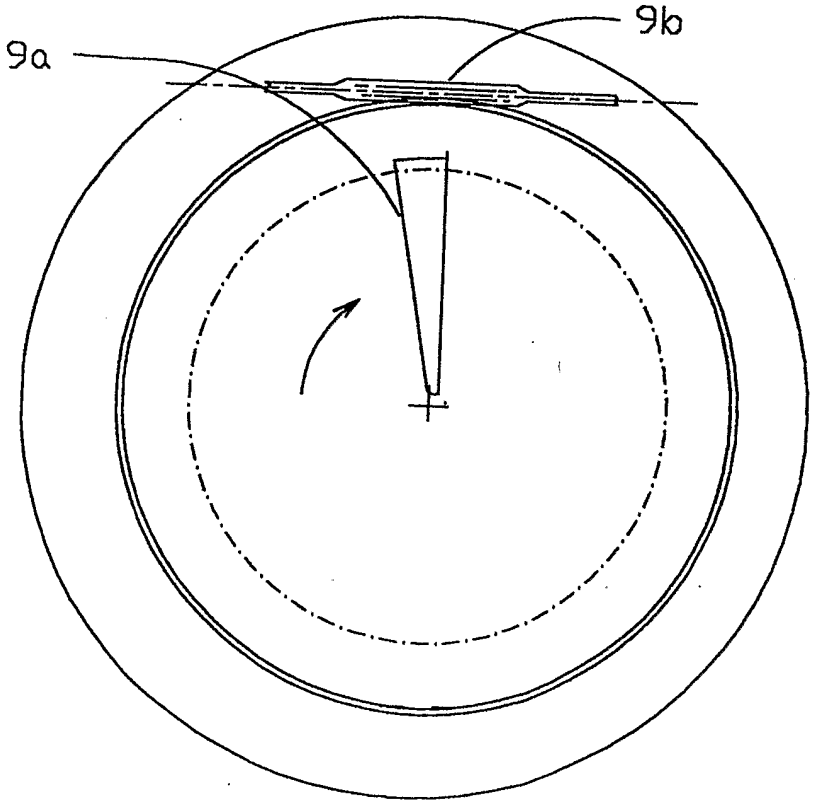

9a
9b

FIG. 7a

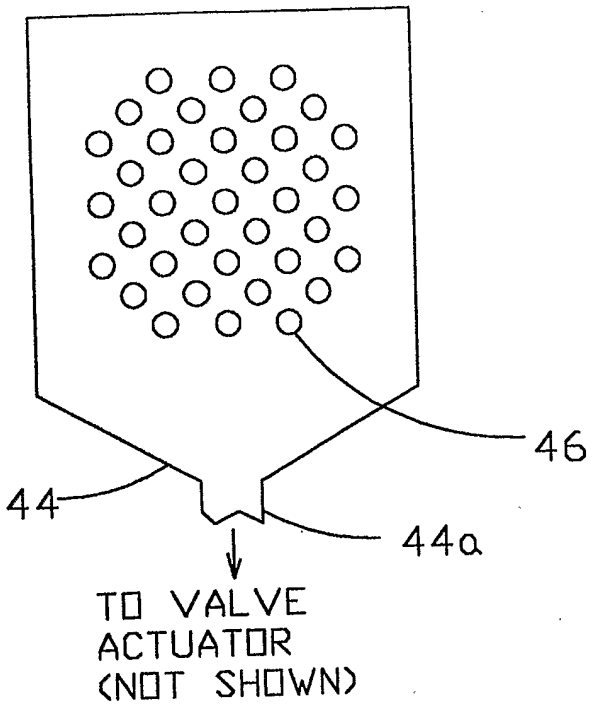


FIG. 9a

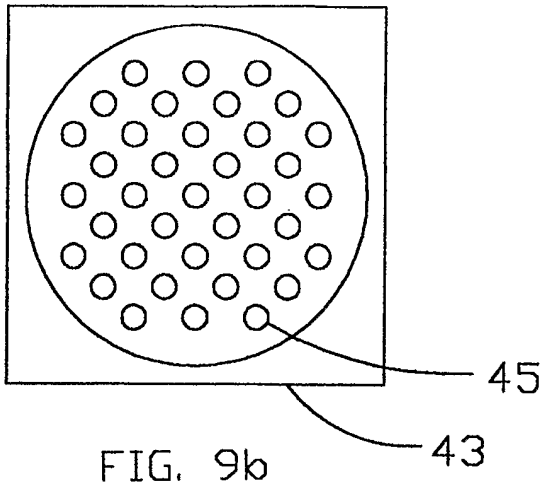


FIG. 9b

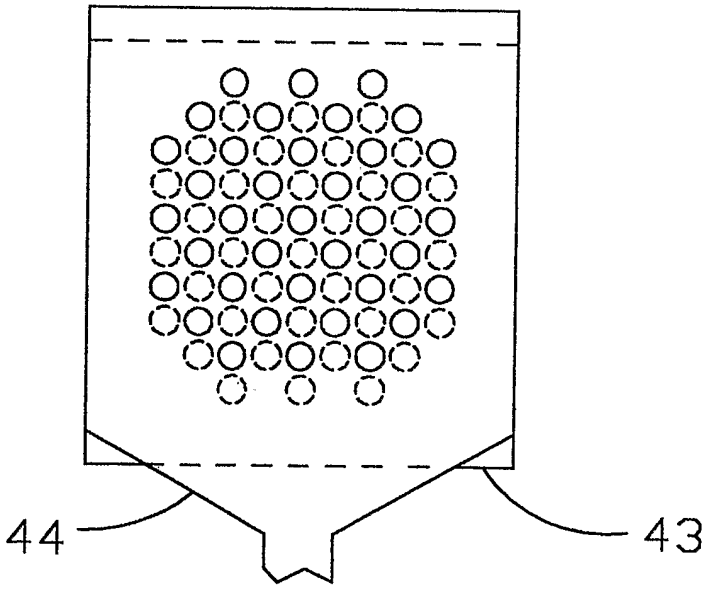


FIG. 11

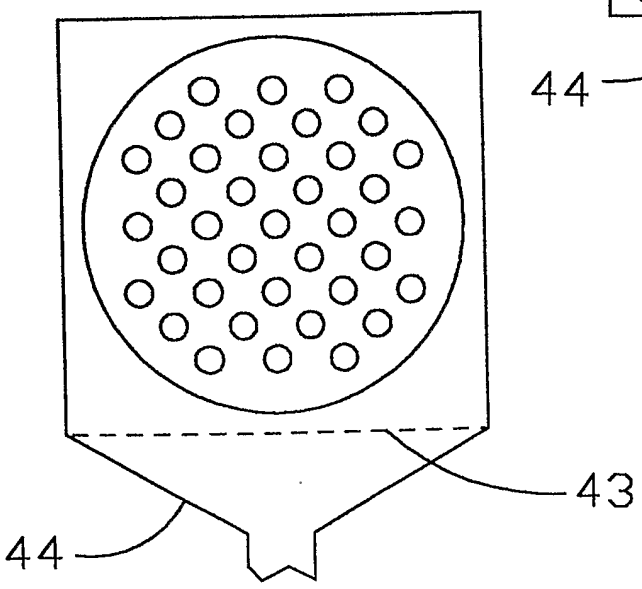


FIG. 10

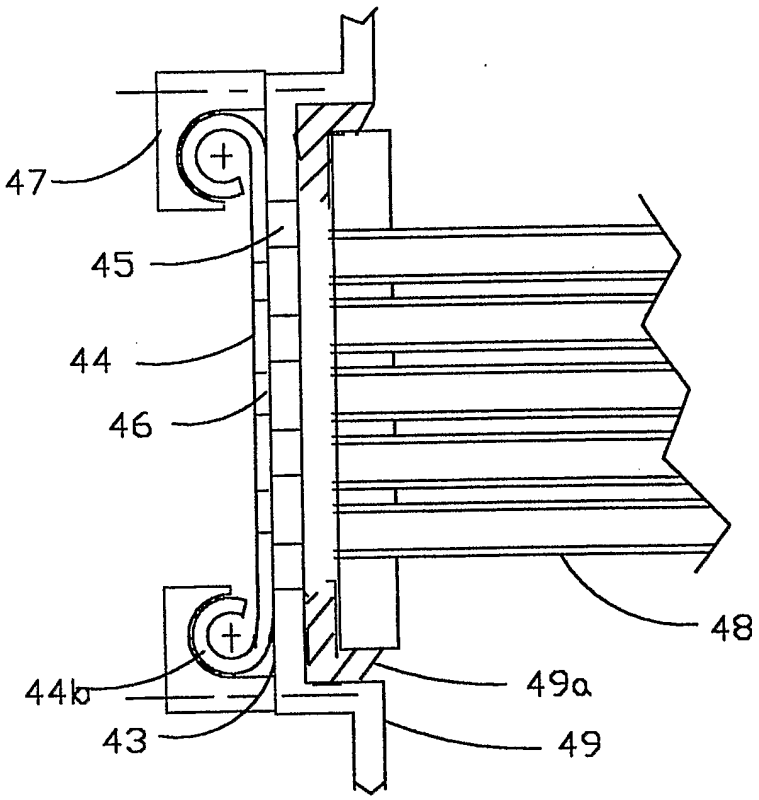


FIG. 12

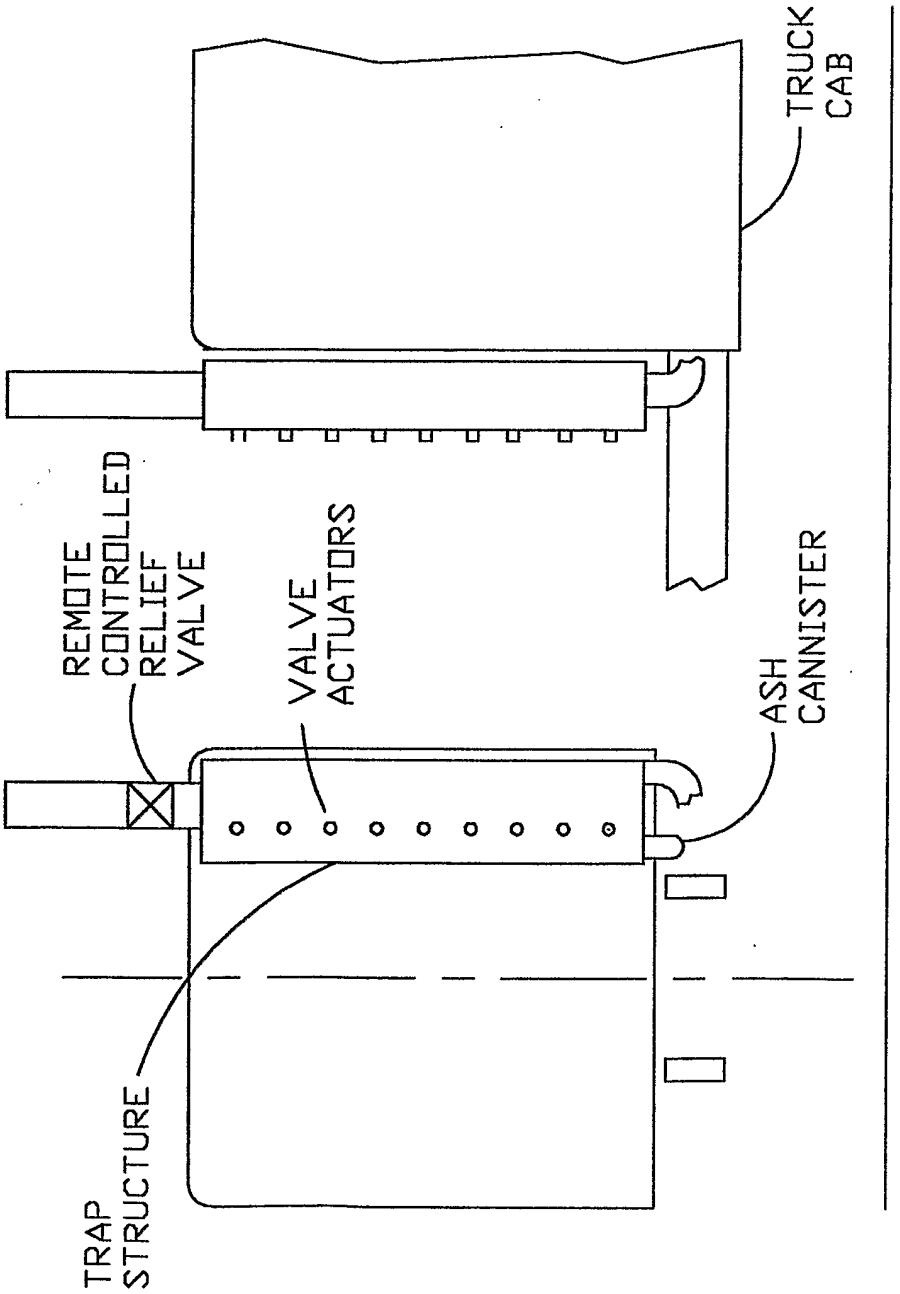

TRUCK CAB
REMOTE CONTROLLED RELIEF VALVE
VALVE ACTUATORS
