US009879580B2

(12) **United States Patent**
Gupta et al.

(10) **Patent No.: US 9,879,580 B2**
(45) **Date of Patent: Jan. 30, 2018**

(54) **DIAGNOSTIC METHODS FOR A HIGH EFFICIENCY EXHAUST AFTERTREATMENT SYSTEM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 62 days.

(21) Appl. No.: **14/830,112**

(22) Filed: **Aug. 19, 2015**

(65) **Prior Publication Data**

US 2017/0051654 A1 Feb. 23, 2017

(51) **Int. Cl.**

F01N 3/00	(2006.01)
F01N 3/035	(2006.01)
F01N 3/08	(2006.01)
F01N 3/10	(2006.01)
F01N 3/20	(2006.01)
F01N 11/00	(2006.01)
F01N 13/00	(2010.01)

(52) **U.S. Cl.**

CPC ***F01N 3/035*** (2013.01); ***F01N 3/0835*** (2013.01); ***F01N 3/0842*** (2013.01); ***F01N 3/103*** (2013.01); ***F01N 3/2066*** (2013.01); ***F01N 11/00*** (2013.01); ***F01N 13/0093*** (2014.06); *F01N 2550/02* (2013.01); *F01N 2560/021* (2013.01); *F01N 2560/026* (2013.01); *F01N 2560/06* (2013.01); *F01N 2560/14* (2013.01); *F01N 2610/02* (2013.01); *F01N 2900/1402* (2013.01); *F01N 2900/1616* (2013.01); *Y02T 10/24* (2013.01); *Y02T 10/47* (2013.01)

(58) **Field of Classification Search**

CPC F01N 3/035; F01N 3/0835; F01N 3/0842; F01N 3/103

USPC 60/285

See application file for complete search history.

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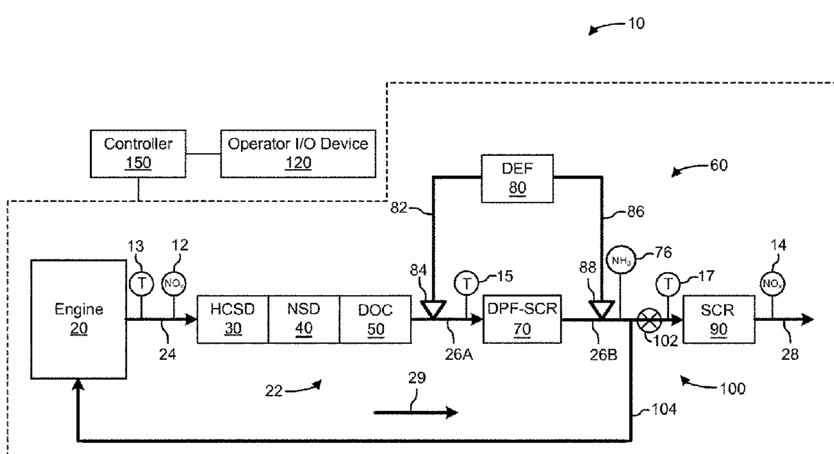
(57) **ABSTRACT**

An apparatus includes a nitrogen oxide (NOx) module and a selective catalytic reduction (SCR) diagnostic module. The NOx module is in exhaust gas communication with an exhaust flow of an exhaust aftertreatment system from an engine. The NOx module is structured to interpret NOx data indicative of an amount of NOx exiting the engine and an amount of NOx exiting the exhaust aftertreatment system, and determine a NOx conversion efficiency fault is present based on the amount of NOx exiting the engine and the amount of NOx exiting the exhaust aftertreatment system. The SCR diagnostic module is structured to determine at least one of a SCR catalyst and a diesel particulate filter including a coating of a SCR reaction catalyst (DPF-SCR) are responsible for the NOx conversion efficiency fault based on at least one of a reductant slip amount and a NOx conversion value across at least one of the SCR catalyst and the DPF-SCR.

15 Claims, 7 Drawing Sheets



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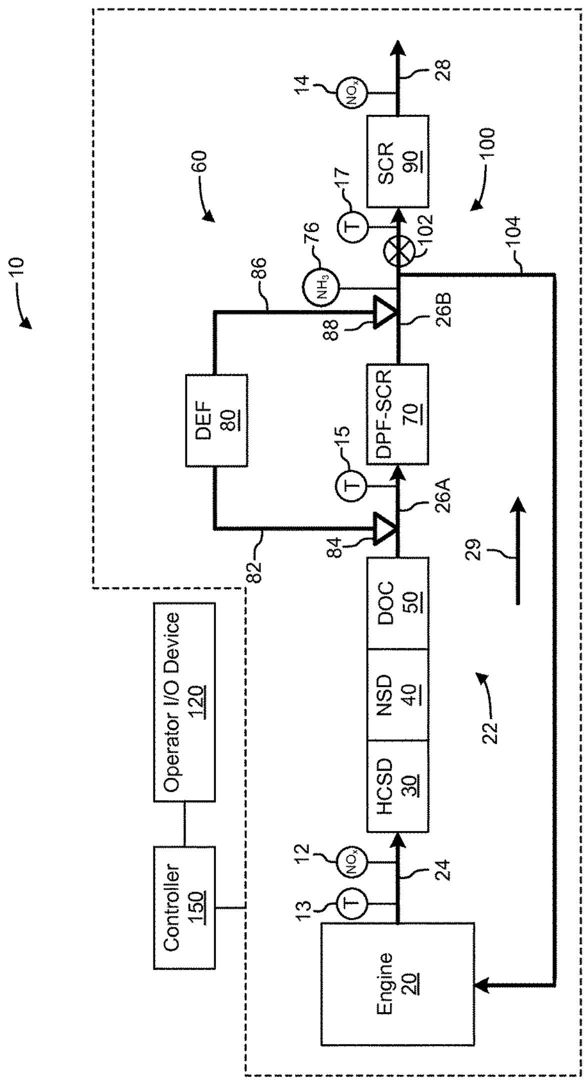
10
60
100
Engine
20
Controller
150
Operator I/O Device
120
HCSD
30
NSD
40
DOC
50
DPF-SCR
70
DEF
80
SCR
90
T
NO_x
NH_3
12
13
14
15
17
22
24
26A
26B
28
29
76
82
84
86
88
102
104

FIG. 1

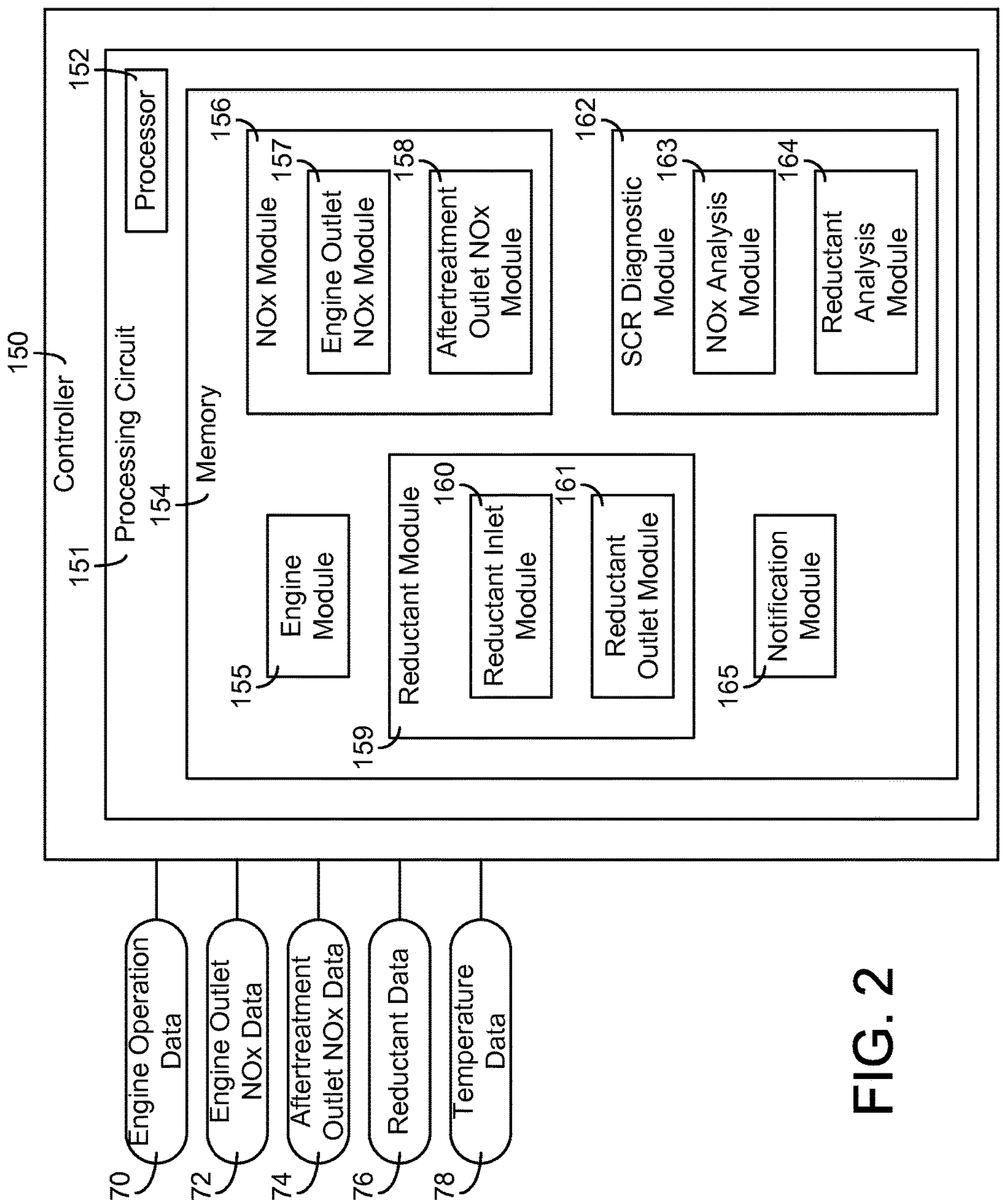
150
Controller
151
Processing Circuit
152
Processor
154
Memory
155
Engine Module
156
NOx Module
157
Engine Outlet NOx Module
158
Aftertreatment Outlet NOx Module
159
Reductant Module
160
Reductant Inlet Module
161
Reductant Outlet Module
162
SCR Diagnostic Module
163
NOx Analysis Module
164
Reductant Analysis Module
165
Notification Module
170
Engine Operation Data
172
Engine Outlet NOx Data
174
Aftertreatment Outlet NOx Data
176
Reductant Data
178
Temperature Data

FIG. 2

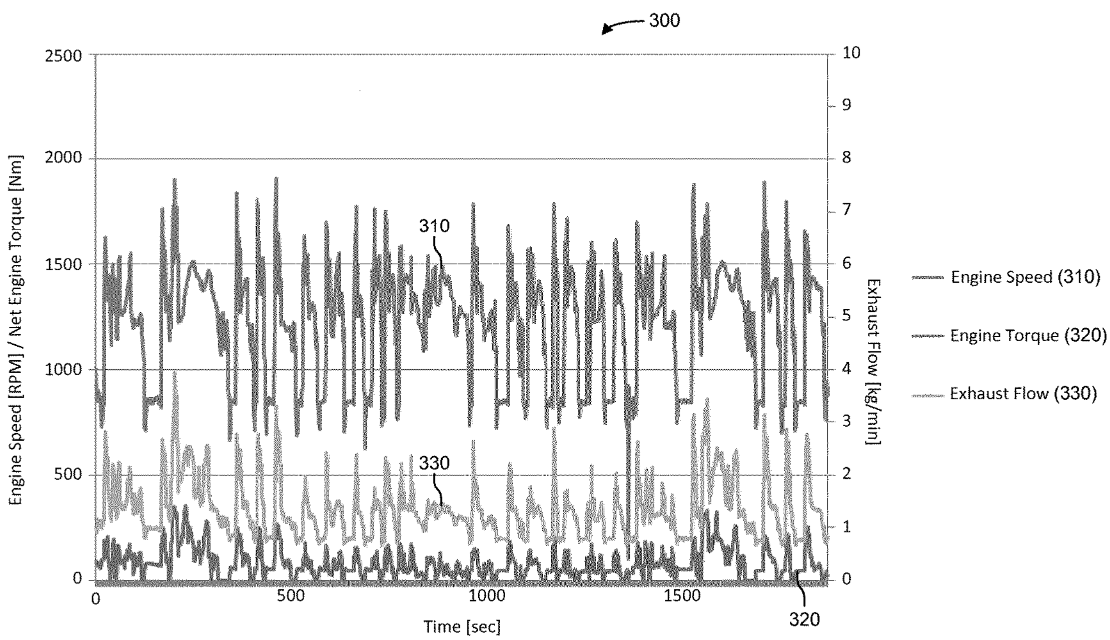
300
2500
2000
1500
1000
500
0
10
9
8
7
6
5
4
3
2
1
0
0
500
1000
1500
Time [sec]
Engine Speed [RPM] / Net Engine Torque [Nm]
Exhaust Flow [kg/min]
310
330
320
Engine Speed (310)
Engine Torque (320)
Exhaust Flow (330)

