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(54) **VEHICLE WITH GASOLINE PARTICULATE FILTER SOOT REGENERATION STRATEGY WITH CRITERIA EMISSION REDUCTION FOR LOW NOX EMISSIONS**

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F01N 1/14 (2006.01)
(Continued)

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CPC ***F02D 41/029*** (2013.01); ***F02D 41/1453*** (2013.01); *F01N 1/14* (2013.01); *F01N 3/05* (2013.01); *F01N 3/22* (2013.01); *F01N 3/225* (2013.01); *F01N 3/30* (2013.01); *F01N 3/32* (2013.01); *F01N 2270/04* (2013.01); *F01N 2550/12* (2013.01); *F01N 2550/14* (2013.01); *F01N 2900/1804* (2013.01); *F01N 2900/1824* (2013.01); *F02D 2200/0802* (2013.01)

(58) **Field of Classification Search**
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See application file for complete search history.

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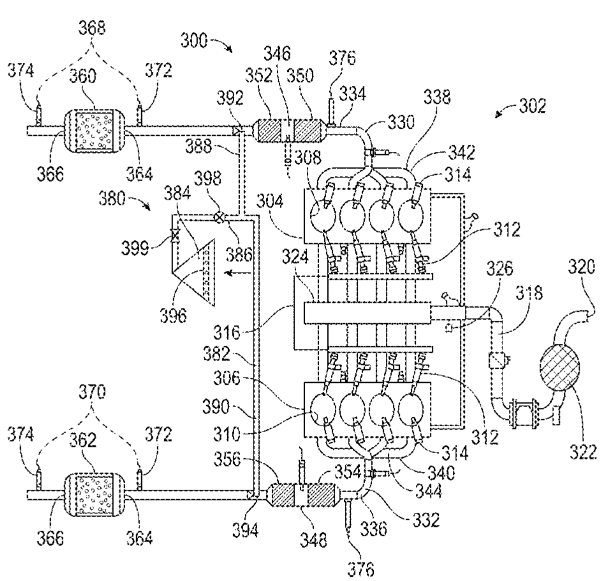
(57) **ABSTRACT**

In accordance with example implementations, a vehicle includes a body, an engine within the body, and at least one exhaust tube extending from the engine and having a particulate filter fluidly coupled to the exhaust tube to receive exhaust material from the exhaust tube. The vehicle also has at least one air injection pipe having a first end with an inlet arranged to receive air flow entering the body while the vehicle is moving, wherein the air injection pipe comprises a second end fluidly coupled to the exhaust tube and having an outlet positioned to provide air flow from the injection pipe into the exhaust tube upstream from the particulate filter. Passive soot regeneration with THC and CO reductions is realized by this introduced air flow.

20 Claims, 6 Drawing Sheets



(51) **Int. Cl.**

F01N 3/05	(2006.01)
F01N 3/22	(2006.01)
F01N 3/30	(2006.01)
F01N 3/32	(2006.01)
F02D 41/14	(2006.01)

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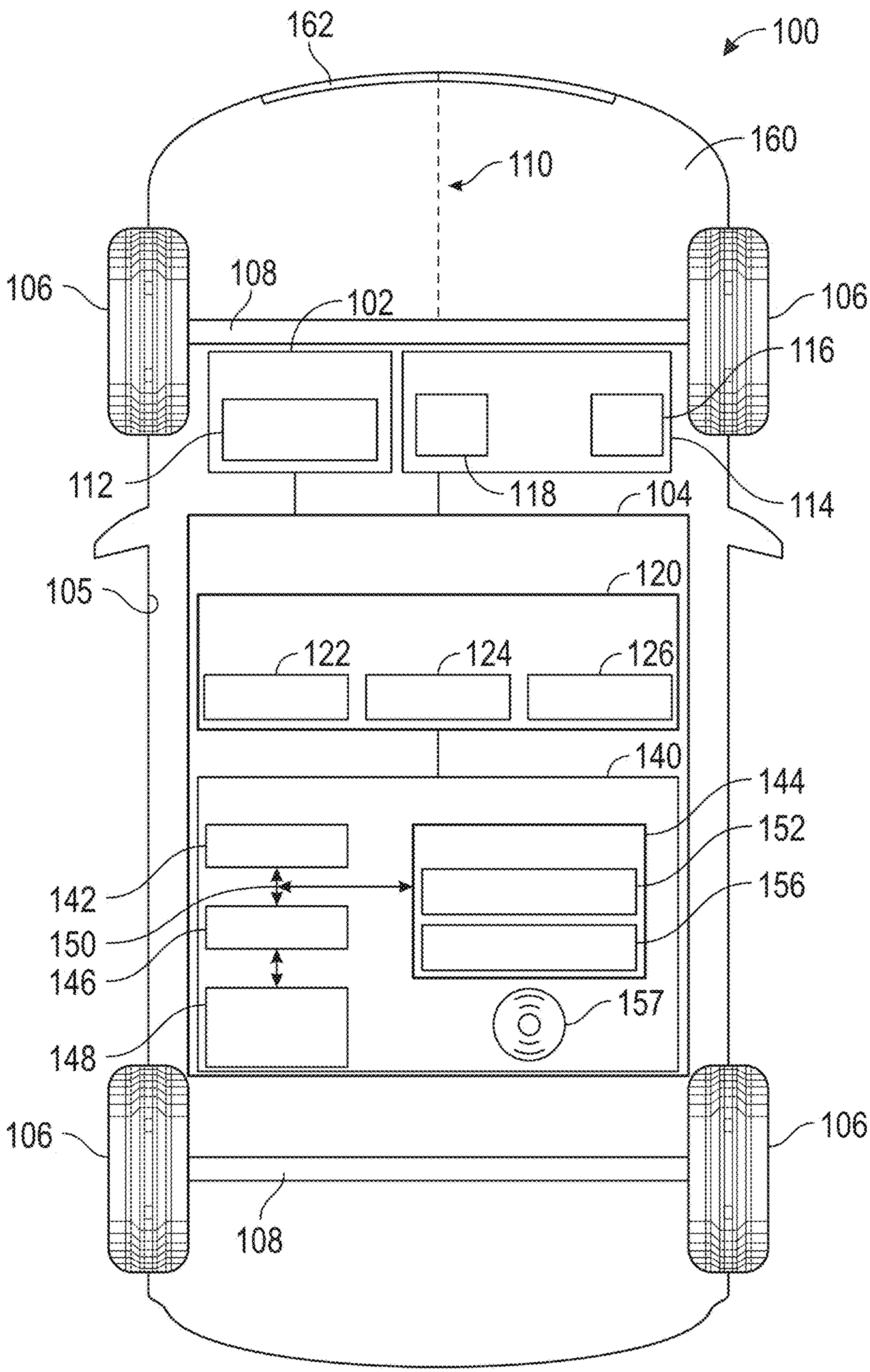
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FIG. 1

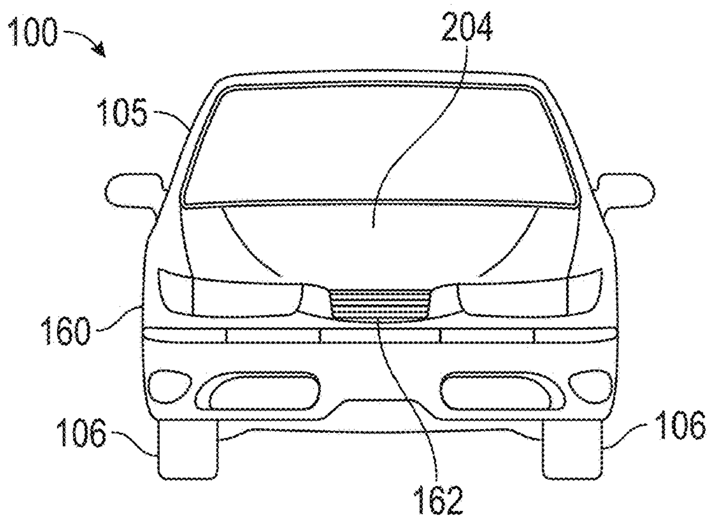
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FIG. 2