ASH CANNISTER
TRAP STRUCTURE

FIG. 13

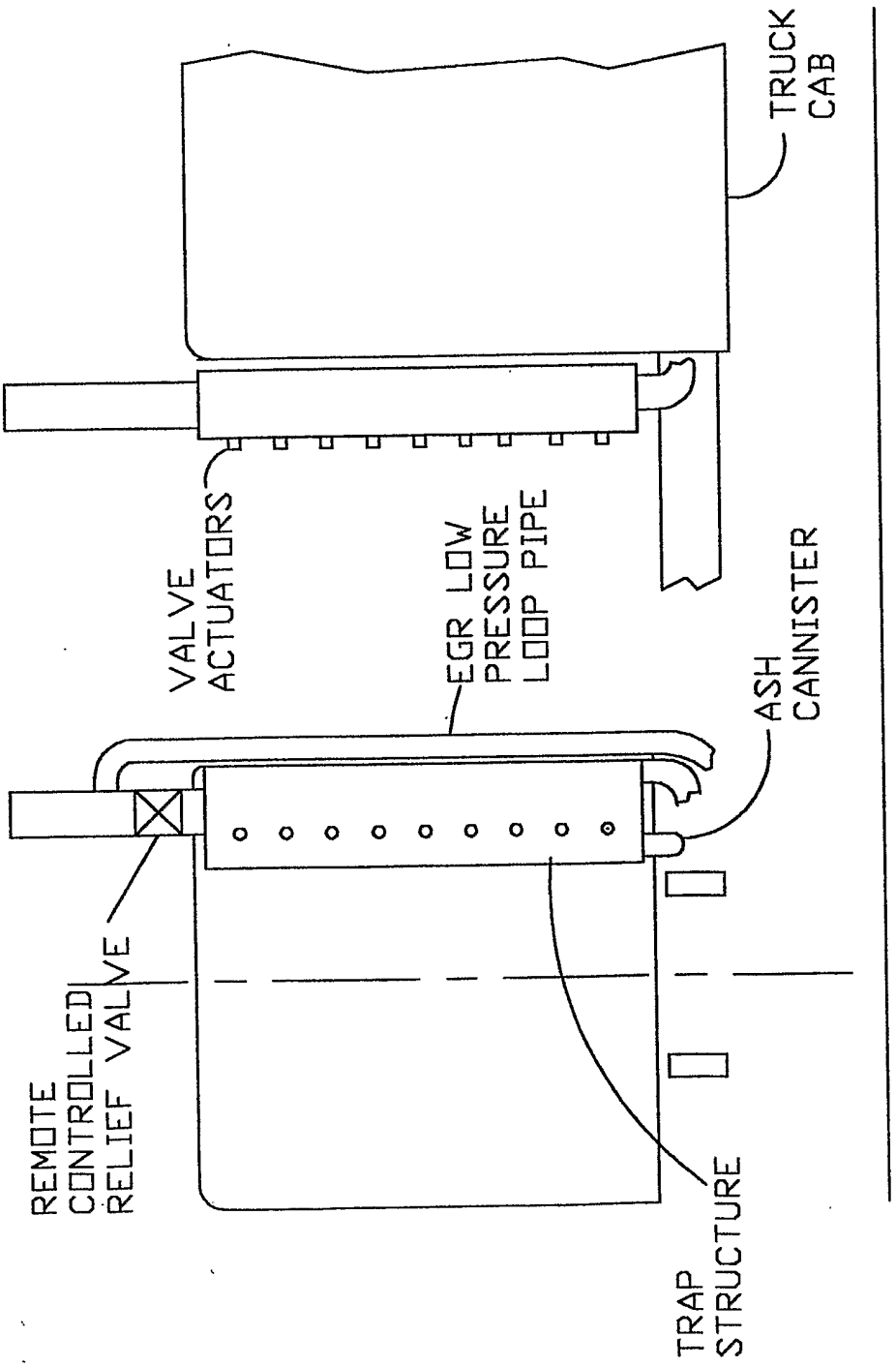

TRUCK CAB
VALVE ACTUATORS
EGR LOW PRESSURE LOOP PIPE
ASH CANNISTER
REMOTE CONTROLLED RELIEF VALVE
TRAP STRUCTURE

FIG. 14

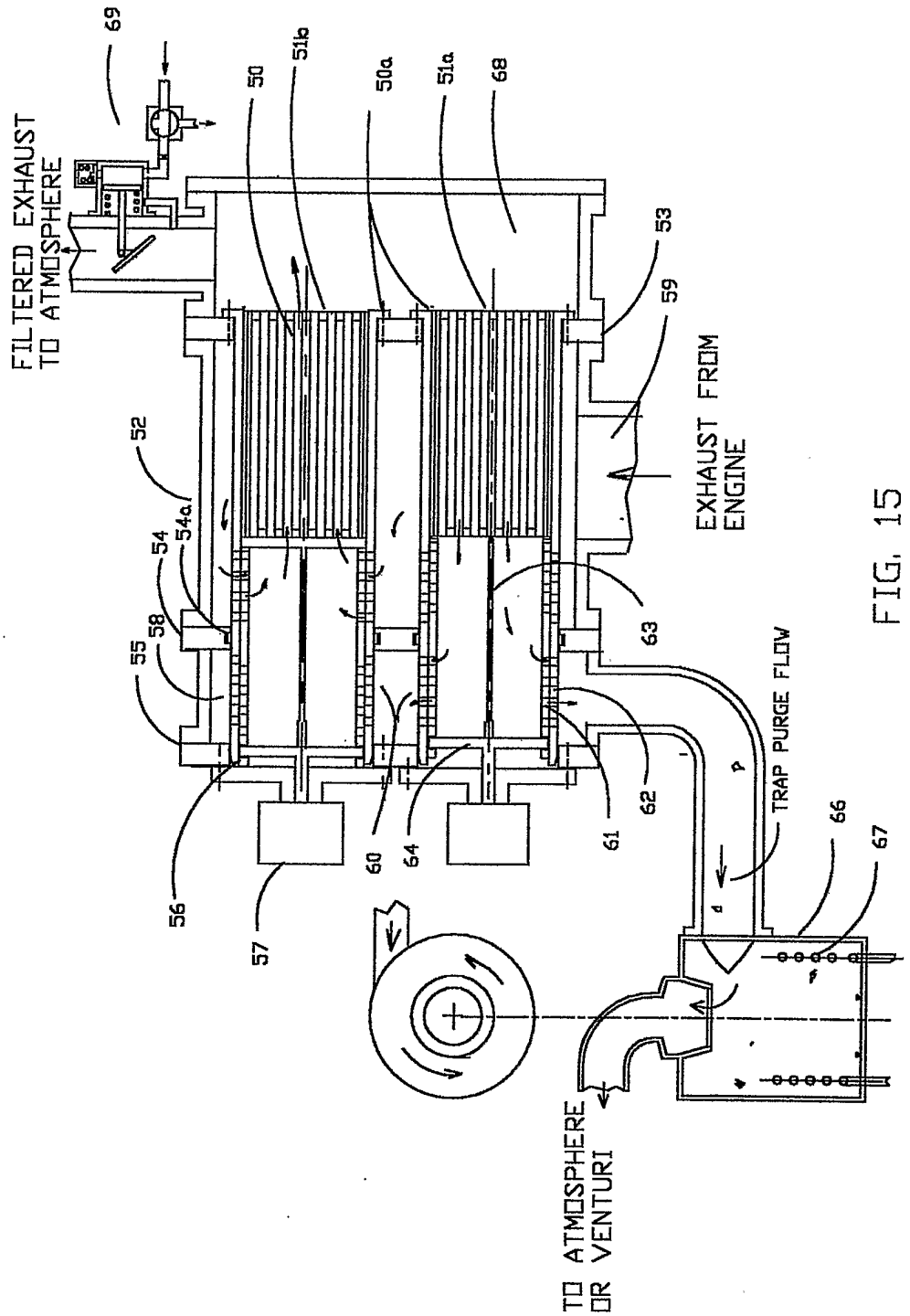

FILTERED EXHAUST
TO ATMOSPHERE
EXHAUST FROM
ENGINE
TRAP PURGE FLOW
TO ATMOSPHERE
OR VENTURI
69
50
51b
50a
51a
68
53
59
52
54
54a
58
55
63
62
61
60
64
56
57
66
67