FIG. 3

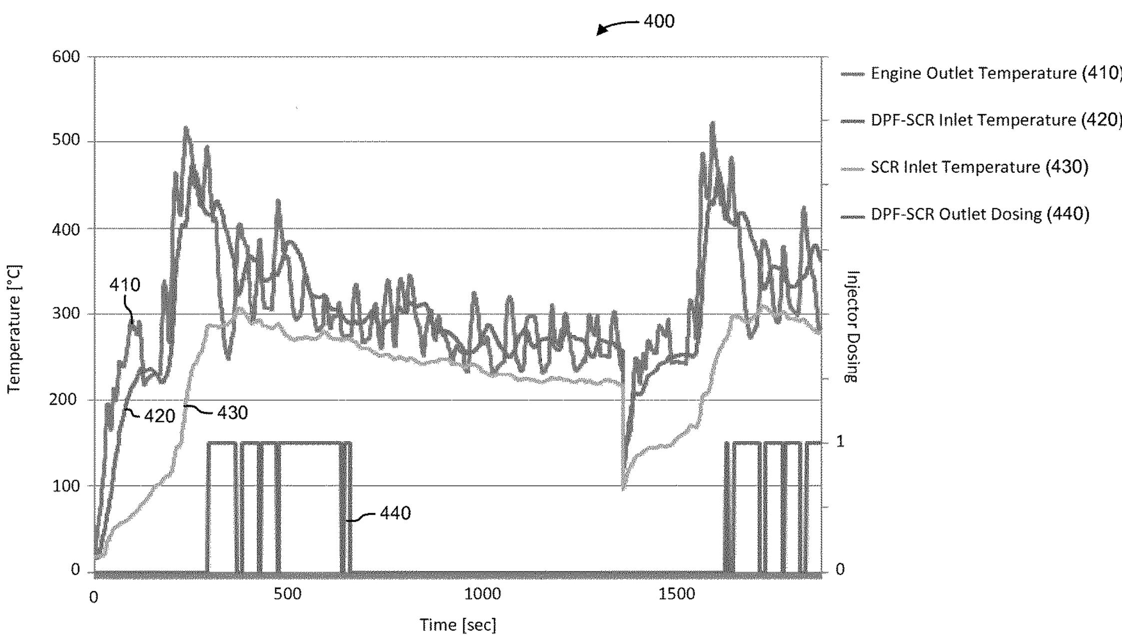
400
600
500
400
300
200
100
0
Temperature [°C]
410
420
430
440
0
500
1000
1500
Time [sec]
Injector Dosing
1
0
Engine Outlet Temperature (410)
DPF-SCR Inlet Temperature (420)
SCR Inlet Temperature (430)
DPF-SCR Outlet Dosing (440)

FIG. 4

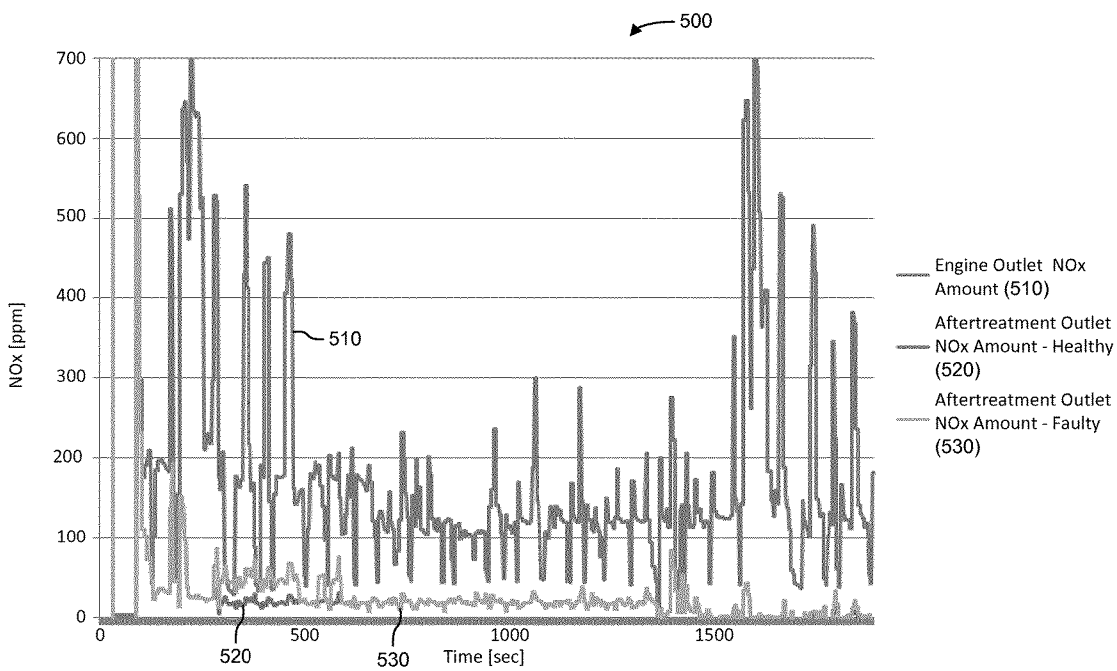
500
700
600
500
400
300
200
100
0
NOx [ppm]
0
500
1000
1500
Time [sec]
510
520
530
Engine Outlet NOx Amount (510)
Aftertreatment Outlet NOx Amount - Healthy (520)
Aftertreatment Outlet NOx Amount - Faulty (530)

FIG. 5

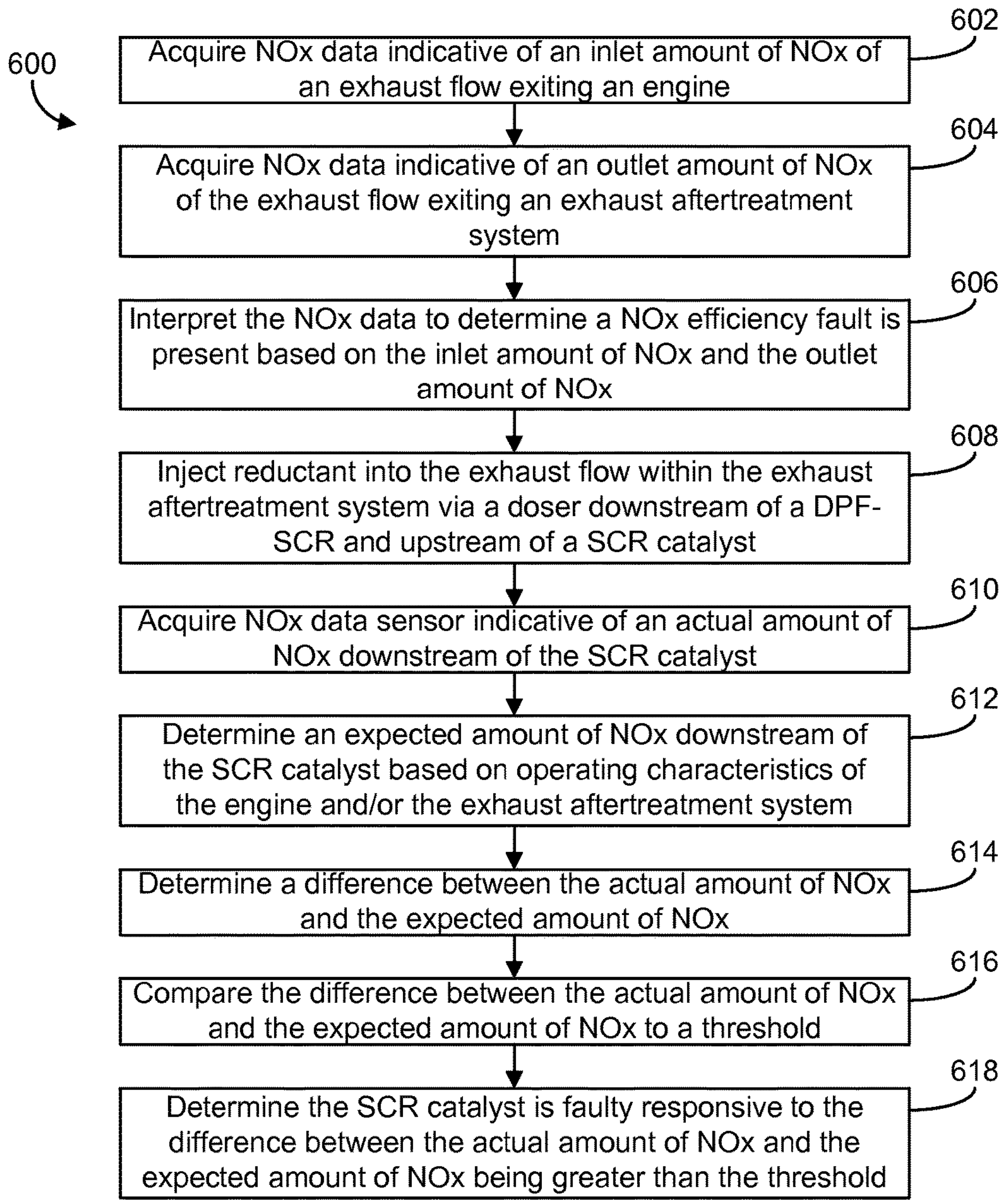
600
602
Acquire NOx data indicative of an inlet amount of NOx of an exhaust flow exiting an engine
604
Acquire NOx data indicative of an outlet amount of NOx of the exhaust flow exiting an exhaust aftertreatment system
606
Interpret the NOx data to determine a NOx efficiency fault is present based on the inlet amount of NOx and the outlet amount of NOx
608
Inject reductant into the exhaust flow within the exhaust aftertreatment system via a doser downstream of a DPF-SCR and upstream of a SCR catalyst
610
Acquire NOx data sensor indicative of an actual amount of NOx downstream of the SCR catalyst
612
Determine an expected amount of NOx downstream of the SCR catalyst based on operating characteristics of the engine and/or the exhaust aftertreatment system
614
Determine a difference between the actual amount of NOx and the expected amount of NOx
616
Compare the difference between the actual amount of NOx and the expected amount of NOx to a threshold
618
Determine the SCR catalyst is faulty responsive to the difference between the actual amount of NOx and the expected amount of NOx being greater than the threshold

