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(54) **METHOD AND APPARATUS FOR EXHAUST AFTERTREATMENT OF AN INTERNAL COMBUSTION ENGINE**

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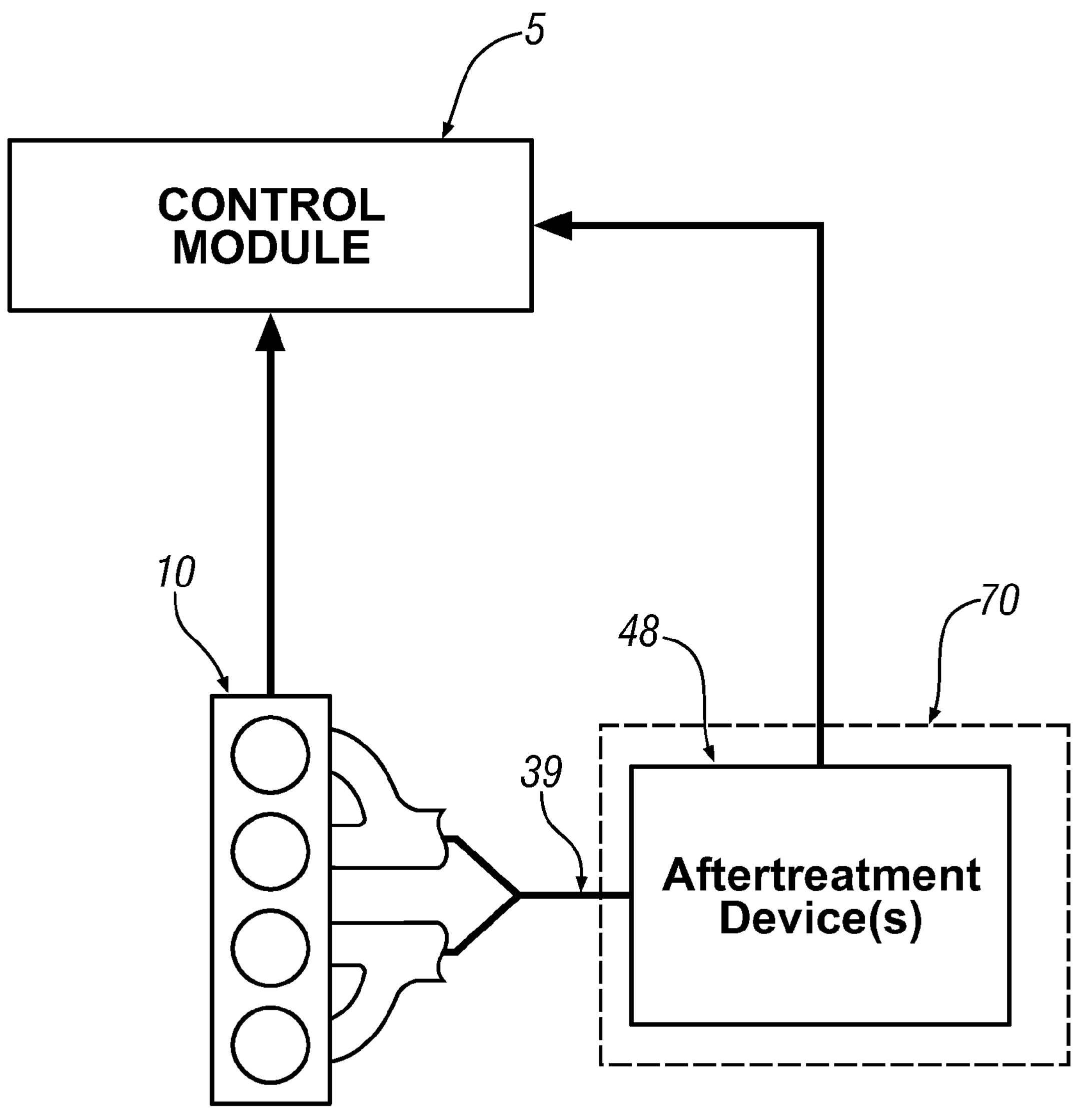
(57) **ABSTRACT**

An exhaust gas aftertreatment device includes a single intake path for an exhaust gas feedstream from an internal combustion engine and a coated substrate including a first substrate portion fluidly in parallel with a second substrate portion. A flow modification device selectively restricts flow of the exhaust gas feedstream exclusively to the first substrate portion, exclusively to the second substrate portion, and concurrently to the first substrate portion and the second substrate portion in controllably variable proportions.



