

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
14 February 2002 (14.02.2002)

PCT

(10) International Publication Number  
**WO 02/11862 A1**

(51) International Patent Classification<sup>7</sup>: **B01D 53/34**,  
53/94, 53/96, F01N 3/021, 3/022, 3/023, 3/025

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(21) International Application Number: PCT/US01/41547

(22) International Filing Date: 2 August 2001 (02.08.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
09/631,794 3 August 2000 (03.08.2000) US

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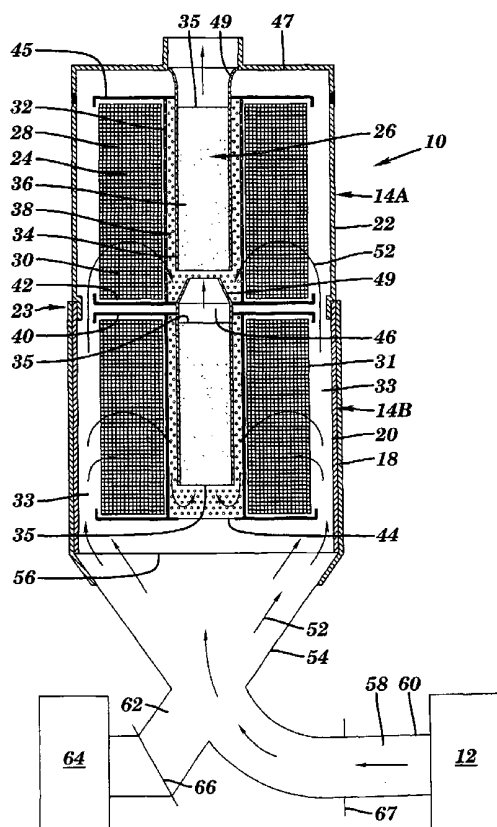
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,  
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU,  
CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH,  
GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC,  
LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW,  
MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK,  
SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM,  
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian  
patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European  
patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,  
IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,  
CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD,  
TG).

[Continued on next page]

(54) Title: FILTER, REGENERATION AND SOOT-REMOVING SYSTEMS AND APPLICATIONS

(57) Abstract: The invention provides a filter system (10), a regeneration system (64), a combined soot-removing system and applications for the systems. The filter system (10) may act as a purifier and a muffler for heavy and light duty diesel vehicles. The invention is a unique dual pass filter system that removes particulates and nitrogen oxides in successive passes before the gas exits the filter (10). The regeneration system (64) includes an electric-powered heat source for safety and better control of the regeneration process. A motor vehicle application is also disclosed.



WO 02/11862 A1

**Published:**

- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

## **FILTER, REGENERATION AND SOOT-REMOVING SYSTEMS AND APPLICATIONS**

### **BACKGROUND OF THE INVENTION**

#### **Technical Field**

5           The present invention relates generally to exhaust filtering and, in particular, to a filter system, regeneration system for the filter system, a combined soot removing system and applications of those systems.

#### **Related Art**

10           Filtering of exhaust is a well-known mechanism to reduce pollution. Related art devices have suffered from a number of drawbacks. For instance, most of the filters are adaptations of substrates used for automotive catalytic converters in which alternating channels are plugged to force the gas through the substrate walls. A number of other filter configurations and materials have been tried, but none have been robust enough or cost effective enough for widespread use. Also, once the particulates or other materials have  
15           been collected, they must be removed before the filter can function effectively. This is typically accomplished by igniting and burning the collected burnable particulates using a variety of techniques. Current techniques in the art of regeneration are expensive, complex, and many are outright hazardous, e.g., some use explosive, compressed gas or highly flammable (compared to diesel fuel) liquids.

20           In addition, the catalytic converter materials were designed to operate at much lower temperatures than can be reached during an uncontrolled regeneration (rapid,

uncontrolled burning of the soot collected in the filter). In many cases, the filter media cracks, melts, or is otherwise damaged by either vehicle induced vibration or very high temperatures. In addition, many filters include two or more integral filter sections for filtering different pollutants. Unfortunately, these filters make regeneration difficult.

5 Further, when one filter section is in need of repair, all of the sections must be replaced.

Another problem with related art devices is their inability to accommodate different applications because of their inflexible size. A new mold must be made for each different size filter unit, which dramatically increases cost or limits the ability to tailor the filter for the application. U.S. Patent No. 5,250,094 to Chung et al. discloses a filter  
10 construction having a number filter sections 114. Unfortunately, the device is limited in application by the size of the enclosure.

Related art devices also do not adequately provide a regeneration system that is safe and controllable. In particular, U.S. Patent No. 5,820,833 to Kawamura includes an electric wire net that is integral with a filter, i.e. in-filter regeneration. Since the  
15 regeneration system and filter are inseparable, the device may be subject to vibrations that may induce damage. U.S. Patent No. 5,394,692 to Teuber-Ernst discloses a separate regeneration system that is fired by an explosive gas, which is an unsafe situation when in an environment where other fuel sources are nearby. Another problem with these regeneration systems is their inability to adequately control the rate of burn and, therefore,  
20 the temperature of the filter during regeneration. Many filters cannot withstand the repeated exposure to higher temperatures caused by some regeneration systems. Further, the potential for regeneration to proceed uncontrollably is potentially dangerous due to the extreme amount of heat that is generated by the burning soot.

Accordingly, there is a need in the art for a filter that includes separate filtering sections for ease of repair and regeneration. Furthermore, there is a need for a readily size-adjustable filter system. It would also be advantageous if this filter could be retrofitted to a variety of exhaust producing devices that exhaust a variety of different pollutants.

5 Moreover, there is also a need for a safe and controllable regeneration system. A system that combines the above filter and regeneration system would also be advantageous.

### SUMMARY OF THE INVENTION

The invention provides an exhaust filter system that serves as a particulate trap, a muffler, and a purifier as well as a regeneration system that is safe and controllable. The filter system design removes the structural load from the filter, while the regeneration system design eliminates most of the failure modes found in current regeneration systems. The invention provides for longer filter life, less complicated regeneration, less modification to an exhaust producing device for retrofitting, and much lower life cycle costs to the end user. In addition, the filter system can tolerate much higher temperatures than conventional filter systems thereby increasing the durability and use range of the filters.

In a first aspect of the invention is provided a filter system for removing soot from the exhaust of an exhaust producing device, the filter system comprising one or more self-contained, module, attachable units for varying the size of the filter system. Each unit includes: a housing; a particulate filter section positioned within the housing; and a nitrogen oxide filter section having a gas-impervious inner cylinder spaced within the particulate filter section and a nitrogen-oxide removing catalyst positioned within the inner

cylinder. This aspect provides a dual pass filter system that has two separate sections. The number of units can be selected to match the type of exhaust producing device, exhaust source size, and expected operating profile. However, even an individual unit can function as a complete, dual-pass filter. In addition, the filter system may replace a muffler in many settings, which reduces costs to an end-user, and may be retrofitted without major modifications to a variety of exhaust producing devices. Further, unlike pure catalyst based filter systems, the filter system is not limited for use with a particular exhaust producing fuel, e.g., expensive low-sulfur diesel fuel.

A second aspect of the invention includes a regeneration system for an exhaust filter, the system comprising an electrically heated regenerator for producing heated gas to be passed through the filter to regenerate the filter. This aspect provides a safer and more easily controlled regeneration process. The system may be implemented separate from the exhaust producing device to prevent vibration induced damage or may be coupled to the device where the device is capable of moving, e.g., a motor vehicle.