FIG. 6

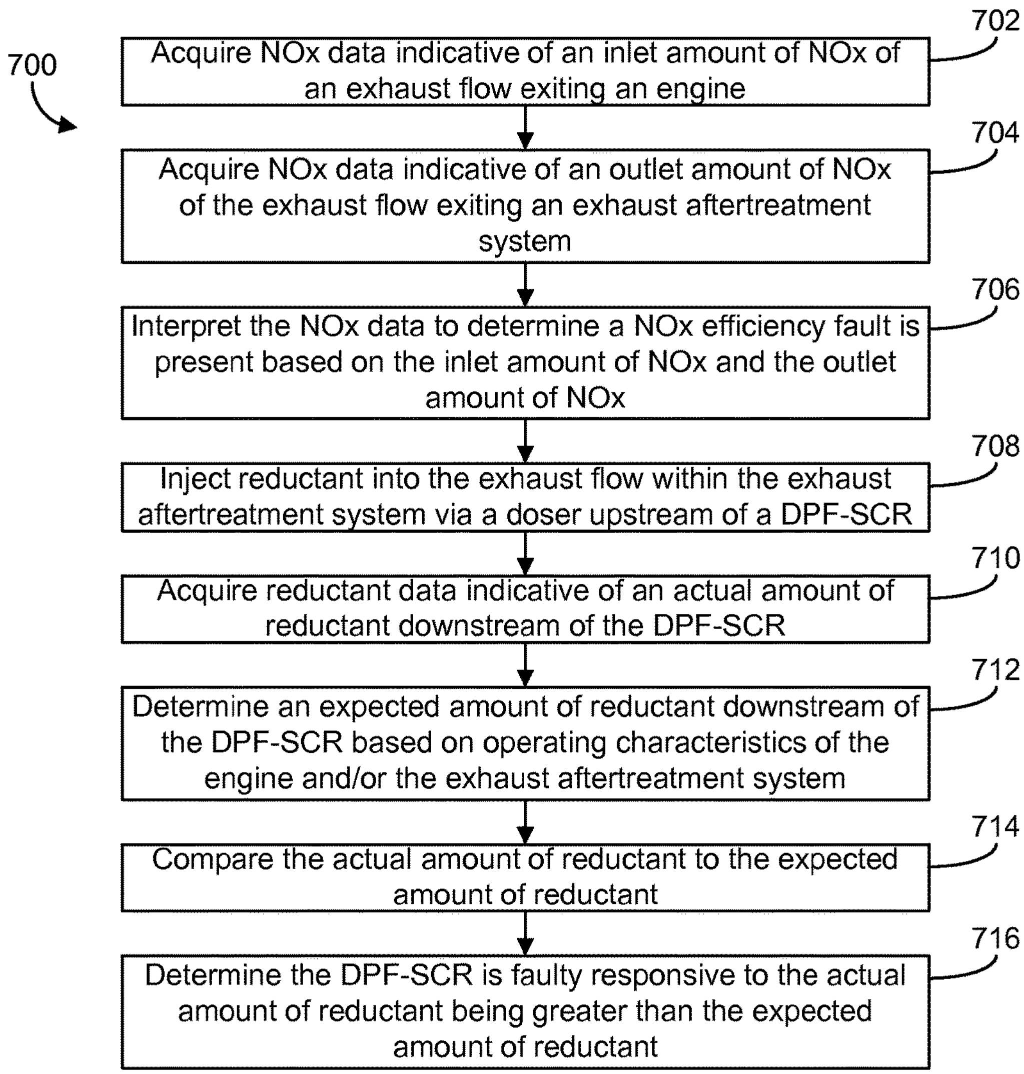
700
Acquire NOx data indicative of an inlet amount of NOx of an exhaust flow exiting an engine
702
Acquire NOx data indicative of an outlet amount of NOx of the exhaust flow exiting an exhaust aftertreatment system
704
Interpret the NOx data to determine a NOx efficiency fault is present based on the inlet amount of NOx and the outlet amount of NOx
706
Inject reductant into the exhaust flow within the exhaust aftertreatment system via a doser upstream of a DPF-SCR
708
Acquire reductant data indicative of an actual amount of reductant downstream of the DPF-SCR
710
Determine an expected amount of reductant downstream of the DPF-SCR based on operating characteristics of the engine and/or the exhaust aftertreatment system
712
Compare the actual amount of reductant to the expected amount of reductant
714
Determine the DPF-SCR is faulty responsive to the actual amount of reductant being greater than the expected amount of reductant
716

FIG. 7

DIAGNOSTIC METHODS FOR A HIGH EFFICIENCY EXHAUST AFTERTREATMENT SYSTEM

BACKGROUND

Emissions regulations for internal combustion engines have become more stringent over recent years. Environmental concerns have motivated the implementation of stricter emission requirements for internal combustion engines throughout much of the world. Governmental agencies, such as the Environmental Protection Agency (EPA) in the United States, carefully monitor the emission quality of engines and set emission standards to which engines must comply. Consequently, the use of exhaust aftertreatment systems on engines to reduce emissions is increasing.

Exhaust aftertreatment systems are generally designed to reduce emission of particulate matter, nitrogen oxides (NOx), hydrocarbons, and other environmentally harmful pollutants. However, the components that make up the exhaust aftertreatment system can be susceptible to failure and degradation. Because the failure or degradation of components may have adverse consequences on performance and the emission-reduction capability of the exhaust aftertreatment system, the detection and, if possible, correction of failed or degraded components is desirable. In fact, some regulations require on-board diagnostic (OBD) monitoring or testing of many of the components of the exhaust aftertreatment system. However, as exhaust aftertreatment system architectures become increasingly more complex, the ability to isolate faults to specific components within the aftertreatment system becomes more challenging. Accordingly, a need exists for repeatable and high accuracy fault isolation within the exhaust aftertreatment system.

SUMMARY

One embodiment relates to an apparatus. The apparatus includes a nitrogen oxide (NOx) module and a selective catalytic reduction (SCR) diagnostic module. The NOx module is in exhaust gas communication with an exhaust flow of an exhaust aftertreatment system from an engine. The NOx module is structured to interpret NOx data indicative of an amount of NOx exiting the engine and an amount of NOx exiting the exhaust aftertreatment system, and determine a NOx conversion efficiency fault is present based on the amount of NOx exiting the engine and the amount of NOx exiting the exhaust aftertreatment system. The SCR diagnostic module is structured to determine at least one of a SCR catalyst and a diesel particulate filter including a coating of a SCR reaction catalyst (DPF-SCR) are responsible for the NOx conversion efficiency fault based on at least one of a reductant slip amount and a NOx conversion value across at least one of the SCR catalyst and the DPF-SCR.

Another embodiment relates to a method. The method includes determining a Nitrogen Oxide (NOx) conversion efficiency fault is present within an exhaust aftertreatment system, monitoring an actual amount of NOx of an exhaust flow of the exhaust aftertreatment system downstream of a selective catalytic reduction (SCR) catalyst when a reductant is injected into the exhaust flow via an injection mechanism positioned upstream of the SCR catalyst, determining an expected amount of NOx of the exhaust flow of the exhaust aftertreatment system downstream of the SCR catalyst when the reductant is injected into the exhaust flow upstream of the SCR catalyst based on at least one operating condition of at least one of the exhaust aftertreatment system and an engine in fluid communication with the exhaust aftertreatment system, comparing the actual amount of NOx to at least one of the expected amount of NOx and a threshold value of NOx, and determining the SCR catalyst is faulty responsive to at least one of the actual amount of NOx differing from the expected amount of NOx by more than a threshold amount and the actual amount of NOx exceeding the threshold value of NOx.

Still another embodiment relates to a method. The method includes determining a Nitrogen Oxide (NOx) conversion efficiency fault is present, monitoring an actual amount of reductant downstream of a diesel particulate filter including a coating of a selective catalytic reduction reaction catalyst (DPF-SCR) when the reductant is injected into the exhaust flow via an injection mechanism positioned upstream of the DPF-SCR, determining an expected amount of reductant downstream of the DPF-SCR based on at least one of the operating conditions of an engine and operating conditions of the exhaust aftertreatment system, comparing the actual amount of reductant to the expected amount of reductant, and determining the DPF-SCR is faulty responsive to the actual amount of reductant being greater than the expected amount of reductant.

Yet another embodiment relates to a system. The system includes an engine, an exhaust aftertreatment system in exhaust gas receiving communication with the engine, and a controller. The exhaust aftertreatment system includes a selective catalytic reduction (SCR) system. The SCR system includes a SCR catalyst and a diesel particulate filter having a coating of a SCR reaction catalyst (DPF-SCR) positioned upstream of the SCR catalyst. The controller is communicably coupled to the engine and the exhaust aftertreatment system. The controller is structured to receive first nitrogen oxide (NOx) data indicative of an amount of NOx in an exhaust flow exiting the engine and second NOx data indicative of an amount of NOx in the exhaust flow exiting the exhaust aftertreatment system, determine a NOx conversion efficiency fault is present based on the first NOx data and the second NOx data, and determine at least one of the SCR catalyst and the DPF-SCR of the SCR system are faulty responsive to the NOx conversion efficiency fault.

These and other features, together with the organization and manner of operation thereof, will become apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an exhaust aftertreatment system with a controller, according to an example embodiment.

FIG. **2** is a schematic diagram of the controller used with the system of FIG. **1**, according to an example embodiment.

FIG. **3** is a graph of certain operating characteristics of an engine over time, according to an example embodiment.

FIG. **4** is a graph of certain operating characteristics of an exhaust aftertreatment system over time, according to an example embodiment.

FIG. **5** is a graph comparing an amount of NOx exiting a healthy exhaust aftertreatment system to an amount of NOx exiting a faulty exhaust aftertreatment system, according to an example embodiment.

FIG. **6** is a flow diagram of a method of diagnosing a SCR catalyst of an exhaust aftertreatment system, according to an example embodiment.

FIG. **7** is a flow diagram of a method of diagnosing a DPF-SCR of an exhaust aftertreatment system, according to an example embodiment.

DETAILED DESCRIPTION

Referring to the Figures generally, the various embodiments disclosed herein relate to a system, apparatus, and method of diagnosing a faulty component of an exhaust aftertreatment system. According to the present disclosure, a controller determines whether (among other failure modes) a component of a SCR system (e.g., a DPF-SCR, a SCR catalyst, etc.) are faulty by utilizing one or more diagnostic procedures, which are described more fully herein. As a brief overview, some engine systems include exhaust aftertreatment systems for decreasing the pollutants emitted from the engine systems. Among other components, these exhaust aftertreatment systems may include a SCR system. The SCR system can include a DPF-SCR and a SCR catalyst that are designed to reduce the amount of nitrogen oxides (NOx) and other constituents in engine exhaust gas to nitrogen and other less pollutant compounds. To accomplish this reduction, a reductant (e.g., ammonia, urea, etc.) is sprayed into the exhaust gas at least one of prior to the exhaust gas reaching the DPF-SCR and the SCR catalyst of the SCR system. Over the DPF-SCR and the SCR catalyst, the NOx reacts with ammonia (NH_3) that is formed from the decomposition of the reductant or that was sprayed directly into the exhaust gas, to form nitrogen and other less harmful compounds. In turn, a decrease in NOx emissions from the exhaust gas is accomplished. The efficiency of the SCR system may be determined by measuring the reduction of NOx emissions from the exhaust gas between the inlet and the outlet of the SCR system, which is described more fully below.

In certain embodiments, SCR system efficiency may be determined by a NOx conversion fraction for the exhaust gas. The NOx conversion fraction may be determined from NOx data regarding the exhaust gas emitted from the engine. For example, the NOx data may include an inlet amount of NOx entering the exhaust aftertreatment system (represented as NOx, inlet in equation (1) below). The NOx data may also include an outlet amount of NOx exiting the exhaust aftertreatment system (represented as NOx, outlet in equation (1) below). Taking a difference between these two amounts, the NOx conversion fraction represents the percent reduction in NOx in the exhaust gas stream accomplished by the SCR system. According to one embodiment, the NOx conversion fraction amount may be determined as follows:

$$NO_x \text{ conversion fraction} = \frac{NO_{x_{inlet}} - NO_{x_{outlet}}}{NO_{x_{inlet}}} \tag{1}$$

The NOx conversion fraction provides an indication of the efficacy of the SCR system and whether a potential NOx conversion efficiency fault may be present. For example, a relatively higher conversion fraction indicates that a substantial amount of the NOx present in the exhaust stream is being reduced to nitrogen and other less pollutant compounds. However, a relatively lower conversion fraction indicates that the NOx in the exhaust gas stream is substantially not being converted to nitrogen and other less pollutant compounds (i.e., one or more components of the SCR system may be faulty, etc.).

