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(54) **AFTERTREATMENT SYSTEM WITH LEAN NOX TRAP FILTER**

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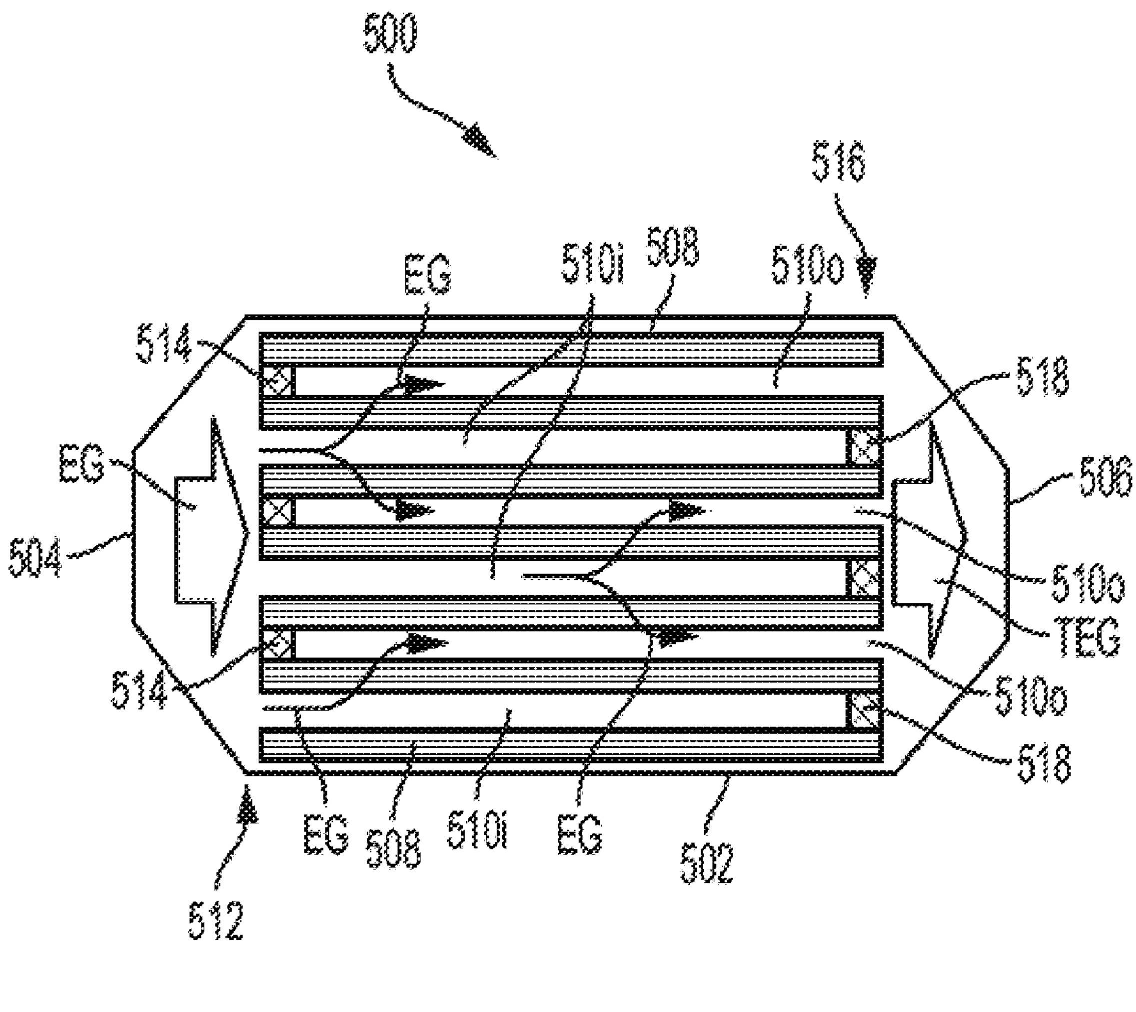
(57) **ABSTRACT**

An aftertreatment system includes a first pipe section in fluid communication with an exhaust manifold on an internal combustion engine. A first aftertreatment device includes a housing and a porous substrate having substrate walls defining a plurality of flow channels including first channels obstructed at a first end of the substrate and second channels obstructed at a second end of the substrate opposite the first end. The first and second channels are interleaved and internal pore surfaces in the porous substrate form a plurality of internal pores. A passive NOx adsorption catalyst is deposited on the substrate walls and internal pore surfaces such that the mean porosity of the porous substrate is not greater than a particulate matter secondary grain size. A second aftertreatment device having an inlet is in fluid communication with the outlet of the first aftertreatment device.