A third aspect of the invention provides a soot removing system for an exhaust producing device comprising: a filter for removing soot from exhaust of the exhaust producing device; and a regeneration system having an electrically heated regenerator for producing heated gas to be passed through the filter to regenerate the filter. This aspect provides for a combined system having the above-described attributes of the filter and regeneration systems.

A fourth aspect of the invention includes a motor vehicle comprising: an engine for driving ground engaging members; an exhaust filter for removing soot from exhaust of the engine, the filter including one or more attachable units for varying the size of the filter;

and an electrically heated regenerator for producing heated gas to be passed through the filter to regenerate the filter.

The foregoing and other features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention.

5

## BRIEF DESCRIPTION OF THE DRAWINGS

The preferred embodiments of this invention will be described in detail, with reference to the following figures, wherein like designations denote like elements, and wherein:

Fig. 1 is a cross-sectional view of a filter system in accordance with the invention;

10

Fig. 2 is an exploded view of a unit of the filter system;

Fig. 3 is a cross-sectional view of a unit of the filter system;

Fig. 4 is a detailed cross-sectional view of a three unit filter system;

Fig. 5 is a cross-sectional view of an alternative aspects of a unit of the filter system;

15

Fig. 6 is a side view of a soot removing system including a regeneration system in accordance with the invention; and

Fig. 7 is a motor vehicle incorporating the systems of the invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

20

Although certain preferred embodiments of the present invention will be shown and described in detail, it should be understood that various changes and modifications may be made without departing from the scope of the appended claims. The scope of the

present invention will in no way be limited to the number of constituting components, the materials thereof, the shapes thereof, the relative arrangement thereof, etc., which are disclosed simply as an example of the preferred embodiment.

For convenience, the disclosure will be broken down into the following headings for organizational purposes only:

I. Filter System

II. Regeneration System

III. Combined Soot Removing System

IV. Applications

#### I. Filter System:

Referring to the Figs. 1-5, a filter system 10 for removing soot from the exhaust of an exhaust producing device 12 is shown. Filter system 10 includes one or more attachable units 14 for varying the size of filter system 10 that are preferably cylindrical in cross-section. As shown, a number of units 14A, 14B, 14C, etc. may be sealingly coupled together to create a filter. In this case, a shell support 18 may be provided to secure a lower unit 20. Alternatively, as shown in Fig. 4, a number of units 14 can be stacked into a shell 16 to produce filters of various capacities. Shell 16 may be a standard muffler shell of, for instance, a diesel engine driven truck. Shell 16 is preferably made of standard muffler steel.

As shown best in Figs. 1-3, each unit 14, 14A, 14B, etc. includes a housing 22, a particulate filter section 24 and a nitrogen oxide (NOX) filter section 26. Housing 22 encloses filter sections 24, 26 and is preferably made of a corrosion-resistant metal such as



high temperature, stainless steel like AISI types 301-325 or 401-440. Each housing 22 also includes a coupling 23 for sequentially attaching a unit 14A to an adjacent unit 14B. Coupling 23 may take a variety of forms known to those skilled in the art; as shown, coupling 23 includes an interference fit-type coupling such that each unit 14 has a recessed  
5 portion that fits into an expanded portion of an adjacent unit 14. This provides structural rigidity and support for the stack. Other mechanisms of attachment such as clips may also be provided.

Particulate filter section 24 includes a filtering section 28 having either a set of radially oriented plates or a set of radially oriented pleats 30, and a porous cylinder 32 for  
10 supporting an inner surface of plates or pleats 30. Plates or pleats 30 are composed of low back pressure filter media such as woven ceramic fiber, ceramic fiber cloth, ceramic fiber paper/felt or a combination of those materials. The fibers are preferably one of the following ceramic materials: aluminum oxide, silicon dioxide, mullite (a mixture of aluminum oxide and silicon dioxide), aluminosilicate (another mixture of aluminum oxide  
15 and silicon dioxide), silicon carbide, silicon carbonitride, or silicon oxycarbide. Ceramic fiber plates or pleats 30 are preferably rigidized, protected, and rendered more durable by a thin coating of ceramic. This media is further improved and stiffened by the use of a coating of pre-ceramic polymers such as that disclosed in U.S. Patent No. 5,153,295 to Whitmarsh et al., hereby incorporated by reference. Preferably, the pre-ceramic polymer  
20 is selected from the group comprising: silicon carbide, oxycarbide, aluminosilicate and alumina. It should be recognized that other pre-ceramic polymers may also be possible. The ceramic coating and pre-ceramic polymers are fired to form a ceramic coating on plates or pleats 30. Filtering section 28 is then more resistant to damage than typical

materials used for filters because the ceramic protects the fibers from the exhaust gas, prevents the fibers from rubbing against each other, and prevents plates or pleats 30 from flexing sufficiently to damage each other. An outer surface 31 of plates or pleats 30 has a smaller outer diameter than an inner diameter of housing 22 to create a substantially  
5 annular chamber 33 for passage of exhaust therebetween. Couplings 23 are also separated from outer surface 31 of plates or pleats 30 to provide for the continuation of annular chamber 33 between units 14.

Porous cylinder 32 is preferably constructed of a corrosion-resistant metal such as high temperature, stainless steel like AISI types 301-325 or 401-440.

10 Nitrogen oxide filter section 26 includes a gas-impervious inner cylinder 34 and a nitrogen-oxide removing catalyst 36 positioned within inner cylinder 34. Inner cylinder 34 is spaced from an inner portion of particulate filter section 24 to create a substantially annular chamber 38 therebetween, i.e., cylinder 34 has a smaller diameter than an inner diameter of porous cylinder 32. Inner cylinder 34 is preferably constructed of a corrosion-  
15 resistant metal such as high temperature, stainless steel like AISI types 301-325 or 401-440, and has open ends 35. NOX catalyst 36 is preferably composed of a non-porous ceramic material that is bonded into gas-impervious cylinder 34. Examples of material suitable for catalyst 36 are: codierite, mullite, silicon carbide and aluminum oxide. It should be recognized, however, that other types of ceramic catalyst support media may be  
20 used and any nitrogen oxide catalyst material available commercially may be suited for use with the invention.

Each unit 14 also preferably includes a first, upper end cap 40 and a second, lower end cap 42. End caps 40, 42 function to seal off the ends of plates or pleats 30 and annular

chamber 38. Additionally, each end cap 40, 42 includes a central aperture 46 that acts to position nitrogen oxide filter section 26 and, in particular, inner cylinder 34, such that section 26 is substantially concentric within particular filter section 24.

A special end cap 44, referred to as a stop cap, may be provided on a lowermost unit 14, as shown in Figs. 1, 4 and 5. Stop cap 44 does not include a central aperture 46 and may be formed as a solid member or may include a plug 48, shown in Fig. 4, to close aperture 46. As illustrated in Fig. 5, stop cap 44 may also include an exhaust directing formation 50 for directing exhaust into nitrogen oxide filter section 26. Formation 50 may be created by, for example, stamping a solid stop cap 44 or plug 48. Another stop cap 45, shown in Fig. 1, may be provided to seal an uppermost unit 14 of filter system 10. Stop cap 45 preferably seals to housing 22 of the uppermost unit 14, as shown in Fig. 1, to prevent exhaust 52 from escaping through annular chamber 33. Sealing is provided by the use of compressible fiber gasketing, rigidized fiber felt or a polymer slurry. Alternatively, as shown in Fig. 5, a filter system output shroud 47 may be coupled directly to housing 22 to eliminate the need for stop cap 45. A vent port 49 may also be provided on gas impervious cylinder 34 to mate with an adjacent unit 14 and, hence, direct exhaust 52 from one NOX filter section 26 to the next (shown in Fig. 1), or to direct exhaust 52 through shroud 47 (shown in Fig. 5).