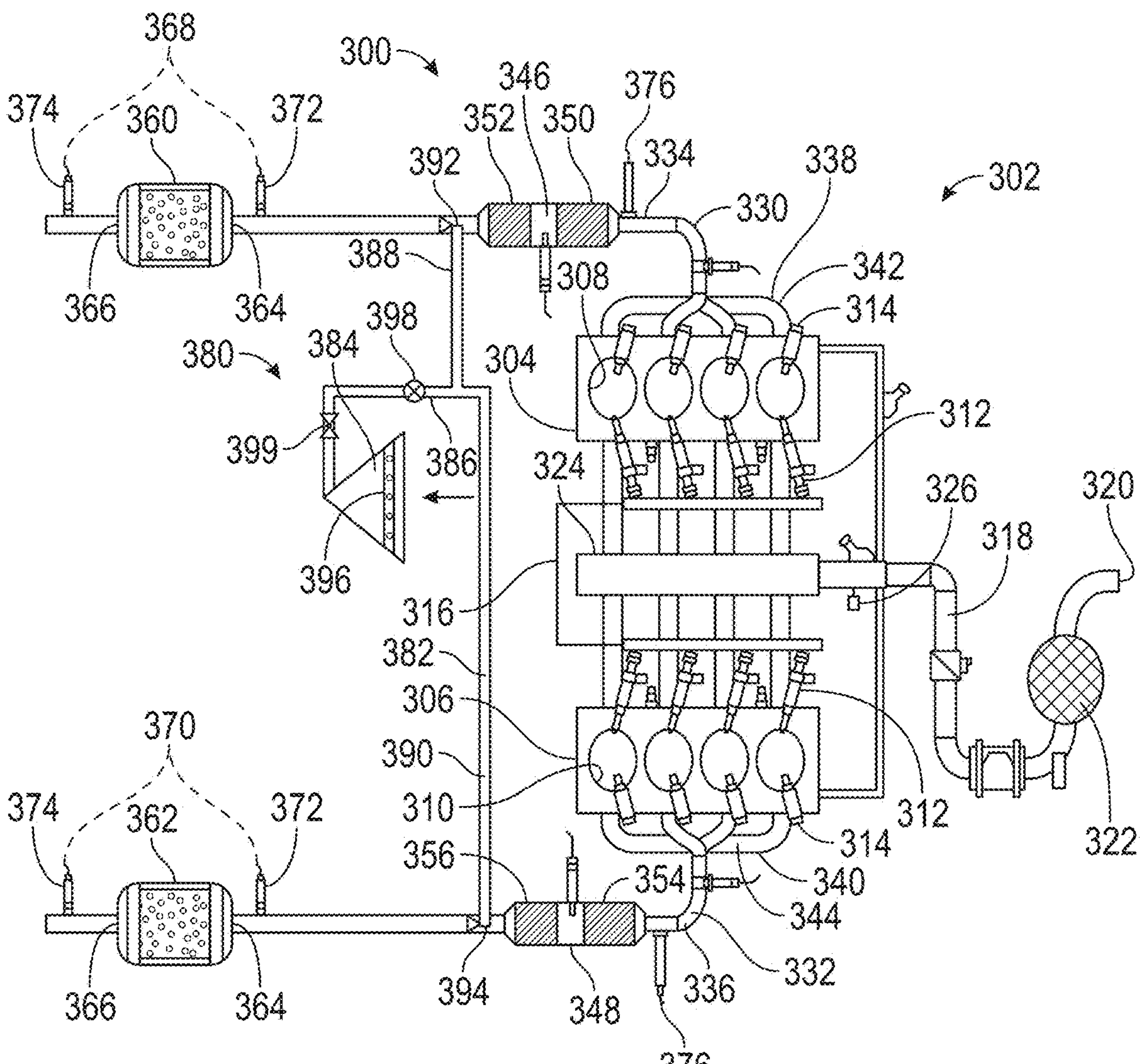
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FIG. 3

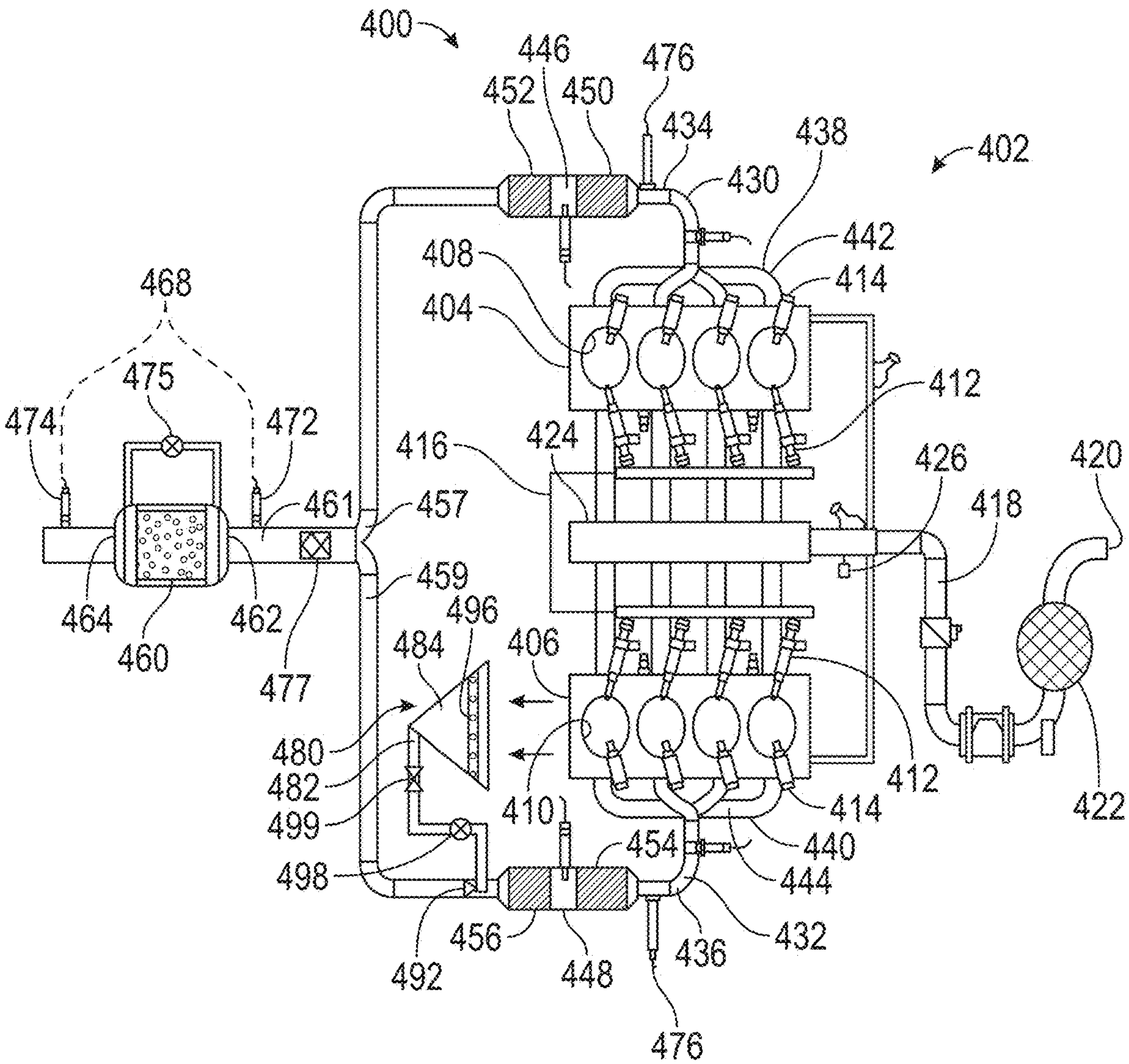
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FIG. 4

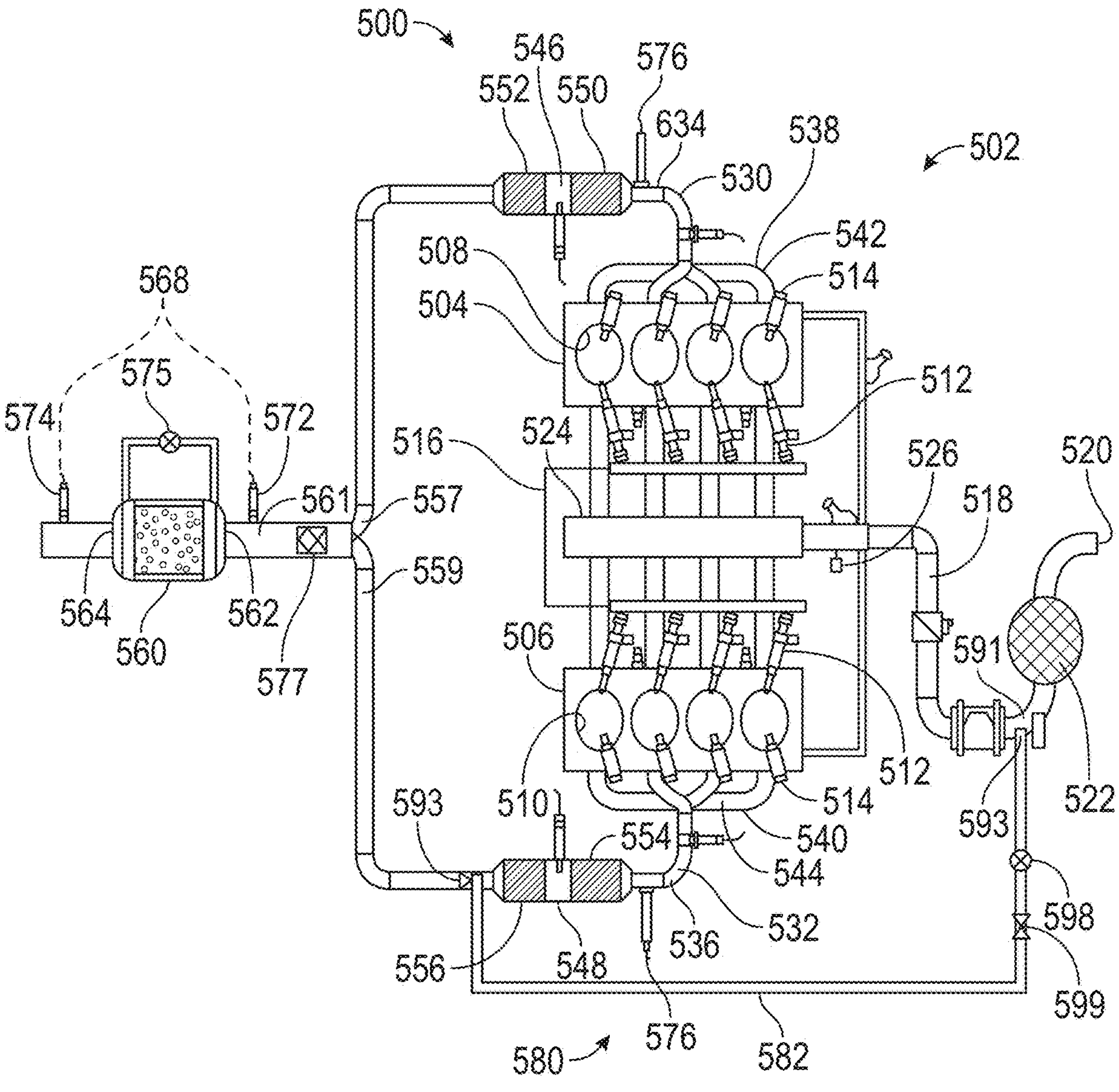
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FIG. 5