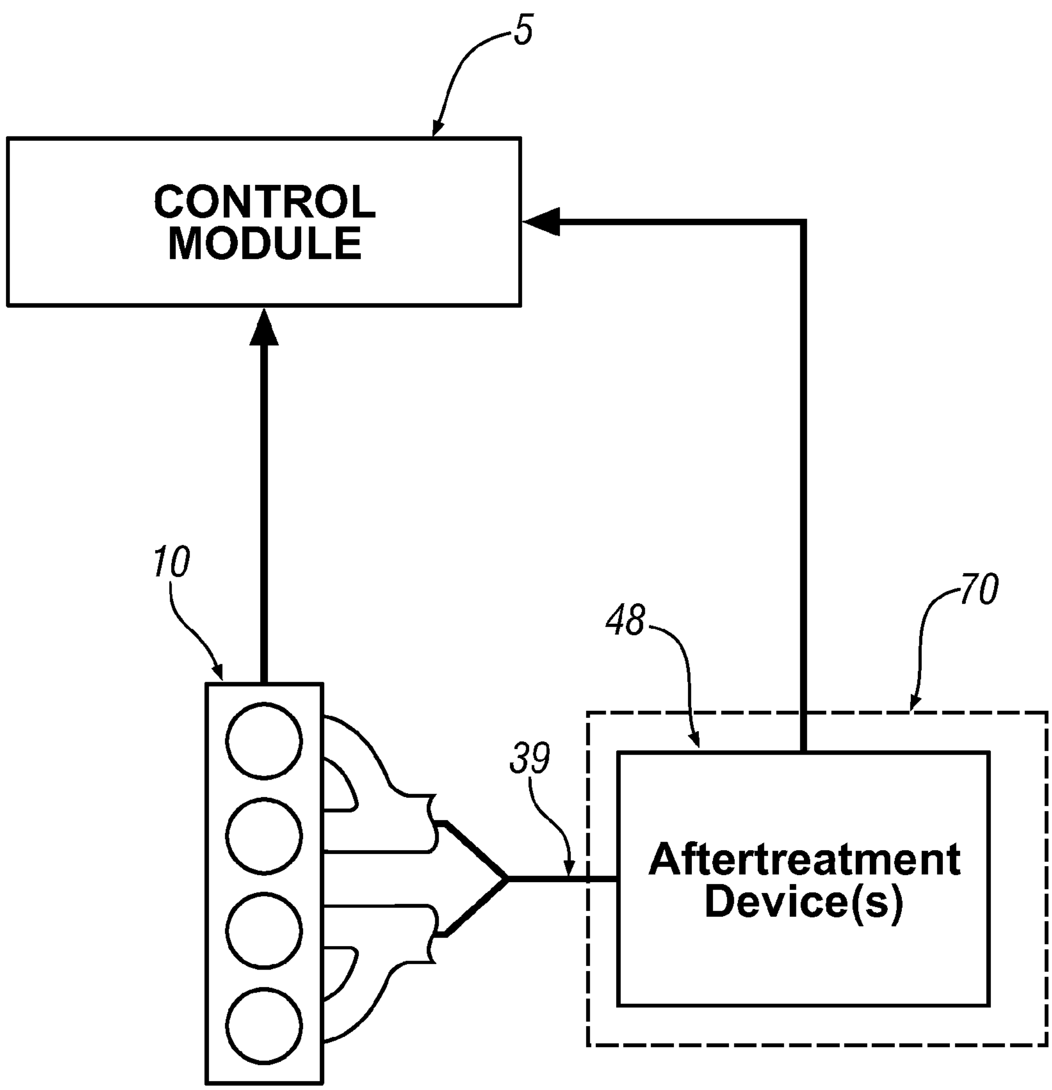


FIG. 1

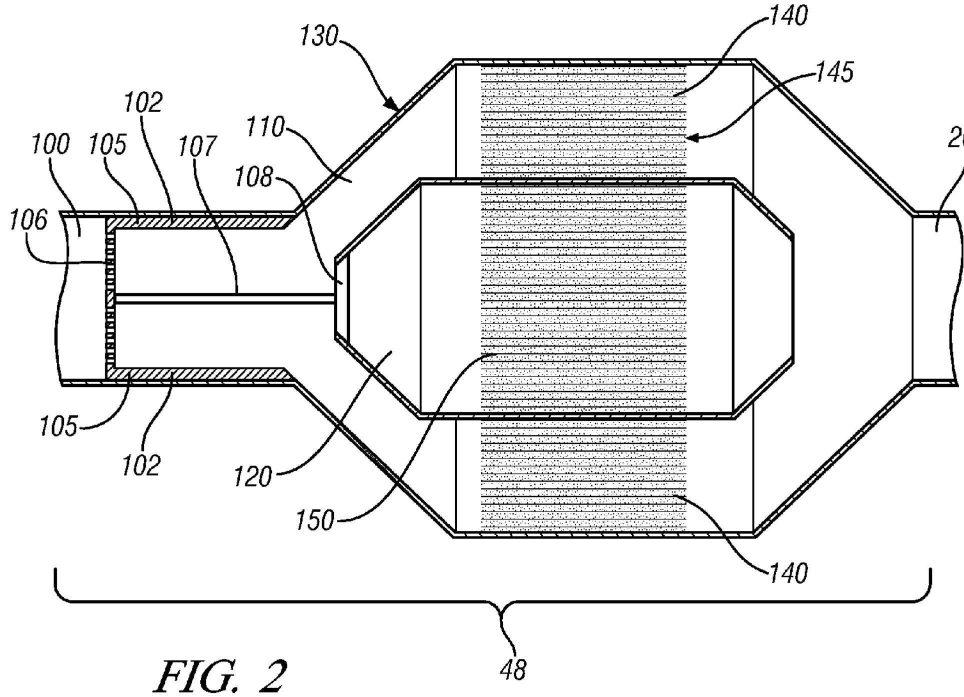

130
140
145
102
110
200
100
105
107
108
106
105
102
120
150
140
48

FIG. 2

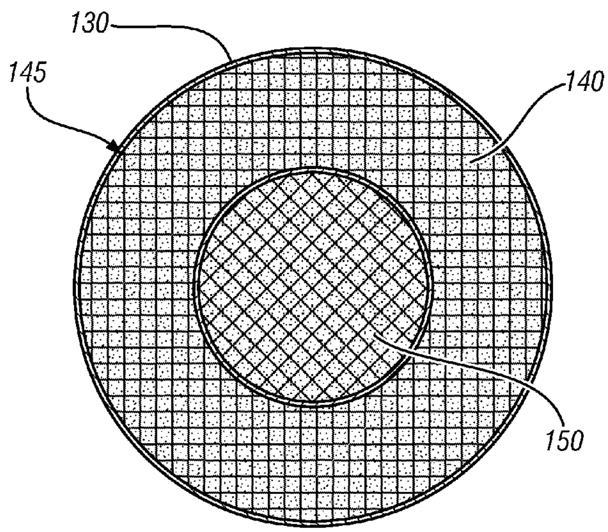

130
145
140
150

FIG. 3