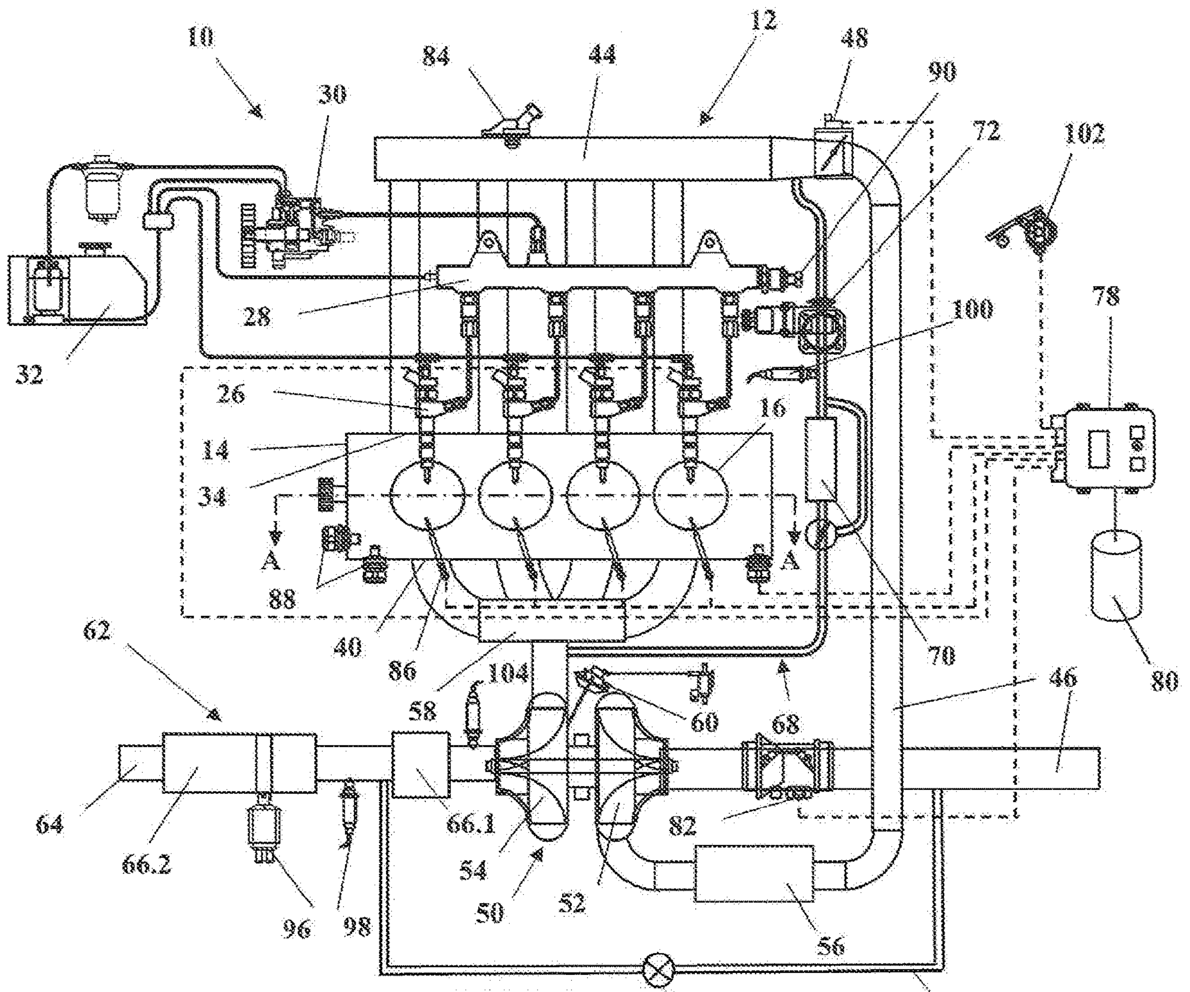

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FIG.1

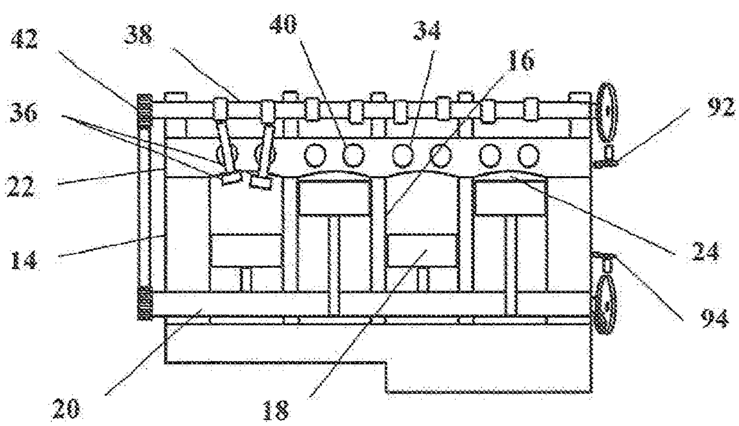
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FIG.2

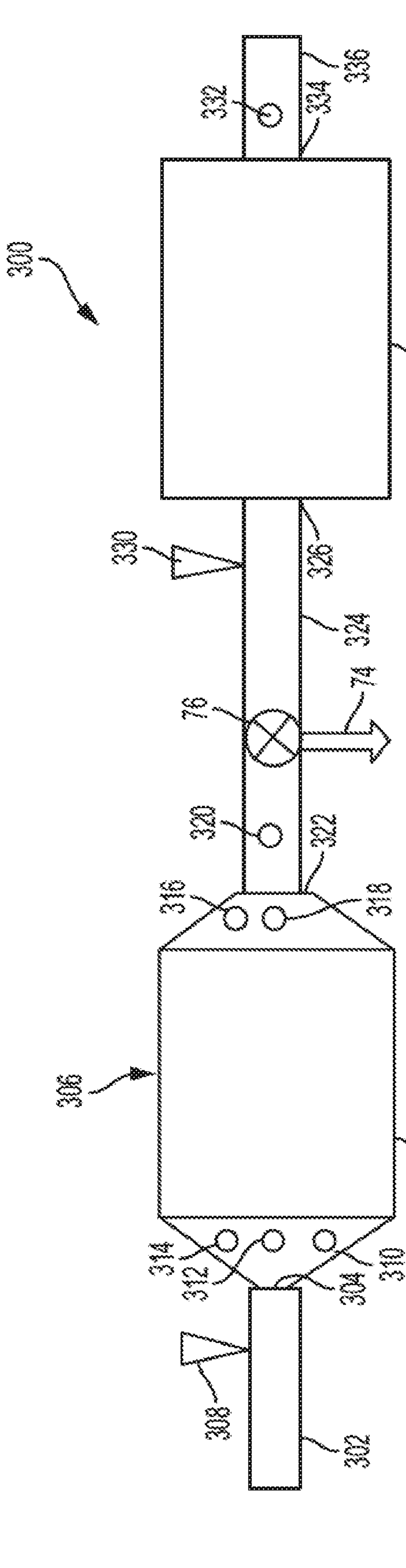
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FIG. 3