According to the present disclosure, a controller is structured to determine a DPF-SCR and/or an underfloor SCR catalyst failure responsive to the NOx conversion efficiency of the SCR system indicating a NOx conversion efficiency fault. The controller is structured to perform a diagnostic test or process that diagnoses the NOx conversion efficiency fault and isolates the fault to the DPF-SCR and/or the underfloor SCR catalyst, respectively. A typical characteristic of a failed SCR system is a complete loss or a partial loss of catalytic activity of a catalyst element (i.e., the DPF-SCR and SCR catalyst, etc.) to an extent where the system outlet NOx levels are above regulated limits (i.e., emission laws and regulations, etc.). The loss of catalytic activity may directly correspond to at least one of (i) a low NOx conversion and (ii) a low total ammonia storage capacity (or a higher tendency to slip ammonia). The diagnostic test may utilize available actuators and sensors (or virtual sensors) to detect the above functionalities of a failed system and isolate the failure to at least one of the DPF-SCR and the SCR catalyst. The loss of partial or complete catalytic activity of the SCR system may result in higher sensitivity to exhaust flux or NOx flux based space velocity (the volume of flow per unit volume of the catalyst). For the exhaust aftertreatment system architecture described herein, the actuators in the system may be used to further tax the DPF-SCR and the underfloor SCR catalyst with high space velocity and the sensor data may be used to diagnose the faults robustly and with higher in use performance ratio (the percentage of time for which the diagnostic test may be run in the operating region of the engine and the exhaust aftertreatment system).

In one embodiment, a passive diagnostic test may be performed while the engine and exhaust aftertreatment system are operational. For example, if embodied in a vehicle, the passive test may be performed while the operator is driving the vehicle. If an error is detected, a fault code or indicator lamp may be actuated to alert the operator of maintenance or service that may be required. In contrast and in another embodiment, an intrusive diagnostic test may be performed. As used herein, the term "intrusive" (in regard to performing one or more diagnostic tests) is used to refer to an active diagnostic test. In other words, an intrusive method, system, and apparatus describe a diagnostic test or protocol that is forced to run on the engine and exhaust aftertreatment system (i.e., causes the engine to operate at a certain speed, etc.). An intrusive diagnostic test may manipulate or excite the NOx emissions in the exhaust gas emitted from the engine system. In this regard, an "intrusive diagnostic test" may include overriding various set engine operating points to perform the diagnostic test. For example, many engine operating points are set to be in compliance with one or more vehicular laws (e.g., emissions, etc.). By overriding one or more of these operating points, the engine may be forced into non-compliance with one or more vehicular laws. As a result, the active or intrusive diagnostic test is often run in a service bay, test center environment, or other controlled environment.

Referring now to FIG. **1**, an engine system, shown as engine system **10**, with a controller **150** is shown, according to an example embodiment. As shown in FIG. **1**, the engine system **10** includes an internal combustion engine, shown as engine **20**, and an aftertreatment system, shown as exhaust aftertreatment system **22**. The exhaust aftertreatment system **22** is in exhaust gas-receiving communication with the engine **20**. According to one embodiment, the engine **20** is structured as a compression-ignition internal combustion engine that utilizes diesel fuel. However, in various alternate embodiments, the engine **20** may be structured as any other type of engine (e.g., spark-ignition, etc.) that utilizes any type of fuel (e.g., gasoline, natural gas, etc.). Within the engine **20**, air from the atmosphere is combined with fuel, and combusted, to power the engine **20**. Combustion of the fuel and air in the compression chambers of the engine **20** produces exhaust gas that is operatively vented to an exhaust manifold and to the exhaust aftertreatment system **22**.

According to the example embodiment depicted in FIG. **1**, the exhaust aftertreatment system **22** includes a low temperature hydrocarbon storage device (HCSD), shown as HCSD **30**, that is upstream and fluidly coupled to a low temperature nitrogen oxide storage device (NSD), shown as NSD **40**, which is upstream and in fluid communication with a diesel oxidation catalyst (DOC), shown as DOC **50**. The DOC **50** is shown to be upstream and in fluid communication with a selective catalytic reduction (SCR) system, shown as SCR system **60**. The SCR system **60** includes a diesel particulate filter having a coating of a selective catalytic reduction reaction catalyst, shown as DPF-SCR **70**; a reductant delivery system, shown as diesel exhaust fluid (DEF) delivery system **80**, and an underfloor SCR catalyst, shown as SCR catalyst **90**.

The HCSD **30** is structured to temporarily store hydrocarbons (HC) at low temperatures (e.g., relative to exhaust gases, etc.). The HCSD **30** is further structured to passively release the HC responsive to the temperature of the exhaust gas increasing (e.g., when the engine **20** is warmed up, running at designed operating conditions, etc.). As the temperature of the exhaust gas increases, the released HC from the HCSD **30** is converted to CO_2 and H_2O by the DOC **50** located downstream of the HCSD **30**. The NSD **40** is structured to temporarily store nitrogen oxides (NOx) at low temperatures (e.g., relative to exhaust gases, etc.). The NSD **40** is further structured to passively release the NOx responsive to the temperature of the exhaust gas increasing (e.g., when the engine **20** is warmed up, running at designed operating conditions, etc.). As the temperature of the exhaust gas increases, the released nitrogen monoxide (NO) of the NOx from the NSD **40** is partially oxidized to NO_2 (e.g., by the DOC **50**, etc.) before effectively being converted to N_2 and H_2O by the DPF-SCR **70** located downstream of the NSD **40**. According to an example embodiment, the DOC **50** and the DPF-SCR **70** are positioned relative to the HCSD **30** and NSD **40** (e.g., closely coupled, etc.) such that the DOC **50** and the DPF-SCR **70** may effectively treat the HC and the NOx released from the HCSD **30** and NSD **40**, respectively.

The DOC **50** may have any of various flow-through designs. Generally, the DOC **50** is structured to oxidize at least some particulate matter, e.g., the soluble organic fraction of soot, in the exhaust and reduce unburned hydrocarbons and CO in the exhaust to less environmentally harmful compounds. For example, the DOC **50** may be structured to reduce the hydrocarbon and CO concentrations in the exhaust gas to meet the requisite emissions standards for those constituents of the exhaust gas. An indirect consequence of the oxidation capabilities of the DOC **50** may be the ability of the DOC **50** to oxidize portions of NO (e.g., of the exhaust gas, released by the NSD **40**, etc.) into NO_2. In this manner, the level of NO_2 exiting the DOC **50** is equal to the NO_2 in the exhaust gas generated by the engine **20** plus the NO_2 converted from NO by the DOC **50**.

The DPF-SCR **70** may be any of various flow-through or wall-flow designs, and is structured to reduce particulate matter concentrations, e.g., soot and ash, in the exhaust gas to meet or substantially meet requisite emission standards. By having a coating of SCR catalyst applied to the DPF, the DPF-SCR **70** may not only filter particulate matter but also provide or facilitate NOx reduction. Advantageously, this structure and architecture reduces the NOx reduction needed or substantially needed from the SCR catalyst **90** itself. The DPF-SCR **70** is configured to capture particulate matter and other constituents, and thus may need to be periodically regenerated to burn off the captured constituents. Additionally, the DPF-SCR **70** may be configured to oxidize NO to form NO_2 independent of the DOC **50**, as well as convert HC to H_2O (e.g., HC that may have passed through the DOC **50**, etc.).

As shown in FIG. **1**, the SCR catalyst **90** is positioned downstream of the DPF-SCR **70**. According to an example embodiment, the DPF-SCR **70** is located as close to the engine **20** as feasible, while the SCR catalyst **90** is located further downstream where there is more space available on the engine system **10** or a vehicle including the engine system **10**. The SCR catalyst **90** may be any of various catalysts known in the art. For example, in some implementations, the SCR catalyst **90** is a vanadium-based catalyst, and in other implementations, the SCR catalyst **90** is a zeolite-based catalyst, such as a Cu-Zeolite or a Fe-Zeolite catalyst. The SCR catalyst **90** is structured to provide additional SCR catalyst volume to the exhaust aftertreatment system **22**. The additional volume may be useful during operating conditions such as at high flow conditions, high NOx flux conditions, and/or high temperature conditions. For example, depending on engine-out conditions, more SCR catalyst volume (i.e., from the SCR catalyst **90**) may be advantageous to achieve the desired NOx conversion beyond what the DPF-SCR **70** may be able to provide individually.

As discussed above, the SCR system **60** may include the DEF delivery system **80** (i.e., a reductant delivery system, etc.) with a reductant (e.g., DEF, etc.) source, a pump, and a delivery line, and a delivery mechanism. The reductant source may be a container, a tank, or other type of supply capable of retaining a reductant, such as, for example, ammonia (NH_3), urea, diesel oil, or any other suitable DEF alternatives. The reductant source is in reductant supplying communication with the pump, which is configured to pump reductant from the reductant source to the delivery mechanism via a reductant delivery line. In one embodiment, the DEF delivery system **80** includes a first delivery line **82** fluidly coupled to the reductant source of the DEF delivery system **80** and configured to provide reductant to a first delivery mechanism, shown as first doser **84**. As shown in FIG. **1**, the first doser **84** is positioned upstream of the DPF-SCR **70**. The first doser **84** may be selectively controlled to facilitate the injection of reductant directly into the exhaust gas stream prior to entering the DPF-SCR **70**. As described herein, the controller **150** is structured to control the timing and amount of the reductant delivered to the exhaust gas upstream of the DPF-SCR **70** via the first doser **84**. In some embodiments, the DEF delivery system **80** includes a second delivery line **86** fluidly coupled to the reductant source of the DEF delivery system **80** and configured to provide reductant to a second delivery mechanism, shown as second doser **88**. As shown in FIG. **1**, the second doser **88** is positioned downstream of the DPF-SCR **70** and upstream of the SCR catalyst **90**. The second doser **88** may be selectively controlled to facilitate the injection of reductant directly into the exhaust gas stream after exiting the DPF-SCR **70** and prior to entering the SCR catalyst **90**. As described herein, the controller **150** is structured to control the timing and amount of the reductant delivered to the exhaust gas downstream of the DPF-SCR **70** and upstream of the SCR catalyst **90** via the second doser **88**.

In some embodiments, the reductant is either ammonia or urea (which decomposes to produce ammonia). The ammonia reacts with NOx in the presence of the DPF-SCR **70** and/or the SCR catalyst **90** to reduce the NOx to less harmful emissions, such as N_2 and H_2O. The NOx in the exhaust gas may include NO_2 and/or NO. Generally, both NO_2 and NO are reduced to N_2 and H_2O through various chemical reactions driven by the catalytic elements of the DPF-SCR **70** and the SCR catalyst **90** in the presence of ammonia.

According to an example embodiment, the SCR catalyst **90** is used to optimize the temperature for SCR reactions. By way of example, since the DPF-SCR **70** is positioned closer to the engine **20**, the DPF-SCR **70** may get relatively hot under high load conditions. The increase in temperature may drive the DPF-SCR **70** into a temperature zone where the DPF-SCR **70** may oxidize the reductant (e.g., ammonia, etc.). Since the SCR catalyst **90** is positioned further downstream from the engine **20** in the exhaust aftertreatment system **22**, the SCR catalyst **90** may operate at a relatively cooler temperature (i.e., as compared to the DPF-SCR **70**). Thus, by switching to the second dosing location (e.g., via the second doser **88**, etc.), the SCR catalyst **90** may oxidize a lesser amount of the reductant. This may provide for a more efficient utilization of the reductant injection to further reduce the NOx emissions.

Based on the foregoing, in the illustrated embodiment, the HCSD **30** is positioned at the inlet of the exhaust aftertreatment system **22**, upstream of the NSD **40**. The NSD **40** is positioned between the HCSD **30** and the DOC **50** (i.e., downstream of the HCSD **30** and upstream of the DOC **50**). The DOC **50** is positioned downstream of the NSD **40** and upstream of the DPF-SCR **70**. The first doser **84** is positioned between the DOC **50** and the DPF-SCR **70**. The SCR catalyst **90** is positioned downstream of the DPF-SCR **70**, near the outlet of the exhaust aftertreatment system **22**. The second doser **88** is positioned between the DPF-SCR **70** and the SCR catalyst **90** (i.e., upstream of the SCR catalyst **90** and downstream of the DPF-SCR **70**). However, in alternative embodiments, other arrangements of the components of the exhaust aftertreatment system **22** are also possible (e.g., components may be omitted, added, rearranged, etc.). In an alternative embodiment, the HCSD **30** and the NSD **40** are omitted. In yet another alternative embodiment, the function of the HCSD **30**, the NSD **40**, and the DOC **50** is performed by a single catalyst system. In still another alternative embodiment, the DPF-SCR **70** includes two separate elements, a DPF and a SCR catalyst, with or without the HCSD **30** and/or the NSD **40** present in the exhaust aftertreatment system **22**. In some alternative embodiments, the SCR catalyst **90** may include one or more catalysts (e.g., two, three, etc.) aligned in a serial manner.