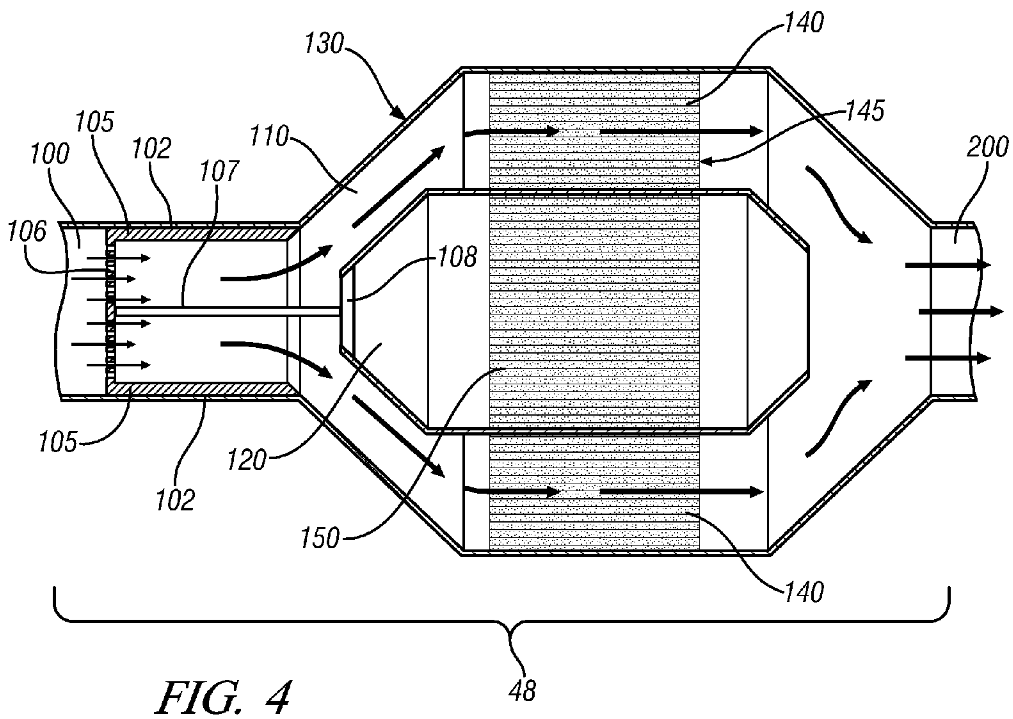

130
140
145
200
105
102
100
110
107
106
108
105
120
102
150
140
48

FIG. 4

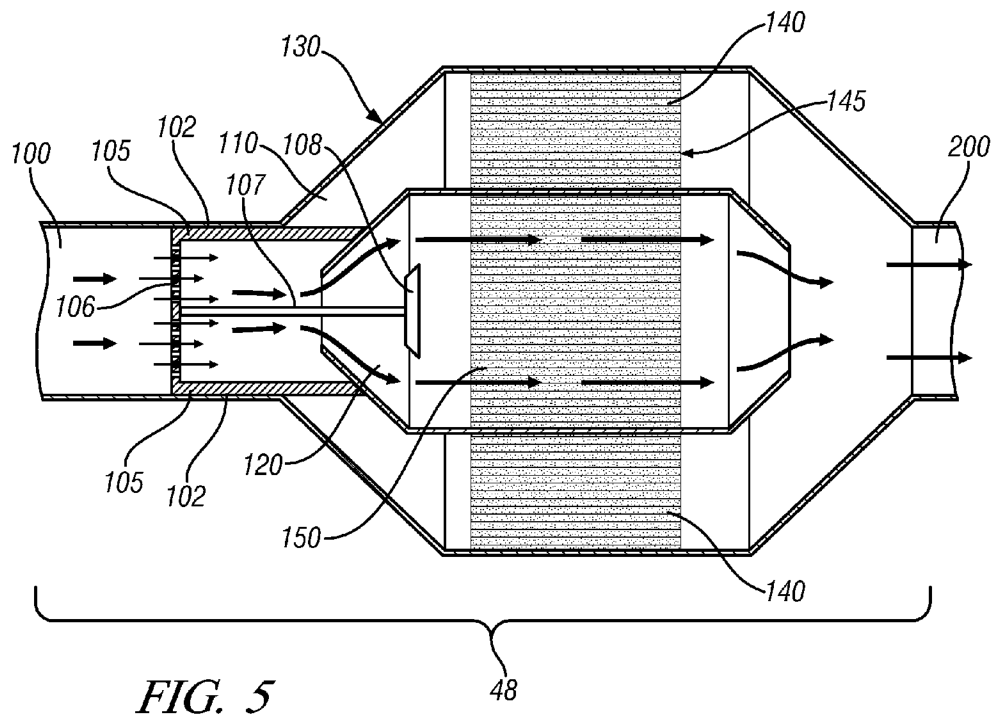

130
140
145
102
110
108
200
100
105
107
106
120
105
102
150
140
48

FIG. 5