FIG. 15

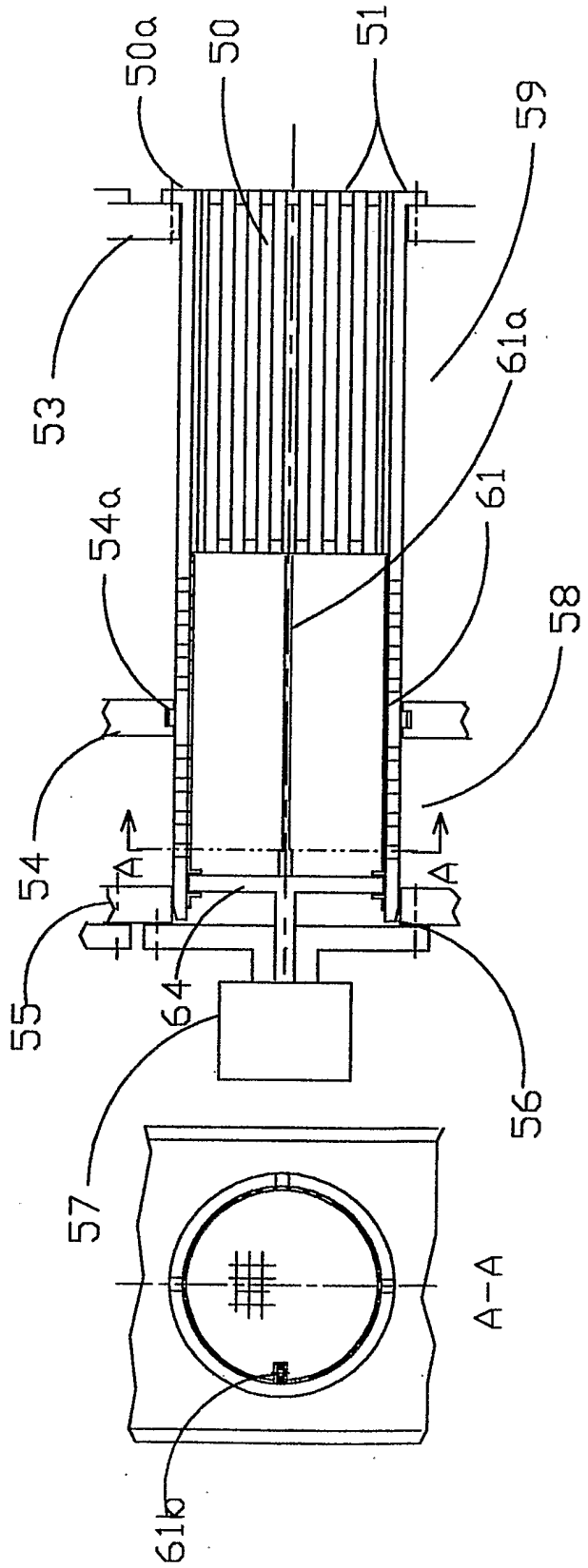


FIG. 16

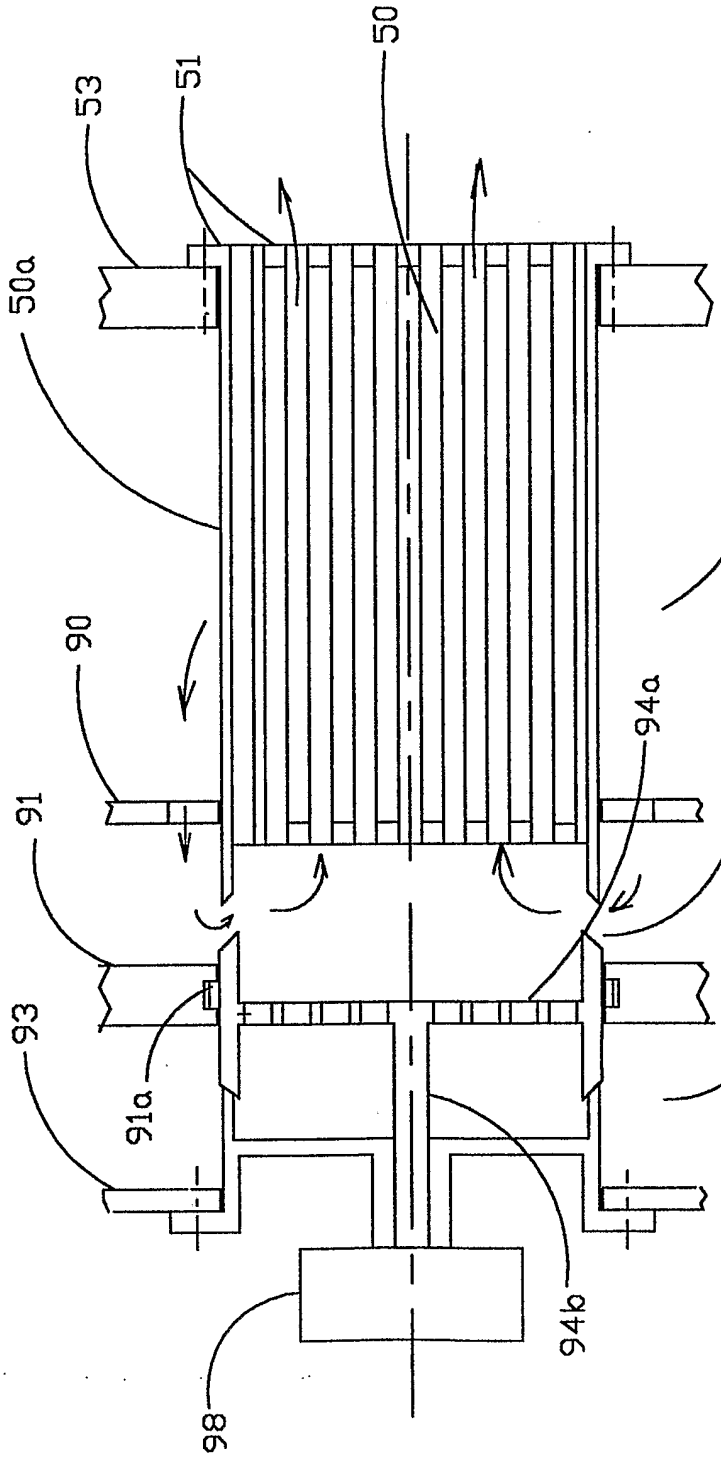


FIG. 17

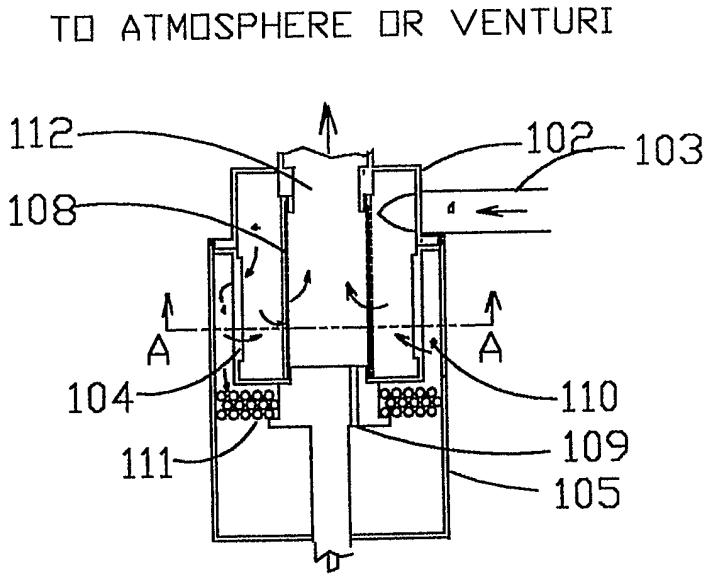


FIG. 18

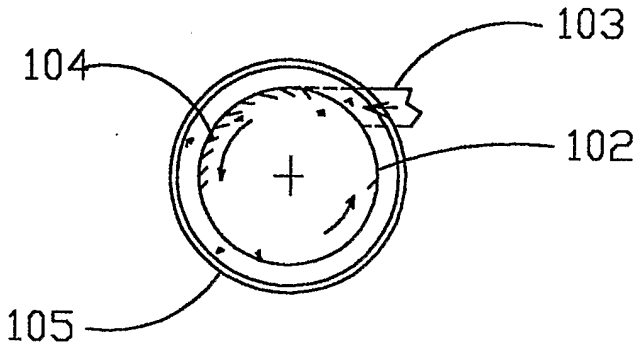


FIG. 18a

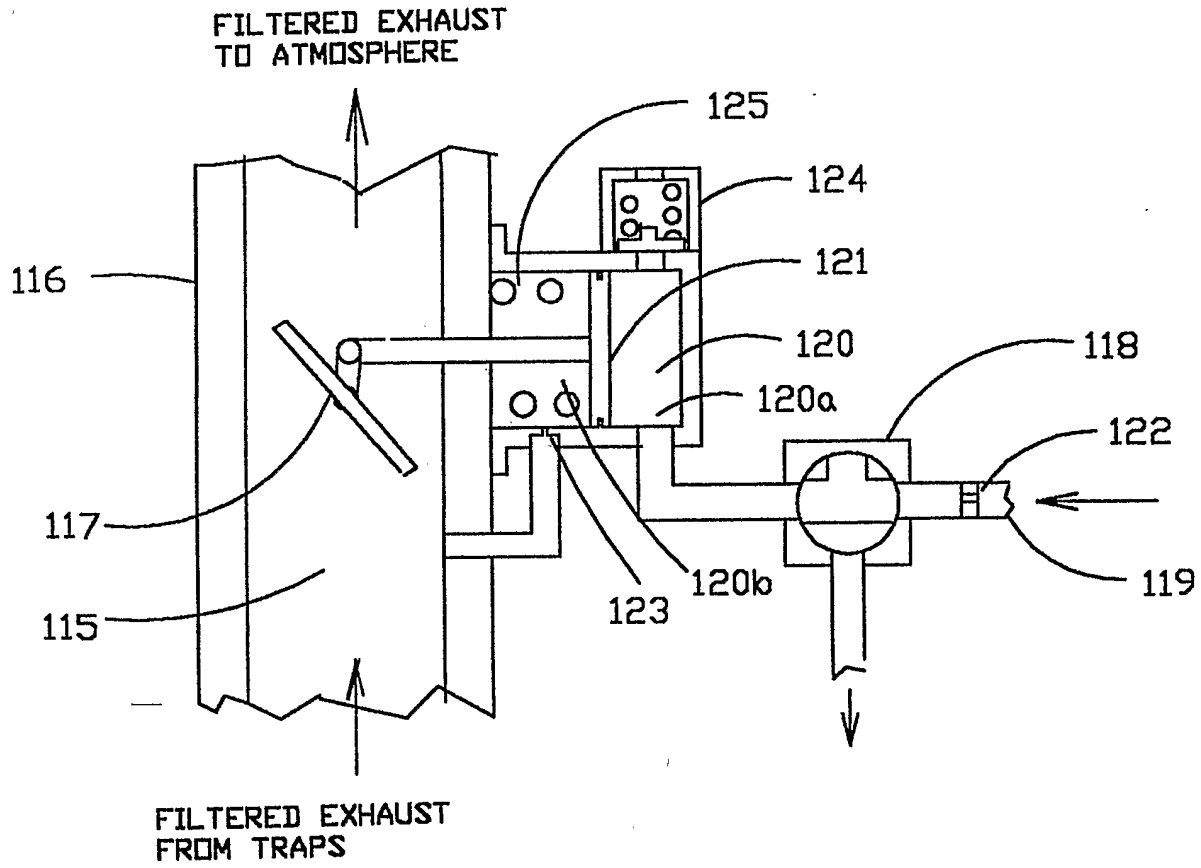

FILTERED EXHAUST
TO ATMOSPHERE
125
124
121
116
120
118
120a
122
117
120b
119
123
115
FILTERED EXHAUST