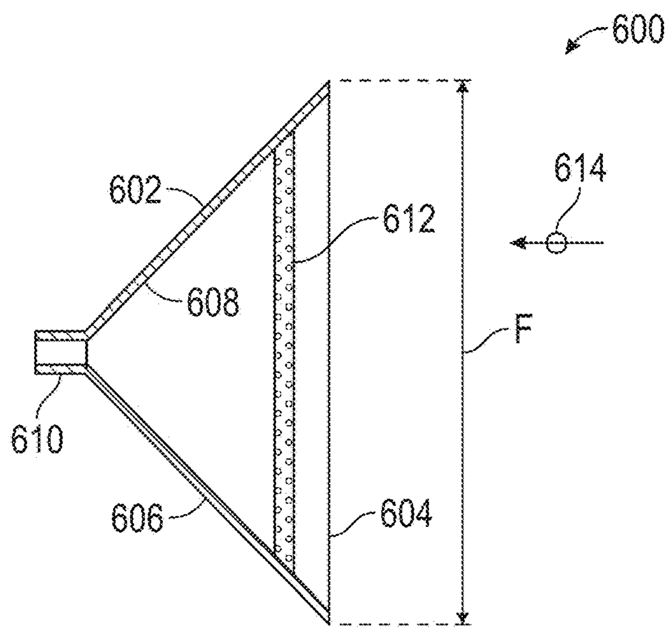
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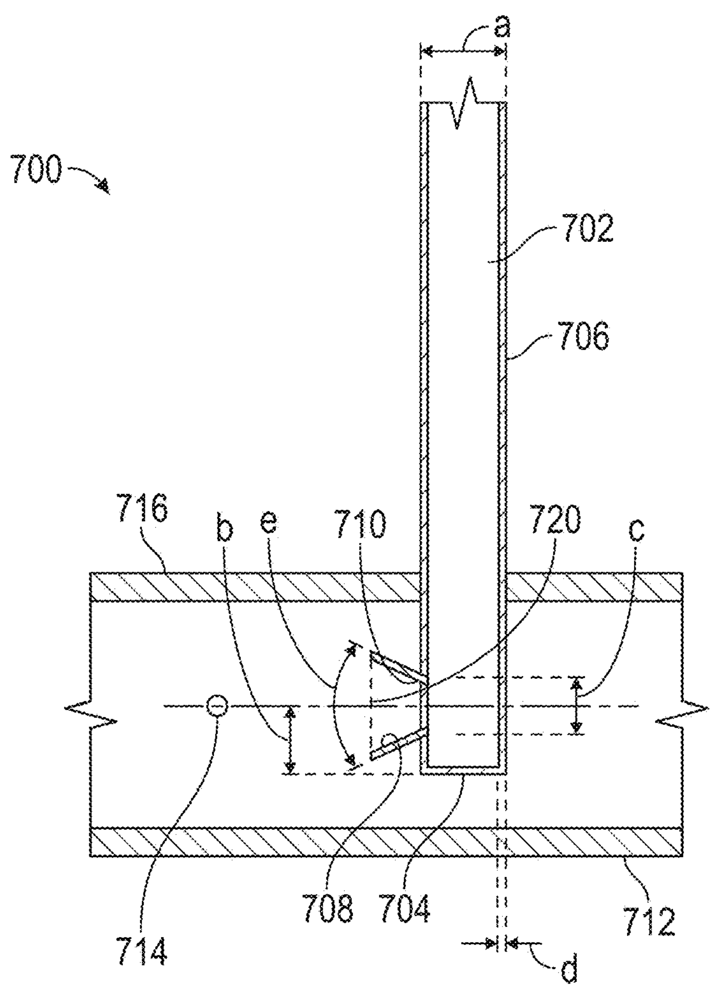
FIG. 6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b
e
710
720
c
714
708
704
712
d

FIG. 7

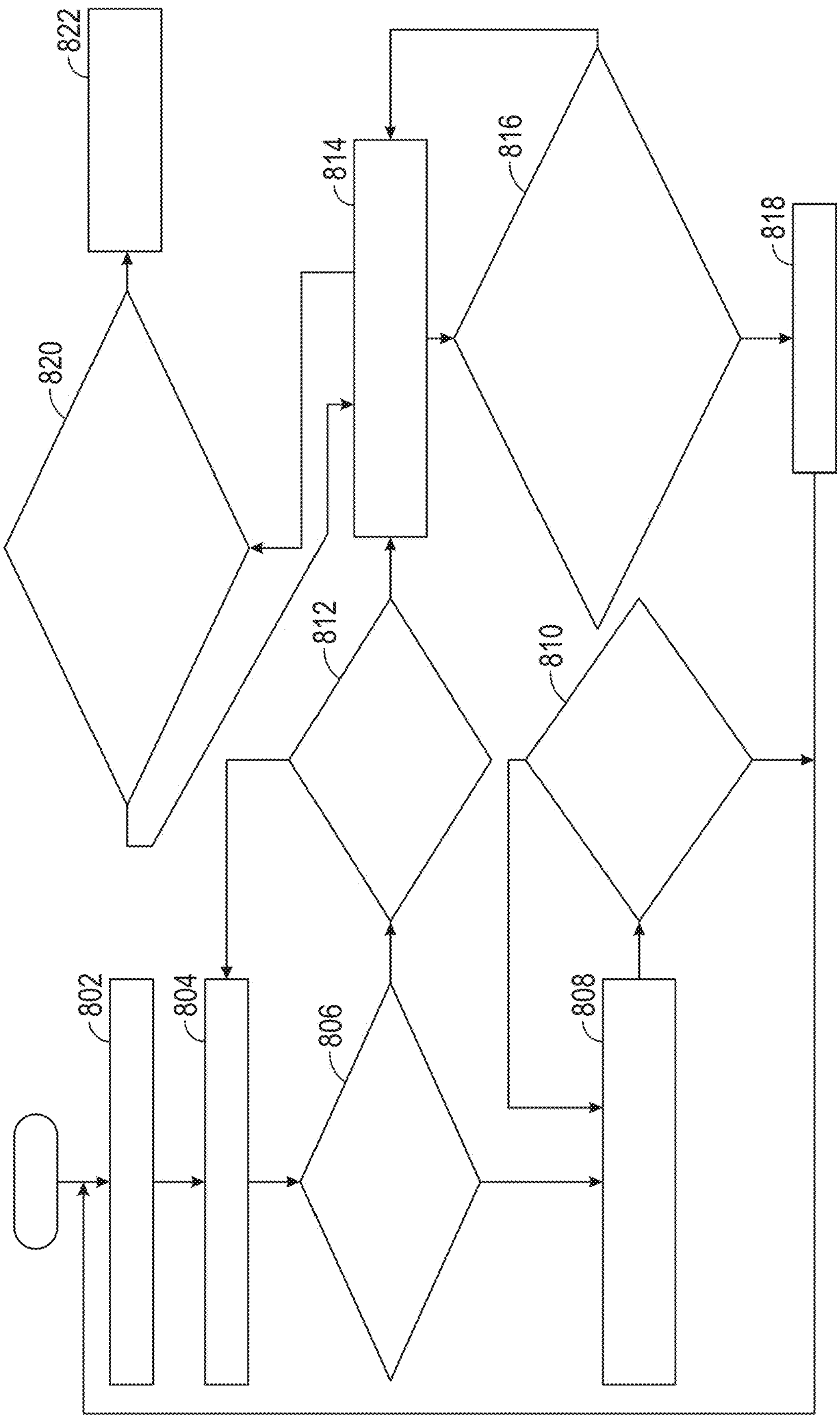

FIG. 8

VEHICLE WITH GASOLINE PARTICULATE FILTER SOOT REGENERATION STRATEGY WITH CRITERIA EMISSION REDUCTION FOR LOW NOX EMISSIONS

INTRODUCTION

The technical field generally relates to vehicles and, more specifically, to methods and systems for controlling particulate filter regeneration for gasoline engines of vehicles.

Many vehicles have exhaust aftertreatment systems with particulate filters to reduce harmful emissions. The particulate filters often require regeneration from time to time due to soot buildup within the filter. However, some existing passive and active regeneration techniques could be improved.

SUMMARY

In an example implementation, a vehicle includes a body, an engine within the body, and at least one exhaust tube extending from the engine and having a particulate filter fluidly coupled to the exhaust tube to receive exhaust material from the exhaust tube. The vehicle also has at least one air injection pipe having a first end with an inlet arranged to receive air flow entering the body while the vehicle is moving. The air injection pipe includes a second end fluidly coupled to the exhaust tube and has an outlet positioned to provide air flow from the injection pipe into the exhaust tube upstream from the particulate filter.

Also in an example implementation, the vehicle includes a valve on the air injection pipe and arranged to be opened and closed depending on a temperature at the particulate filter.

Also in an example implementation, the inlet includes a collector with a free end facing toward a front of the vehicle.