In some embodiments, the exhaust aftertreatment system **22** includes an exhaust gas recirculation (EGR) system, shown as EGR system **100**. According to the example embodiment shown in FIG. **1**, the EGR system **100** includes an exhaust throttle **102** and low pressure exhaust gas recirculation (LPEGR) piping **104**. The LPEGR piping **104** is structured to recirculate exhaust gas back to an intake of the engine **20** from the exhaust aftertreatment system **22**. As shown in FIG. **1**, the LPEGR piping **104** is positioned downstream of the DPF-SCR **70** and upstream of the SCR catalyst **90**. In other embodiments, the LPEGR piping **104** is positioned in any one of a variety of other locations (e.g., upstream of the DPF-SCR **70**, downstream of the SCR catalyst **90**, etc.). The exhaust throttle **102** is configured to modulate (i.e., control, etc.) the exhaust flow through the exhaust aftertreatment system **22**. By way of example, the exhaust throttle **102** may be configured to increase the exhaust flow through the LPEGR piping **104** by closing or actuating towards a closed position. By way of another example, the exhaust throttle **102** may be configured to increase the exhaust flow through the SCR catalyst **90** and out of the exhaust aftertreatment system **22** by opening or actuating towards an open position.

In some embodiments, the exhaust aftertreatment system **22** includes an ammonia oxidation (AMOx) catalyst. The AMOx catalyst may be positioned in various locations along the exhaust aftertreatment system **22**. The AMOx catalyst may be any of various flow-through catalysts configured to react with ammonia to produce mainly nitrogen. The AMOx catalyst is structured to remove ammonia that may have slipped through or exited the DPF-SCR **70** and/or the SCR catalyst **90** without reacting with NOx in the exhaust gas. In certain instances, the exhaust aftertreatment system **22** may be operable with or without an AMOx catalyst. Further, although the AMOx catalyst is described as a separate unit from the DPF-SCR **70** and the SCR catalyst **90**, in some implementations, the AMOx catalyst may be integrated with the DPF-SCR **70** or the SCR catalyst **90**. For example, the AMOx catalyst and the SCR catalyst **90** may be located within the same housing.

In an exhaust flow direction, as indicated by directional arrow **29**, exhaust gas flows from the engine **20** to an ambient environment through exhaust piping of the exhaust aftertreatment system **22**. As indicated by direction arrow **29**, the exhaust gas from the engine **20** flows into an inlet piping section **24** (e.g., headers, downpipes, tubes, conduit, etc.) of exhaust piping of the exhaust aftertreatment system **22**. From the inlet piping section **24**, the exhaust gas flows into the HCSD **30** and exits the HCSD **30** into the NSD **40**. The exhaust gas flows through the NSD **40** into the DOC **50**. The exhaust gas exits the DOC **50** into a first mid-pipe section **26**A of the exhaust piping of the exhaust aftertreatment system **22**. From the first mid-pipe section **26**A, the exhaust gas flows into the DPF-SCR **70** and exits the DPF-SCR **70** into a second mid-pipe section **26**B of the exhaust piping of the exhaust aftertreatment system **22**. From the second mid-pipe section **26**B, the exhaust gas flows into the SCR catalyst **90** and exits the SCR catalyst **90** into outlet piping section **28** (e.g., tailpipe, muffler, etc.) of the exhaust piping before the exhaust gas is expelled from the exhaust aftertreatment system **22** (e.g., into an ambient environment, etc.).

By way of example, as the exhaust gas flows through the first mid-pipe section **26**A of the exhaust piping, it may periodically be dosed with reductant by the first doser **84**. Accordingly, the first mid-pipe section **26**A of the exhaust piping may act as a decomposition chamber or tube to facilitate the decomposition of the reductant (e.g., urea, etc.) to ammonia (e.g., if the reductant is urea, etc.). By way of another example, as the exhaust gas flows through the second mid-pipe section **26**B of the exhaust piping, it may periodically be dosed with reductant by the second doser **88**. Accordingly, the second mid-pipe section **26**B of the exhaust piping may act as a decomposition chamber or tube to facilitate the decomposition of the reductant (e.g., urea, etc.) to ammonia (e.g., if the reductant is urea, etc.).

Referring still to FIG. **1**, the exhaust aftertreatment system **22** may include various sensors, such as NOx sensors, temperature sensors, and/or reductant sensors. The various sensors may be strategically disposed throughout the exhaust aftertreatment system **22** and may be in communication with the controller **150** to monitor operating conditions of the exhaust aftertreatment system **22**. As shown in FIG. **1**, the exhaust aftertreatment system **22** includes a first NOx sensor (e.g., an engine out NOx sensor, etc.), shown as inlet NOx sensor **12**, and a second NOx sensor (e.g., system out NOx sensor, tailpipe NOx sensor, etc.), shown as outlet NOx sensor **14**. The inlet NOx sensor **12** is positioned along the inlet piping section **24** of the exhaust piping of the exhaust aftertreatment system **22**. According to an example embodiment, the inlet NOx sensor **12** is configured to acquire NOx data indicative of an amount of NOx within the exhaust gas exiting from the engine **20** (e.g., engine outlet NOx data, etc.) and entering into the exhaust aftertreatment system **22** through the inlet piping section **24**. The outlet NOx sensor **14** is positioned along the outlet piping section **28** of the exhaust piping of the exhaust aftertreatment system **22**, downstream of the SCR catalyst **90**. According to an example embodiment, the outlet NOx sensor **14** is configured to acquire NOx data indicative of an amount of NOx of the exhaust gas exiting from the SCR catalyst **90** (e.g., aftertreatment outlet NOx data, etc.) through the outlet piping section **28** of the exhaust piping of the exhaust aftertreatment system **22** into an ambient environment (e.g., an outside environment, an environment external to the engine system **10**, etc.).

In an alternative embodiment, the inlet NOx sensor **12** is positioned along the first mid-pipe section **26**A between the DOC **50** and the DPF-SCR **70**, and configured to acquire NOx data indicative of an inlet amount of NOx entering the DPF-SCR **70**. In some embodiments, the exhaust aftertreatment system **22** includes additional NOx sensors (e.g., in addition to the inlet NOx sensor **12** and the outlet NOx sensor **14**, etc.) configured to acquire NOx data at different sections of the exhaust piping and/or between different components of the exhaust aftertreatment system **22**. Due to the DOC **50** and/or the DPF-SCR **70** potentially oxidizing some portion of the amount of NOx exiting from the engine **20** (e.g., NO, etc.), the proportions of the amount of NOx exiting from the engine **20** (e.g., NO, NO_2, etc.) may not be equal to the proportions of the amount of NOx entering the DPF-SCR **70** and/or the SCR catalyst **90**. For example, NO may be oxidized to NO_2 in the DOC **50** and/or DPF-SCR **70** such that the relative proportions of NO, NO_2, etc. may not be equal to the original proportions from the engine **20**. Therefore, it may be beneficial to acquire NOx data at the inlet of the DPF-SCR **70** and/or the SCR catalyst **90**. By way of example, the exhaust aftertreatment system **22** may include a third NOx sensor positioned along the first mid-pipe section **26**A between the DOC **50** and the DPF-SCR **70**, and configured to acquire NOx data indicative of an inlet amount of NOx of the exhaust gas entering the DPF-SCR **70**. By way of another example, the exhaust aftertreatment system **22** may include a fourth NOx sensor positioned along the second mid-pipe section **26**B between the DPF-SCR **70** and the SCR catalyst **90**, and configured to acquire NOx data indicative of an inlet amount of NOx of the exhaust gas entering the SCR catalyst **90**. Therefore, the amount of NOx within the exhaust gas at various locations of the exhaust aftertreatment system **22**, and/or the amount of NOx converted (e.g., decomposed, etc.) during chemical reactions within the DPF-SCR **70** and/or SCR catalyst **90** may be monitored by the controller **150**.

As shown in FIG. **1**, the exhaust aftertreatment system **22** includes a first temperature sensor, shown as engine outlet temperature sensor **13**, a second temperature sensor, shown as DPF-SCR inlet temperature sensor **15**, and a third temperature sensor, shown as SCR inlet temperature sensor **17**. The engine outlet temperature sensor **13** is positioned along the inlet piping section **24** of the exhaust piping of the exhaust aftertreatment system **22**. According to an example embodiment, the engine outlet temperature sensor **13** is configured to acquire temperature data indicative of a temperature of the exhaust gas exiting from the engine **20** and entering into the exhaust aftertreatment system **22** through the inlet piping section **24**. As shown in FIG. **1**, the DPF-SCR inlet temperature sensor **15** is positioned along the first mid-pipe section **26**A of the exhaust piping of the exhaust aftertreatment system **22**. According to an example embodiment, the DPF-SCR inlet temperature sensor **15** is configured to acquire temperature data indicative of a temperature of the exhaust gas entering the DPF-SCR **70**. As shown in FIG. **1**, SCR inlet temperature sensor **17** is positioned along the second mid-pipe section **26**B of the exhaust piping of the exhaust aftertreatment system **22**. According to an example embodiment, the SCR inlet temperature sensor **17** is configured to acquire temperature data indicative of a temperature of the exhaust gas entering the SCR catalyst **90**.

In some embodiments, the exhaust aftertreatment system **22** includes additional temperature sensors configured to acquire temperature data at different sections of the exhaust piping of the exhaust aftertreatment system **22**. For example, temperature sensors may be positioned along the outlet piping section **28** of the exhaust piping and/or in-between at least two of the HCSD **30**, the NSD **40**, and the DOC **50**. By way of example, temperature sensors may be strategically positioned before and after any component within the exhaust aftertreatment system **22** such that the temperature of the exhaust gas flowing into and out of any component may be detected and communicably transmitted to the controller **150**.

As shown in FIG. **1**, the exhaust aftertreatment system **22** includes a reductant sensor, shown as reductant sensor **76**. The reductant sensor **76** is positioned along the second mid-pipe section **26**B of the exhaust piping of the exhaust aftertreatment system **22**, downstream of the second doser **88**. According to an example embodiment, the reductant sensor **76** is configured to acquire reductant data indicative of an amount of reductant within the exhaust gas downstream of the DPF-SCR **70** and the second doser **88**, and upstream of the SCR catalyst **90**.

In alternative embodiments, the exhaust aftertreatment system **22** does not include the reductant sensor **76**. In some embodiments, the exhaust aftertreatment system **22** includes additional reductant sensor and/or the reductant sensor **76** is positioned in a different location of the exhaust aftertreatment system **22**. By way of example, a reductant sensor may be positioned near the inlet of the DPF-SCR **70** downstream of the first doser **84** and configured to acquire reductant data indicative of an amount of reductant injected in to the exhaust gas by the first doser **84** and entering the DPF-SCR **70**. By way of another example, a reductant sensor may be positioned near the outlet of the DPF-SCR **70** upstream of the second doser **88** and configured to acquire reductant data indicative of an amount of reductant in the exhaust gas after flowing through the DPF-SCR **70**. By way of yet another example, a reductant sensor may be positioned downstream of the SCR catalyst **90** and configured to acquire reductant data indicative of an amount of reductant in the exhaust gas after flowing through the SCR catalyst **90**. Therefore, the amount of reductant injected by at least one of the first doser **84** and the second doser **88**, and/or the amount of reductant decomposed during chemical reactions with NOx and other exhaust gas constituents within the DPF-SCR **70** and/or SCR catalyst **90** may be monitored by the controller **150**.