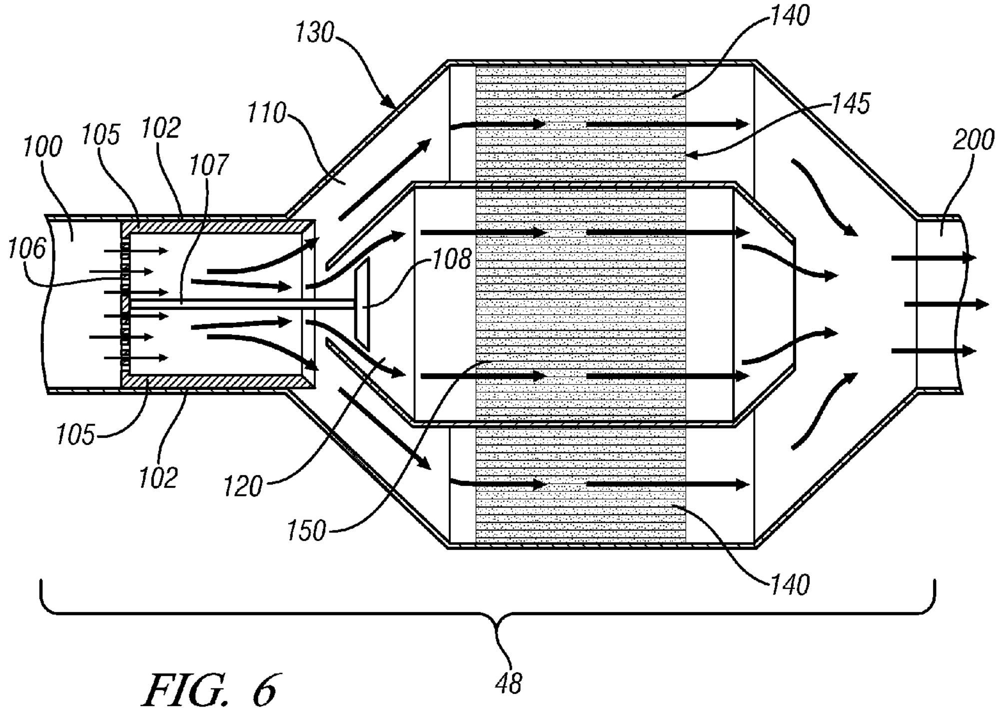

130
140
110
145
100
105
102
107
200
106
108
105
102
120
150
140
48

FIG. 6

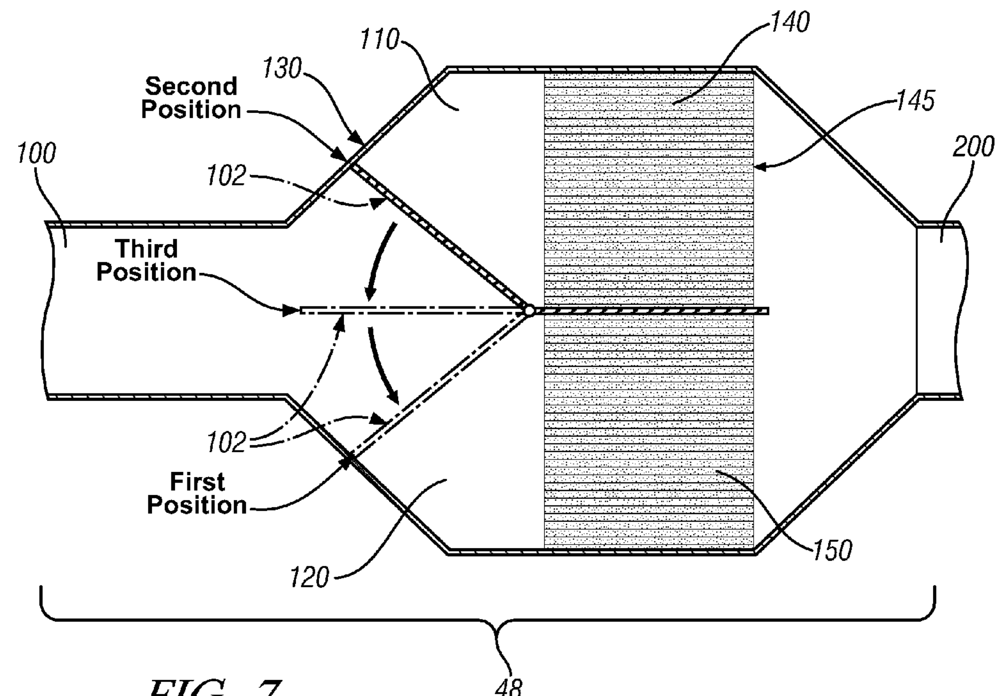

110
140
Second Position
130
145
100
200
102
Third Position
102
First Position
120
150
48