Each end cap 40, 42, 44, 45 and plug 48 are preferably made of a corrosion-resistant metal such as high temperature, stainless steel like AISI types 301-325 or 401-440. Filtering section 28 may be sealed to the appropriate caps 40, 42, 44, 45 by the use of compressible fiber gasketing, rigidized fiber felt or a polymer slurry.

Operation of filter system 10 will be described with reference to Figs. 1, 4 and 5.

In operation, exhaust 52 from an exhaust producing device 12 is directed to filter system 10 by an adaptor 54. Adaptor 54 is preferably made of standard muffler steel. Adaptor 54 is preferably in the form of an inverted Y with three openings 56, 58 and 62. First opening 56 is shaped and sized to mate with a lowermost unit 14 of filter system 10; second opening 58 is shaped and sized to mate with an exhaust port 60 of exhaust producing device 12; and third opening 62 is shaped and sized to mate with a regeneration system 64, as will be described below. As will be recognized by those skilled in the art, adapter 54 may also require other adapter components (not shown) for proper coupling to filter system 10, exhaust producing device 12 and regeneration system 64.

Referring to Fig. 1, during operation of filter system 10, third opening 62 is closed by a flange or valve 66. Exhaust 52 from exhaust producing device 12 is communicated by adapter 54 to filter system 10 where it enters annular chamber 33 between housing 22 and particulate filter section 24. Exhaust 52 may pass from one unit 14B to an adjacent unit 14A within annular chamber 33, and so on through all of the units in system 10. As exhaust 52 is routed through chamber 33, it radially enters particulate filter section 28, i.e., it moves inwardly, where particulates from the exhaust 52, such as soot, sulfates, oxides and other particulates are removed. Subsequently, exhaust 52 is routed through porous cylinder 32 and into annular chamber 38. Because of the sealed ends of annular chamber 38, exhaust 52 is routed into NOX filter section 26 at an open end 35 of gas impervious cylinder 34 where it passes longitudinally through section 26. NOX catalyst 36 reacts with and removes nitrogen oxides (NOX) from exhaust 52. Further removal of NOX is provided as exhaust 52 passes from unit, e.g., 14B, to another unit, e.g., 14A and so on

through all units 14, i.e., exhaust 52 that passes through lower units 14 is subject to repeated NOX removal as it passes through adjacent unit(s) 14. The resulting exhaust gas, when it emerges from filter system 10 will be significantly depleted in NOX and particulates. Another advantage of filter system 10 is that it also acts to muffle noise from exhaust producing device 12, i.e., system 10 acts as a muffler and a filter.

It should be recognized that any number of units 14, 14A, 14B, etc. may be stacked together to form a filter. The particular illustrations of two units (Fig. 1), three units (Fig. 4) and one unit (Fig. 5) are for illustration purposes only. Furthermore, as shown in Fig. 1, NOX filter section 26 may be shorter than particulate filter section 24 to promote routing of exhaust 52. However, this is not necessary, as shown in Fig. 5, where stop cap 45 includes formation 50 to promote routing of exhaust 52 to nitrogen oxide filtering section 26.

## II. Regeneration System:

Referring to Fig. 6, a regeneration system 64 of the invention is shown in greater detail. Regeneration entails the burning out of soot from a filter, such as filter system 10, to restore the filtration capacity of a filter. Regeneration system 64 includes an electrically powered regenerator or heat source 70 for producing heated gas 72 to be passed through a filter such as filter system 10 to regenerate the filter. Regenerator 70 preferably includes an electric powered metal wire, an electric powered ceramic element or an electric powered intermetallic element having a power rating of 1000-15,000 watts.

Regeneration system 64 also preferably includes: adaptor 54; an air pump or blower 74 for pressurizing heated gas 72; a source of inert gas 76; and a computer control system 78. Adapter 54, as described above, may include a second flange or valve 67 for closing off second opening 58 to exhaust producing device 12 during regeneration. As an  
5 alternative, adaptor 54 may simply be disconnected from exhaust producing device 12.

Source of inert gas 76 is preferably provided to supply inert gas 80 with heated gas 72 to control the burn rate of soot within filter system 10, i.e., the amount of inert gas 76 controls the temperature of the filter by controlling the amount of oxygen available for burning. A preferred inert gas for use in system 64 is nitrogen.

10 Computer-control system 78 operates to control the regeneration process by controlling: regenerator or heat source 70, the temperature of filter system 10 and air pump or blower 74. In order to control the above parameters, computer control system 78 may include: a thermocouple 84 for measuring temperature in filter system 10 during regeneration; a heat source temperature controller 90; and an air supply controller 92.

15 Thermocouple(s) 84 may be provided anywhere along filter system 10 to accurately determine temperature of filter system 10, e.g., within each unit 14. Heat source temperature controller 90 controls the amount of heat produced by regenerator 70, and air supply controller 92 controls the amount of air supplied by air pump or blower 74.

Advantageously, air supply controller 92 also may control the amount of inert gas 80  
20 supplied from source of inert gas 76.

Regeneration system 64 also may include a scrubber 82 that attaches to an outlet of filter system 10. Scrubber 82 collects pollutants generated during the regeneration process.

In operation, filter system 10 is regenerated once it collects enough soot to increase the back-pressure therein to a pre-determined point; a condition that may be determined by a pressure gauge (not shown) on filter system 10. At that stage, filter system 10 would be brought to a regeneration system 64, or vice versa, where regenerator 70 is quickly  
5 attached to filter system 10 at adaptor 54 opening 62, e.g., by using flange or valve 66. Second flange or valve 67 is closed to block flow of heated gas 72 and inert gas 80 to exhaust producing device 12. The temperature inside filter system 10 is tracked by thermocouple(s) 84 that feed back information to computer control system 78 for control of regenerator 70 and air supply controller 74.

10 As heat is applied to filter system 10 from regenerator 70, the soot will combine with the pumped-in heated gas 72 to burn and generate its own heat. The burning will propagate through filter system 10 and from unit 14 to unit 14 until all of the burnable soot is removed. The effluent from the burning soot may be cleaned by scrubber 86, if one is provided, and subsequently vented to the atmosphere. Thermocouple(s) 84 may be  
15 provided in each unit 14 to monitor temperature. Computer control system 78 may then prevent overheating by decreasing either the heat or the air supply or increasing the amount of inert gas to maintain a controlled burn rate.

After the regeneration process is complete, scrubber 86 and regenerator 70 are disconnected, flange/valve 66 closed, and flange/valve 67 opened for communication with  
20 exhaust producing device 12. Filter system 10 may then be re-used.

### III. Combined Soot Removing System:

As also shown in Fig. 6, the invention also includes a soot removing system 98 that, in general terms, is a combination of aspects of filter system 10 and regeneration system 64. Soot removing system includes a filter, such as filter system 10, for removing soot from exhaust 52 of an exhaust producing device 12 and a regeneration system 64 having an electrically heated regenerator 70 for producing heated gas 72 to be passed through the filter to regenerate the filter. Aspect of the above-described systems that may be part of soot removing system include: source of inert gas 76 for supplying an inert gas 80, e.g., nitrogen, to the filter with hot gases 72; adaptor 54 for coupling to the filter for directing exhaust of exhaust producing device 12 or heated gas 72 from regenerator 70 through the filter. As discussed above, adaptor 54 preferably includes a first opening 56 coupled to a first end of the filter, a second opening 58 for coupling to an exhaust port 60 of exhaust producing device 12, a third opening 62 for coupling to regenerator 70; and a valve 66 for closing off second opening 58 during regeneration. A scrubber 82 may be attached to an output end of the filter.