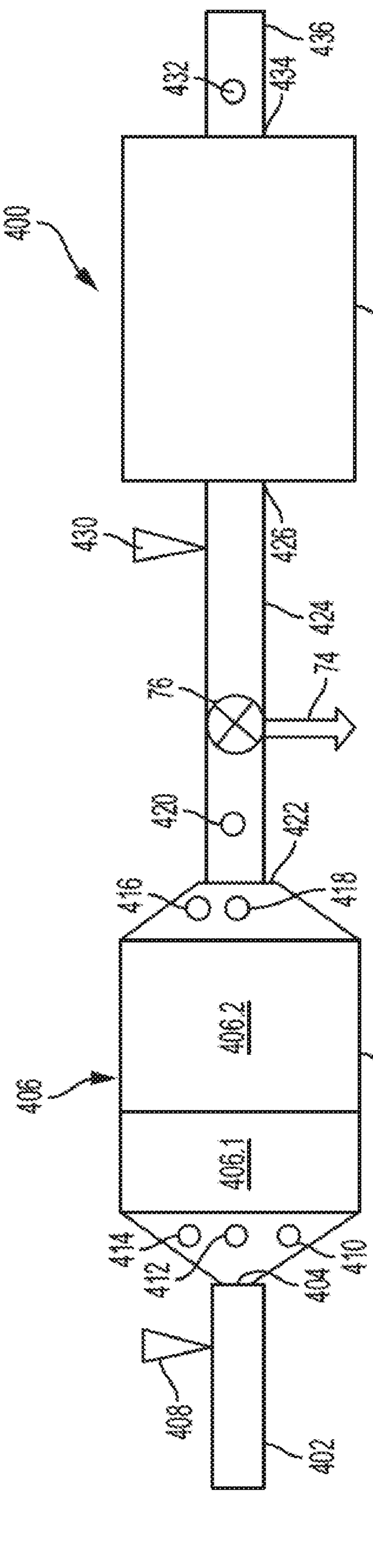
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FIG. 4

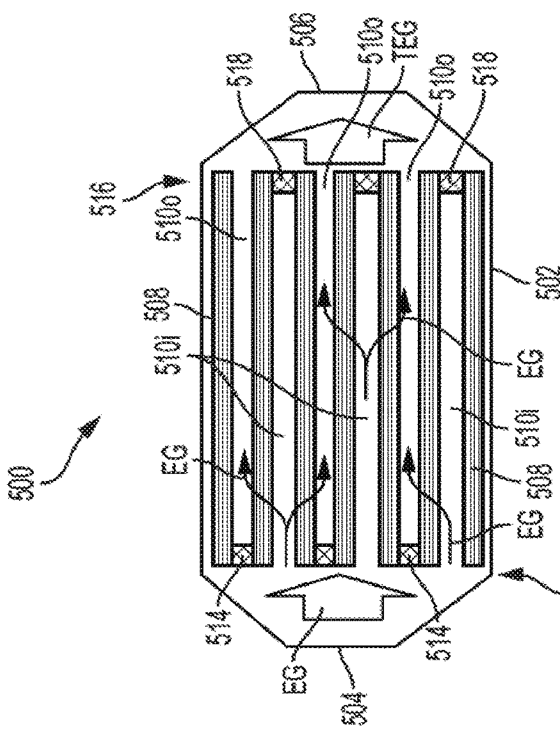

FIG. 5

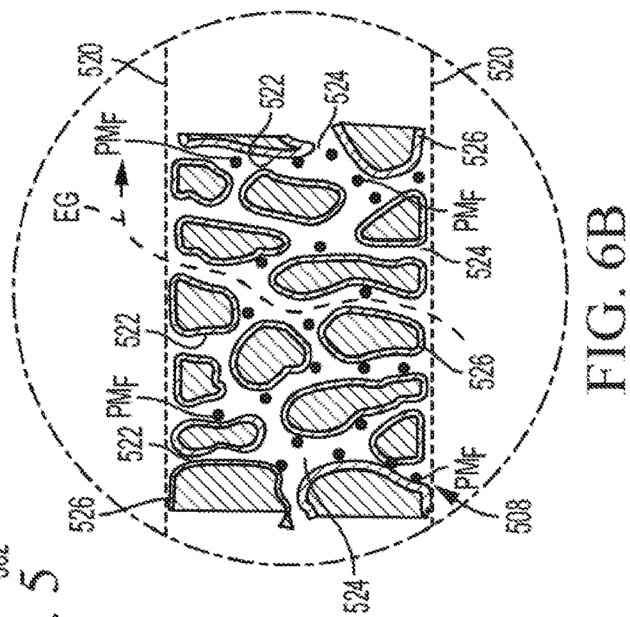

FIG. 6B

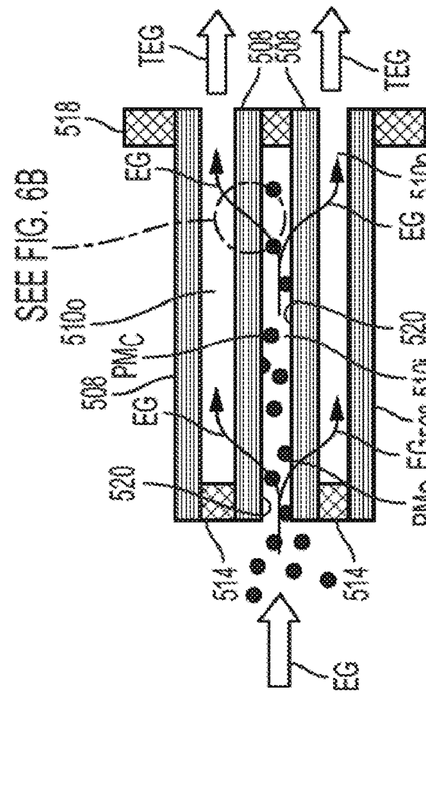

FIG. 6A

AFTERTREATMENT SYSTEM WITH LEAN NOX TRAP FILTER

TECHNICAL FIELD

[0001] The present disclosure generally relates to an aftertreatment system for exhaust gases from an internal combustion engine, and more particularly to an aftertreatment architecture having a lean NOx trap filter in combination with a selective catalyst reduction device.

BACKGROUND

[0002] Generally, vehicles, such as motor vehicles, are powered by a propulsion system. Certain motor vehicles employ an internal combustion engine, such as a Diesel engine, as a propulsion system, which provides power that is transferred to a transmission and used to drive the motor vehicle. To meet the recent, more stringent emissions regulations, an aftertreatment system having one or more after treatment devices may be employed to remove combustion byproducts, such as diesel particulate matter, carbon monoxide, nitrogen oxides (NOx), sulfur oxides (SOx), unburned hydrocarbons, and the like, from an exhaust stream prior to the exhaust stream being discharged from the internal combustion engine.