FIG. 7

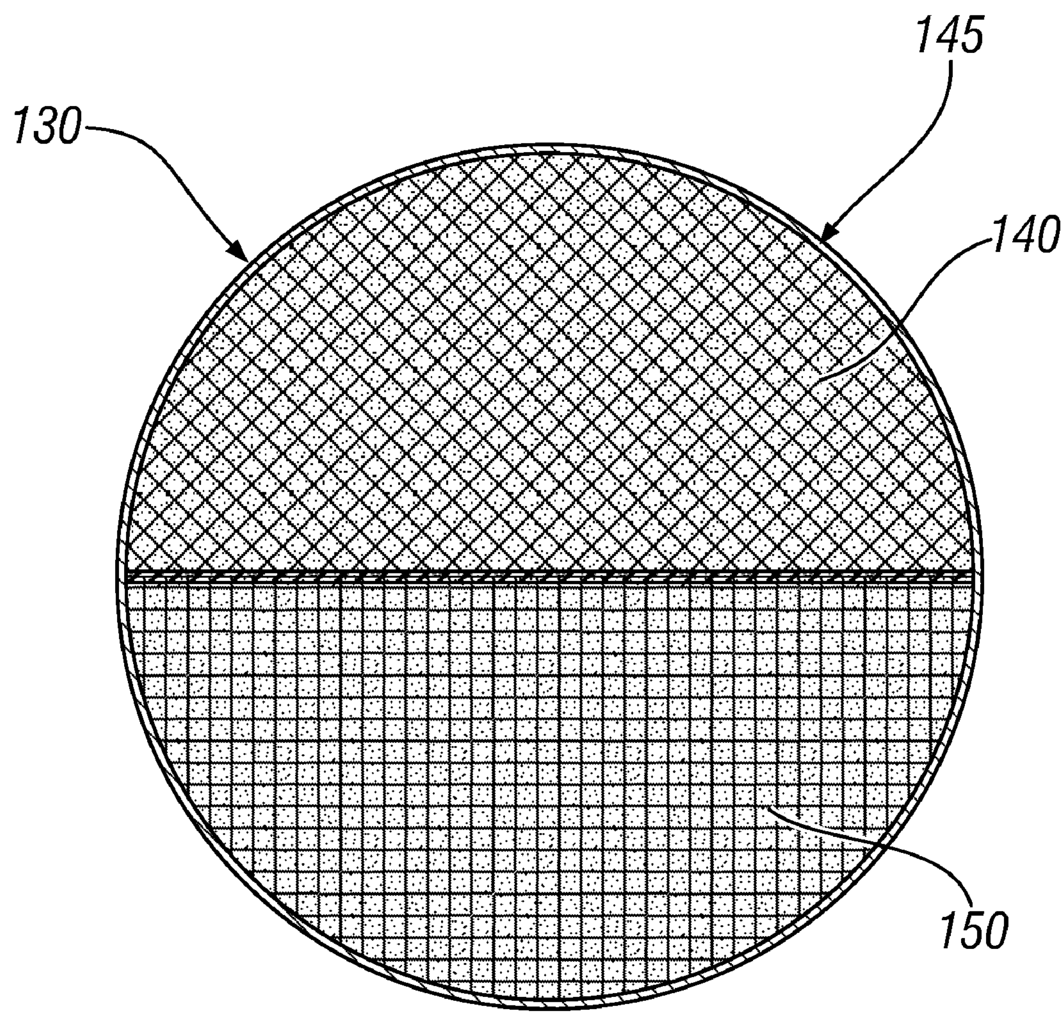


FIG. 8

METHOD AND APPARATUS FOR EXHAUST AFTERTREATMENT OF AN INTERNAL COMBUSTION ENGINE

TECHNICAL FIELD

[0001] This disclosure is related to exhaust aftertreatment systems for internal combustion engines.

BACKGROUND

[0002] The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

[0003] Known combustion by-products ejected into an exhaust gas feedstream include carbon monoxide (CO), nitrides of oxygen (NOx), and particulate matter (PM), among others. Unburned hydrocarbons (HC) are also present in engine-out emissions. Operating the engine at varying air/fuel ratios including rich, lean and stoichiometric ratios produces different proportions of the by-products and the unburned HC.

[0004] Known aftertreatment systems can include multiple aftertreatment devices. Each aftertreatment device includes a coated substrate and/or particulate filter to oxidize, adsorb, desorb, reduce, and combust elements of the exhaust gas feedstream. Each aftertreatment device processes different by-products and different proportions of the by-products produced at various air/fuel ratios. Aftertreatment systems including multiple aftertreatment devices may be disadvantaged by requirements for additional space in the underbody and engine compartment devices, thermal inefficiencies associated with the additional thermal mass and surface area for thermal dissipation, and engine torque losses attributable to forcing the exhaust gas feedstream through the devices in the form of back pressure.

SUMMARY

[0005] An exhaust gas aftertreatment device includes a single intake path for an exhaust gas feedstream from an internal combustion engine and a coated substrate including a first substrate portion fluidly in parallel with a second substrate portion. A flow modification device selectively restricts flow of the exhaust gas feedstream exclusively to the first substrate portion, exclusively to the second substrate portion, and concurrently to the first substrate portion and the second substrate portion in controllably variable proportions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] One or more embodiments will now be described, by way of example, with reference to the accompanying drawings, in which:

[0007] FIG. **1** is a schematic drawing of an exemplary engine system, in accordance with the present disclosure;

[0008] FIG. **2** is a is a schematic drawing of a first exemplary aftertreatment device with a control valve, in accordance with the present disclosure;

[0009] FIG. **3** is a cross-sectional view of a first exemplary substrate device, in accordance with the present disclosure;

[0010] FIG. **4** is a schematic drawing of the first exemplary aftertreatment device the control valve in a first position, in accordance with the present disclosure;

[0011] FIG. **5** is a schematic drawing of the first exemplary aftertreatment device the control valve in a second position, in accordance with the present disclosure;

[0012] FIG. **6** is a schematic drawing of the first exemplary aftertreatment device the control valve in a third position, in accordance with the present disclosure;

[0013] FIG. **7** is a schematic drawing of a second exemplary aftertreatment device with a control valve, in accordance with the present disclosure; and

[0014] FIG. **8** is a cross-sectional view of an alternate embodiment of a second exemplary substrate device, in accordance with the present disclosure.

DETAILED DESCRIPTION

[0015] Referring now to the drawings, wherein the showings are for the purpose of illustrating certain exemplary embodiments only and not for the purpose of limiting the same, FIG. **1** schematically shows an exemplary spark-ignition direct-injection internal combustion engine **10**, an accompanying control module **5**, and an exhaust aftertreatment system **70** that have been constructed in accordance with embodiments of the disclosure. Like numerals refer to like elements in the embodiments. The exemplary engine **10** may be selectively operative in a plurality of combustion modes, including a controlled auto-ignition combustion mode, a homogeneous spark-ignition combustion mode, a stratified-charge spark-ignition combustion mode, and a compression ignition mode. The exemplary engine **10** is selectively operative at an air/fuel ratio that is primarily lean of stoichiometry. The disclosure can be applied to various combustion cycles and internal combustion engine systems including homogeneous-charge compression-ignition, diesel, pre-mixed charge compression ignition, and stratified-charge spark-ignition direct-injection and is not limited thereby.