In a preferred embodiment, shown in Fig. 6, regenerator 70 is separate from exhaust producing device 12 and filter system 10. Alternatively, regenerator 70 may be attached to exhaust producing device 12, as shown in Fig. 7. Filter system 10 includes one or more units 14 including: a housing 22; a particulate filter section 24; and a nitrogen oxide filter section 26 having a gas-impervious inner cylinder 34 having a first and second open end 35 and a nitrogen-oxide removing catalyst 36 located within inner cylinder 34. Regenerator 70 includes a heat source chosen from the group comprising: an electric powered metal wire, an electric powered ceramic element and an electric powered



intermetallic element. Regeneration system 64 includes an air pump or blower for pressurizing heated gas 72 and a computer-control system 78. Computer-control system 78 includes: a thermocouple 84 for measuring temperature in the filter during regeneration, a heat source temperature controller 90; and an air supply controller 92. .

5 IV. Applications:

Filter system 10, regeneration system 64 and soot removing system 98 in accordance with the invention have applications with a variety of exhaust producing devices 12. For instance, exhaust producing device 12 may be: an engine, a paint booth, a furnace, a stove, a cement making kiln, an asphalt paving machine, etc. The types of engine the systems 10, 64, 98 may be applied to are limitless and include, for example, 10 light and heavy duty diesel engines, one and two cylinder engines, two and four cycle engines, etc.

As shown in Fig. 7, another aspect of the invention is the application of the above systems to a motor vehicle 100 and, especially, a diesel powered motor vehicle. Motor vehicle 100 includes an engine 104 (i.e., an exhaust producing device) for driving ground 15 engaging members 106, e.g., wheels or tracks; an exhaust filter 10 for removing soot from exhaust of engine 104, the filter including one or more attachable units 14 for varying the size of the filter; and an electrically heated regenerator 170 for producing heated gas to be passed through the filter to regenerate the filter. As illustrated, regeneration system 64 can 20 be a part of motor vehicle 100. As an alternative, as illustrated in Fig. 6, regeneration system 64 may be a separate system to which a motor vehicle 100 is occasionally attached to, when necessary, for regenerating filter system 10.

When filter system 10 is used on a motor vehicle 100, units 14 may be housed in a metal shell 16, shown in Fig. 6, that is approximately the dimensions of a muffler, e.g., a diesel muffler, or can form the muffler themselves. For a typical heavy duty diesel truck, a stack of 3-4 segments would be mounted into a steel muffler shell 16 that would be  
5 mounted in place of a contemporary muffler. Alternatively, as shown in Fig. 7, units 14 may form the outermost shell of a filter/muffler themselves.

While a particular application of the invention has been discussed, it should be recognized that other applications are possible. For instance, the teachings of the invention may be applied to: heavy duty and light duty diesel engines such as used on trucks or  
10 trains; stationary diesel generators, mining vehicles, and power plants; smoke removal; and the collection and burning/oxidizing (rendering harmless) of Volatile Organic Compounds (VOCs) generated from for paint booths. Additional applications include smoke and hydrocarbon removal for cooking establishments; particulate removal for cement manufacturers; VOC and hydrocarbon emission prevention for asphalt paving  
15 equipment; etc.

While this invention has been described in conjunction with the specific embodiments outlined above, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, the preferred  
embodiments of the invention as set forth above are intended to be illustrative, not  
20 limiting. Various changes may be made without departing from the spirit and scope of the invention as defined in the following claims.

## CLAIMS

What is claimed is:

1        1.        A filter system for removing soot from exhaust of an exhaust producing device, the  
2                filter system comprising one or more attachable units for varying the size of the  
3                filter system, each unit including:

4                        a housing;

5                        a particulate filter section positioned within the housing; and

6                        a nitrogen oxide filter section having a gas-impervious inner cylinder  
7                spaced within the particulate filter section and a nitrogen-oxide removing catalyst  
8                positioned within the inner cylinder.

1        2.        The filter system of claim 1, wherein the housing includes:

2                        an outer metal shell; and

3                        a coupling for sequentially attaching a unit to an adjacent unit.

1        3.        The filter system of claim 1, wherein exhaust gases pass radially through the  
2                particulate filter section and longitudinally through the nitrogen oxide filter section.

1        4.        The filter system of claim 1, wherein the gas impervious cylinder has open ends  
2                and is spaced from an inner portion of the particulate filter section.

1        5.        The filter system of claim 1, wherein the nitrogen oxide filter section is shorter in  
2                length than the particulate filter section.

1        6.        The filter system of claim 1, wherein each unit further comprises:

2                    a porous cylinder for supporting an inner portion of the particulate filter  
3 section; and

4                    a first end cap for spacing the nitrogen oxide filter section concentrically  
5 within the particulate filter section.

1        7.        The filter system of claim 6, wherein each unit further comprises a second end cap  
2 for spacing the nitrogen oxide filter section concentrically within the particulate  
3 filter section.

1        8.        The filter system of claim 7, wherein the gas impervious cylinder includes a vent  
2 port for mating with an adjacent unit.

1        9.        The filter system of claim 6, further comprising a stop cap sealing an end of a unit  
2 that is adjacent an exhaust port of the exhaust producing device.

1        10.       The filter system of claim 1, wherein the particulate filter section is spaced from an  
2 inner surface of the housing.

1        11.       The filter system of claim 1, wherein the particular filter section is made of a  
2 material chosen from the group comprising: ceramic fiber paper, ceramic cloth and  
3 ceramic woven fiber.

- 1        12.    The filter system of claim 11, wherein the particulate filter section includes one of  
2                    a set of radially oriented plates of the material and a set of radially oriented pleats  
3                    of the material.
- 1        13.    The filter system of claim 11, wherein the material is coated with a pre-ceramic  
2                    polymer chosen from the group comprising: silicon carbide, oxycarbide,  
3                    aluminosilicate and alumina.
- 1        14.    The filter system of claim 1, further comprising a Y-shaped adaptor for directing  
2                    exhaust to one of the filter system and a regeneration system.
- 1        15.    The filter system of claim 1, wherein each unit muffles noise from the exhaust  
2                    producing device.

- 1        16.    A soot removing system for an exhaust producing device comprising:  
2                a filter for removing soot from exhaust of the exhaust producing device; and  
3                a regeneration system having an electrically heated regenerator for producing  
4        heated gas to be passed through the filter to regenerate the filter.
- 1        17.    The system of claim 16, further comprising a source of inert gas for supplying an  
2                inert gas to the filter with the heated gas.
- 1        18.    The system of claim 17, wherein the inert gas is nitrogen.
- 1        19.    The system of claim 16, further comprising an adaptor coupled to the filter for  
2                directing exhaust of the exhaust producing device or heated gas from the  
3                regenerator through the filter.
- 1        20.    The system of claim 19, wherein the adaptor includes:  
2                a first opening coupled to a first end of the filter;  
3                a second opening for coupling to an exhaust port of the exhaust producing device;  
4                a third opening for coupling to the regenerator; and  
5                a valve for closing off the second opening during regeneration of a filter.
- 1        21.    The system of claim 20, further comprising a scrubber attached to a second end of  
2                the filter.