[0003] Conventional aftertreatment devices have particular working temperature ranges that must be reached to provide adequate conversion efficiencies. For example, a selective catalytic reduction (SCR) device may not reach adequate conversion efficiency until it attains a working temperature in the range of 200-300° C. In these situations, the aftertreatment system will not provide adequate conversion efficiencies at lower temperature ranges (e.g. below 200° C.) during engine start-up conditions or extremely low ambient operating conditions. An additional aftertreatment device such as a lean NOx trap (LNT) device may be included to extend the temperature range of the aftertreatment system for removing the combustion byproducts in lower temperature ranges. However, the LNT device may not be as efficient in removing the combustion byproducts as the SCR system in the higher working temperature range and another device for removing particulate matter.

[0004] Accordingly, it is desirable to provide a system and method of aftertreatment for an exhaust stream in one or more aftertreatment devices over a relatively wide working temperature range. The use of staged aftertreatment device would provide for efficient removal of combustion byproducts over a range of operating temperatures. Furthermore, other desirable features and characteristics of the present disclosure will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the foregoing technical field and background.

SUMMARY

[0005] In accordance with the present disclosure, an exhaust gas aftertreatment device for exhaust gases from an internal combustion engine is provided. The aftertreatment device includes a housing having an inlet and an outlet. A porous substrate is disposed in the housing and includes substrate walls defining a plurality of flow channels including first channels obstructed at a first end of the substrate and second channels obstructed at a second end of the substrate opposite the first end. The first and second channels are interleaved and internal pore surfaces in the porous substrate form a plurality of internal pores that define tortuous passageways between the substrate walls. A passive NOx adsorption catalyst is deposited on the substrate walls and internal pore surfaces such that the mean porosity of the porous substrate is not greater than a particulate matter secondary grain size. In accordance with an additional embodiment, the mean porosity of the substrate is not less than 10 μm and not greater than 20 μm for adequately filtering particulate matter while limiting the pressure drop across the device.

[0006] In accordance with an additional embodiment, the porous substrate is uniformly coated with the catalyst such that the concentration of the catalyst on the substrate in the exhaust gas flow direction remains substantially constant over the length of the substrate. In accordance with an alternate embodiment, the porous substrate is zone coated with the catalyst such that the concentration of the catalyst varies over the length of the substrate to define distinct zones based on the catalyst concentration in each region of the substrate.

[0007] In accordance with an additional embodiment, the exhaust gas aftertreatment device further includes a Diesel oxidation catalyst section disposed in the housing between the inlet and the porous substrate.

[0008] In accordance with an additional embodiment, the exhaust gas aftertreatment device further includes a fuel injector configured to inject a hydrocarbon fuel into the exhaust gas stream downstream of the internal combustion engine and upstream of the porous substrate.

[0009] In accordance with the present disclosure, an aftertreatment system is disclosed for exhaust gas from an internal combustion engine having an exhaust manifold. The aftertreatment system includes a first pipe section configured to be in fluid communication with an exhaust manifold of the internal combustion engine. A first aftertreatment device includes a housing having an inlet and an outlet. A porous substrate is disposed in the housing and has substrate walls defining a plurality of flow channels including first channels obstructed at a first end of the substrate and second channels obstructed at a second end of the substrate opposite the first end. The first and second channels are interleaved and internal pore surfaces in the porous substrate form a plurality of internal pores that define tortuous passageways between the substrate walls. A passive NOx adsorption catalyst is deposited on the substrate walls and internal pore surfaces such that the mean porosity of the porous substrate is not greater than a particulate matter secondary grain size. A second aftertreatment device includes an inlet in fluid communication with the outlet of the first aftertreatment device. In accordance with an additional embodiment, the porous substrate in the first aftertreatment device has a mean porosity not less than 10 μm and not greater than 20 μm for adequately filtering particulate matter while limiting the pressure drop across the device.

[0010] In accordance with an additional embodiment, the porous substrate in the first aftertreatment device is uniformly coated with the catalyst such that the concentration of the catalyst on the substrate in the exhaust gas flow direction remains substantially constant over the length of the substrate. In accordance with an alternate embodiment, the porous substrate in the first aftertreatment device is zone coated with the catalyst such that the concentration of the catalyst varies over the length of the substrate to define distinct zones based on the catalyst concentration in each region of the substrate.

[0011] In accordance with an additional embodiment, the aftertreatment system further includes a Diesel oxidation catalyst section disposed in the housing between the inlet and the porous substrate.

[0012] In accordance with an additional embodiment, the aftertreatment system further includes a fuel injector configured to inject a hydrocarbon fuel into the aftertreatment system downstream of the exhaust manifold and upstream of the first aftertreatment device.

[0013] In accordance with an additional embodiment, the second aftertreatment device includes a selective catalytic reduction (SCR) unit downstream of the first aftertreatment device. In accordance with an additional embodiment, the aftertreatment system further includes a fluid injector configured to inject a diesel exhaust fluid into the aftertreatment system downstream of the first aftertreatment device and upstream of the SCR unit.

[0014] In accordance with an additional embodiment, the first aftertreatment device has a NOx conversion efficiency greater than 40% in a first temperature range between about 100° C. and 300° C. and the second aftertreatment device has a NOx conversion efficiency greater that 55% in a second temperature range between about 200° C. and 450° C.

[0015] In accordance with an additional embodiment, the aftertreatment system further includes a second pipe section having a first end in fluid communication with the outlet of the first aftertreatment device and a second end in fluid communication with the SCR unit such that second pipe section separates the first and second aftertreatment devices. In accordance with an additional embodiment, the aftertreatment system further includes a low-pressure exhaust gas recirculation circuit in fluid communication with the second pipe section.

DESCRIPTION OF THE DRAWINGS

[0016] The exemplary embodiments will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements.