In some embodiments, the exhaust aftertreatment system **22** includes one or more particulate matter (PM) sensors configured to acquire data indicative of an amount of particulate matter flowing through the exhaust aftertreatment system **22**. The PM sensors may be strategically positioned before and/or after any component within the exhaust aftertreatment system **22** such that the particulate matter of the exhaust gas flowing into and out of any component may be detected and communicably transmitted to the controller **150**. In some embodiments, the engine **20** includes various sensors configured to acquire engine operation data. The various sensors of the engine **20** may be in communication with the controller **150** such that the controller **150** may monitor operating conditions of the engine **20** indicated by the engine operation data. By way of example, the engine **20** may include a speed sensor, a torque sensor, and/or a flow sensor configured to acquire data indicative of engine speed, engine torque, and exhaust flow characteristics.

In other embodiments, a virtual NOx sensor, a virtual reductant sensor, or any other virtual sensor is used instead of actual physical sensor at the locations shown in FIG. **1**. While FIG. **1** depicts a several NOx sensors (and reductant sensors, temperature sensors, etc.), it should be understood that one or more of these NOx sensors (or reductant sensors, temperature sensors, etc.) may be replaced by virtual sensor in other embodiments. In this regard, the NOx amount (reductant amount, temperature, etc.) at various locations may be estimated, determined, or otherwise correlated with various operating conditions of the engine **20** and exhaust aftertreatment system **22**. For example, based on the engine speed, throttle position, ambient air temperature, and intake mass air flow, an indicative amount of NOx exiting the engine **20** may be determined. The determination may utilize a look-up table that correlates various operating conditions with expected NOx amounts, which can be based on data determined during testing. The determination may also utilize any of a model, formula, equation, process, and the like to otherwise determine a NOx amount at a various location without the use of a physical sensor. This embodiment may be beneficial in exhaust aftertreatment system architectures that are positioned in rather tight spaces, such that the electrical circuitry otherwise used to power and establish a communication protocol with the physical sensors may be eliminated. Further, this embodiment may be beneficial from the standpoint that the need to replace faulty sensors may be substantially avoided. In turn, an operator may realize a rather higher uptime for the system than downtime (e.g., in a repair shop, etc.).

FIG. **1** is also shown to include an operator input/output (I/O) device **120**. The operator I/O device **120** is communicably coupled to the controller **150**, such that information may be exchanged between the controller **150** and the I/O device **120**. The information may relate to one or more components of FIG. **1** or determinations (described below) of the controller **150**. The operator I/O device **120** enables an operator of the engine system **10** to communicate with the controller **150** and one or more components of the engine system **10** of FIG. **1**. For example, the operator input/output device **120** may include, but is not limited to, an interactive display, a touchscreen device, one or more buttons and switches, voice command receivers, etc. In some embodiments, the controller **150** and components described herein may be implemented with non-vehicular applications (e.g., a power generator, etc.). Accordingly, the operator I/O device **120** may be specific to those applications. For example, in those instances, the operator I/O device **120** may include a laptop computer, a tablet computer, a desktop computer, a phone, a watch, a personal digital assistant, etc. Via the I/O device **120**, the controller **150** may provide a fault or service notification based on the determined state of the SCR catalyst **90** and the DPF-SCR **70**.

The controller **150** is structured to control the operation of the engine system **10** and associated sub-systems, such as the internal combustion engine **20** and the exhaust aftertreatment system **22**. According to one embodiment, the components of FIG. **1** are embodied in a vehicle. The vehicle may include an on-road or an off-road vehicle including, but not limited to, line-haul trucks, mid-range trucks (e.g., pick-up trucks), cars, boats, tanks, airplanes, and any other type of vehicle that utilizes an exhaust aftertreatment system. In various alternate embodiments, as described above, the controller **150** may be used with any engine-exhaust aftertreatment system (e.g., a stationary power generation system, etc.). Communication between and among the components may be via any number of wired or wireless connections (e.g., any standard under IEEE 802, etc.). For example, a wired connection may include a serial cable, a fiber optic cable, a CAT5 cable, or any other form of wired connection. In comparison, a wireless connection may include the Internet, Wi-Fi, cellular, Bluetooth, Zigbee, radio, etc. In one embodiment, a controller area network (CAN) bus provides the exchange of signals, information, and/or data. The CAN bus can include any number of wired and wireless connections that provide the exchange of signals, information, and/or data. The CAN bus may include a local area network (LAN), or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

Because the controller **150** is communicably coupled to the systems and components of FIG. **1**, the controller **150** is structured to receive engine operation data and/or exhaust aftertreatment system operation data from one or more sensors shown in FIG. **1**. For example, the exhaust aftertreatment system operation data may include NOx data (e.g., engine out NOx data from the inlet NOx sensor **12**, aftertreatment outlet NOx data from the outlet NOx sensor **14**, etc.), reductant data (e.g., timing and amount of reductant injected into the exhaust gas from the first doser **84** and/or the second doser **88**, etc.), and temperature data (e.g., temperature of the exhaust flow at various locations from the first, second, and/or third temperature sensors **13**, **15**, **17**, etc.). The engine operation data may include engine speed, vehicle speed, engine temperature, engine torque, engine power, exhaust flow, etc. received via one or more sensors.

As the components of FIG. **1** are shown to be embodied in an engine system **10**, in one embodiment the controller **150** may be embodied as add-on to an electronic control module (ECM). In some embodiments, the controller **150** may be a stand-alone tool that performs all required data logging, data tracking, data analysis, etc. needed to diagnose the SCR system **60**. In some embodiments, the controller **150** is included in the ECM of a vehicle. The ECM may include a transmission control unit and any other vehicle control unit (e.g., exhaust aftertreatment control unit, powertrain control module, engine control module, etc.). In an alternative embodiment, the controller **150** is web based, server based, and/or application based (e.g., a smartphone app, a controller on the internet, etc.). The structure and function of the controller **150** is further described in regard to FIG. **2**.

As such, referring now to FIG. **2**, an example structure for the controller **150** is shown according to one embodiment.

As shown, the controller **150** includes a processing circuit **151** including a processor **152** and a memory **154**. The processor **152** may be implemented as a general-purpose processor, an application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a digital signal processor (DSP), a group of processing components, or other suitable electronic processing components. The one or more memory devices **154** (e.g., RAM, ROM, Flash Memory, hard disk storage, etc.) may store data and/or computer code for facilitating the various processes described herein. Thus, the one or more memory devices **154** may be communicably connected to the processor **152** and provide computer code or instructions to the processor **152** for executing the processes described in regard to the controller **150** herein. Moreover, the one or more memory devices **154** may be or include tangible, non-transient volatile memory or non-volatile memory. Accordingly, the one or more memory devices **154** may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described herein.

The memory **154** is shown to include various modules for completing the activities described herein. More particularly, the memory **154** includes an engine module **155**, a NOx module **156**, a reductant module **159**, a SCR system diagnostic module **162**, and a notification module **165**. The modules are structured to determine a NOx conversion efficiency fault and diagnose one or more components of the SCR system **60** faulty; more specifically, isolate the failure to at least one of the DPF-SCR **70** and the SCR catalyst **90**. Faulty can mean that replacement of a component (e.g., the DPF-SCR **70**, the SCR catalyst **90**, etc.) is necessary. Faulty can also mean that the component should be checked. In practicality, faulty can mean a check engine light on the dashboard, a notification to a remote interface, etc. While various modules with particular functionality are shown in FIG. **2**, it should be understood that the controller **150** and memory **154** may include any number of modules for completing the functions described herein. For example, the activities of multiple modules may be combined as a single module, additional modules with additional functionality may be included, etc. Further, it should be understood that the controller **150** may further control other vehicle activity beyond the scope of the present disclosure.

Certain operations of the controller **150** described herein include operations to interpret and/or to determine one or more parameters. Interpreting or determining, as utilized herein, includes receiving values by any method known in the art, including at least receiving values from a datalink or network communication, receiving an electronic signal (e.g. a voltage, frequency, current, or PWM signal) indicative of the value, receiving a computer generated parameter indicative of the value, reading the value from a memory location on a non-transient computer readable storage medium, receiving the value as a run-time parameter by any means known in the art, and/or by receiving a value by which the interpreted parameter can be calculated, and/or by referencing a default value that is interpreted to be the parameter value.

The engine module **155** is structured to receive engine operation data **170** (e.g., from one or more sensors of the engine **20**, from a virtual sensor, etc.). In this regard and in one embodiment, the engine module **155** may include the engine **20** and any sensor operatively coupled to the engine **20**. In other embodiments, the engine module **155** may only include the sensor(s) communicably coupled to the engine **20**. In further embodiments, the engine module **155** may include communication circuitry for obtaining and/or receiving the engine data **170** from one or more virtual and/or physical sensors of the engine **20**. The engine operation data **170** may include, but is not limited to, a vehicle speed, an engine speed, an engine torque, an engine power, an exhaust flow characteristic, and the like. The engine operation data **170** may be stored within the engine module **155** for further use by other modules of the controller **150**. In some embodiments, the engine module **155** is further structured to provide an engine operation command (e.g., instruction, etc.) to the engine **20**. The engine operation command may be configured to adjust or perturb an amount of NOx out of the engine **20** (e.g., during an intrusive diagnostic test, during a passive diagnostic test, etc.). Adjusting the amount NOx in the exhaust flow may allow for the test to be run at multiple testing states or with a sufficient amount of NOx to accurately perform the diagnostic test. Adjusting the engine operation command may include, but is not limited to, an exhaust gas recirculation (EGR) flow amount adjustment, an ignition timing adjustment, an engine speed adjustment, fuel injection timing adjustment, fuel injection pressure adjustment, a fuel injection amount adjustment, an air flow amount, a number of fuel injection pulses, a fuel flow amount, and an engine torque output, among other alternatives. The engine operation commands may be provided individually or with other commands. The extent to which any of the aforementioned engine operation commands may be used and in what combination may vary based on engine design, engine application, or type of diagnostic test (e.g., passive, intrusive, etc.).

The engine operation command from the engine module **155** may include a command to actuate the exhaust throttle **102** (e.g., open, close, etc.) to adjust the EGR flow from the exhaust aftertreatment system **22** to an intake of the engine **20** through the LPEGR piping **104**. EGR is an emission control technology allowing substantial decreases in NOx emissions when the EGR flow is increased (e.g., the exhaust throttle **102** is actuated towards a closed position, etc.), and substantial increases when the EGR flow is decreased or stopped (e.g., the exhaust throttle **102** is actuated towards an open position, etc.). Essentially, the amount of NOx decreases as the EGR rate increases. Also, NOx reduction at a given EGR rate increases as the engine load may become higher. For example, a given decrease in NOx emissions may require less EGR at high loads (e.g., high engine torque, etc.) than at low loads (e.g., low engine torque, etc.).

The engine operation command from the engine module **155** may adjust injection pressure. An increase in the fuel injection pressure may result in an increase in the NOx emissions at medium and at high engine loads (e.g., mid-to-high engine torque, etc.), while a decrease in the fuel injection pressure may decrease the NOx emissions. Multi-pulse injection may be used to lengthen the combustion event, thus increasing the amount of heat is the system, thereby facilitating the generation of greater amounts of NOx emissions. In some embodiments, engine brakes may be used to increase the load on the engine **20** or a variable geometry turbocharger (VGT) may also be used to increase load and flow by building exhaust backpressure. Greater engine load may increase the NOx emissions.

The ignition timing adjustment command may include at least one of an advance to ignition timing and a retarding to ignition timing. In a compression-ignition engine, ignition timing adjustment refers to when fuel is injected into a combustion chamber. In comparison, ignition timing adjustment in a spark-ignition engine refers to when a spark is commanded. Thus, when the controller **150** is embodied with a compression-ignition engine, the engine module **155** may provide a command to a fuel injector (including a solenoid or other fuel injector driver and the components related to the fuel injector, such as a common rail) to adjust when fuel is injected into the combustion chamber. When the controller **150** is embodied in a spark-ignition engine, the engine module **155** may provide a command to a spark plug or igniter (including any spark plug or igniter drivers, such as a solenoid or a transformer for a power supply) to adjust when the spark event is initiated. Accordingly, while the description below is substantially in regard to compression-ignition engines (e.g., fuel injectors), it should be understood that similar commands may be provided with spark-ignition commands such that all such variations fall within the spirit and scope of the present disclosure.