- 1        22.    The system of claim 16, wherein the regeneration system is releasably attachable  
2                from the exhaust producing device and the filter.
- 1        23.    The system of claim 16, wherein the regeneration system is attached to the exhaust  
2                producing device.
- 1        24.    The system of claim 16, wherein the filter includes one or more units comprising:  
2                a housing;  
3                a particulate filter section; and  
4                a nitrogen oxide filter section having a gas-impervious inner cylinder having a first  
5                open end and a second open end and a nitrogen-oxide removing catalyst located within the  
6                inner cylinder.
- 1        25.    The system of claim 16, wherein the regenerator includes a heat source chosen  
2                from the group comprising: an electric powered metal wire, an electric powered  
3                ceramic element and an electric powered intermetallic element.
- 1        26.    The system of claim 16, wherein the regeneration system includes an air blower for  
2                pressurizing the heated gas.
- 1        27.    The system of claim 16, wherein the regeneration system includes a computer-  
2                control system.

- 1        28.    The system of claim 27, wherein the computer-control system includes:  
2            a thermocouple for measuring temperature in the filter during regeneration;  
3            a heat source temperature controller; and  
4            an air supply controller.



1       29.    A regeneration system for an exhaust filter, the system comprising an electrically  
2            heated regenerator for producing heated gas to be passed through the filter to  
3            regenerate the filter.

1       30.    The system of claim 29, further comprising a source of inert gas for supplying an  
2            inert gas with the heated gas into the filter to control the temperature of the filter.

1       31.    The system of claim 30, wherein the inert gas is nitrogen.

1       32.    The system of claim 29, further comprising an adaptor for coupling the exhaust  
2            filter and the regenerator, including:  
3            a first opening coupled to a first end of the exhaust filter;  
4            a second opening coupled to a source of exhaust;  
5            a third opening coupled to the regenerator; and  
6            a flange for closing off the third opening during operation of the regenerator.

1       33.    The system of claim 32, further comprising a scrubber attached to a second end of  
2            the exhaust filter.

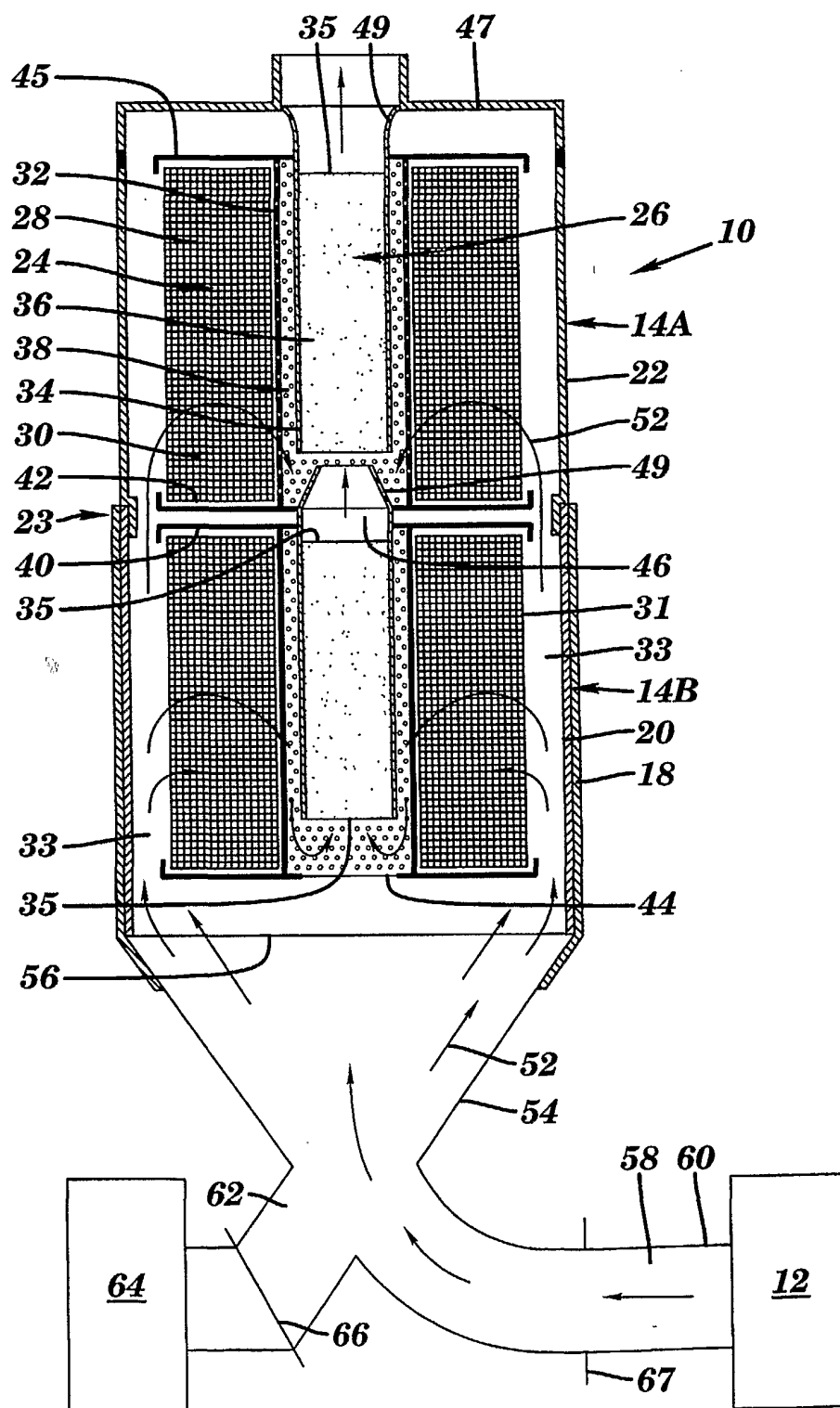
1       34.    The system of claim 29, wherein the regenerator includes an air blower for  
2            pressurizing the heated gas.

- 1        35.    The system of claim 29, wherein the regenerator includes a computer-control  
2            system including:  
3            a thermocouple for measuring temperature in the exhaust filter during regeneration;  
4            a heat source temperature controller; and  
5            an air supply controller.

1       36.    A motor vehicle comprising:  
2               an engine for driving ground engaging members;  
3               an exhaust filter for removing soot from exhaust of the engine, the filter including  
4       one or more attachable units for varying the size of the filter; and  
5               an electrically heated regenerator for producing heated gas to be passed through the  
6       filter to regenerate the filter.