[0017] FIG. **1** schematically shows an automotive system according to an embodiment of the present disclosure;

[0018] FIG. **2** is the section A-A of an internal combustion engine belonging to the automotive system of FIG. **1**;

[0019] FIG. **3** shows an aftertreatment system having a first aftertreatment device in the form of a lean NOx trap (LNT) filter upstream of a second aftertreatment device in the form of a selective catalytic reduction (SCR) unit;

[0020] FIG. **4** shows an aftertreatment system having a first aftertreatment device including a Diesel oxidation catalyst (DOC) and an LNT filter upstream of a second aftertreatment device in the form of an SRC unit;

[0021] FIG. **5** is a schematic representation showing a cross-section of a LNT filter;

[0022] FIG. **6**A is a detail of the LNT filter shown in FIG. **5** indicating the exhaust gas flow through the LNT filter; and

[0023] FIG. **6**B is a detail at **6**B of FIG. **6**A indicating the exhaust gas flow through the porous substrate.

DETAILED DESCRIPTION

[0024] The following detailed description is merely exemplary in nature and is not intended to limit the invention disclosed herein or the application and uses of the invention disclosed herein. Furthermore, there is no intention to be bound by any principle or theory, whether expressed or implied, presented in the preceding technical field, background, summary or the following detailed description, unless explicitly recited as claimed subject matter.

[0025] Some embodiments may include an automotive system **10**, as shown in FIGS. **1** and **2**, that includes an internal combustion engine (ICE) **12** having an engine block **14** defining at least one cylinder **16** having a piston **18** coupled to rotate a crankshaft **20**. A cylinder head **22** cooperates with the piston **18** to define a combustion chamber **24**. A fuel and air mixture may be injected in the combustion chamber **24** and ignited, resulting in hot expanding exhaust gasses causing reciprocal movement of the piston **18**. The fuel is provided at high pressure to the fuel injector **26** from a fuel rail **28** in fluid communication with a high pressure fuel pump **30** that increase the pressure of the fuel received from a fuel source **32**. The air is provided through at least one intake port **34**. Each of the cylinders **16** has at least two valves **36**, actuated by a camshaft **38** rotating in time with the crankshaft **20**. The valves **36** selectively allow air through the intake port **34** into the combustion chamber **24** and alternately allow exhaust gases to exit through an exhaust port **40**. In some examples, a cam phaser **42** may selectively vary the timing between the camshaft **38** and the crankshaft **20**.

[0026] The air may be distributed to the air intake port(s) **34** through an intake manifold **44**. An air intake duct **46** may provide air from the ambient environment to the intake manifold **44**. In other embodiments, a throttle body **48** may be provided to regulate the flow of air into the manifold **44**. In still other embodiments, a forced air system such as a turbocharger **50**, having a compressor **52** rotationally coupled to a turbine **54**, may be provided. Rotation of the compressor **52** increases the pressure and temperature of the air in the duct **46** and manifold **44**. An intercooler **56** disposed in the duct **46** may reduce the temperature of the air. The turbine **54** rotates by receiving exhaust gases from an exhaust manifold **58** that directs exhaust gases from the exhaust ports **40** and through a series of vanes prior to expansion through the turbine **54**. This example shows a variable geometry turbine (VGT) with a VGT actuator **60** arranged to move the vanes to alter the flow of the exhaust gases through the turbine **54**. In other embodiments, the turbocharger **50** may be fixed geometry and/or include a waste gate.

[0027] The exhaust gases exit the turbine **54** and are directed into an aftertreatment system **62**. The aftertreatment system **62** may include an exhaust pipe **64** having one or more exhaust aftertreatment devices **66.1**, **66.2**. The aftertreatment devices **66.1**, **66.2** (collectively **66**) may be any device configured to change the composition of the exhaust gases. Additional details concerning preferred aftertreatment devices **66** are provided below. As illustrated, the internal combustion engine **12** includes a high-pressure short-route exhaust gas recirculation (HP-EGR) circuit **68** coupled between the exhaust manifold **58** and the intake manifold **44**. The HP-EGR circuit **68** may include an EGR cooler **70** to reduce the temperature of the exhaust gases in the EGR circuit **68**. An HP-EGR valve **72** regulates a flow of high-pressure exhaust gases in the HP-EGR circuit **68**. The internal combustion engine **12** also includes a low-pressure, long-route exhaust gas recirculation (LP-EGR) circuit **74** coupled to the exhaust pipe **64** downstream of the turbine **54** and recirculates exhaust gasses into the air intake duct **46** upstream of the compressor **52**. An LP-EGR valve **76** regulates a flow of low-pressure exhaust gases in the LP-EGR circuit **74**.

[0028] The automotive system **10** may further include an electronic control unit (ECU) **78** in communication with one or more sensors and/or devices associated with the ICE **12**. The ECU **78** may include a digital central processing unit (CPU) in communication with a memory system, or data carrier **80**, and an interface bus. The CPU is configured to execute instructions stored as a program in the memory system, and send and receive signals to/from the interface bus. The memory system may include various storage types including optical storage, magnetic storage, solid state storage, and other non-volatile memory. The interface bus may be configured to send, receive, and modulate analog and/or digital signals to/from the various sensors and control devices. The program may embody the methods disclosed herein, allowing the CPU to carry out the steps of such methods and control the ICE **12**. Instead of an ECU **78**, the automotive system **100** may have a different type of processor to provide the electronic logic, e.g. an embedded controller, an onboard computer, or any processing module that might be deployed in the vehicle.

[0029] The program stored in the memory system is transmitted from outside via a cable or in a wireless fashion. Outside the automotive system **10** it is normally visible as a computer program product, which is also called computer readable medium or machine readable medium in the art, and which should be understood to be a computer program code residing on a carrier, said carrier being transitory or non-transitory in nature with the consequence that the computer program product can be regarded to be transitory or non-transitory in nature.

[0030] An example of a transitory computer program product is a signal, e.g. an electromagnetic signal such as an optical signal, which is a transitory carrier for the computer program code. Carrying such computer program code can be achieved by modulating the signal by a conventional modulation technique such as QPSK for digital data, such that binary data representing said computer program code is impressed on the transitory electromagnetic signal. Such signals are e.g. made use of when transmitting computer program code in a wireless fashion via a Wi-Fi connection to a laptop.

[0031] In case of a non-transitory computer program product the computer program code is embodied in a tangible storage medium. The storage medium is then the non-transitory carrier mentioned above, such that the computer program code is permanently or non-permanently stored in a retrievable way in or on this storage medium. The storage medium can be of conventional type known in computer technology such as a flash memory, an Asic, a CD or the like.