FROM TRAPS

FIG. 19

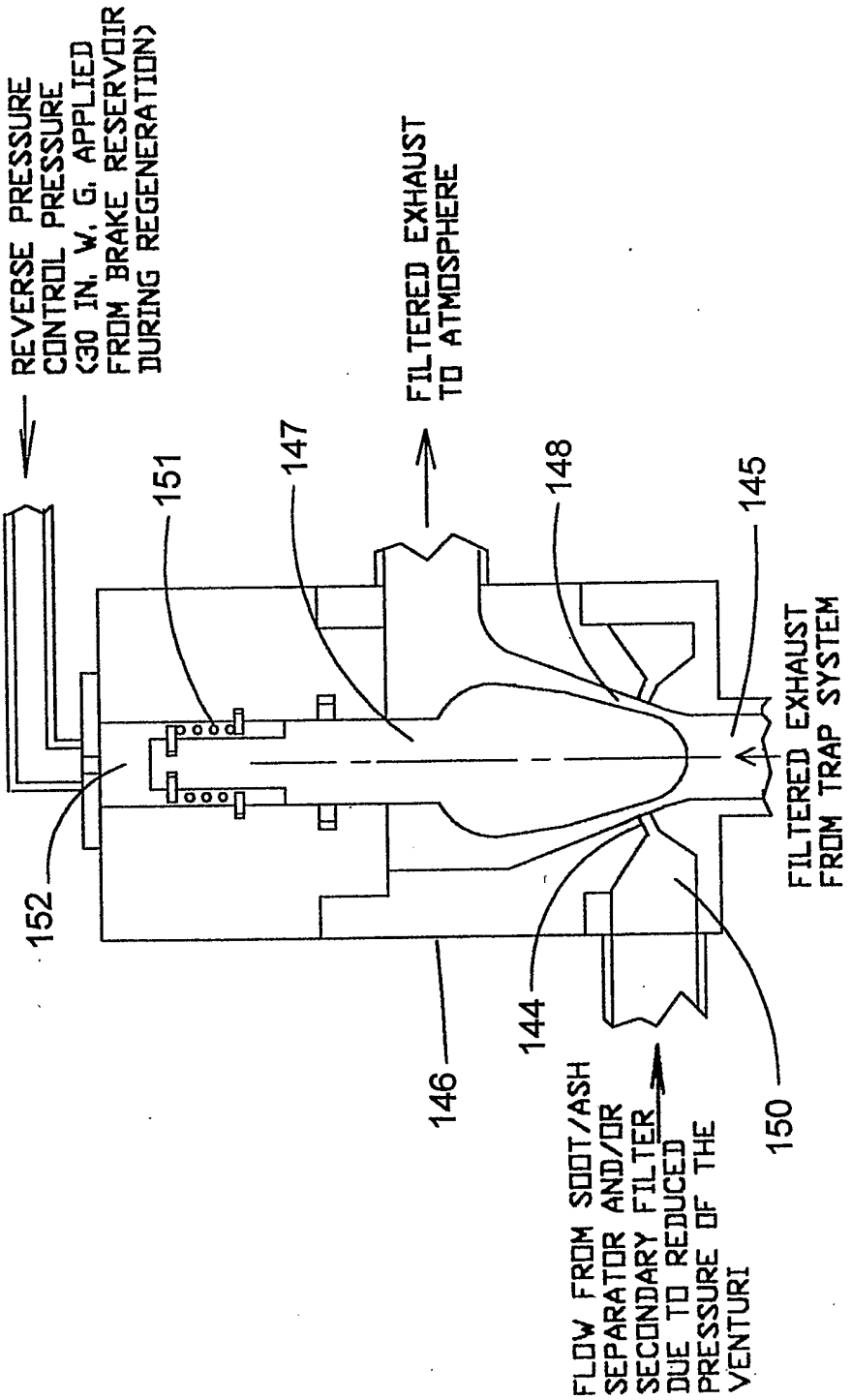

REVERSE PRESSURE
CONTROL PRESSURE
(30 IN. W. G. APPLIED
FROM BRAKE RESERVOIR
DURING REGENERATION)
FILTERED EXHAUST
TO ATMOSPHERE
FILTERED EXHAUST
FROM TRAP SYSTEM
FLOW FROM SOOT/ASH
SEPARATOR AND/OR
SECONDARY FILTER
DUE TO REDUCED
PRESSURE OF THE
VENTURI
151
147
148
145
152
146
144
150