Also in an example implementation, the vehicle includes an air intake manifold with a manifold conduit to direct airflow. The inlet is coupled to the manifold conduit.

Also in an example implementation, the vehicle includes at least one catalytic converter fluidly coupled to the exhaust pipe between the engine and the outlet.

Also in an example implementation, the engine includes two cylinder blocks each with one of the exhaust tubes, and the injection pipe comprises a single inlet and a split into two outlet sections each having one of the second ends and an outlet fluidly coupled to a different one of the exhaust tubes.

Also in an example implementation, the engine includes multiple cylinder blocks, and the at least one exhaust tube comprises two fluidly parallel exhaust pipe sections. Each exhaust pipe section has a first end coupled to a different one of the cylinder blocks and a second end that merges together at a merged exhaust pipe section fluidly coupled to the particulate filter. The injection pipe is coupled to only one of the parallel exhaust pipe sections.

Also in an example implementation, the injection tube has a sidewall with a conical rim defining the outlet.

Also in an example implementation, the vehicle includes temperature sensors of the particulate filter, a valve of the injection pipe, and a controller with at least one processor communicatively coupled to the temperature sensors and the valve. The processor is arranged to operate by controlling the valve to permit air flow through the air injection pipe and to the particulate filter when both temperatures before and after the particulate filter are above a threshold and exhaust pressure in the exhaust tube is less than air pressure at the inlet.

In an example implementation, a method includes obtaining, by processor circuitry forming at least one processor, sensor data indicating a temperature of at least one particulate filter of an emission system of a vehicle. The particulate filter is fluidly coupled to an exhaust tube extending from an engine of the vehicle. Depending on a sensed temperature at the particulate filter, the method includes opening, by the at least one processor, an air injection pipe having an inlet facing forward on the vehicle and disposed to capture under hood airflow entering the vehicle while the vehicle is moving in a deceleration. The air injection pipe includes an outlet fluidly coupled to the exhaust tube between the particulate filter and the engine.

Also in an example implementation, the method includes controlling a maximum air mass flow rate of air to be injected by setting an air injector nozzle diameter at the outlet of the injection pipe and an air collector diameter at the inlet of the injection piper.

Also in an example implementation, the method includes passively activating regeneration of the particulate filter by permitting air flow through the injection pipe when the particulate filter has a temperature of at least 600 deg C. for a non-catalyst particulate filter and 350 deg C. for a catalyst particulate filter.

Also in an example implementation, the method includes passively activating regeneration of the particulate filter by permitting air flow through the injection pipe when the vehicle is decelerating sufficiently to lower exhaust pressure below air pressure at the inlet.

Also in an example implementation, the method includes reducing the THC and CO emissions during a tip-in after deceleration by releasing oxygen stored in catalytic converters during a deceleration dynamic cylinder cut-off (DCCO) event.

Also in an example implementation, the method includes closing the air injection pipe when the particulate filter temperature rises 900 deg C. or 950 deg C.

In an example implementation, an emission system of a vehicle includes at least one exhaust tube extending from an engine of the vehicle and having a particulate filter fluidly coupled on the exhaust tube. At least one temperature sensor is arranged to sense a temperature at the particulate filter. At least one injection pipe has an inlet facing forward on the vehicle and is disposed to capture under hood airflow entering the vehicle while the vehicle is moving in a deceleration. The air injection pipe includes an outlet fluidly coupled to the exhaust tube between the particulate filter and the engine and a valve. Processor circuitry forms at least one processor communicatively coupled to the at least one temperature sensor and the valve, and is arranged to operate by opening and closing the air injection pipe depending on a sensed temperature of the particulate filter.

Also in an example implementation, the emission system comprises a mixer device within the exhaust tube between the outlet and the particulate filter.

Also in an example implementation, the air injection pipe has a sidewall with an opening forming the outlet, and the opening is sized to control an amount of air mass flow rate.

Also in an example implementation, the at least one processor is arranged to operate by opening the air injection pipe when the vehicle is determined to be running in a DCCO event. The air injection pipe may be opened for two seconds or more at a time.

Also in an example implementation, the particulate filter has an inlet temperature sensor and outlet temperature sensor. The at least one processor is arranged to operate by performing a health diagnosis of an air injection system and the particulate filter including determining at least one of: a particulate filter temperature difference between before and after air injections into the particulate filter and at multiple different engine speeds, or particulate filter inlet and outlet temperature differences with and without air injection under different engine speeds.

DESCRIPTION OF THE DRAWINGS

The present disclosure will hereinafter be described in conjunction with the following drawing figures, where like numerals denote like elements and the drawings are not to scale, and where:

FIG. **1** is a schematic diagram of an example vehicle according to at least one of the implementations herein;

FIG. **2** is a schematic diagram of a front view of the example vehicle of FIG. **1** according to at least one of the implementations herein;

FIG. **3** is a schematic diagram of an example emission system on the vehicle of FIG. **1** according to at least one of the implementations herein;

FIG. **4** is a schematic diagram of an alternative example emission system on the vehicle of FIG. **1** according to at least one of the implementations herein;

FIG. **5** is a schematic diagram of another alternative example emission system on the vehicle of FIG. **1** according to at least one of the implementations herein;

FIG. **6** is a schematic diagram of a cross-sectional view of an air collector according to at least one of the implementations herein;

FIG. **7** is a schematic diagram of a cross-sectional view of an air injection pipe according to at least one of the implementations herein; and

FIG. **8** is a flow chart of a process of particulate filter regeneration for vehicles according to at least one of the implementations herein.

DETAILED DESCRIPTION

The following detailed description merely describes example implementations and are not intended to limit the disclosure or the application and uses thereof. Furthermore, no intention exists to be bound by any theory presented in the preceding background or the following detailed description.

Referring to FIG. **1**, an example vehicle **100** has a drive system **102**, an emission system **114**, and a control system **104**. Also as described below in accordance with various implementations, the drive system **102** includes an engine **112**, and the emission system **114** has a particulate filter (PF) **116** with an air injection assembly (AIA) **118**. The control system **104** controls particulate filter regeneration of the PF via the AIA **118** (for example as described in greater detail below in connection with the vehicle **100** of FIG. **1**, and the process **800** of FIG. **8** in accordance with various implementations).

In various implementations, the vehicle **100** comprises an automobile. The vehicle **100** may be any one of a number of different types of automobiles, such as, for example, a sedan, a wagon, a truck, or a sport utility vehicle (SUV), and may be two-wheel drive (2WD) (i.e., rear-wheel drive or front-wheel drive), four-wheel drive (4WD) or all-wheel drive (AWD), and/or various other types of vehicles. In certain implementations, the vehicle **100** may also comprise a motorcycle or other vehicle, such as an aircraft, spacecraft, watercraft, and so on, and/or one or more other types of mobile platforms (e.g., a robot and/or other mobile platform) that have an emission system.

As depicted in FIG. **1**, the vehicle **100** includes a body **105** that is arranged on a chassis **110**. The body **105** substantially encloses other components of the vehicle **100** and has a front **160** with a front or air grille **162**. As shown on FIG. **2**, the body **105** may include a hood **204** that covers the engine **112**, while the air grille **162** on the front **160** of the vehicle, and in turn in front of engine **112**, provides passages for airflow to enter the body from outside of the body and onto or over (or under) the engine **112**, referred to herein as under-hood air or air flow. Air may reach the engine **112** and emission system **114** from underneath the body **105** as well as other opening on the body **105**. The body **105** and the chassis **110** may jointly form a frame. The vehicle **100** also includes a plurality of wheels **106** and wheel axles **108** coupled thereto. The wheels **106** are each rotationally coupled to the chassis **110** near a respective corner of the body **105** to facilitate movement of the vehicle **100**. In one implementation, the vehicle **100** includes four wheels **106**, although this may vary in other implementations (for example for trucks and certain other vehicles).

In various implementations, the drive system **102** is mounted on the chassis **110**, and drives the wheels **106** via the wheel axles **108**. In the depicted implementation, the drive system **102** is a propulsion system that includes the engine **112** as an internal combustion engine **112**. The engine **112** is fluidly coupled to the emission system **114**. In various implementations, the emission system **114** directs exhaust from the engine **112** to emission reduction devices such as the PF **116** before ejecting the exhaust from the vehicle **100**. The PF **116** filters soot in exhaust gases generated by the engine **112** and needs to be periodically regenerated to remove the soot from the PF **116**. The present vehicle **100** adds an air injection assembly **118** to the emission system **114** as well as operations of a control system **104** to control the air injection assembly **118**. The details are provided below.

Referring to FIG. **3**, an example emission system **114** of vehicle **100** is the same or similar to emission system **300**. The system **300** extends from an engine **302** that may be the same or similar to engine **112**. The engine **302** has two cylinder blocks **304** and **306** each with cylinder bores **308** and **310** with spark plugs **314** and fuel injectors **312**. A fuel rail **316** delivers fuel to the fuel injectors **312**.

An air intake manifold **318** has an inlet (or inlet portion) **320** that directs air through an air filter **322** and then to an arrangement of conduits **324** that directs the air to the cylinder blocks **304** and **306**. An air pressure (or intake manifold pressure) **326** monitors the air pressure inside the intake manifold **318**. Air and fuel delivered to the cylinder bores **308** and **310** combust and cause pistons (not shown) within the bores to reciprocate within the bores thereby driving a drive shaft, which in turn drives the wheel axles **108** and wheels **106**. The engine **302** and components thereof may or may not be considered part of the emission system **300**.