[0032] The ECU **78** may receive input signals from various sensors configured to generate the signals in proportion to various physical parameters associated with the ICE **12**. The sensors include, but are not limited to, a mass airflow and temperature sensor **82**, a manifold pressure and temperature sensor **84**, a combustion pressure sensor **86**, coolant and oil temperature and level sensors **88**, a fuel rail pressure sensor **90**, a cam position sensor **92**, a crank position sensor **94**, a differential pressure sensor **96**, an exhaust gas temperature sensors **98**, an EGR temperature sensor **100**, and an accelerator pedal position sensor **102**. Furthermore, the ECU **78** may generate output signals to various control devices that are arranged to control the operation of the ICE **12**, including, but not limited to, combustion fuel injectors **26**, throttle body **48**, EGR valves **72**, **76** the VGT actuator **60**, cam phaser **42** and aftertreatment fuel injector **104**. Note, dashed lines are used to indicate communication between the ECU **78** and the various sensors and devices, but some are omitted for clarity.

[0033] With reference now to FIG. **3**, an aftertreatment system **300** in accordance with the present disclosure will be further described. It should be appreciated that aftertreatment system **300** further details the components and configuration of the architecture for the aftertreatment system **62** shown in FIG. **1**. The aftertreatment system **300** includes a first pipe section **302** having a first end in fluid communication the exhaust manifold **58** (shown in FIG. **1**) and a second end in fluid communication with an inlet **304** of a first aftertreatment device **306**. In the embodiment shown in FIG. **3**, the first aftertreatment device is a lean NOx trap (LNT) filter **306**. The LNT filter **306** is a catalyst system developed to decrease both particulate matter (PM) and nitrogen oxides (NOx) in a single unit. Additional details of the LNT filter are set forth below. Several sensors **310**, **312**, **314** are positioned at the inlet **304** and several sensors **316**, **318**, **320** are positioned at the outlet **322** of the first aftertreatment device **306** and provide sensor signals to the ECU **78** for controlling the aftertreatment system **300**. These sensors include oxygen/NOx sensors (aka lambda sensors) **310**, **320**, exhaust gas temperature sensors **312**, **318** and differential pressure sensors **314**, **316**.

[0034] A first AT (aftertreatment) injector **308** is configured to inject hydrocarbon (HC) fuel into the exhaust gas stream downstream of the exhaust manifold and independent from the fuel injectors **26** of the internal combustion engine **12**. As illustrated herein, the first AT injection **308** is located in the first pipe section **302** downstream of the turbocharger **50**. However, one skilled in the art should understand that the first AT fuel injector **308** may be in the exhaust system upstream of the turbocharger **50**. The ECU **78** is in communication with the first AT injector **308** for precisely controlling HC injections into the aftertreatment system **300**. In general, the AT fuel injector **308** has similar components and functions to the combustion fuel injectors **26** with the exception that it is intended to operate at a lower working pressure. Implementation of a dedicated AT fuel injector, instead of a post injection strategy with fuel injectors **26**, provides several distinct advantages for reducing particulate matter and NOx production. Controlling the aftertreatment HC injection independent of combustion injections removes any practical limitation of operational range otherwise imposed with post-injection rich strategies. As such HC emissions can be controlled by increasing the rich-spike frequency and the number of injections independent of combustions constraint. Moreover, the AT fuel injector may be used in combinations with multiple after injections to reduce the possibility of oil dilution.

[0035] The aftertreatment system **300** includes a second pipe section **324** having a first end in fluid communication with an outlet **322** of the lean NOx trap filter **306** and a second end in fluid communication with an inlet **326** of a second aftertreatment device **328**. In the embodiment shown in FIG. **3**, the second aftertreatment device **328** is a selective catalytic reduction (SCR) unit. A second AT injector **330** is configured to inject diesel exhaust fluid or urea (DEF) into the exhaust gas stream downstream of the first aftertreatment device **306**. The ECU **78** is in communication with the second AT injector **330** for precisely controlling DEF injections into the aftertreatment system **300**. An oxygen/NOx sensor (aka lambda sensor) **332** is positioned at the outlet **334** of the second aftertreatment device **328** and provides sensor signals to the ECU **78** for controlling the aftertreatment system **300**. The aftertreatment system **300** includes a third pipe section **336** having a first end in fluid communication with the outlet **334** of the second aftertreatment device **328**. The LP-EGR circuit **74** (shown in FIG. **1**) is in fluid communication with the second pipe section **324** for recirculating a portion of the exhaust gas passing therethrough to the inlet manifold **44** as previously indicated.

[0036] With reference now to FIG. **4**, an aftertreatment system **400** in accordance with the present disclosure will be further described. It should be appreciated that aftertreatment system **400** further details the components and configuration of the architecture for the aftertreatment system **62** shown in FIG. **1**. The aftertreatment system **400** includes a first pipe section **402** having a first end in fluid communication the exhaust manifold **58** (shown in FIG. **1**) and a second end in fluid communication with an inlet **404** of a first aftertreatment device **406**. In the embodiment shown in FIG. **4**, the first aftertreatment device **406** is multi-function aftertreatment device having a diesel oxidation catalyst (DOC) section **406.1** upstream of a lean NOx trap (LNT) filter **406.2**. Several sensors **410**, **412**, **414** are positioned at the inlet **404** and several sensors **416**, **418**, **420** are positioned at the outlet **422** of the first aftertreatment device **406** and provide sensor signals to the ECU **78** for controlling the aftertreatment system **400**. These sensors include oxygen/NOx sensors (aka lambda sensors) **410**, **420**, exhaust gas temperature sensors **412**, **418** and differential pressure sensors **414**, **416**.

[0037] A first AT (aftertreatment) injector **408** is configured to inject hydrocarbon (HC) fuel into the exhaust gas stream downstream of the exhaust manifold and independent from the fuel injectors **26** of the internal combustion engine **12**. As illustrated herein, the first AT injection **408** is located in the first pipe section **402** downstream of the turbocharger **50**. However, one skilled in the art should understand that the first AT injector **408** may be located in the exhaust system upstream of the turbocharger **50**. The ECU **78** is in communication with the first AT injector **408** for precisely controlling HC injections into the aftertreatment system **400**.