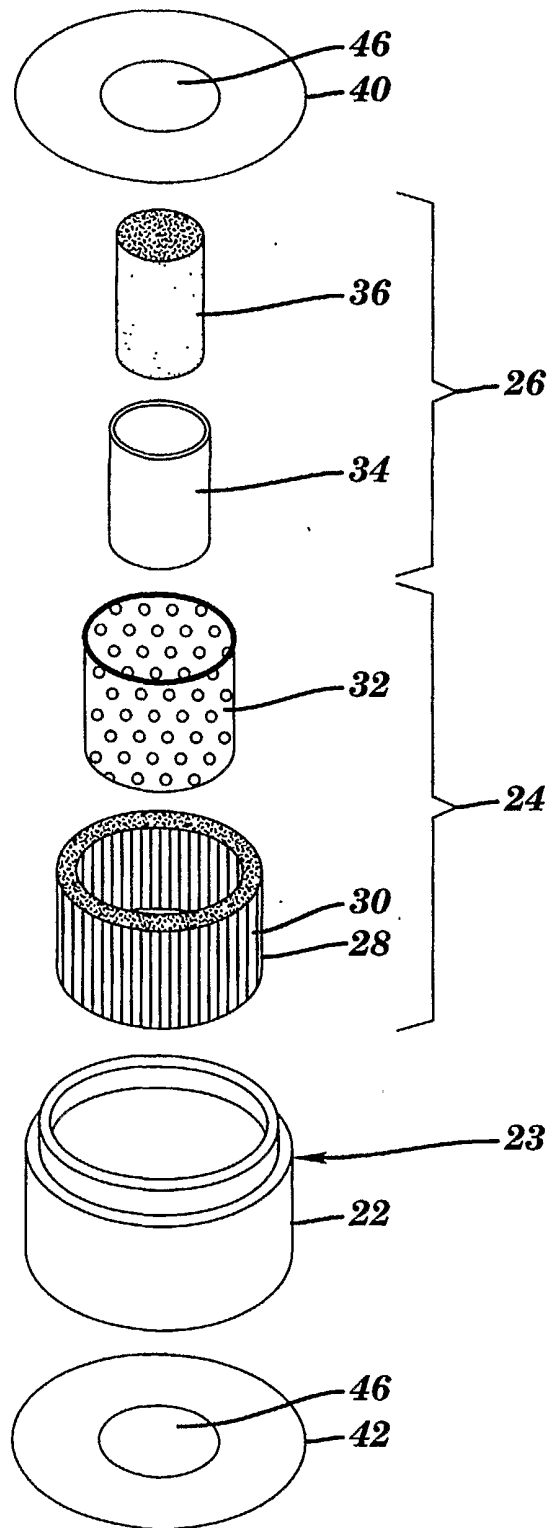
1       37.    The motor vehicle of claim 36, wherein each unit includes:  
2               a housing;  
3               a particulate filter section positioned within the housing; and  
4               a nitrogen oxide filter section having a gas-impervious inner cylinder spaced  
5       within the particulate filter section and a nitrogen-oxide removing catalyst positioned  
6       within the inner cylinder.

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**FIG. 1**

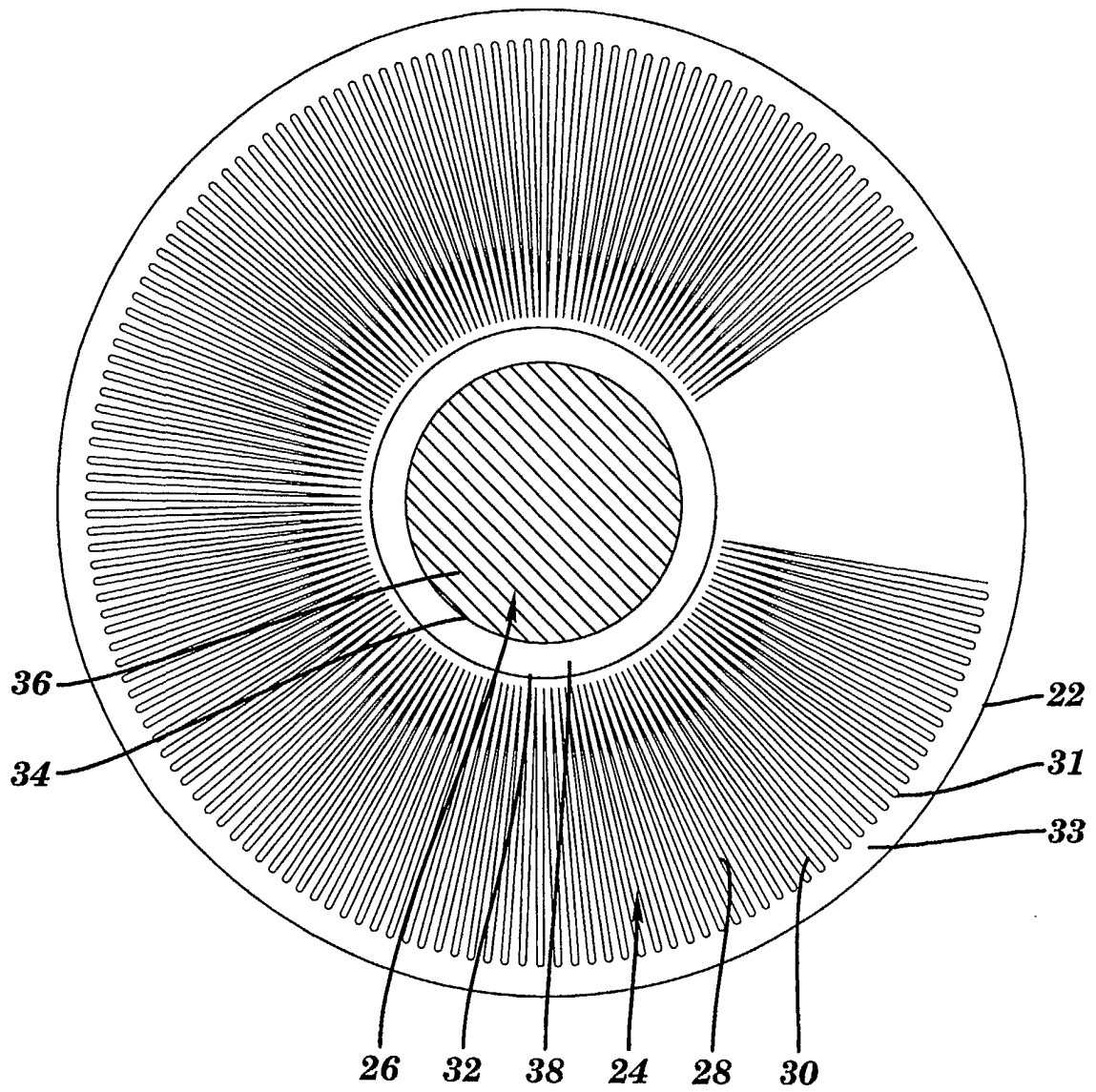
SUBSTITUTE SHEET (RULE 26)