Therefore, as mentioned above, the engine module **155** may provide an ignition timing adjustment command that includes at least one of retarding and advancing ignition timing. The timing may be adjusted to increase or decrease the NOx production of the engine **20**. Advancing the ignition timing refers to commanding fuel injection relatively earlier than it otherwise would occur. In comparison, retarding ignition timing refers to delaying a fuel injection event. For example, if the ignition timing of an engine is set to nine degrees before top dead center (BTDC) and is adjusted to twelve degrees BTDC, the ignition timing is advanced. Proper ignition timing may be critical for optimum performance, fuel economy, and emissions. Advancing ignition timing may result in increases to both the temperature and pressure within the engine cylinders. Because NOx formation tends to occur at relatively higher combustion temperatures, the NOx amount out of the engine may increase due to this command. In comparison, retarding ignition timing may result in lower temperature and pressures within the combustion cylinder. As a result, a relatively smaller amount of NOx out of the engine may occur. Thus, the engine module **155** may provide one or more commands to adjust the ignition timing, which results in a change in a NOx amount out of the engine and excites the amount of NOx within the exhaust gas.

As mentioned above, the engine operation command from the engine module **155** may also include an adjustment to engine speed (i.e., revolutions-per-minute (RPM)). By increasing the engine speed, the average temperature of the engine cylinders may rise as heat is spread relatively more rapidly throughout the combustion chamber. Over time, the average temperature in the cylinder rises. Therefore, because NOx production is highly dependent on high temperature, by increasing engine speed, the engine out NOx amount exhaust may increase. On the other hand, decreasing engine speed may have the opposite effect. As such, the temperature may decrease and in turn, the engine out amount of NOx may decrease. Increasing the engine speed demands a significant increase to the indicated torque and fuel flow to the engine **20**, which may increase NOx production. Further, the increased flow through the engine provides a wider operating space to adjust the engine operation commands, allowing the possibility for finding a combination of engine operation commands that provides a higher NOx concentration than is possible at a lower speed.

Thus, the engine module **155** may provide one or more commands that are structured to excite (e.g., increase or decrease) an engine out NOx amount. As such, multiple engine commands may be used simultaneously to affect an increase or decrease in the NOx emissions of the engine **20**. However, it should be understood that other parameters may also be controlled by the engine module **155**.

As shown in FIG. **2**, the NOx module **156** includes an engine outlet NOx module **157** and an aftertreatment outlet NOx module **158**. The engine outlet NOx module **157** is structured to receive and store engine outlet NOx data **172** indicative of an amount of NOx exiting the engine **20**. Therefore, the engine outlet NOx module **157** may be communicably coupled with the inlet NOx sensor **12**. In other embodiments, the NOx module **156** may include the NOx sensor **12** (or a virtual sensor for determining an indicative amount of engine out NOx). The aftertreatment outlet NOx module **158** is structured to receive and store aftertreatment outlet NOx data **174** indicative of an amount of NOx exiting the SCR catalyst **90** (e.g., an actual/measured amount of NOx downstream of the SCR catalyst **90**, etc.). Therefore, the aftertreatment outlet NOx module **158** may be communicably coupled with the outlet NOx sensor **14**. The NOx module **156** is structured to interpret the engine outlet NOx data **172** and the aftertreatment outlet NOx data **174** to determine whether a NOx conversion efficiency fault is present based on NOx conversion efficiency for the SCR system **60**. The NOx module **156** may determine the NOx conversion efficiency fault on an instantaneous or a cumulative basis to determine if the exhaust aftertreatment system **22** is operating nominally.

The reductant module **159** is structured to provide a dosing command to a reductant doser, such as the first doser **84** and the second doser **88**, to control an amount of reductant injected into the exhaust flow. In this regard and in some embodiments, the reductant module **159** may include the reductant doser while in other embodiments the reductant module **159** may include communication circuitry for communicating with the doser. The dosing command may include at least one of a command to suspend reductant dosing injection by one of the dosers into the exhaust flow and a command to increase, decrease, or maintain a reductant dosing injection by one of the dosers into the exhaust flow. The reductant module **159** is further structured to provide a command to control the injection location of the reductant into the exhaust flow (e.g., upstream of the DPF-SCR **70**, downstream of the DPF-SCR **70**, etc.). According to an example embodiment, the reductant module **159** provides the dosing command to one of the first doser **84** and the second doser **88** at a time (i.e., only one of the first doser **84** and the second doser **88** inject reductant into the exhaust flow at a time, etc.). Reductant dosing may be used by the reductant module **159** to decreases the levels of NOx in the exhaust gas. According to an example embodiment, the reductant module **159** is structured to provide the dosing commands to maintain NOx conversion efficiency requirements of the exhaust aftertreatment system **22** (e.g., based on efficiency regulations, laws, etc.) while reducing the amount of reductant consumed to maintain the NOx conversion efficiency requirements (e.g., optimizing the total consumption of reductant, etc.). In one embodiment, the reductant module **159** provides the dosing command to the first doser **84** to inject reductant upstream of the DPF-SCR **70** such that the exhaust aftertreatment system **22** relies more on the DPF-SCR **70** for NOx conversion. In another embodiment, the reductant module **159** provides the dosing command to the second doser **88** to inject reductant downstream of the DPF-SCR **70** such that the exhaust aftertreatment system **22** relies more on the SCR catalyst **90** for NOx conversion.

Reductant oxidation does not aid in the NOx conversion and is a function of the temperature of the SCR system **60**. The dosing commands provided to the first and second dosers **84** and **88** are based on monitoring the temperatures of the DPF-SCR **70** and SCR catalyst **90** indicated by temperature data **178**, as well as other operating characteristics regarding the engine **20** and/or the exhaust aftertreatment system **22** (e.g., the engine operation data **170**, the engine outlet NOx data **172**, the aftertreatment outlet NOx data **174**, etc.). The temperature of the exhaust flow throughout the exhaust aftertreatment system **22** may directly affect which of the first doser **84** and the second doser **88** the reductant module **159** provides the dosing command to. Therefore, the reductant module **159** may be communicably coupled with at least one of the engine outlet temperature sensor **13**, the DPF-SCR inlet temperature sensor **15**, and the SCR inlet temperature sensor **17**. The reductant module **159** is further structured to receive the temperature data **178** indicative of a temperature of the exhaust flow at various locations of the exhaust aftertreatment system **22** including at least one of a temperature at the outlet of the engine **20** (e.g., from the engine outlet temperature sensor **13**, etc.), a temperature at the inlet of the DPF-SCR **70** (e.g., from the DPF-SCR inlet temperature sensor **15**, etc.), and a temperature at the inlet of the SCR catalyst **90** (e.g., from the SCR inlet temperature sensor **17**, etc.).

Referring now to FIGS. **3-4**, engine operating characteristics and exhaust aftertreatment system operating characteristics are shown according to an example embodiment. As shown in FIG. **3**, an engine operating characteristics graph **300** illustrates operating characteristic of the engine **20** during an example operation of the engine system **10**. The operating characteristics of the engine **20** include, but are not limited to, engine speed **310**, engine torque **320**, and exhaust flow **330**. As shown in FIG. **4**, an exhaust aftertreatment system operating characteristics graph **400** corresponding to the engine operating characteristics graph **300** illustrates operating characteristics of the exhaust aftertreatment system **22** during the example operation of the engine system **10**. The operating characteristics of the exhaust aftertreatment system **22** include, but are not limited to, engine outlet temperature **410**, DPF-SCR inlet temperature **420**, SCR catalyst inlet temperature **430**, and DPF-SCR outlet dosing **440**. As shown in FIGS. **3-4**, as the operating characteristics of the engine **20** fluctuate (e.g., during operation of the engine, etc.), the temperature of the exhaust at various locations of the exhaust aftertreatment system **22** vary, as well as which of the reductant dosers (e.g., the first doser **84**, the second doser **88**, etc.) provides the reductant injection into the exhaust flow.

Referring to FIGS. **2** and **4**, as the DPF-SCR inlet temperature **420** increases above a threshold temperature (e.g., approximately 450° C., etc.), the reductant module **159** provides a dosing command to the second doser **88** downstream of the DPF-SCR **70** as indicated by the DPF-SCR outlet dosing **440** (i.e., when the DPF-SCR outlet dosing **440** is at a value of 1, the reductant module **159** provides a dosing command to the second doser **88**; when the DPF-SCR outlet dosing **440** is at a value of 0, the reductant module **159** provides a dosing command to the first doser **84**; etc.). Therefore, according to the example embodiment shown in FIG. **4**, the reductant module **159** is structured to provide the dosing command to the second doser **88** when the DPF-SCR **70** operates at a temperature above the temperature threshold, and provide the dosing command to the first doser **84** when the DPF-SCR **70** operates at a temperature below the temperature threshold.

Referring back to FIG. **2**, the reductant module **159** includes a reductant inlet module **160** and a reductant outlet module **161**. The reductant inlet module **160** may be communicably coupled to the first doser **84** and the second doser **88**. The reductant inlet module **160** is configured to acquire and store reductant data **176** indicative of an amount of reductant injected into the exhaust flow. Therefore, the reductant inlet module **160** may be communicably coupled to a flow sensor structured to monitor the amount of reductant injected by the first doser **84** and/or the second doser **88** or otherwise determine the amount of reductant injected (e.g., based on the dosing command, based on the amount of reductant measured by a reductant sensor, etc.). The reductant outlet module **161** is structured to receive and store reductant data **176** indicative of an actual/measured amount of reductant exiting the DPF-SCR **70** (i.e., downstream of the DPF-SCR **70**, etc.). Therefore, the reductant outlet module **161** may be communicably coupled with the reductant sensor **76**.

The SCR system diagnostic module **162** is structured to determine at least one of the DPF-SCR **70** and the SCR catalyst **90** are faulty in response to the NOx module **156** determining that the exhaust aftertreatment system **22** is experiencing the NOx conversion efficiency fault. The SCR system diagnostic module **162** may be communicably coupled to the various modules of the controller **150**. Therefore, the SCR system diagnostic module **162** is structured to receive and interpret operating characteristics of the engine **20** indicated by the engine operation data **170** and operating characteristics of the exhaust aftertreatment system **22** indicated by at least one of the engine outlet NOx data **172**, the aftertreatment outlet NOx data **174**, the reductant data **176**, and the temperature data **178**. As shown in FIG. **2**, the SCR system diagnostic module **162** includes a NOx analysis module **163** and a reductant analysis module **164**. The NOx analysis module **163** is structured to determine whether the DPF-SCR **70** and/or the SCR catalyst **90** is faulty, while the reductant analysis module is structured to determine whether the DPF-SCR **70** is faulty.

According to an example embodiment, the NOx analysis module **163** is structured to receive the aftertreatment outlet NOx data **174** indicative a NOx conversion value. The NOx conversion value is based on an actual amount of NOx entering the exhaust aftertreatment system **22** and an actual amount of NOx downstream of the SCR catalyst **90** exiting the exhaust aftertreatment system **22**. The NOx analysis module **163** is further structured to determine an expected NOx conversion value based on the actual amount of NOx entering the exhaust aftertreatment system **22** and an expected amount of NOx of the exhaust flow downstream of (i.e., exiting, etc.) the SCR catalyst **90**. The expected amount of NOx downstream of the SCR catalyst **90** may be determined based on at least one of the operating characteristics of the engine **20** (e.g., exhaust flow, engine speed, etc.) and the operating characteristics of the exhaust aftertreatment system **22** (e.g., the temperature of the exhaust flow at various locations, the amount of reductant injected into the system, the amount of NOx exiting entering the exhaust aftertreatment system **22**, etc.). In one embodiment, the determination of the expected amount of NOx downstream of the SCR catalyst **90** is determined and the actual amount of NOx is measured (e.g., via the inlet NOx sensor, the outlet NOx sensor **14**, etc.) when the reductant is injected into the exhaust flow downstream of the DPF-SCR **70** and upstream of the SCR catalyst **90** by the second doser **88**. The determination of whether the SCR catalyst **90** is faulty may be substantially easier and more accurate when the SCR catalyst **90** performs most of the NOx conversion. As indicated above, the reductant module **159** may inject the reductant via the second doser **88** when the exhaust aftertreatment system **22** relies more on the SCR catalyst **90** for NOx conversion.