[0038] The aftertreatment system **400** includes a second pipe section **424** having a first end in fluid communication with an outlet **422** of the first aftertreatment device **406** and a second end in fluid communication with an inlet **426** of a second aftertreatment device **428**. In the embodiment shown in FIG. **4**, the second aftertreatment device **428** is a selective catalytic reduction (SCR) unit. A second AT injector **430** is configured to inject diesel exhaust fluid or urea (DEF) into the exhaust gas stream downstream of the first aftertreatment device **406**. The ECU **78** is in communication with the second AT injector **430** for precisely controlling DEF injections into the aftertreatment system **400**. An oxygen/NOx sensor (aka lambda sensor) **432** is positioned at the outlet **434** of the second aftertreatment device **428** and provides sensor signals to the ECU **78** for controlling the aftertreatment system **400**. The aftertreatment system **400** includes a third pipe section **436** having a first end in fluid communication with the outlet **434** of the second aftertreatment device **428**. The LP-EGR circuit **74** (shown in FIG. **1**) is in fluid communication with the second pipe section **424** for recirculating a portion of the exhaust gas passing therethrough to the inlet manifold **44** as previously indicated.

[0039] The SCR unit **328** used in the aftertreatment system **300** and the diesel oxidation catalyst section **406.1** and the SCR unit **428** used in the aftertreatment system **400** described above are adapted using conventional technology for selective catalytic reduction and oxidation of compounds with a reducing character such as hydrocarbons and sulfate particulates. Thus, further discussion of the substrates, catalytic treatments and regeneration processes are not further discussed herein.

[0040] With reference to FIG. **5**, a lean NOx trap (LNT) filter **500**, as represented by **306** in aftertreatment system **300** and **406.2** in the aftertreatment system **400**, includes a housing **502** having an inlet **504** and an outlet **506**. The housing encloses a porous substrate **508** having inlet flow channels **510***i* interleaved with outlet flow channels **510***o* bounded by the porous substrate **508**. In this regard, an inlet flow channel **510***i* is open at an end **512** adjacent to the inlet **504** and blocked by a plug **514** at an end **516** adjacent the outlet **506**. Conversely, an outlet flow channel **510***o* is blocked by a plug **518** at the end **512** adjacent the inlet **504** and open at the end **516** adjacent the outlet **506**. Plugs **514**, **518** are significantly less porous than the porous substrate **508** to ensure that exhaust gas is not permitted to flow therethrough.

[0041] As shown in FIGS. **5** and **6**A, exhaust gas EG flowing through the LNT filter **500** enters an inlet flow channel **510***i* and is force through the porous substrate **508** and into an outlet flow channel **510***o*. Exhaust gas may flow through more than one inlet flow channel and/or one exhaust flow channel depending on the differential pressures therein. With reference to FIG. **6**B, the porous substrate **508** forms substrate walls **520** and internal pore surfaces **522** having a plurality of internal pores **524** that define tortuous passageways between the substrate walls **520**. The porous substrate **508** is coated a passive NOx adsorption catalyst **526** such that the substrate walls **520** and internal pore surfaces **522** have an exposed layer of catalyst. Conventional acid-based washcoat chemistry for a passive NOx adsorption catalyst (e.g., zeolites-based catalysts and/or alkali/alkaline oxide constituents) may be used as catalyst **526** for adsorbing NOx under lower temperature conditions such as during vehicle cold starts and releasing NOx when the temperature of the exhaust gas increases without requiring a rich regeneration cycle. Other passive or partially active NOx adsorption catalysts which are effective to control cold start/low temperature NOx emissions may be implemented as the catalyst **526** in the present disclosure.

[0042] In one embodiment, the concentration of the catalyst **526** on the substrate **508** in the exhaust gas flow direction remains substantially constant over the length of the substrate **508** such that it is generally uniformly coated. In an alternate embodiment, the concentration of catalyst **526** on the substrate **508** in the exhaust gas flow direction may be varied over the length of the substrate **508** such distinct zones are defined based on the catalyst concentration in each region of the substrate **508**. In other words, the substrate is zone-coated to promote Diesel particulate filter regeneration in this alternate embodiment.

[0043] The material of the porous substrate **508** is selected to filter particulate matter in the exhaust gases having an aerodynamic diameter in the range of about 10 to 20 micrometers (μm), which generally corresponds to the secondary grain size of the particulate matter. Particulate matter in the exhaust gases having an aerodynamic diameter larger than about 20 μm are filtered at the interface of the substrate wall **520**, or in other words are trapped in the inlet flow channels **510***i*. Particulate matter having an aerodynamic diameter smaller than about 10 μm pass through the internal pores **524** of the substrate **508**. Deposition of the catalyst **526** on the internal pore surface **522** should be taken into account when selecting the material for the porous substrate to achieve the above-stated filtering function. In this regard, the mean porosity of the coated substrate is not greater than a particulate matter secondary grain size.

[0044] With reference now to FIGS. **6**A and **6**B in the context of FIGS. **3** and **4**, exhaust gas EG enters the LNT filter **500** at the inlet end **512** and is directed into inlet flow channels **510***i* (one being shown). A hydrocarbon fuel may be injected into the exhaust gas EG with the first AT injector **308**, **408** based on the chemical composition of the exhaust gas EG and the desired stoichiometry for the first aftertreatment device **306**, **406** to promote both particulate matter and NOx reduction. By using a dedicated injector, a higher NOx conversion efficiency can be reached with no potential limitation otherwise encountered as compared to conventional post-injection rich strategies. Likewise, hydrocarbon emissions can be control by increasing the rich-spike frequency and the number of injections with a dedicated injector, independent of fuel injections for combustion. Furthermore, the use of a dedicated injector in combination with multiple after injections may reduce oil dilution experienced with some conventional post-injection rich strategies.