As to the emission system **300**, one or more (here two) exhaust assemblies **330** and **332** respectively extend back from cylinder blocks **304** and **306**, and have respective exhaust tubes **334** and **336** with a branched inlet end **338** and **340** each with branches **342** and **344**, respectively, that fluidly couple to a different cylinder bore **308** or **310** to provide an exit for exhaust material from the cylinder bores **308** and **310**. It should be noted that the terms tube, pipe, and conduit are used interchangeably herein and refer to members that provide passage for solids, liquids, and/or gases and are not limited to a specific cross-sectional shape (such as circular or cylindrical) unless the context indicates otherwise. Also, it will be appreciated that one or more exhaust valve phasers (not shown) may be on or attached to the engine **302** to control the flow of exhaust gases from the cylinder bores **308** and **310** and into the exhaust tubes **334** and **336**.

In this example form, the emission system **300** is a dual catalytic converter, three way catalyst (such as TWC-1) system, although other types of emission systems could be used here instead. In this example, the exhaust tubes **334** and **336** each are fluidly coupled to, or have, a catalytic converter device **346** or **348** downstream (or further back from, in this example) the engine **112**, and each catalytic converter device **346** and **348** respectively has a front closed coupled catalytic converter **350** or **352** and a rear closed catalytic converter **354** or **356**, although many other types and arrangements of catalytic converter devices can be used instead.

Also in this example implementation, the exhaust tubes **334** and **336** each have a fluidly coupled particulate filter (PF) **360** or **362**, and by one example, is a gasoline particulate filter (GPF) that may be a bare PF or catalyst PF. Each PF **360** and **362** has an inlet end **364** and an outlet end **366**. Downstream from the PFs **360** and **362**, the exhaust tube may fluidly connect to other known components, such as a muffler, before terminating at an outlet (not shown) typically disposed at a rear of the vehicle **100**. It will be appreciated that other types of PFs **360** and **362** can be used.

The emission system **300** also has several sensors throughout the system **300** to monitor various parameters of the operation of the system **300**. Most relevant here, each PF **360** and **362** has a thermocouple **368** and **370** where each thermocouple has an inlet side exhaust gas temperature (EGT) sensor **372** near the inlet end **364** of the PF **360** and **362**, and an outlet side exhaust gas temperature (EGT) sensor **374** near the outlet ends **366** of the PFs **360** and **362**. In this example, other pressure and temperature sensors are provided as well, including an EGT sensor **376** upstream from the PFs **360** and **362** by one example, and also upstream from the catalytic converter devices **346** and **348** and downstream from the engine **302**.

The emission system **300** has an air injection assembly (AIA) **380**, similar to or the same as AIA **118** (FIG. **1**), that fluidly couples to the exhaust tubes **334** and **336** to inject air, which may be external air, into the exhaust tubes **334** and **336**, and in turn, into the PFs **360** and **362**. Specifically, the AIA **380** has an air injection pipe **382**, and in this example, in three sections including an inlet section **386** that has an inlet collector **384** and that splits into at least two outlet branches **388** and **390** that each have outlets (or outlet ends) **392** and **394** respectively coupled to a different one of the exhaust tubes **334** and **336**. It will be understood that the air injection pipe **382** may have one outlet branch for each exhaust tube being coupled to. Also, by one alternative the outlets **392** and **394** are near, at, or within outlets of the catalytic converter devices **346** or **348**.

The air injection pipe **382** of the AIA **380** may be made of steel, mild steel, stainless steel, aluminum steel, composite materials such as carbon fiber or fiberglass-reinforced plastics (FRP), and so forth, as long as the material adequately handles the temperatures and air or gas pressures expected to be experienced by an AIA **380** in an emission system.

The AIA **380** optionally may have an air injection pipe valve **398** that may be an open/close valve, shut-off valve, and so forth that is controlled to completely open or close, but could be a valve, such as a control valve, that has intermediate positions to precisely vary the amount of air flow. The AIA **380** also may have a one way valve **399** to block any undesired reverse flow. The collector **384** has an air filter **396** as well. Other details of the collector **384** are provided at FIG. **6**, and other details of the outlets **392** and **394**, including an optional nozzle, are provided at FIG. **7**.

With this arrangement, the particulate filter **360** or **362** can be passively regenerated when the vehicle is moving in a deceleration mode. Specifically, deceleration may occur when a user is not pressing the accelerator and the vehicle is coasting, or an autonomous drive system control is not injecting fuel into the engine, and this be in a short or transient period as short as two seconds. In other situations, the vehicle may be in a dynamic cylinder cut off (DCCO) mode, where less than all cylinders, or no cylinders, of the engine **112** are used. The DCCO mode is often used to reduce test cycle nitrogen oxide (NOx) emissions. Another situation is a deceleration fuel cut-off (DFCO) mode where fuel injection is momentarily ceased during deceleration to save fuel. While the vehicle **100** is moving forward, these and other deceleration modes cause a situation where exhaust from the engine **112** in the exhaust tubes **334** and **336** have a low exhaust back pressure compared to relatively higher air pressure of relatively high air mass flow rate or air energy of external or ambient air entering into the vehicle body under the hood **204** from the front air grille **162** by one example. Air could also enter under the hood **204** and/or into the air intake manifold **318** from other locations.

The low exhaust pressure permits the air (or more air) to be introduced into the particulate filter (PF) **360** or **362** via the air injection tube **382**. The trapped air in the PFs **360** and **362** burn particulate matter (PM), total hydrocarbons (THC), and carbon monoxide (CO) emissions, or in other words soot, at sufficiently high temperatures in the PF **360** or **362**. This is a passive rather than active process. This avoids active regeneration that tends to raise NOx emissions instead. The reduction in NOx and soot is accomplished by controlling the air flow rate to the PFs **360** and **362**. While the engine **302** is propelling the vehicle, the oxygen stored in the GPF can further reduce HC and CO emissions at the tip-in rich operation. This provides the vehicle **100** with better compliance with governmental vehicle emission regulations. Also, the present passive regeneration can indirectly result in a reduction of consumption of platinum group metals (PGMs) at the catalytic converter devices **346** and **348**, creating substantial financial savings.

The low exhaust pressure and high air mass flow rate (or high air flow pressure) causes intake air pressure pulses when the engine cylinders shut off suddenly, which causes the injection of the air to the front of the PF **360** or **362** at the beginning of the deceleration (DCCO) events. In addition, this situation also improves drive quality performance at the tip-in (when the engine is re-activated to propel the vehicle again) after the deceleration events by further releasing or pulsing air in the intake manifold **318** to the PF **360** or **362**. In this case, the PF **360** or **362** uses the additional oxygen in the PF **360** or **362** to burn additional THC and CO.

Regarding the valve **398**, a controller **140** (FIG. **1**) can open and close the valve **398** depending on PF activation and deactivation temperatures, and detection (or assumption) of the lower exhaust pressure, as described in detail below. By an alternative form, however, the valve **398** may be omitted entirely in order to save costs. In this case, the air injection pipe **382** remains open. In the present example, the valve **398** may be an open/close valve or shut-off valve that only has a fully open or fully closed position. In other forms, the valve **398** may have varying positions between open and closed to more precisely control the air mass flow rate as desired.

Referring again to FIG. **1**, in various implementations when the control system **104** controls regeneration of the particulate filter (PF) **360** or **362** (or **116**) for example, the control system **104** provides instructions or control signals that control the valve **398** to selectively open or close, for example as described in greater detail below in connection with the process **800** of FIG. **8**. Also in various implementations, the control system **104** may be coupled to the drive system **102** and emission system **114** to provide various other control functionality for the drive system **102**, emission system **114**, and/or for various other systems and components of the vehicle **100**.

In various implementations, the control system **104** includes a sensor array **120** and the controller **140**. In various implementations, the sensor array **120** includes sensors that obtain sensor data pertaining to the emission system **114** and for use in controlling the drive system **102**, including the regeneration of the PF **116**. In the depicted implementation, the sensor array **120** includes one or more soot sensors **122** and temperature sensors **124**. It will be appreciated that in certain implementations the sensor array **120** may also contain any number of other sensors **126** including air or exhaust pressure sensors.

In various implementations, the soot sensors **122** detect a presence, amount, and/or concentration of soot in the PF **116**. As used herein throughout this Application, the term "soot" is used to refer to any particles or matter generated by the combustion of the engine **112**, including without limitation powdery, flaky, or other carbon substances generated by the combustion. In certain implementations, the soot sensors **122** may comprise one or more pressure sensors, such as a differential pressure sensor or delta P sensor. Otherwise, the temperature sensors themselves may be used to compute pressure, and in turn an indication of the amount of soot in the PF **116**. However, this may vary in other implementations, for example in that one or more other sensors may also be utilized in certain implementations.

In various implementations, the temperature sensors **124** include exhaust gas temperature (EGT) sensor thermocouples **368** and **370** (FIG. **3**), upstream exhaust temperature sensors **376** (FIG. **3**), and others when desired that are configured to measure air temperature of one or more portions of the air of the emission system **114**. In various implementations, the temperature sensors **124** are used to measure a temperature of exhaust at the inlet **364** and/or outlet **366** at the PF **360** or **362**, for example.

In certain implementations, the sensor array **120** may also include one or more additional types of sensors **126**, such as the air intake pressure sensor **326**, oxygen sensors, intake manifold air flow sensors, as well as many other sensors as desired such as, by way of example, one or more engine torque sensors, among other different possible types of sensors.

In various implementations, the controller **140** is coupled to the sensor array **120**. In various implementations, the controller **140** is also coupled to the drive system **102** and emission system **114**. In various implementations, the controller **140** may also be coupled to one or more other systems and/or components of the vehicle **100**.