[0016] The exemplary engine **10** includes a multi-cylinder direct-injection four-stroke internal combustion engine having reciprocating pistons slidably movable in cylinders which define variable volume combustion chambers. Each piston is connected to a rotating crankshaft by which their linear reciprocating motion is translated to rotational motion. An air intake system provides intake air to an intake manifold which directs and distributes air into an intake runner to each combustion chamber. The air intake system includes airflow ductwork and devices for monitoring and controlling the air flow. The air intake devices preferably include a mass airflow sensor for monitoring mass airflow and intake air temperature. A throttle valve preferably includes an electronically controlled device which controls air flow to the engine in response to a control signal from the control module **5**. A pressure sensor in the manifold is adapted to monitor manifold absolute pressure and barometric pressure. An external flow passage recirculates exhaust gases from engine exhaust to the intake manifold, having a flow control valve, referred to as an exhaust gas recirculation valve. The control module **5** is operative to control mass flow of exhaust gas to the intake manifold by controlling opening of the exhaust gas recirculation valve.

[0017] At least one intake valve and one exhaust valve corresponds to each cylinder and combustion chamber. There is preferably one valve actuator for each one of the intake and exhaust valves. Each intake valve can allow inflow of air and fuel to the corresponding combustion chamber when open. Each exhaust valve can allow flow combustion by-products out of the corresponding combustion chamber to the aftertreatment system **70** when open.

[0018] The engine can include a fuel injection system, including a plurality of high-pressure fuel injectors each adapted to directly inject a mass of fuel into one of the combustion chambers, in response to a signal from the control module **5**. The fuel injectors are supplied pressurized fuel from a fuel distribution system. The engine can include a spark-ignition system by which spark energy is provided to a spark plug for igniting or assisting in igniting cylinder charges in each of the combustion chambers in response to a signal from the control module **5**.

[0019] The exemplary engine **10** is preferably equipped with various sensing devices for monitoring engine operation and exhaust gases, e.g., air/fuel ratio sensor. An exhaust gas sensor monitors the exhaust gas feedstream, and can include an air/fuel ratio sensor in one embodiment.

[0020] The control module **5** executes algorithmic code stored therein to control actuators to control engine operation, including throttle position, spark timing, fuel injection mass and timing, intake and/or exhaust valve timing and phasing, and exhaust gas recirculation valve position to control flow of recirculated exhaust gases. Valve timing and phasing may include negative valve overlap and lift of exhaust valve reopening (in an exhaust re-breathing strategy). The control module **5** is configured to receive input signals from an operator (e.g., a throttle pedal position and a brake pedal position) to determine an operator torque request and input from the sensors indicating the engine speed and intake air temperature, and coolant temperature and other ambient conditions.

[0021] The control module **5** is preferably a general-purpose digital computer generally including a microprocessor or central processing unit, storage mediums including non-volatile memory including read only memory and electrically programmable read only memory, random access memory, a high speed clock, analog to digital and digital to analog circuitry, and input/output circuitry and devices and appropriate signal conditioning and buffer circuitry. The control module **5** has a set of control algorithms, including resident program instructions and calibrations stored in the non-volatile memory and executed to provide desired functions. The algorithms are preferably executed during preset loop cycles. Algorithms are executed by the central processing unit and are operable to monitor inputs from the aforementioned sensing devices and execute control and diagnostic routines to control operation of the actuators, using preset calibrations. Loop cycles may be executed at regular intervals, for example each 3.125, 6.25, 12.5, 25 and 100 milliseconds during ongoing engine and vehicle operation. Alternatively, algorithms may be executed in response to occurrence of an event.

[0022] The exhaust aftertreatment system **70** is fluidly connected to the exhaust manifold **39** and includes catalytic and/or trap substrates operative to oxidize, adsorb, desorb, reduce, and combust elements of the exhaust gas feedstream. The exhaust aftertreatment system **70** includes one or more exhaust aftertreatment device(s) **48** that are preferably closely coupled to the exhaust manifold **39** of the exemplary engine **10**.

[0023] FIGS. **2** and **3** show the exhaust aftertreatment device **48** constructed in accordance with the present disclosure. The exhaust aftertreatment device **48** includes a single intake end **100** fluidly connected to the exhaust manifold **39** and an outlet end **200** for containing the exhaust gas feedstream. The exhaust aftertreatment device **48** includes a housing **130** attached to the single intake end **100** and the outlet end **200**. The housing **130** in one embodiment is a cylindrical shape constructed from stainless steel or other material. The single intake end **100** of the housing **130** divides into two flow paths including a first exhaust gas path **110** and a second exhaust gas path **120**. A flow modification mechanism, e.g., a control valve **102**, is signally connected to the control module **5** and configured to modify the exhaust gas feedstream flowing to the first and second exhaust gas paths **110** and **120**. The first exhaust gas path **110** is configured to channel exhaust gas flow to a first substrate portion **140** of a substrate device **145** and the second exhaust gas path **120** is configured to channel exhaust gas flow to a second substrate portion **150** of the substrate device **145**.