FIG. 20

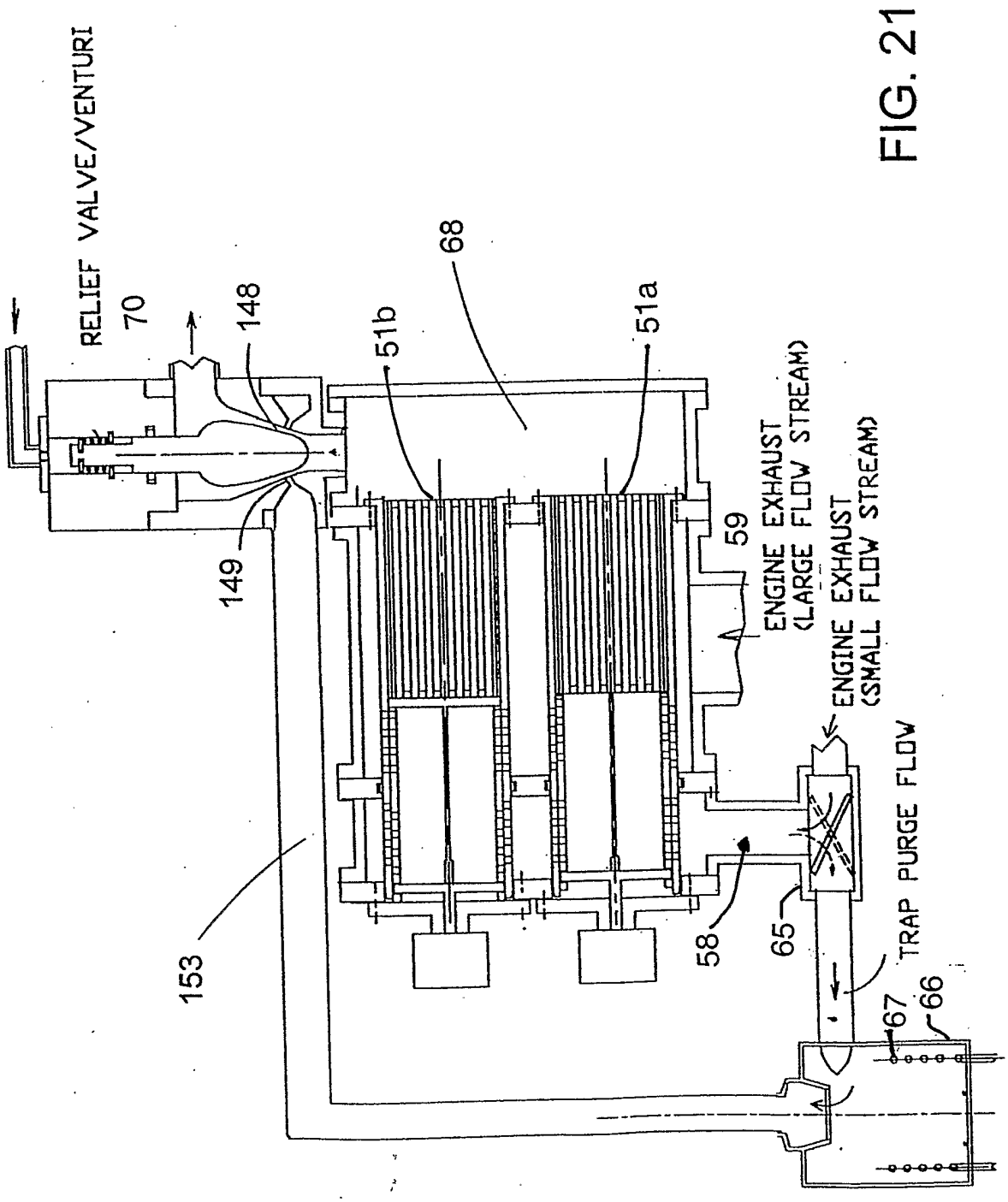

RELIEF VALVE/VENTURI
70
148
68
51b
51a
149
59
ENGINE EXHAUST
(LARGE FLOW STREAM)
ENGINE EXHAUST
(SMALL FLOW STREAM)
153
58
65
TRAP PURGE FLOW
67
66

FIG. 21

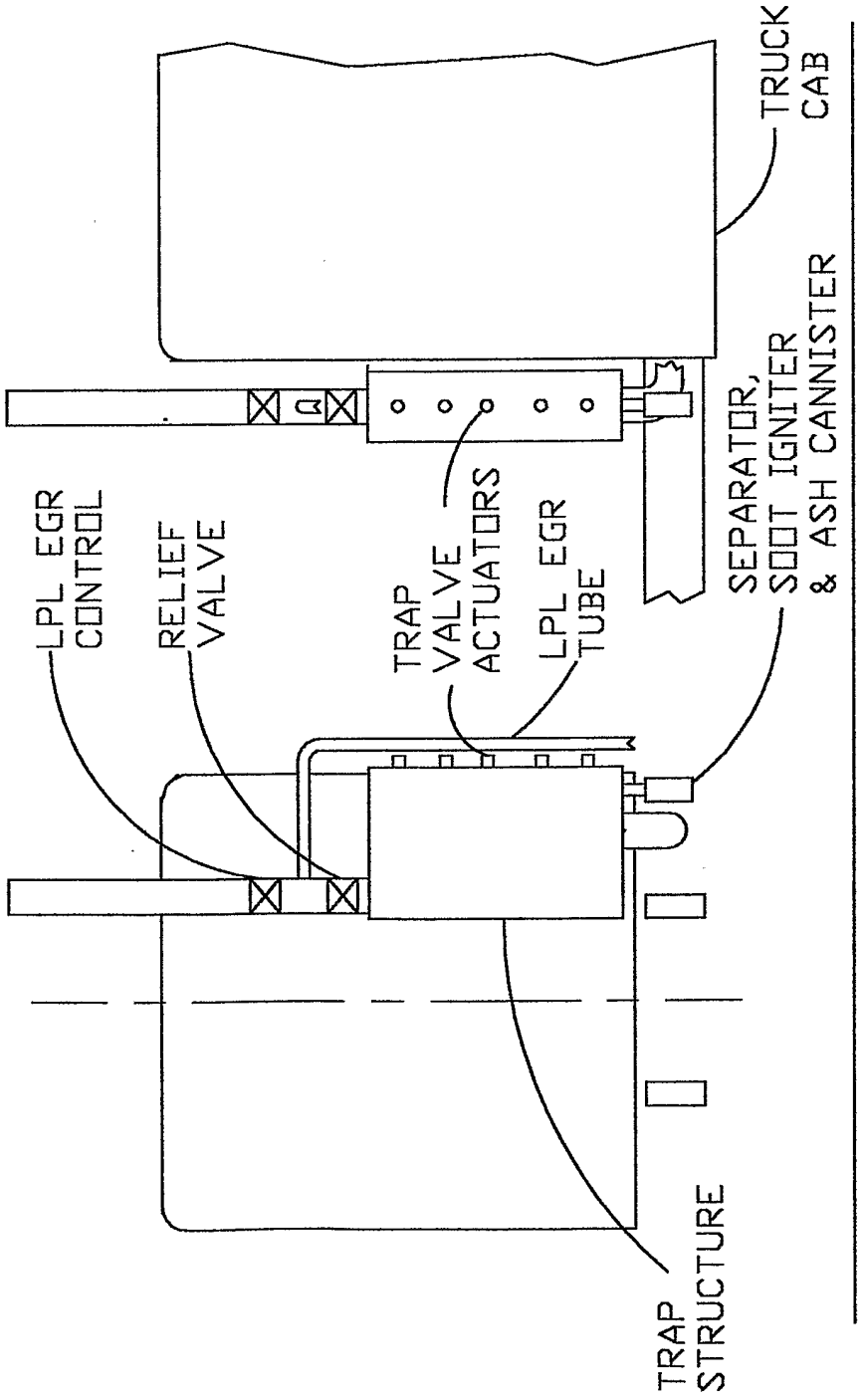

TRUCK CAB
SEPARATOR, SOOT IGNITER & ASH CANNISTER
LPL EGR TUBE
TRAP VALVE ACTUATORS
RELIEF VALVE
LPL EGR CONTROL
TRAP STRUCTURE