As depicted in FIG. **1**, in various implementations the controller **140** comprises a computer system (also referred to herein as computer system **140**), and includes processor circuitry forming at least one processor **142**, a memory **144**, an interface **146**, a storage device **148**, and a computer bus **150**. In various implementations, the controller (or computer system) **140** controls regenerative filtering of the PF **116**. In various implementations, the controller **140** controls various other functions of the vehicle **100**, including movement of the vehicle **100**, and various other functions of the drive system **102** and various other vehicle systems and components. In various implementations, the controller **140** provides these and other functions in accordance with the operations of the process **800** of FIG. **8** and as described further below in connection therewith.

In various implementations, the controller **140** (and, in certain implementations, the control system **104** itself) is disposed within the body **105** of the vehicle **100**. In one implementation, the control system **104** is mounted on the chassis **110**. In certain implementations, the controller **140** and/or control system **104** and/or one or more components thereof may be disposed outside the body **105**, for example on a remote server, in the cloud, or other device where image processing is performed remotely. Thus, it will be appreciated that the controller **140** may otherwise differ from the implementation depicted in FIG. **1**. For example, the controller **140** may be coupled to or may otherwise utilize one or more remote computer systems and/or other control systems, for example as part of one or more of the above-identified vehicle **100** devices and systems.

The at least one processor **142** performs the computation and control functions of the controller **140**, and may comprise any type of processor or multiple processors, single integrated circuits such as a microprocessor, multiple processor cores, system on a chip (SoC), or any suitable number of integrated circuit devices and/or circuit boards working in cooperation to accomplish the functions of a processing unit.

During operation, the at least one processor **142** executes one or more programs **152** contained within the memory **144** and, as such, controls the general operation of the controller **140** and the computer system of the controller **140**, generally in executing the processes described herein, such as the process **800** of FIG. **8** and as described further below in connection therewith. Thus, process **800** may be performed by a program **152** operated by the at least one processor **142** such as a particulate filter (PF) regeneration program or system, and the processor **142** may perform each operation of process **800** by operating a separate unit or module of program **152** that performs individual operations of process **800** by any combination of software, firmware, and/or hardware. It will be understood that a single unit or module of the program **152** may perform multiple operations of process **800**. It will be appreciated that one or more of the units of program **152** performing operations of process **800**, as well as one or more processors **142**, may be remote from vehicle **100** and communicate wirelessly with units or programs **152** that are still onboard to operate the air injection pipe valve **398**.

Memory **144** can be any type of suitable memory. For example, memory **144** may include various types of dynamic random access memory (DRAM) such as SDRAM, the various types of static RAM (SRAM), and the various types of non-volatile memory (PROM, EPROM, and flash). In certain examples, memory **144** is located on and/or co-located on the same computer chip as the processor **142**. In the depicted implementation, memory **144** stores the above-referenced program **152** along with one or more stored values **156** (e.g., threshold values for controlling particulate filter regeneration).

The bus **150** serves to transmit programs, data, status and other information or signals between the various components of the computer system of the controller **140**. The interface **146** allows communication to the computer system of the controller **140**, for example from a system driver and/or another computer system, and can be implemented using any suitable method and apparatus. In one implementation, the interface **146** obtains the various data from the sensor array **120**. The interface **146** can include one or more network interfaces to communicate with other systems or components. The interface **146** may also include one or more network interfaces to communicate with technicians, and/or one or more storage interfaces to connect to storage apparatuses, such as the storage device **148**.

The storage device **148** can be any suitable type of storage apparatus, including various different types of direct access storage and/or other memory devices. In one example implementation, the storage device **148** comprises a program product from which memory **144** can receive a program **152** that executes one or more implementations of the process **800** of FIG. **8** and as described further below in connection therewith. In another example implementation, the program product may be directly stored in and/or otherwise accessed by the memory **144** and/or a disk (e.g., disk **157**), such as that referenced below.

The bus **150** can be any suitable physical or logical structure of connecting computer systems and components. This includes, but is not limited to, direct hard-wired connections, fiber optics, infrared and wireless bus technologies. During operation, the program **152** is stored in the memory **144** and executed by the processor **142**.

It will be appreciated that while this example implementation is described in the context of a fully functioning computer system, those skilled in the art will recognize that the mechanisms of the present disclosure are capable of being distributed as a program product with one or more types of non-transitory computer-readable signal bearing media used to store the program and the instructions thereof and carry out the distribution thereof, such as a non-transitory computer readable medium bearing the program and containing computer instructions stored therein for causing a computing device or computer processor (such as the processor **142**) to perform and execute the program. Such a program product may take a variety of forms, and the present disclosure applies equally regardless of the particular type of computer-readable signal bearing media used to carry out the distribution. Examples of signal bearing media include: recordable media such as floppy disks, hard drives, memory cards and optical disks, and transmission media such as digital and analog communication links. It will be appreciated that cloud-based storage and/or other techniques may also be utilized in certain implementations. It will similarly be appreciated that the computer system of the controller **140** may also otherwise differ from the implementation depicted in FIG. **1**, for example in that the computer system of the controller **140** may be coupled to or may otherwise use one or more remote computer systems and/or other control systems.

Referring to FIG. **4**, an alternative emission system **400** for vehicle **100** has many of the same or similar parts that are numbered similarly to that already numbered on emission system **300** (FIG. **3**) such that these parts need not be described again. Different here, however, exhaust tubes **432** and **434** each have a merging outlet end **457** and **459**, respectively that merge together into a single shared or joint exhaust pipe **461** that has one or more shared PFs **460** with an inlet end **462**, outlet end **464**, and a thermocouple **468** with an inlet temperature sensor **472** and an outlet temperature sensor **474**. In this example, the PF **460** also may have a delta P sensor (or other type of pressure sensor) that measures the pressure differential across the PF **460**, which can be used to measure an amount of soot at the PF **460**. The exhaust pipe **461** may lead to a single GPF and other known exhaust components rather than multiple components for multiple exhaust tubes as in emission system **300** (FIG. **3**) in order to reduce financial costs.

In this example with merging parallel exhaust tubes **432** and **434**, an air injection assembly (AIA) **480** has an air injection pipe **482** that extends from one of the parallel exhaust tubes **432** or **434** but not both. Similar to air injection assembly **380**, air injection assembly **480** has a widened, free end collector **484** as an inlet of the air injection pipe **482**, and an outlet **492** fluidly coupled to one of the exhaust tubes **432** or **434** to provide the collected high air mass flow to the PF **460** via the exhaust tube **432** or **434** and exhaust pipe **461**. The injected air from one side of the engine bank (or a single exhaust tube **432** or **434**) can achieve better mixing, and in turn a better uniformity resulting in air-exhaust gas mixed at the shared or joint pipe **461** entering the PF **460**, thereby resulting in more reduction of THC, CO, and PM soot within the PF **460**.

The AIA **480** has an open/close (or shut off or other) valve **498** on the air injection pipe **482** to control the air mass flow rate to the PF **460**, and a one-way valve **499** to limit reverse flow in the air injection pipe **482**. The valve **498** may be controlled by controller **140** and program **152** as described elsewhere herein.

The present arrangement collects and filters the high air mass flow when the vehicle is moving in a low exhaust pressure mode as mentioned above, and the other advantages mentioned above with emission system **300**, such as further soot burning upon a tip-in, still apply equally here as well.

By yet another alternative, a mixer device **477**, such as a swirl vane or ball-shaped mixer for example, may be placed upstream the inlet **462** of the PF **460** in the joint exhaust pipe **461** to provide further mixing of the injected air and any exhaust gas present to generate an even more homogeneous mixed flow before entering the PF **460**.

Referring to FIG. **5**, an alternative emission system **500** for vehicle **100** has many of the same or similar parts that are numbered similarly to that already numbered in emission systems **300** (FIG. **3**) and/or **400** (FIG. **4**) such that these parts need not be described again. Different here, however, an air injection assembly (AIA) **580** has an air injection pipe **582** with an inlet **593** that fluidly couples directly (or fluidly sealed) to a conduit **591** of the air intake manifold **518** rather than using a collector at a free inlet end. The AIA **580** still has a one-way valve **599** and optionally a valve **598** to open or close the air injection pipe **582** as controlled by controller **140** and program **152** for example. Again, many of the advantages of emission systems **300** and **400** of providing a high or good air mass flow rate to the PF during low exhaust pressure also apply here for emission system **500** as well.

Referring to FIG. **6**, a collector **600**, similar or the same as collector **384** (FIG. **3**) or **484** (FIG. **4**), has a funnel-shaped body **602** with an inlet end **604** to form an inlet of the air injection pipe **382** or **482**. The collector **600** also has an opening of the inlet end **604** with an inner diameter or width F that can be sized by experimentation to set or limit a maximum air mass flow rate. A pyramidal sidewall **606** extends from the inlet end **604** to an outlet end **610** for connection to the air injection pipe. An air filter **612**, formed of paper, fabric, or other known filter materials, is mounted at an inner surface **608** of the sidewall **606**. The inlet end **604** is positioned under the hood of the vehicle to face forward and collect air entering the vehicle under the hood. The inlet end is a free end, which refers to the fact that the free end is not fluidly enclosed in another conduit or air passage to collect ambient or under-hood air. Thus, the inlet end **604** still may be fixed to other structures to limit or stop the motion of the inlet end **604** relative to the vehicle or other components in the vehicle **100**.