[0024] The exhaust aftertreatment device **48** includes the substrate device **145** including the first and second substrate portions **140** and **150**. The first and second substrate portions **140** and **150** are fluidly parallel in relationship to the exhaust gas feedstream, and each has a multiplicity of parallel flow passages through which exhaust gas can flow. Fluidly parallel portions are understood to mean that an exhaust gas flowing through one portion does not also flow through the other portion. In one embodiment, the substrate **145** is formed from ceramic material, e.g., cordierite, and having flow-through passages at a density of about 62 to 96 cells per square centimeter (400-600 cells per square inch), and a wall thickness between the flow passages of about three to seven mils. In one embodiment, the substrate **145** is formed from corrugated stainless steel. The flow passages for the first and second substrate portions **140** and **150** of the substrate **145** can be individually coated with differing washcoat materials, e.g., alumina and zeolite, and differing densities and masses of active materials, i.e., platinum-group metals and other metals. Exemplary catalytically active metals can include platinum group metals including platinum (Pt), palladium (Pd), and rhodium (Rh) and non-platinum group metals including iron (Fe), copper (Cu) thallium (Tl) and vanadium (Va). In one embodiment, one of the first and second substrate portions **140** and **150** includes a washcoat and catalytically active materials to process oxygen-rich exhaust gas at lower temperatures and the other includes a washcoat and catalytically active materials to process exhaust gas at higher temperatures.

[0025] FIG. **3** shows a cross-sectional view of one embodiment of the substrate device **145** having the first and second fluidly parallel substrate portions **140** and **150**. The cross-sectional view shows the substrate **145** having a substantially circular cross-section. The second substrate portion **150** has a circular cross-section of a diameter less than the diameter of the substrate device **145**, and the second substrate portion **150** has an annular cross-section that circumscribes the first substrate portion **140**.

[0026] The control valve **102** is positioned in the single intake end **100** of the exhaust aftertreatment device **48**, although the control valve **102** may alternatively be suitably positioned elsewhere within the exhaust aftertreatment device **48**, e.g., in the outlet end **200**. The control valve **102** includes a flow control valve configured to direct flow of the exhaust gas feedstream via flow diffusing, flow diverting and/or flow blocking mechanisms or devices. The control valve **102** is preferably centrally positioned within the exhaust aftertreatment device **48**. The control valve **102** is configured to prohibit exhaust gas flow through one of the first and second substrate portions **140** and **150**. The control valve **102** may be actuated or otherwise controlled by, for example, a solenoid or other actuation device known in the art configured to receive actuation commands from the control module **5**. As one skilled in the art will recognize, the control valve **102** may be implemented in the exhaust aftertreatment device **48** using any one of multiple flow modification devices and this disclosure is not limited thereby.

[0027] The control valve **102** is controllable to any one of a first position, a second position and a third position to effect a desired exhaust gas flow. The first position permits exhaust gas flow through the first substrate portion **140** while prohibiting exhaust gas flow through the second substrate portion **150**. The second position permits exhaust gas flow through the second substrate portion **150** while prohibiting exhaust gas flow through the first substrate portion **140**. The third position permits simultaneous exhaust gas flow through both the first and second substrate portions **140** and **150**.

[0028] FIG. **2** illustrates an embodiment of the control valve **102** including a hollow tube structure **105** having a porous end **106** connected to a member **107** including a capped end **108**. During engine operation, the engine **10** generates an exhaust gas feedstream containing constituent elements including hydrocarbons (HC), carbon monoxide (CO), nitrides of oxygen (NOx), and particulate matter (PM), among others. Operating the engine **10** at varying air/fuel ratios including rich, lean and stoichiometric ratios produce different proportions of the constituent elements and therefore result in different aftertreatment considerations, e.g., different catalysts for NOx emissions during lean engine operation. Preferably, the exhaust aftertreatment device **48** is configured to process the different proportions of the constituent elements produced by the varying air/fuel ratios.

[0029] Engine operation can include transitions between combustion modes and variations in engine-out air/fuel ratios. The control valve **102** can direct the exhaust gas feedstream to flow to one of the first exhaust gas path **110**, the second exhaust gas path **120**, and both the first and second exhaust gas paths **110** and **120** concurrently. For example, the exhaust gas feedstream may be directed through the second exhaust path **120** during lean engine operation and directed through the first exhaust path **110** during stoichiometric or rich engine operation.

[0030] FIGS. **4-6** show the control valve **102** in multiple positions within the exhaust aftertreatment device **48**. As the control valve **102** is controlled away from the first and second substrate portions **140** and **150**, the hollow tube structure **105** permits exhaust flow to the first exhaust path **110**, thereby incrementally increasing exhaust gas flow through the first substrate portion **140** and incrementally decreasing exhaust gas flow through the second substrate portion **150**. The member **107** and the capped end **108** incrementally inhibit exhaust gas flow through the second substrate portion **150**. When the control valve **102** is controlled to a first position (shown in FIG. **4**), the capped end substantially prohibits exhaust gas flow to the second substrate portion **150** and the hollow tube structure **105** permits exhaust gas flow to the first substrate portion **140**. As the control valve **102** is controlled towards the first and second substrate portions **140** and **150**, the hollow tube structure **105** inhibits exhaust flow to the first exhaust path **110**, thereby incrementally increasing exhaust flow through the second substrate portion **150** and incrementally decreasing exhaust flow through the first substrate portion **140**. When the control valve **102** is controlled to a second position (shown in FIG. **6**), the hollow tube structure **105** substantially prohibits exhaust gas flow to the first substrate portion **140**, and the capped end **108** of the member **107** permits exhaust gas flow to the second substrate portion **150**.

[0031] FIG. **4** shows the exhaust aftertreatment device **48** with the control valve **102** in a first position whereby the exhaust gas feedstream is controlled through the first exhaust path **110**. The exhaust gas feedstream is prohibited from going through the second exhaust path **120**. Thus, the first substrate portion **140** oxidizes, adsorbs, reduces, and combusts elements in the exhaust gas feedstream.