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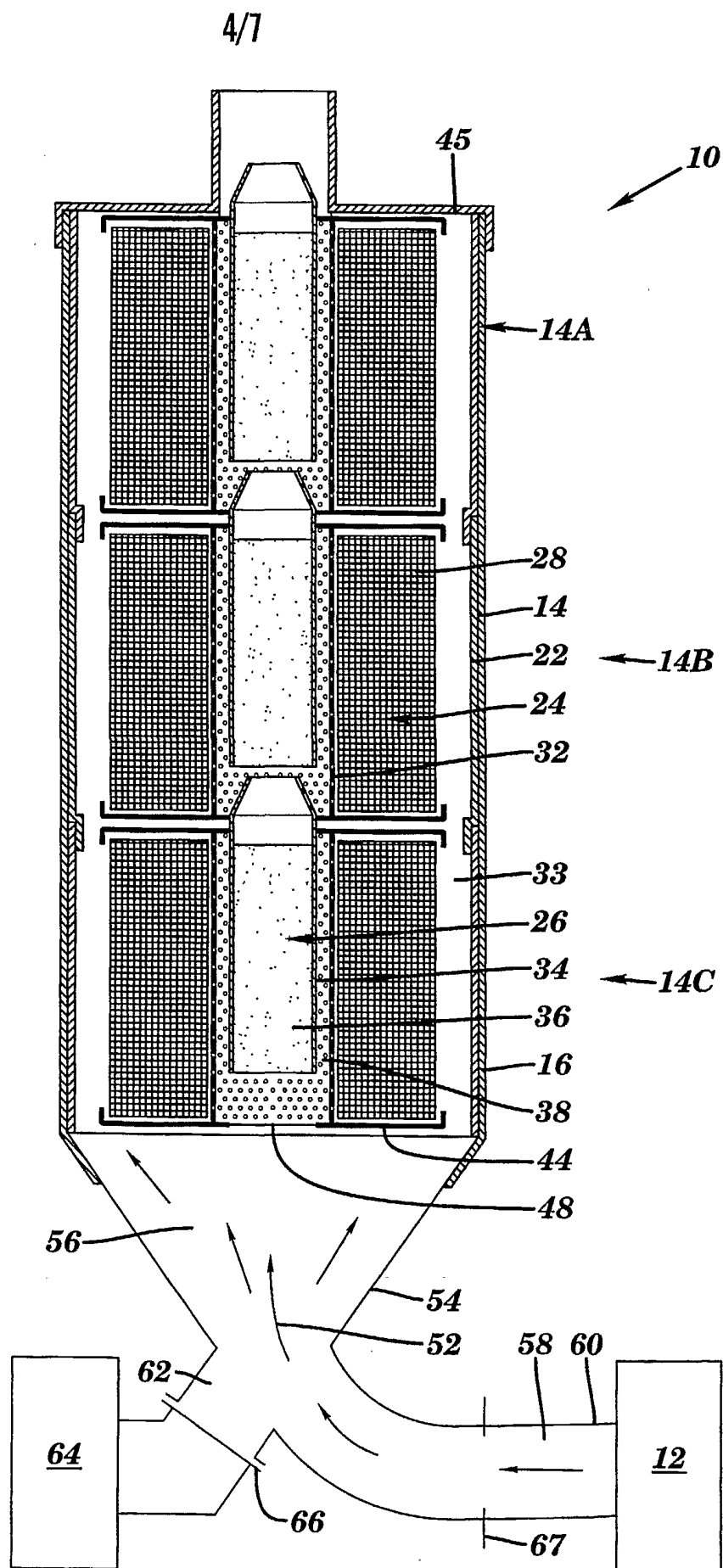
**FIG. 2**

SUBSTITUTE SHEET (RULE 26)

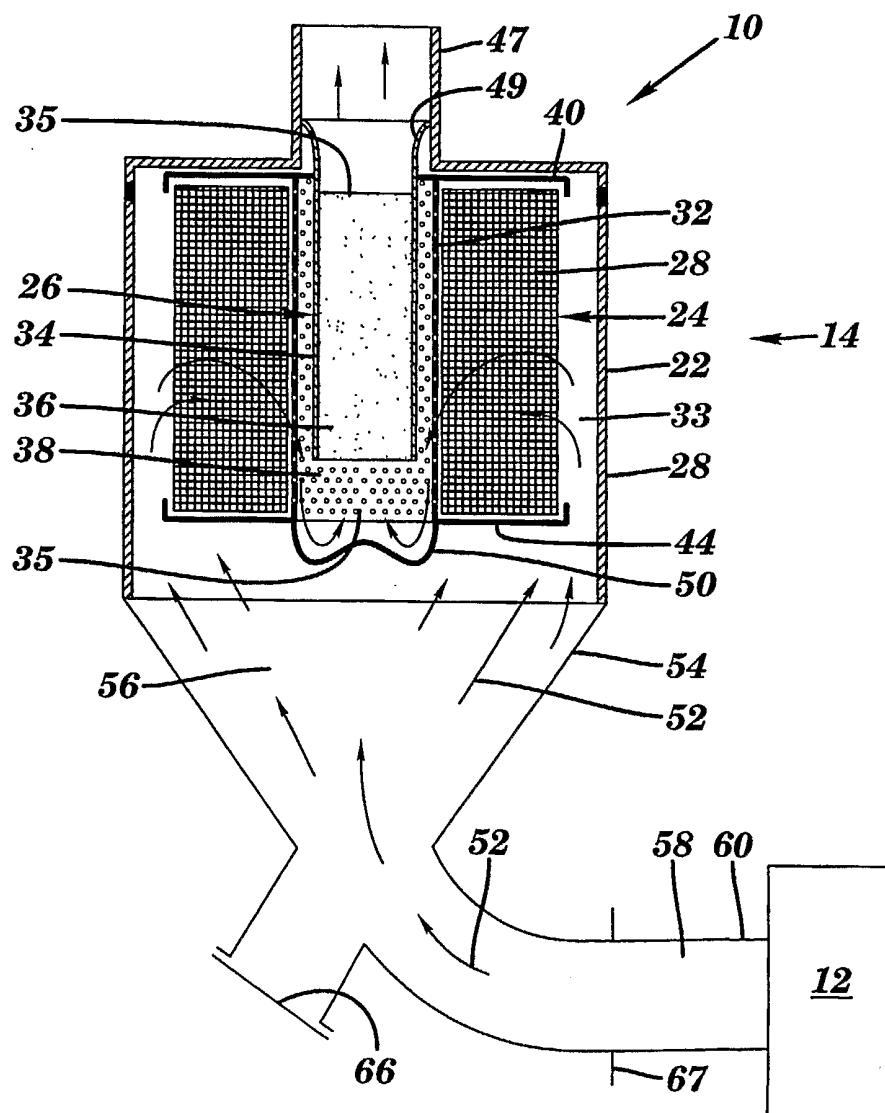
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**FIG. 3**