Referring to FIG. **7**, an air injection pipe **700**, similar or the same as air injection pipe **382**, **482**, or **582**, has a tubular body **702** that may be made of stainless steel or other material mentioned above. The body **702** is shown here to be straight but need not always be straight. The body **702** has an outlet end **704**, here being welded closed. The inlet of the air injection pipe **700** is shown above in FIGS. **3-6**. The outlet end **704** has a sidewall **706** with an outlet opening (or outlet or opening) **708** defined by a rim **710**. By one form, the rim **710** is circular and slants outward to have a frustoconical surface so that an outer edge of the rim **710** has a larger diameter than a diameter of the inner edge of the rim **710**. By one alternative, the outlet **708** is coupled to a nozzle **720**, such as by welding, molding, or other attachment, and that is frustoconical with the same or different slope as the rim **710**, or finishing a tapered hole. The slop of the rim **710** and/or nozzle **720** directs the injected air to spread when entering an exhaust tube **712**. The air injection pipe **700** is shown extending through a sidewall **716** of the exhaust tube **712**.

The dimensions of the air injection pipe **700** can be sized to control the air mass flow rate, and may include an outer diameter a and a wall thickness d, an inner diameter c of the outlet **708**, a distance b from a centerline **714** of the outlet **708** and a distal end of the outlet end **704**, and an included angle e at the frustoconical rim **710** or nozzle **720**. By one example form, a=1.0 inch, b=0.4 inches, c=0.5 inches, d=0.3 inches, and e=80 degrees. The dimensions of the injection pipe **700**, particularly at the rim **710** and nozzle **720** as well as the diameters at the collector **600**, can be sized to set a maximum air mass flow rate to be injected. The air inlet diameters determine how much air is to be trapped at the PF, and the air injection nozzle diameter values determine the flow coefficients that are to be used for the emission system and the air distribution of the air injections.

Specifically for one possible example, the air flow when using a nozzle **720** can be found by computing:

$$m = \frac{Cnozzle * a_{Nozzle} P_1}{\sqrt{RT}} \sqrt{\frac{2\gamma}{\gamma - 1}\left(\frac{P_2}{P_1}\right)^{\frac{2}{\gamma}}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]} \quad (1)$$

where m is air flow rate (or air mass flow rate), where Cnozzle is the nozzle discharge coefficient, a_{Nozzle} is the cross-sectional area of the nozzle's throat, where P_1 and P_2 are the upstream and downstream pressures relative to the nozzle respectively, where R is the gas constant J/kg, K, where T is a temperature before the inlet of the PF, and where y is the specific heat ratio. One example way to determine the relationship between P_1 and P_2 is as follows:

$$P_1 + (1/2)\rho v_1^2 + \rho g h_1 = P_2 + (1/2)\rho v_2^2 + \rho g h_2 \quad (2)$$

where ρ is fluid density, v is fluid velocity, and to include hydrostatic pressure, g is acceleration due to gravity, and h is fluid depth.

Referring now to FIG. **8**, a process **800** of particulate filter regeneration with air injection is described in accordance with example implementations herein. The process **800** is described herein with operations **802** to **822**, generally numbered evenly. In various implementations, the process **800** can be implemented in connection with the vehicle **100** of FIG. **1**, including the drive system **102**, emission systems **114**, **300**, **400**, or **500** of FIGS. **1** and **3-5**, the control system **104** of FIG. **1**, and components thereof, which are referred to herein where relevant.

The process **800** includes "operate vehicle" **802**, and this refers to a first stage with normal operation where it does not matter if the vehicle is accelerating or decelerating, or even in an idle since at this point, the system or process **800** will first check the soot amount in the PFs **116**. It will be appreciated that this operation and others of process **800** may be performed continuously in a loop during operation of the vehicle while the vehicle is moving.

The process **800** includes "receive emission parameters" **804**, and in various implementations, where sensor data is obtained. In various implementations, sensor data is obtained with respect to the operation of the drive system **102** and emission systems **114**, **300**, **400**, and **500** of FIGS. **1** and **3-5**. In various implementations, the sensor data is obtained via sensors of the sensor array **120** and are provided to the processor **142** (FIG. **1**) for processing.

Specifically, in various implementations, the sensor data includes engine control module (ECM) data including soot detection data as to the presence and amount of soot (e.g., an estimated volume, mass, and/or percentage concentration thereof) in the particulate filter **116** (FIG. **1**). In various implementations, the soot data is obtained via one or more soot sensors **122** (FIG. **1**), such as one or more differential pressure sensors such as a delta P sensor since the pressure difference across the PF indicates soot load. Otherwise, one or more temperature sensors (mentioned below) can be used to convert temperature into pressures at the PFs **360** and **362** (or **116**) for example. Other types of soot detection sensors may be used as well, and the sensor data provided to the processor **142** for processing.

Also in various implementations, the sensor data of operation **804** further includes temperature data as to one or more temperatures of air along the flow path of exhaust tubes **334** and **336** of FIG. **3** for example. In various implementations, the temperature data is generated from thermocouples **368** and **370** at the PFs **368** and **370**, as well as temperature sensors **376** at the upstream ends of the exhaust tubes **334** and **336** near the engine **302**. The temperature data is also provided to the processor **142** for processing. In various implementations, the sensor data (including the soot amount data and the temperature data) is collected and used continuously throughout the process **800**.

Other sensors **126** may include those that measure engine speed, torque, air flow, coolant, ambient temperature, intake manifold air pressure, and so forth that may be used by the emission system.

By one optional form, particulate filter regeneration is not performed until it is requested. In this example approach, particulate filter regeneration is requested in accordance with instructions provided by the processor **142** when a concentration of soot in the particulate filter **116** exceeds a predetermined threshold that may be stored in the memory **144** as a stored value **156** thereof, or, alternatively, when particulate filter regeneration is warranted, and this includes for both active and passive regeneration.

By the alternative used herein, no such request is used, and a continuous monitoring of the soot in the PF **116** is performed and acted upon. In this case, when the soot amount is high, active regeneration is performed, and when the soot amount is lower, it is assumed at least some soot exists in the PF **116**. Then depending on the pressures and temperatures at the emission system as well as the motion of the vehicle (or presence of sufficient air flow), the disclosed passive regeneration with air injection is performed. This process may be performed in a continuous loop as long as the vehicle is moving.

The process **800** includes the inquiry "soot load over active regeneration threshold?" **806**. This threshold refers to an amount of soot that is too much for passive regeneration to adequately and efficiently burn off, and the threshold may be determined by experimentation, which may be provided in grams.

If the soot load is too high, the process **800** includes "perform lean active regeneration" **808**. Specifically, in various implementations, the processor **142** provides instructions for the heating of the particulate filter **116**. In various implementations, the particulate filter **116** is heated to a predetermined temperature (e.g., stored in the memory **144** as a stored value **156** thereof) in order to provide regeneration for the particulate filter **116** (e.g., including burning off of soot in the particulate filter **116**). In various implementations, the engine is operated at a slightly lean condition with a delayed post fuel injection to burn the PF soot out of the PF. Also, the active regeneration may be performed as long as the exhaust temperatures at the PF **116** inlet and outlet are below an active regeneration maximum threshold temperature.

The process **800** includes the inquiry "soot loads below threshold of stopping soot regeneration" **810**. The soot load is measured periodically during the operation **808**, and is stopped once the soot amount is below the threshold of operation **806**, although this could be a different threshold when desired. If the soot load is still above the soot load threshold, the process **800** loops back to operation **808** to continue the active regeneration. If the soot load is below the soot load threshold, the process **800** loops back to operation **802** to restart process **800**.

When the soot load at operation **806** is found to be below the soot load threshold, process **800** includes the inquiry "exhaust temperature upstream from the PF above activation threshold?" **812**. Thus, during operation of the vehicle, the exhaust gases (and/or previous active regeneration) will heat the PF **116**. The exhaust temperature upstream from the PF should be above a certain minimum temperature to efficiently ignite the soot at the PF **116** to burn it off. By one form then, the exhaust or a minimum temperature threshold (or passive regeneration activation threshold) is 350 deg C. for a catalyst GPF or 600 deg C. for a bare GPF. By one form, the threshold temperature is a single temperature at the inlet or outlet of the PF **116**, but could be both, or some combination. If it is determined that the temperature of the exhaust gas at the PF **116** is below the minimum threshold, then process **800** loops back to operation **804** to continue monitoring for better circumstances for passive regeneration.

Otherwise, if the PF **116** temperature is above the minimum threshold, process **800** includes "start passive air injection when exhaust pressure is lower" **814**. Thus, the passive air generation can be performed during deceleration events, such as during DCCO events, DFCO events, and other deceleration events or modes as described above. This may simply involve monitoring when the accelerator is not depressed by a user or when no injection fuel is being injected to the engine cylinders, and so forth. Also as mentioned, this may be performed as long as the inlet and/or outlet exhaust temperatures at the PF **116** are or remain above the activation threshold. The temperature may be continuously monitored.

It should be noted that the passive regeneration may or may not need the air intake manifold to be open, when under-hood air is being used rather than air directly obtained from the air intake manifold. Likewise, the passive regeneration can occur while both intake and exhaust phasers are closed.

Also as mentioned above, the vehicle should be moving to collect under-hood air at relatively high speed (compared to not moving) or in other words, high air mass flow rate, which by some forms, may be at least 5 MPH, but otherwise may be 20-100 or 20 to 80 MPH.