[0032] FIG. **5** shows the exhaust aftertreatment device **48** with the control valve **102** in a second position whereby the exhaust gas feedstream is controlled through the second exhaust path **120**. The exhaust gas feedstream is prohibited from going through the first exhaust path **110**. Thus, the second substrate portion **150** oxidizes, adsorbs, reduces, and combusts elements in the exhaust gas feedstream.

[0033] FIG. **6** shows the exhaust aftertreatment device **48** with the control valve **102** in a third position intermediate the first and second positions whereby the exhaust gas feedstream is permitted to concurrently flow through both the first and second exhaust paths **110** and **120**. Both the first and second substrate portions **140** and **150** oxidize, adsorb, reduce, and combust elements in the exhaust gas feedstream.

[0034] FIG. **7** shows an alternate embodiment of the exhaust aftertreatment device **48**. In the alternate embodiment, the substrate **145** includes first substrate portion **140** contiguous to the second substrate portion **150**. The control valve **102** is signally connected to the control module **5** and configured to control the exhaust gas feedstream flow to the first and second substrate portions **140** and **150**. When the control valve **102** is in a first position, the exhaust gas flows through the first exhaust gas path **110** to the first substrate portion **140** and prohibits exhaust gas flow to the second substrate portion **150**. When the control valve **102** is in a second position, the exhaust gas flows through the second exhaust gas path **120** to the second substrate portion **150** and prohibits exhaust gas flow to the first substrate portion **140**. When the control valve **102** is in a third position intermediate the first and second positions, exhaust gas flows through the first and second exhaust gas paths **110** and **120** to both the first and second substrate portions **140** and **150**.

[0035] FIG. **8** shows a cross sectional view of an the substrate described with reference to FIG. **7**, with the first substrate portion **140** contiguous to the second substrate portion **150**.

[0036] The disclosure has described certain preferred embodiments and modifications thereto. Further modifications and alterations may occur to others upon reading and understanding the specification. Therefore, it is intended that the disclosure not be limited to the particular embodiment(s) disclosed as the best mode contemplated for carrying out this disclosure, but that the disclosure will include all embodiments falling within the scope of the appended claims.

1. An exhaust gas aftertreatment device, comprising:

a single intake path for an exhaust gas feedstream from an internal combustion engine;

a coated substrate including a first substrate portion fluidly in parallel with a second substrate portion; and

a flow modification device configured to selectively restrict flow of the exhaust gas feedstream exclusively to the first substrate portion, exclusively to the second substrate portion, and concurrently to the first substrate portion and the second substrate portion in controllably variable proportions.

2. The exhaust gas aftertreatment device of claim **1**, further comprising the first substrate portion including a washcoat configured to process a stoichiometric exhaust gas feedstream and the second substrate portion including a washcoat configured to process a lean exhaust gas feedstream.

3. The exhaust gas aftertreatment device of claim **1**, wherein the first substrate portion is annular to the second substrate portion.

4. The exhaust gas aftertreatment device of claim **1**, wherein the flow modification device is controllable to a plurality of positions including one of a first position to effect flow of the exhaust gas feedstream exclusively to the first substrate portion, a second position to effect flow of the exhaust gas feedstream exclusively to the first substrate portion, and a third position intermediate the first and second positions to effect flow of the exhaust gas feedstream concurrently to the first substrate portion and the second substrate portion in proportions corresponding to the third position.

5. The exhaust gas aftertreatment device of claim **4**, wherein the first position permits exhaust gas flow exclusively through the first substrate portion.

6. The exhaust gas aftertreatment device of claim **4**, wherein the second position permits exhaust gas flow exclusively through the second substrate portion.

7. The exhaust gas aftertreatment device of claim **4**, wherein the third position permits exhaust gas flow concurrently through both the first and second substrate portions.

8. The exhaust gas aftertreatment device of claim **1**, wherein the first substrate portion is contiguous to the second substrate portion.

9. The exhaust gas aftertreatment device of claim **1**, wherein the flow modification device is positioned upstream of the coated substrate relative to exhaust gas flow.

10. The exhaust gas aftertreatment device of claim **1**, wherein the flow modification device is positioned downstream of the coated substrate relative to exhaust gas flow.

11. The exhaust gas aftertreatment device of claim **1**, wherein the first substrate portion is configured to process an oxygen-rich exhaust gas.

12. Method for managing an exhaust gas feedstream with an exhaust gas aftertreatment device, the method comprising:

equipping the exhaust gas aftertreatment device with a single intake path, a substrate including a first portion configured fluidly in parallel with a second portion, and a flow modification device configured to control flow of the exhaust gas feedstream through one of the first portion exclusively, the second portion exclusively, and the first portion and the second portion concurrently;

monitoring engine operation; and

controlling the flow modification device based upon the engine operation.

13. The method of claim **12**, further comprising:

controlling the flow modification device to a first position when the engine operates at a stoichiometric air/fuel ratio.

14. The method of claim **13**, further comprising:

controlling the flow modification device to a second position when the engine operates at a lean air/fuel ratio.

15. The method of claim **14**, further comprising:

controlling the flow modification device to a third position when the engine operates at a rich air/fuel ratio.

16. The method of claim **12**, further comprising:

monitoring temperature of the exhaust gas feedstream; and

controlling the flow modification device based upon the temperature.

17. The method of claim **16**, further comprising:

controlling the flow modification device to direct the exhaust gas feedstream to one of the first portion exclusively and second portion exclusively based upon the temperature of the exhaust gas feedstream.

* * * * *