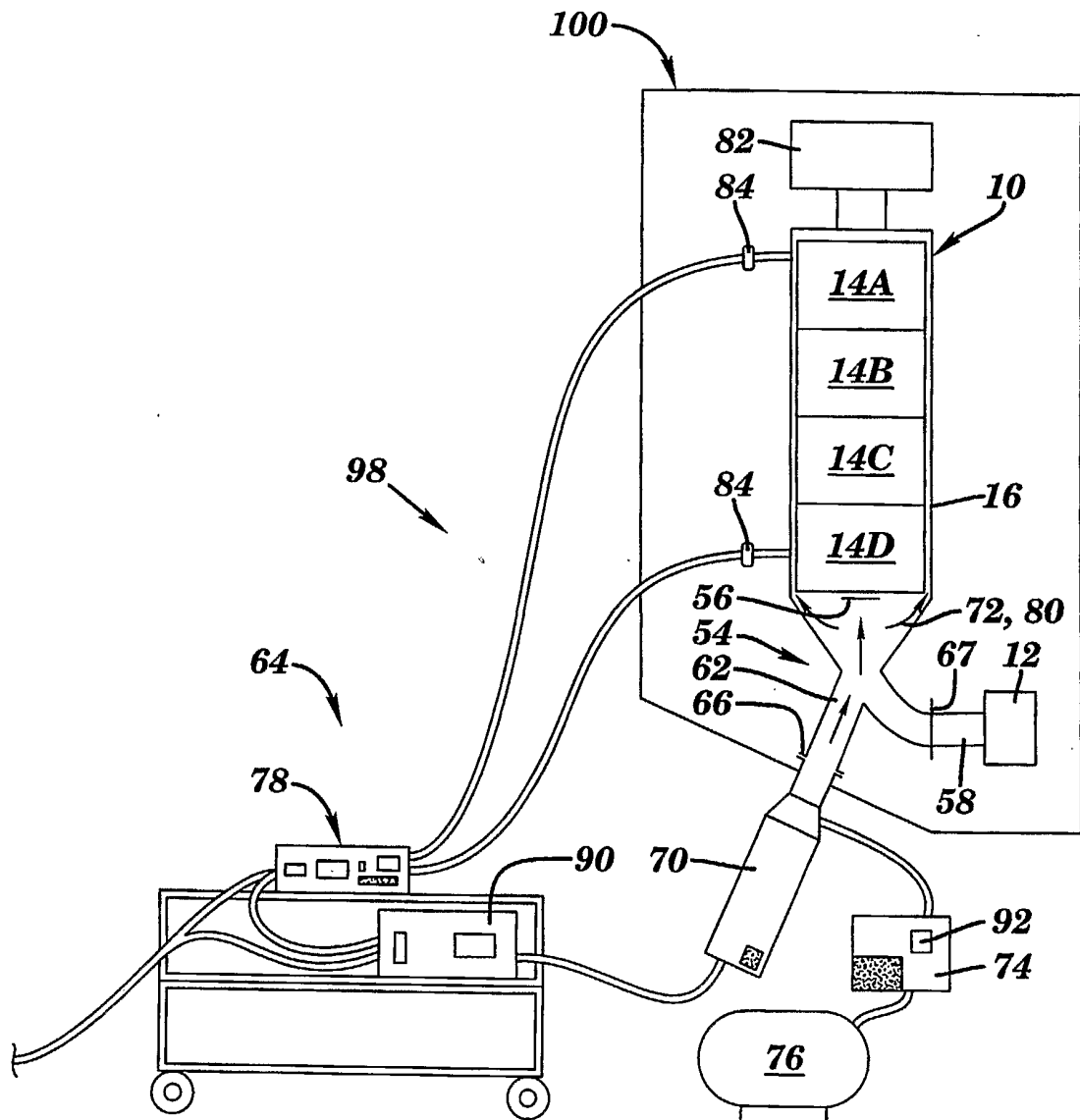
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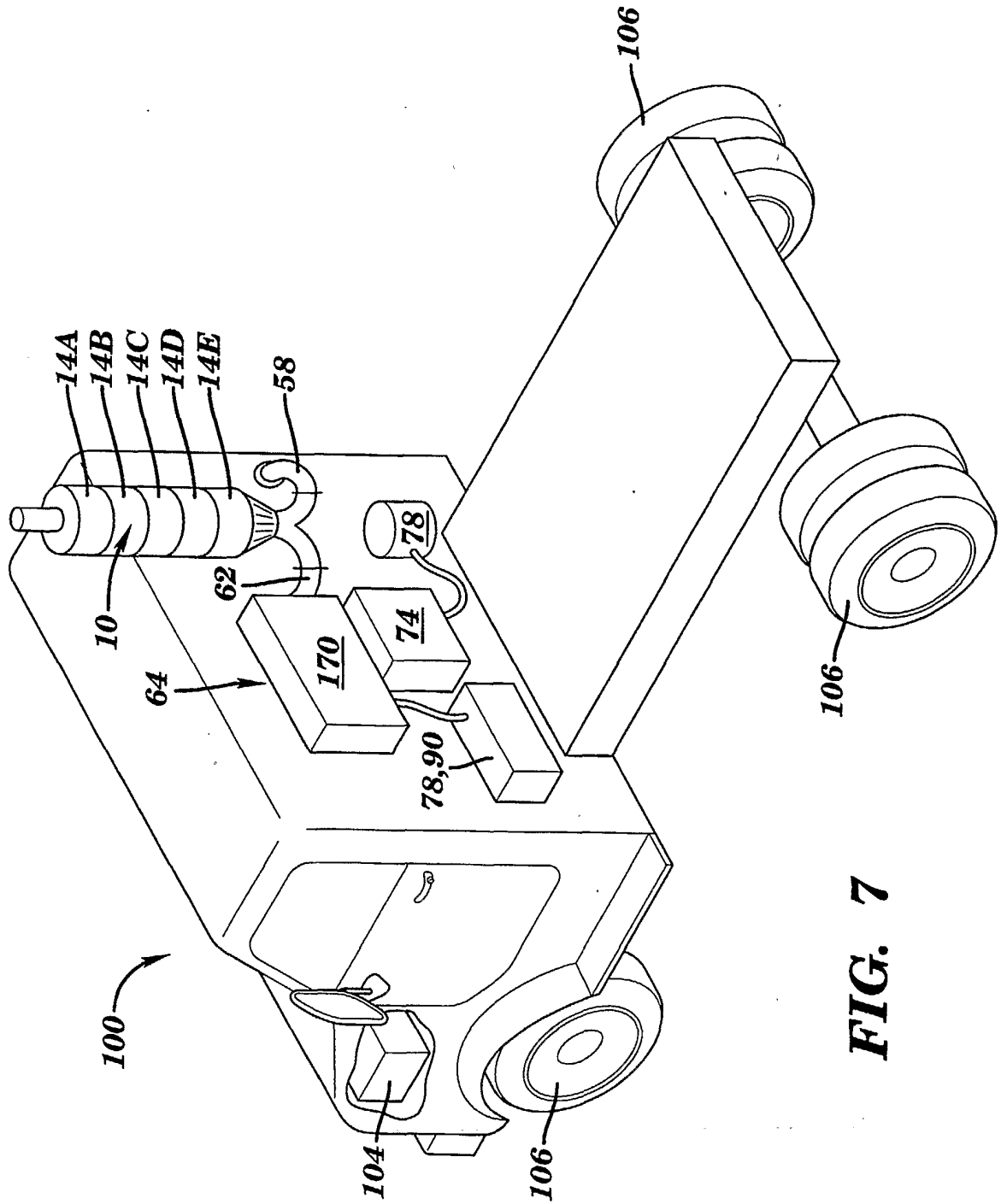


**FIG. 5**



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**FIG. 6**



**FIG. 7**

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/41547

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B01D 53/34, 53/94, 53/96; F01N 3/021, 3/022, 3/023, 3/025

US CL : 422/171, 174, 177, 178; 60/295, 297, 299, 303, 311; 55/486, 523, dig. 10, dig. 30

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. : B01D 53/34, 53/94, 53/96

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONE

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

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,899,540 A (WAGNER et al) 13 February 1990, see entire document.	16, 29, 36 ----- 1-15, 17-28, 30-35, 37
X --- Y	US 5,551,971 A (CHADDERTON et al) 03 September 1996, see entire document.	16, 29 ----- 1-15, 17-28, 30-37
X --- Y	US 5,682,740 A (KAWAMURA) 04 November 1997, see entire document.	16, 29, 36 ----- 1-15, 17-28, 30-35, 37
X --- Y	US 5,809,777 A (KAWAMURA) 22 September 1998, see entire document.	16, 29, 36 ----- 1-15, 17-28, 30-35, 37

☒ 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

22 October 2001 (22.10.2001)

Date of mailing of the international search report

14 DEC 2001

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# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/41547

## C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,820,833 A (KAWAMURA) 13 October 1998, see entire document.	16, 29, 36
---		-----
Y		1-15, 17-28, 30-35, 37

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/41547

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claim Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claim Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:  
Please See Continuation Sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐  
☐

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/41547

### BOX II. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s) 1-15, drawn to a filter system.

Group II, claims(s) 16-28, drawn to a soot removing system.

Group III, claim(s) 29-35, drawn to a regeneration system.

Group IV, claim(s) 36-37, drawn to a motor vehicle.

The inventions listed as Groups I, II, III, IV do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical feature of Group I is the nitrogen oxide filter section spaced within the particulate filter section, while the corresponding technical feature of Group II is the soot filter, the corresponding technical feature of Group III is the electrically heated regenerator, and the corresponding technical feature of Group IV is the engine, and therefore holding of lack of unity is proper.

### Continuation of B. FIELDS SEARCHED Item 3:

EAST

Search terms: diesel, filter, regeneration,