Also, the duration of the deceleration can be very short, such as a minimum of two seconds. By another form, as little as 1 gram of air mass (or pulse of air) may be sufficient to perform passive regeneration with the air injection. Thus, it is sufficient that the passive regeneration with the air injection can be repeated many times all at very short durations when the vehicle is being moved in a way such that only short deceleration durations are available for the passive regeneration with the air injection.

The process **800** includes an inquiry "particulate filter inlet or outlet temperatures or both are above a deactivation (GPF) temperature limit threshold or below a GPF air injection (or activation) temperature threshold?" **816**. Thus, when exhaust gas (or air) temperatures are over a maximum GPF limit temperature at or near the PF **116**, the soot regeneration should be stopped for safety reasons to avoid damage to the PF **116**, fire, or other reasons. By one form, the maximum (or deactivation) temperature threshold is set at 900 deg C. for catalyst PF, and set at 950 deg C. for bare PF. Likewise, when the exhaust temperature is below the activation temperature thresholds from operation **812**, the air injection may be stopped at this point as well. For either threshold comparison, the temperature of the exhaust gas (or air) at the PF inlet alone, the PF outlet alone, or some combination of the two may be used to compare to corresponding thresholds. In various implementations, this determination is made based on the temperature values of the exhaust air as measured from the temperature sensors of the thermocouples **368** and **370** as shown on PFs **360** and **362** for example.

If the temperatures still satisfy the thresholds, process **800** loops back to operation **814** to continue the air injection and passive regeneration. If any of the thresholds are not met, then process **800** includes "stop air injection" **818**, and the process **800** loops back to operation **802** to operate the vehicle and to restart the regeneration process again.

As yet another alternative in implementations herein, a diagnosis routine to check the status of the particulate filter, referred to herein as a health diagnosis may be performed. For the health diagnosis, the process **800** includes an example inquiry "particulate filter inlet temperature change before and after air injection at different engine speeds less than health thresholds" **820**, and this refers to operation of the vehicle at deceleration conditions such as DCCO or DFCO conditions sufficient to result in low exhaust pressure and high air mass flow rate. Alternatively, both the inlet and outlet temperatures at the PF may be used to generate temperature differences instead of just the inlet temperature, and both with and without air injection for both alternatives mentioned. The temperatures may be obtained from the thermocouple sensors described herein, and the temperatures may be compared to thresholds determined during experimentation. The temperatures can be used to determine pressures, which in turn can be used to determine soot loads at the PF. Thereafter, process **800** may include "report air injection status" **822**, which refers to at least reporting a system failure when the health thresholds are not met, but otherwise can include reporting an acceptable or pass when thresholds are met.

Accordingly, methods, systems, and vehicles are provided for controlling regeneration for the particulate filter. In various implementations, as discussed above in connection with the process **800** of FIG. **8**, passive regeneration with air injection is performed during particulate filter regeneration.

In various implementations, the techniques disclosed herein (including the operations and functions of the process **800** of FIG. **8** and as described above) provides for expanded conditions in which particulate filter regeneration using an air injection pipe are performed. In various implementations, this may result in cleaner air for the exhaust air, and/or other improved performance for the drive system **102** and/or for the vehicle **100**.

It will be appreciated that the systems, vehicles, and methods may vary from those depicted in the Figures and described herein. For example, the vehicle **100** of FIGS. **1** and **2**, and any of the components of FIGS. **1**-**7** may differ from that depicted in FIG. **1**. It will similarly be appreciated that the operations of process **800** may differ from those depicted in FIG. **8**, and/or that various operations of process **800** may occur concurrently and/or in a different order than that depicted in FIG. **8**.

While at least one example implementation 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 example implementation or example implementations 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 example implementation or example implementations. 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.

What is claimed is:

1. A vehicle, comprising:

a body;

an engine within the body and comprising two cylinder blocks;

two exhaust tubes, wherein each cylinder block has one of the exhaust tubes, and wherein both of the exhaust tubes having a particulate filter fluidly coupled to the exhaust tube to receive exhaust material from the exhaust tube; and

at least one air injection pipe having a first end with a single inlet arranged to receive air flow entering the body while the vehicle is moving, wherein the air injection pipe comprises a split part divided into two outlet sections each having a second end and an outlet fluidly coupled to a different one of the exhaust tubes, and wherein each second end being fluidly coupled to the exhaust tube and having an outlet positioned to provide air flow from the injection pipe into the exhaust tube upstream from the particulate filter.

2. The vehicle of claim **1**, comprising a valve on the air injection pipe and arranged to be opened and closed depending on a temperature at the particulate filter.

3. The vehicle of claim **1**, wherein the inlet comprises a collector with a free end facing toward a front of the vehicle.

4. The vehicle of claim **1**, comprising an air intake manifold with a manifold conduit to direct airflow, and wherein the inlet is coupled to the manifold conduit.

5. The vehicle of claim **1**, comprising at least one catalytic converter fluidly coupled to the exhaust tube between the engine and the outlet.

6. An emission system of a vehicle, comprising:

at least one exhaust tube extending from an engine of the vehicle and having a particulate filter fluidly coupled on the exhaust tube;

at least one temperature sensor arranged to sense a temperature at the particulate filter;

at least one injection pipe having an inlet facing forward on the vehicle and disposed to capture under hood airflow entering the vehicle while the vehicle is moving in a deceleration, wherein the air injection pipe comprises an outlet fluidly coupled to the exhaust tube between the particulate filter and the engine and a valve; and

processor circuitry forming at least one processor communicatively coupled to the at least one temperature sensor and the valve and arranged to operate by opening and closing the air injection pipe depending on a sensed temperature of the particulate filter,

wherein the at least one processor is arranged to operate by opening the air injection pipe when the vehicle is determined to be running a deceleration dynamic cylinder cut-off DCCO event, and wherein the air injection pipe may be opened for two seconds or more at a time.

7. The system of claim **6**, wherein the engine comprises multiple cylinder blocks, wherein the at least one exhaust tube comprises two fluidly parallel exhaust pipe sections, each exhaust pipe section having a first end coupled to a different one of the cylinder blocks and a second end that merges together at a merged exhaust pipe section fluidly coupled to the particulate filter, and wherein the injection pipe is coupled to only one of the parallel exhaust pipe sections.

8. The vehicle of claim **1**, wherein the air injection pipe has a sidewall with a conical rim defining the outlet.

9. The vehicle of claim **1**, comprising temperature sensors of the particulate filter, a valve of the injection pipe, and a controller with at least one processor communicatively coupled to the temperature sensors and the valve, and wherein the processor is arranged to operate by controlling the valve to permit air flow through the air injection pipe and to the particulate filter when both temperatures before and after the particulate filter are above a threshold and exhaust pressure in the exhaust tube is less than air pressure at the inlet.

10. A method, comprising:

obtaining, by processor circuitry forming at least one processor, sensor data indicating a temperature of at least one particulate filter of an emission system of a vehicle, wherein the particulate filter is fluidly coupled to an exhaust tube extending from an engine of the vehicle;

depending on a sensed temperature at the particulate filter, opening, by the at least one processor, an air injection pipe having an inlet facing forward on the vehicle and disposed to capture under hood airflow entering the vehicle while the vehicle is moving in a deceleration, wherein the air injection pipe comprises an outlet fluidly coupled to the exhaust tube between the particulate filter and the engine passively activating regeneration of the particulate filter by permitting air flow through the injection pipe when the vehicle is decelerating sufficiently to lower exhaust pressure below air pressure at the inlet; and

reducing the total hydrocarbons (THC) and CO emissions during a tip-in after deceleration by releasing oxygen stored in the catalytic converters during a deceleration dynamic cylinder cut-off (DCCO) event.

11. The method of claim **10**, comprising controlling a maximum air mass flow rate of air to be injected by setting an air injector nozzle diameter at the outlet of the injection pipe and an air collector diameter at the inlet of the injection pipe.

12. The method of claim **10**, comprising passively activating regeneration of the particulate filter by permitting air flow through the injection pipe when the particulate filter has a temperature of at least 600 deg C. for a non-catalyst particulate filter and 350 deg C. for a catalyst particulate filter.

13. The system of claim **6**, comprising passively activating regeneration of the particulate filter by permitting air flow through the injection pipe when the vehicle is decelerating sufficiently to lower exhaust pressure below air pressure at the inlet.

14. The system of claim **13**, comprising reducing the total hydrocarbons (THC) and CO emissions during a tip-in after deceleration by releasing oxygen stored in the catalytic converters during a deceleration dynamic cylinder cut-off (DCCO) event.

15. The method of claim **11**, comprising closing the air injection pipe when the particulate filter temperature rises above 900 deg C. or 950 deg C.

16. The system of claim **6**, wherein the engine comprises two cylinder blocks each with one of the exhaust tubes, and wherein the injection pipe comprises a single inlet and a split part divided into two outlet sections each having one of the second ends and an outlet fluidly coupled to a different one of the exhaust tubes.

17. The system of claim **16**, wherein the emission system comprises a mixer device within the exhaust tube between the outlet and the particulate filter.

18. The system of claim **16**, wherein the air injection pipe has a sidewall with an opening forming the outlet, and wherein the opening is sized to control an amount of air mass flow rate.

19. The system of claim **16**, wherein the particulate filter has an inlet temperature sensor and outlet temperature sensor, and wherein the at least one processor is arranged to operate by performing a health diagnosis of an air injection system and the particulate filter comprising determining at least one of:

a front particulate filter temperature difference before and after air injections into the particulate filter and at multiple different engine speeds, or

particulate filter inlet and outlet temperature differences with and without air injection under different engine speeds.

20. The system of claim **18**, wherein the air injection pipe has a sidewall with a conical rim defining the outlet.

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