[0045] Course particulate matter PM_C (>20 μm) in the exhaust gas EG is blocked at the substrate wall **520**. Finer particulate matter PM_F (10-20 μm) in the exhaust gas is trapped in the internal pores **524** of the porous substrate **508**. In addition, the catalyst **526** deposited on the substrate walls **520** and the internal pore surfaces **522** adsorbs NOx in the exhaust gas under cold start/low temperature operating conditions. A treated exhaust gas, from which particulate matter has been filtered and a reduction in the NOx concentration in the exhaust gas EG has achieved under cold start/low temperature operating conditions is discharged through outlet **506** downstream. At conventional engine operating temperatures, a thermal reaction reverses the NOx adsorption on the catalyst **526**. As such, NOx trapped in the first aftertreatment device **306**, **406** is passed through the second aftertreatment device **328**, **428**. Since the aftertreatment system is at conventional engine operating temperatures, the SCR unit **328**, **428** is effective in the reduction and oxidation of NOx and other combustion byproducts in the treated exhaust gas TEG.

[0046] By employing an LNT filter in combination with an SCR unit, the aftertreatment system **300**, **400** is effective over a wide temperature range from about 100° C. to above 400° C. As presently preferred, the first aftertreatment device **306**, **406** is configured to have a NOx conversion efficiency greater than 40% in a first temperature range between about 100° C. and 300° C. and the second aftertreatment device **328**, **428** is configured to have a NOx conversion efficiency greater that 55% in a second temperature range between about 200° C. and 450° C. The LNT filter **306**. **406**.**2** can simultaneously reduce particulate matter and NOx in a single unit with a smaller catalyst volume than a system employing separate lean NOx trap and Diesel particulate filter. The LNT filter **306**, **406**.**2** also advantageously compares to other devices in that the catalyst employed therein does not conflict with platinum group metals (PGMs) which would otherwise poison the catalyst used in a selective catalyst reduction filter (SCRF) unit. Moreover, the configuration of an LNT filter **306**, **406**.**2** separate from the SCR unit **328**, **428** provides protection from damage to the DEF injector assembly **330**, **430** resulting from over-temperature conditions.

[0047] While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the disclosure in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the exemplary embodiment or exemplary embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope of the disclosure as set forth in the appended claims and the legal equivalents thereof.

1. An exhaust gas aftertreatment device for exhaust gases from an internal combustion engine comprising:

a housing having an inlet and an outlet;

a porous substrate having substrate walls defining a plurality of flow channels formed therein including first channels obstructed at a first end of the substrate and second channels obstructed at a second end of the substrate opposite the first end, wherein the first and second channels are interleaved and internal pore surfaces in the porous substrate form a plurality of internal pores that define tortuous passageways between the substrate walls; and

a passive NOx adsorption catalyst deposited on the substrate walls and internal pore surfaces such that the mean porosity of the porous substrate is not greater than a particulate matter secondary grain size.

2. The exhaust gas aftertreatment device according to claim **1**, wherein the mean porosity of the substrate is not less than 10 μm and not greater than 20 μm.

3. The exhaust gas aftertreatment device according to claim **1**, wherein the porous substrate is uniformly coated with the catalyst such that the concentration of the catalyst on the substrate in the exhaust gas flow direction remains substantially constant over the length of the substrate.

4. The exhaust gas aftertreatment device according to claim **1**, the porous substrate is zoned coated with the catalyst such that the concentration of the catalyst varies over the length of the substrate to define distinct zones based on the catalyst concentration in a given region of the substrate.

5. The exhaust gas aftertreatment device according to claim **1**, further comprising a Diesel oxidation catalyst section disposed in the housing between the inlet and the porous substrate.

6. The exhaust gas aftertreatment device according to claim **1**, further comprising a fuel injector configured to inject a hydrocarbon fuel into the exhaust gas stream downstream of the internal combustion engine and upstream of the porous substrate.

7. An aftertreatment system for exhaust gas from an internal combustion engine having an exhaust manifold, the aftertreatment system comprising:

a first pipe section configured to be in fluid communication with the exhaust manifold;

a first aftertreatment device including a housing having an inlet and an outlet, a porous substrate having substrate walls defining a plurality of flow channels formed therein including first channels obstructed at a first end of the substrate and second channels obstructed at a second end of the substrate opposite the first end, wherein the first and second channels are interleaved and internal pore surfaces in the porous substrate form a plurality of internal pores that define tortuous passageways between the substrate walls, and a passive NOx adsorption catalyst deposited on the substrate walls and internal pore surfaces such that the mean porosity of the porous substrate is not greater than a particulate matter secondary grain size;

a second aftertreatment device having an inlet in fluid communication with the outlet of the first aftertreatment device.

8. The aftertreatment system according to claim **7**, wherein the porous substrate in the first aftertreatment device has a mean porosity not less than 10 μm and not greater than 20 μm.

9. The aftertreatment system according to claim **7**, wherein the porous substrate in the first aftertreatment device is uniformly coated with the catalyst such that the concentration of the catalyst on the substrate in the exhaust gas flow direction remains substantially constant over the length of the substrate.

10. The aftertreatment system according to claim **7**, wherein the porous substrate in the first aftertreatment device is zoned coated with the catalyst such that the concentration of the catalyst varies over the length of the substrate to define distinct zones based on the catalyst concentration in a given region of the substrate.

11. The aftertreatment system according to claim **7**, further comprising a Diesel oxidation catalyst section disposed in the housing between the inlet and the porous substrate.

12. The aftertreatment system according to claim **7** further comprising a fuel injector configured to inject a hydrocarbon fuel into the aftertreatment system downstream of the exhaust manifold and upstream of the first aftertreatment device.

13. The aftertreatment system according to claim **7**, wherein the second aftertreatment device comprises a selective catalytic reduction (SCR) unit.

14. The aftertreatment system according to claim **13**, further comprising a fluid injector configured to inject a diesel exhaust fluid into the aftertreatment system downstream of the first aftertreatment device and upstream of the SCR unit.

15. The aftertreatment system according to claim **7** wherein the first aftertreatment device has a NOx conversion efficiency greater than 40% in a first temperature range between about 100° C. and 300° C. and the second aftertreatment device has a NOx conversion efficiency greater that 55% in a second temperature range between about 200° C. and 450° C.

16. The aftertreatment system according to claim **7**, further comprising a second pipe section having a first end in fluid communication with the outlet of the first aftertreatment device and a second end in fluid communication with the second aftertreatment device such that second pipe section separates the first and second aftertreatment devices.

17. The aftertreatment system according to claim **16**, further comprising a low-pressure exhaust gas recirculation circuit in fluid communication with the second pipe section.

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