FIG. 22

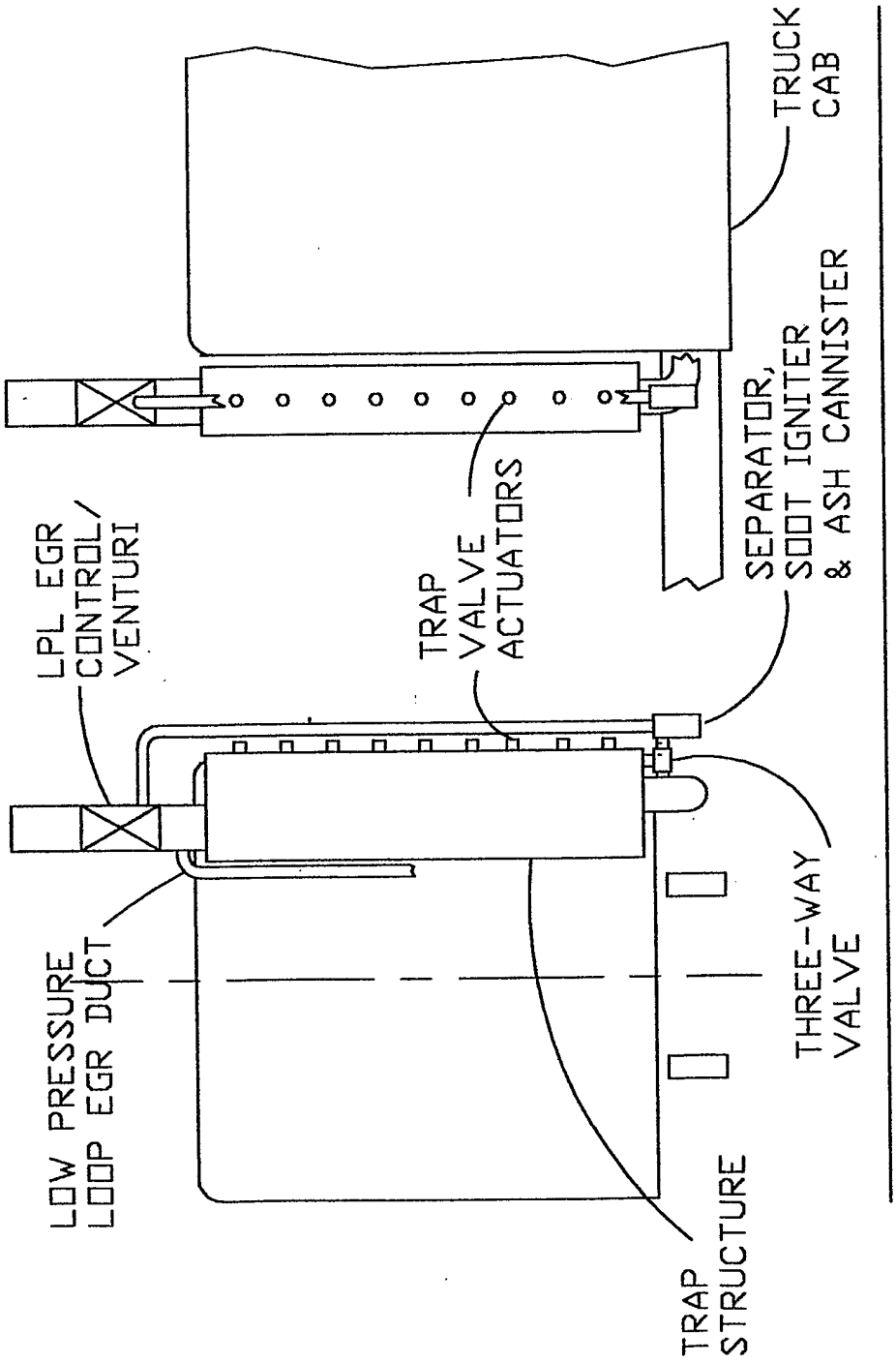

TRUCK CAB
SEPARATOR, SOOT IGNITER & ASH CANNISTER
TRAP VALVE ACTUATORS
LPL EGR CONTROL/ VENTURI
THREE-WAY VALVE
LOW PRESSURE LOOP EGR DUCT
TRAP STRUCTURE

FIG. 23

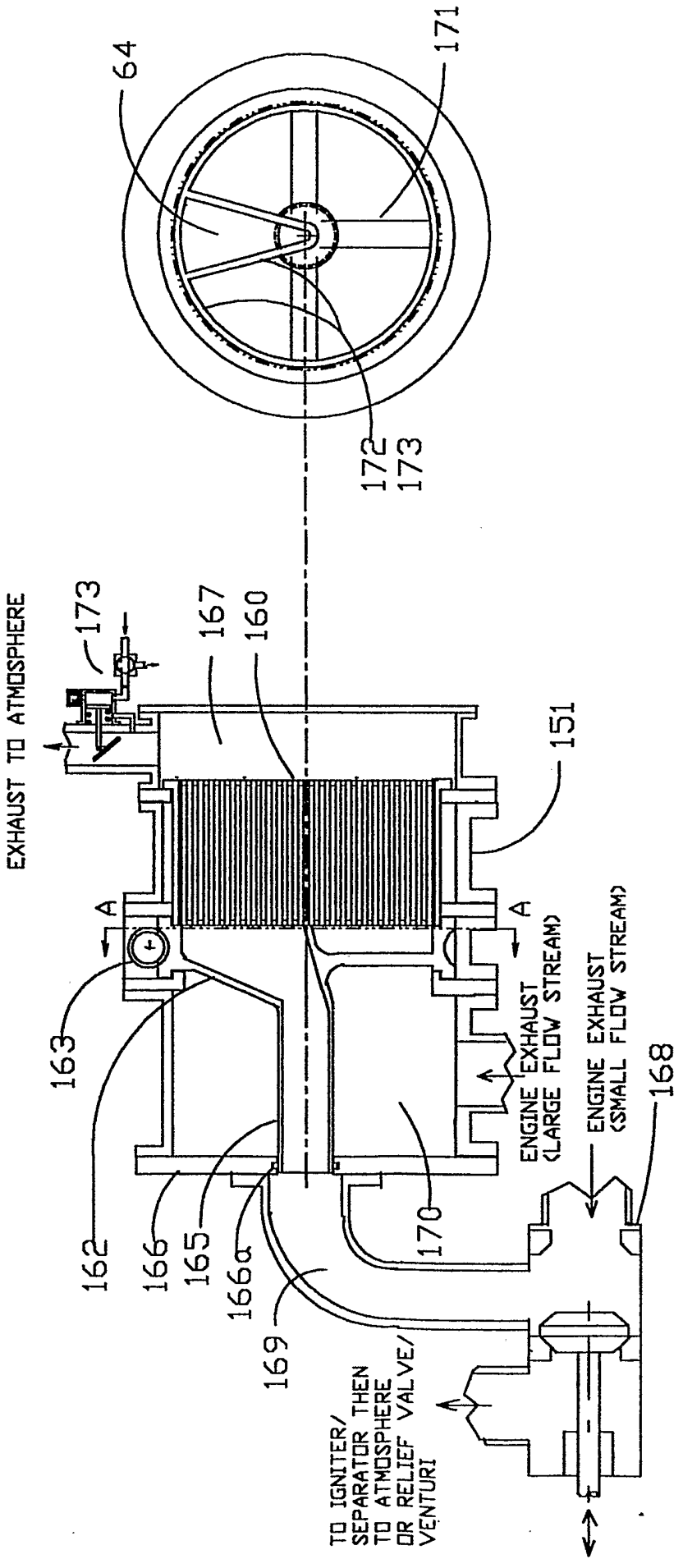


FIG. 24a

FIG. 24

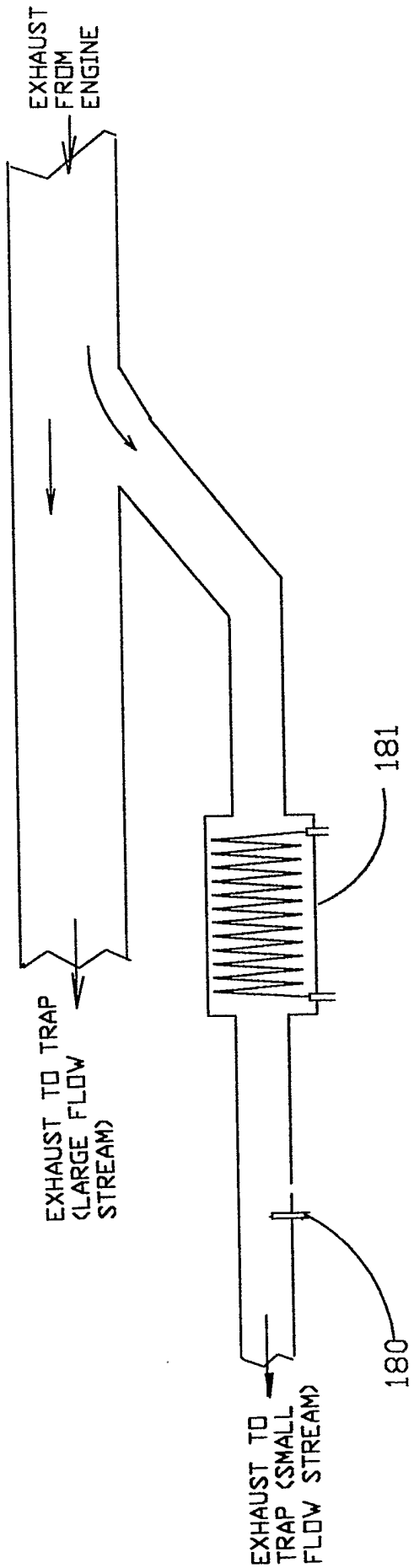

EXHAUST FROM ENGINE
EXHAUST TO TRAP (LARGE FLOW STREAM)
181
180
EXHAUST TO TRAP (SMALL FLOW STREAM)

FIG. 25

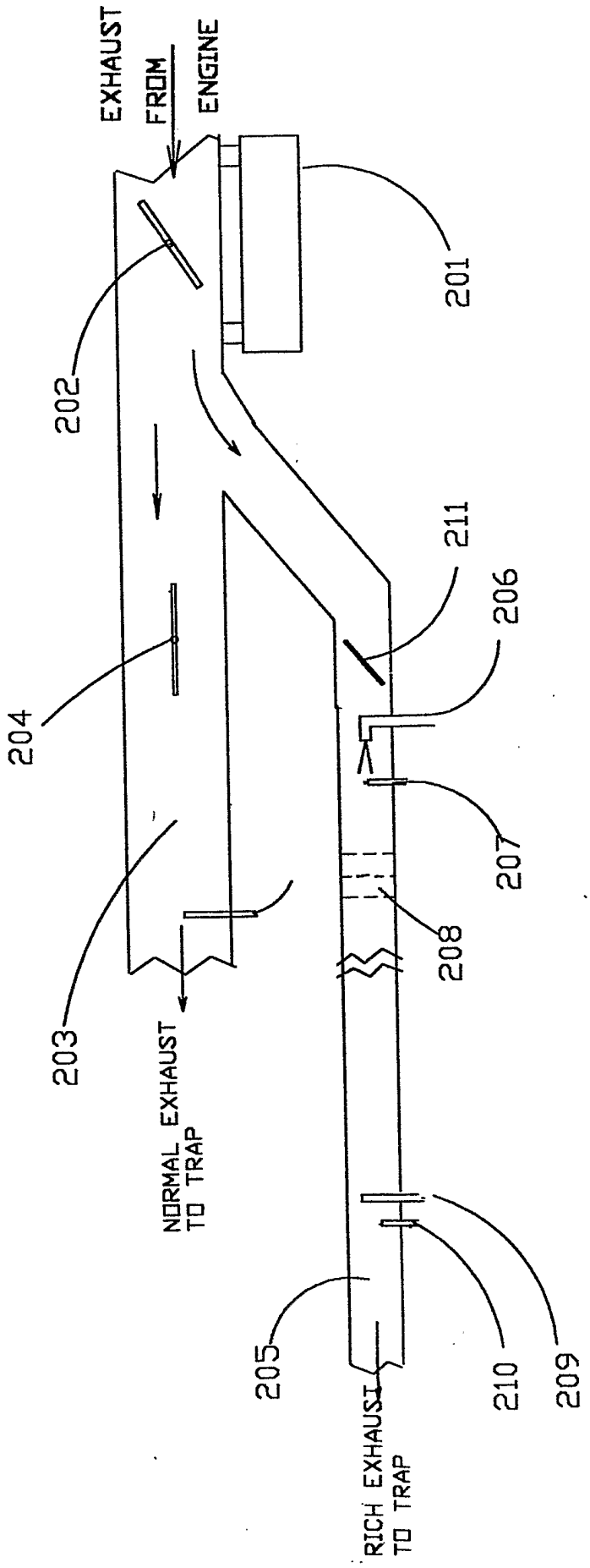

EXHAUST
FROM
ENGINE
201
202
204
203
211
206
207
208
NORMAL EXHAUST
TO TRAP
205
210
209
RICH EXHAUST
TO TRAP

FIG. 26

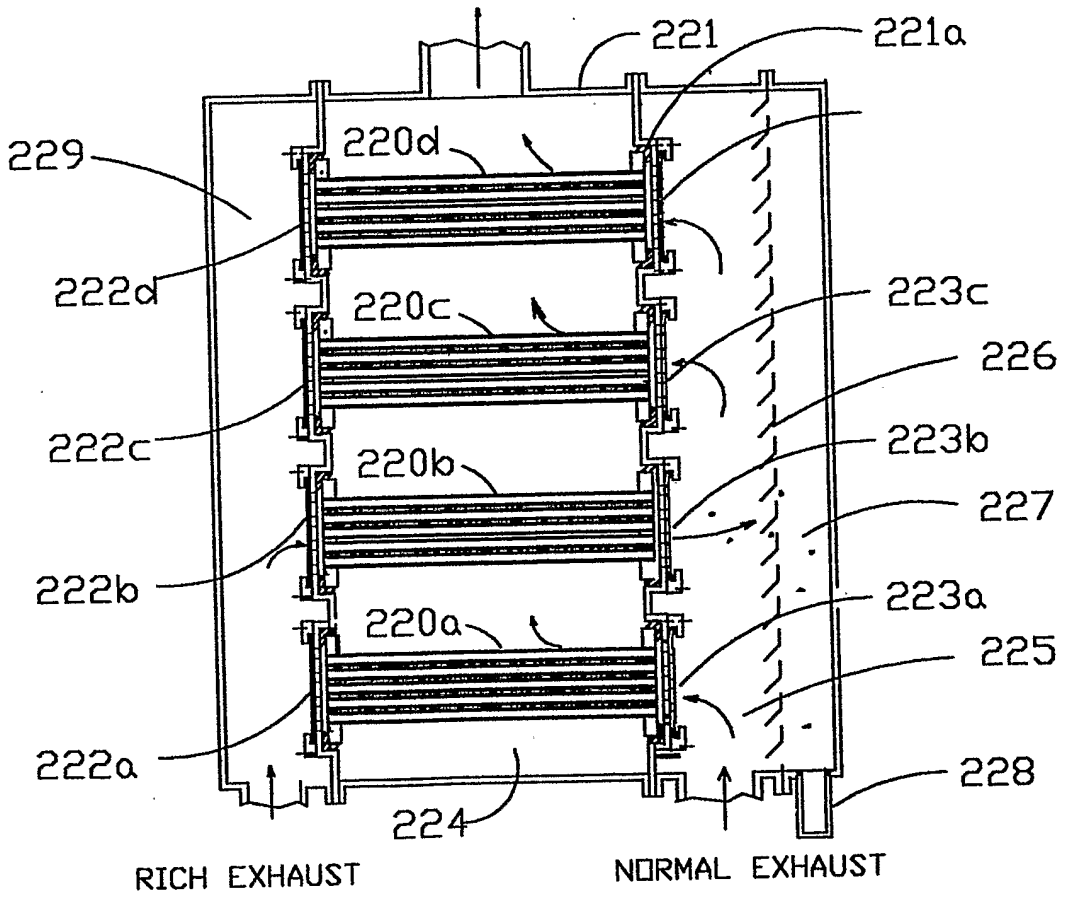

221
221a
229
220d
222d
220c
223c
226
222c
220b
223b
227
222b
223a
220a
225
222a
228
224
RICH EXHAUST
NORMAL EXHAUST

FIG. 27

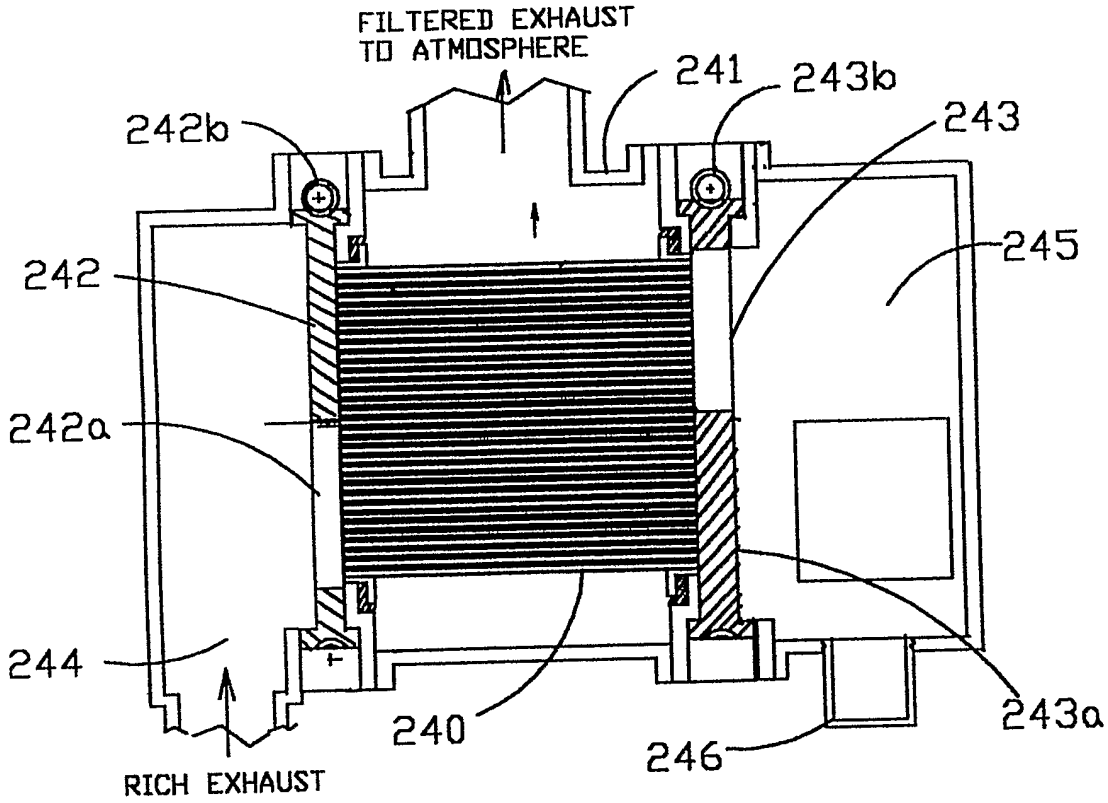
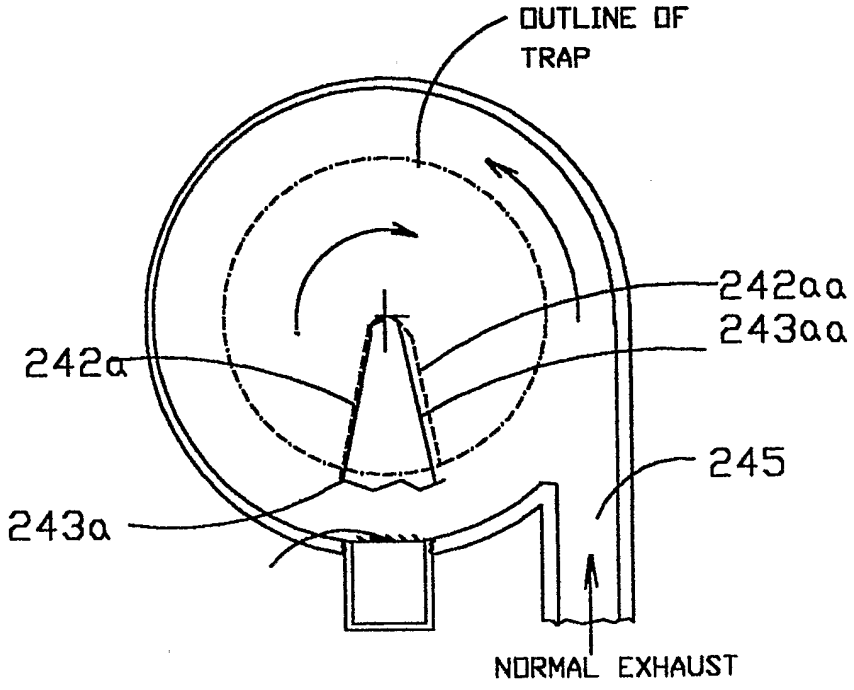

FILTERED EXHAUST
TO ATMOSPHERE
241
243b
243
242b
245
242
242a
244
240
243a
246
RICH EXHAUST

FIG. 28a


OUTLINE OF
TRAP
242aa
243aa
242a
245
243a
NORMAL EXHAUST

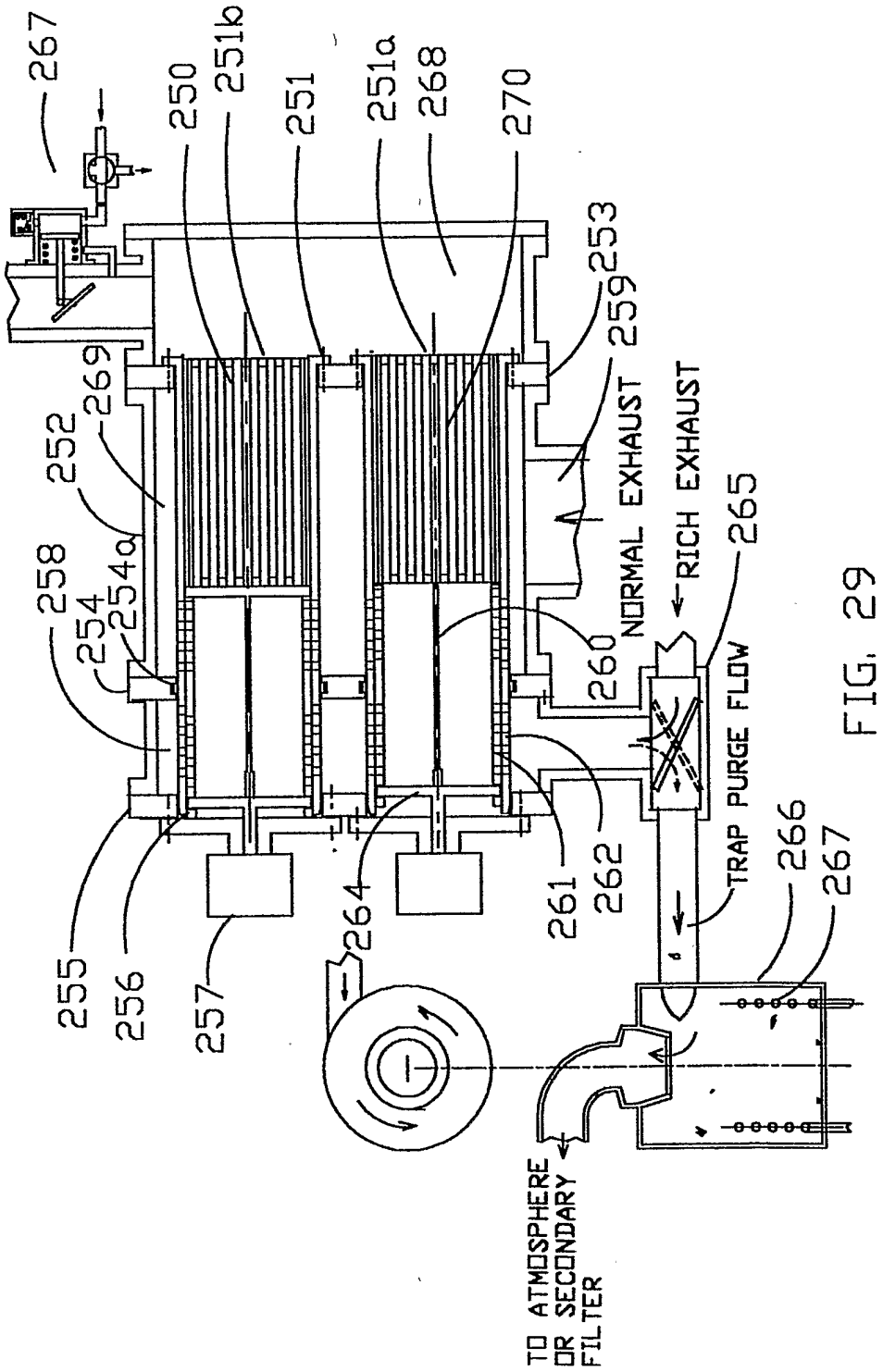

267
250
251b
251
251a
268
270
253
259
269
252
254a
254
258
260
NORMAL EXHAUST
RICH EXHAUST
265
TRAP PURGE FLOW
266
267
255
256
257
264
261
262
TO ATMOSPHERE
OR SECONDARY
FILTER

FIG. 29

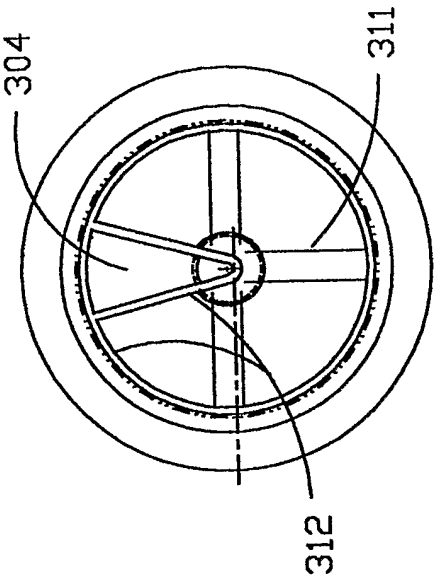


FIG. 30b

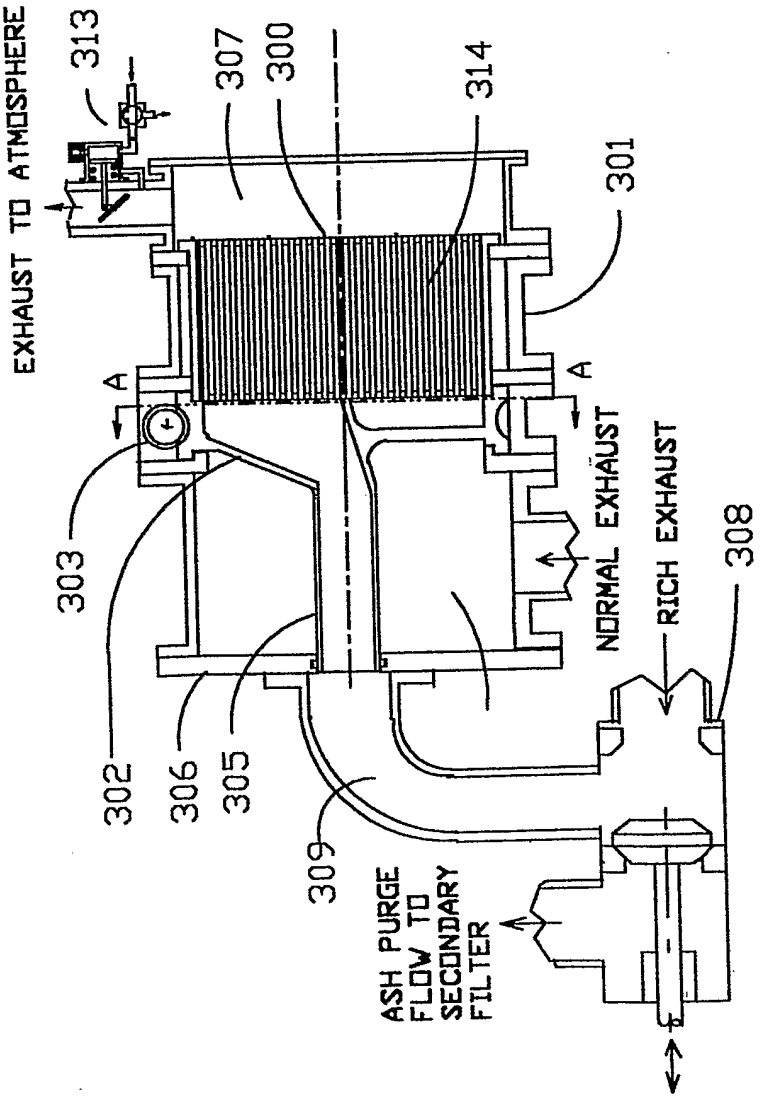


FIG. 30a

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/40107

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B01D 46/00; F01N 3/00, 3/023, 3/033, 3/36
US CL : 55/284, 302, 303, 385.3, 428.1, 523, DIG.10, DIG.30; 60/274, 295, 296, 297, 299, 303, 311

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : Please See Continuation Sheet

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,233,926 B1 (BAILEY et al) 22 May 2001 (22.05.2001), Figures 1-12 and column 1, line 5 to column 20, line 50.	1, 2, 4, 64, and 65
X --- Y	US 5,930,995 A (WATANABE et al) 03 August 1999 (03.08.1999), Figures 1-10 and column 1, line 4 to column 8, line 22.	1, 3, 64, and 65 --- 2
X --- Y	JP 4-31613 (NISSAN MOTOR CO LTD) 03 February 1992 (03.02.1992), Figure 1.	1, 3, 64, and 65 --- 2
Y	US 4,833,883 A (ODA et al) 30 May 1989 (30.05.1989), Figures 1-3 and column 1, lines 20-38.	2
A	US 6,314,722 B1 (MATROS et al) 13 November 2001 (13.11.2001).	39-63 and 66
A	US 6,023,929 A (MA) 15 February 2000 (15.02.2000).	39-63 and 66

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 March 2003 (14.03.2003)	08 APR 2003
Name and mailing address of the ISA/US *Commissioner of Patents and Trademarks* Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Jason M. Greene Telephone No. 703-308-0661

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

PCT/US02/40107

Continuation of B. FIELDS SEARCHED Item 1:
55/282.3, 284, 302, 303, 385.3, 392.1, 394, 423, 428.1, 429, 432, 433, 523, DIG.10, DIG.30; 60/274, 295, 296, 297, 299, 301, 303, 311