The NOx analysis module **163** is further structured to compare the actual NOx conversion value (i.e., the actual amount of NOx downstream of the SCR catalyst **90**, etc.) to at least one of the expected NOx conversion value (i.e., the expected amount of NOx downstream of the SCR catalyst **90**, etc.) and a threshold value of NOx to determine whether the underfloor SCR catalyst **90** is the component or the primary component of the SCR system **60** causing the NOx conversion efficiency fault. The threshold value of NOx may be preset within the NOx analysis module **163** and may be based on the respective aftertreatment system **22** architecture and components and/or engine **20**. The NOx analysis module **163** is structured to determine that the SCR catalyst **90** is faulty in response to at least one of the actual NOx conversion value across the SCR catalyst **90** differing from the expected NOx conversion value across the SCR catalyst **90** greater than a threshold amount (i.e. the actual NOx amount downstream of the SCR catalyst **90** differing from the expected amount of NOx downstream of the SCR catalyst **90** greater than a threshold NOx difference, etc.) and the actual NOx amount of NOx downstream of the SCR catalyst **90** being greater than the threshold value of NOx. Conversely, if the NOx module **157** determines that the SCR system **60** is experiencing a NOx conversion efficiency fault, and the NOx analysis module **163** determines that the SCR catalyst **90** is not faulty (e.g., the actual NOx conversion value across the SCR catalyst **90** differing from the expected NOx conversion value across the SCR catalyst **90** less than the threshold, the actual amount of NOx downstream of the SCR catalyst **90** being less than the threshold value of NOx, etc.), the NOx analysis module **163** is structured to determine that the DPF-SCR **70** is faulty (i.e., the cause of the NOx conversion efficiency fault of the SCR system **60**). The reductant analysis module **164** may be structured to verify (e.g., provide supplementary confirmation, etc.) that the DPF-SCR **70** is in-fact faulty, which is described more fully herein. The threshold NOx difference may be a magnitude difference, a percentage difference, or the like between the actual amount of NOx and the expected amount of NOx. The notification module **165** is structured to provide an alert or notification to an operator (e.g., an driver, a technician, etc.) via the operator I/O device **120** that the SCR catalyst **90** may be faulty responsive to the NOx conversion efficiently fault and at least one of the threshold NOx difference and the threshold value of NOx being exceeded.

According to another embodiment, the NOx analysis module **163** is structured to construct a map and/or a table of expected NOx conversion efficiency based on the engine out NOx amount, aftertreatment temperatures, exhaust flow characteristics, and/or any other information from the engine **20** and/or the exhaust aftertreatment system **22**. In one embodiment, the map and/or table may be created to include multiple operating points of the engine **20** and the exhaust aftertreatment system **22**. In another embodiment, the map and/or table include a narrower region of operation where the information from inlet and outlet NOx sensors **12** and **14** are more readily available and a better separation is observed between a healthy and failed SCR system **60**. The NOx analysis module **163** may also create multiple maps for different contributions to NOx conversion of the SCR catalyst **90** and/or the DPF-SCR **70** (e.g., based on when exactly the reductant injection is switched between the first doser **84** and the second doser **88**, etc.). With multiple maps, the performance of DPF-SCR **70** may also be diagnosed in addition to the SCR catalyst **90**. For example, during a NOx and/or an exhaust flow spike, the effect on NOx conversion computed from the inlet and outlet NOx sensors **12** and **14** may be more pronounced for failures in both the DPF-SCR **70** and the SCR catalyst **90** as compared to a failure only in the SCR catalyst **90**.

The NOx analysis module **163** may compare the map and/or table of expected NOx conversion efficiency with the computed (i.e., actual, etc.) NOx conversion efficiency from the inlet and outlet NOx sensors **12** and **14** used to detect the conversion fault. In one embodiment, the computed NOx conversion efficiency is lower than the map based efficiency. This may indicate that the SCR catalyst is unhealthy (i.e., faulty, etc.). In another embodiment, the computed NOx conversion efficiency is substantially similar to map based efficiency. This may indicate that the DPF-SCR **70** is unhealthy. In this example embodiment, the reductant sensor **76** may be omitted. The notification module **165** is structured to provide an alert or notification to an operator (e.g., an driver, a technician, etc.) via the operator I/O device **120** that the DPF-SCR **70** and/or the SCR catalyst **90** may be faulty based on the map based efficiency and the computed NOx conversion efficiency. In other embodiments, the notification module **165** may include other functionality, such as derating the engine **20** responsive to a determined faulty component in order to reduce strain on that component until a servicing event can occur. Another action may be for the notification module **165** to cause a regeneration event to burn off soot and other accumulated materials in the exhaust aftertreatment system **22** followed by a re-running of the processes described herein to confirm a faulty determination.

Referring now to FIG. **5**, a NOx graph **500** is shown according to an example embodiment. The NOx graph **500** compares an amount of NOx exiting a healthy exhaust aftertreatment system **22** to an amount of NOx exiting a faulty exhaust aftertreatment system **22**. The NOx graph **500** includes an engine outlet NOx amount **510** (e.g., indicated by engine outlet NOx data **172**, etc.), an aftertreatment outlet NOx amount **520** for a healthy exhaust aftertreatment system **22** (e.g., the expected amount of NOx downstream of the SCR catalyst **90**, etc.), and an aftertreatment outlet NOx amount **530** for a faulty exhaust aftertreatment system **22** (e.g., the actual amount of NOx downstream of the SCR catalyst **90**, indicated by the aftertreatment outlet NOx data **174**, etc.). FIG. **5** corresponds with FIGS. **3**-**4**. As shown in FIG. **4**, at around approximately 300 seconds, the DPF-SCR inlet temperature **420** reaches the temperature threshold such that the reductant module **159** begins injecting reductant into the exhaust aftertreatment system **22** via the second doser **88** (i.e., relying on the SCR catalyst **90** for NOx conversion, etc.). As shown in FIG. **5**, the aftertreatment outlet NOx amount **530** for a faulty exhaust aftertreatment system **22** begins to deviate from the aftertreatment outlet NOx amount **520** for a healthy exhaust aftertreatment system **22** at around 300 seconds as well (i.e., the actual amount of NOx differs from the expected amount of NOx by a threshold NOx difference, etc.). Therefore, this indicates that the SCR catalyst **90** is faulty since the SCR catalyst **90** provides the majority of the NOx conversion when the second doser **88** injects the reductant into the exhaust flow (as indicated by the DPF-SCR outlet dosing **440** of FIG. **4**). In some embodiments, the controller **150** may deliberately affect the amount of NOx in the exhaust flow with an engine operation command (e.g., EGR flow amount adjustment, an ignition timing adjustment, an engine speed adjustment, fuel injection timing adjustment, fuel injection pressure adjustment, a fuel injection amount adjustment, an air flow amount, a number of fuel injection pulses, a fuel flow amount, and an engine torque output, etc.) to excite the NOx measurements and more easily diagnose a fault with the SCR catalyst **90**.

Referring back to FIG. **2**, according to an example embodiment, the reductant analysis module **164** is structured to receive the reductant data **176** indicative of a reductant conversion across the DPF-SCR **70** that indicates whether reductant may be slipping across the DPF-SCR **70**. During a reductant slip condition, there is an amount of unconverted reductant in the SCR system **60**. The amount of reductant slip across the DPF-SCR **70** is based on an actual amount of reductant downstream of (i.e., exiting, etc.) the DPF-SCR **70** and the amount of reductant injected into the exhaust flow (e.g., upstream of the DPF-SCR **70** by the first doser **84**, etc.). The reductant analysis module **164** is further structured to determine an expected amount of reductant slip based on the amount of reductant injected into the exhaust flow and an expected amount of reductant of the exhaust flow downstream of the DPF-SCR **70**. The expected amount of reductant downstream of the DPF-SCR **70** may be determined based on at least one of the operating characteristics of the engine **20** (e.g., exhaust flow, engine speed, etc.) and the operating characteristics of the exhaust aftertreatment system **22** (e.g., the temperature of the exhaust flow at various locations, the amount of reductant injected into the system upstream of the DPF-SCR **70**, the amount of NOx exiting or entering the exhaust aftertreatment system **22**, etc.). In one embodiment, the determination of the expected amount of reductant downstream of the DPF-SCR **70** is determined and the actual amount of reductant is measured (e.g., via the reductant sensor **76**, etc.) when the reductant is injected into the exhaust flow upstream of the DPF-SCR **70** by the first doser **84**. If the DPF-SCR **70** is faulty, under these conditions the reductant sensor **76** may be reading higher than expected reductant amounts due to a loss of catalytic activity of the DPF-SCR **70**. The loss of catalytic activity may result in lower ammonia storage and hence higher ammonia slip (i.e., higher amounts of reductant downstream of the DPF-SCR **70** than expected, etc.).

In one embodiment, the reductant analysis module **164** is structured to determine whether the DPF-SCR **70** is faulty. This determination may be made based on the reductant slip value. This determination may also be made prior to the NOx analysis module **163**. In other embodiments, the reductant analysis module **164** is structured to confirm (e.g., supplement, verify, etc.) the determination made by the NOx analysis module **163** that, e.g., the DPF-SCR **70** is faulty since the SCR catalyst **90** is not faulty.

In some embodiments, the reductant sensor **76** could be positioned upstream of second doser **88**, then the reductant analysis module **163** can add (e.g., aggregate) the sensed reductant amount from reductant sensor **76** to the commanded reductant amount from the second doser **88** to get an approximation or estimated amount of reductant entering the SCR catalyst **90**. A fault threshold may then be utilized with respect to the estimated amount of reductant entering the SCR catalyst **90**: if the estimated amount is above the threshold, a fault may be triggered whereas if the estimated amount is below the threshold, a fault may not be triggered.

In some embodiments, the reductant module **159** is structured to interpret the amount of reductant slip across the DPF-SCR **70**. The reductant module **159** may be further structured to control an amount of reductant injected into the exhaust flow (e.g., provided by the first doser **84**, the second doser **88**, etc.) based further on the amount of reductant slip. For example, if the amount of slip is above a threshold amount, then dosing may be reduced in order to reduce accumulation of reductant in the system.

The reductant analysis module **164** is further structured to compare the actual reductant slip (i.e., the actual amount of reductant downstream of the DPF-SCR **70**, etc.) to at least one of the expected reductant slip (i.e., the expected amount of reductant downstream of the DPF-SCR **70**, etc.) and a threshold value of reductant to determine whether the DPF-SCR **70** is the component of the SCR system **60** causing the NOx conversion efficiency fault. The reductant analysis module **164** is structured to determine that the DPF-SCR **70** is faulty in response to the actual reductant slip being greater than at the expected reductant slip (i.e., the actual amount of reductant downstream of the DPF-SCR **70** being greater than the expected amount of reductant downstream of the DPF-SCR **70**, etc.) and/or the actual amount of reductant downstream of the DPF-SCR being greater than the threshold value of reductant. The threshold value of reductant may be preset within the reductant analysis module **164** and may be based on the respective aftertreatment system **22** and/or engine **20**. In some embodiments, the difference between the actual amount of reductant and the expected amount of reductant is compared to a threshold reductant difference. The threshold reductant difference may be a magnitude difference, a percentage difference, or the like between the actual amount of reductant and the expected amount of reductant. The notification module **165** is structured to provide an alert or notification to an operator (e.g., a driver, a technician, etc.) via the operator I/O device **120** that the DPF-SCR **70** may be faulty responsive to the NOx conversion efficiently fault and the actual amount of reductant being greater than the expected amount of reductant (or the threshold reductant difference being exceeded) and/or the threshold value of reductant.

Referring now to FIG. **6**, a method **600** of diagnosing a SCR catalyst of an exhaust aftertreatment system is shown according to an example embodiment. In one example embodiment, method **600** may be implemented with the controller **150** of FIGS. **1-2**. Accordingly, method **600** may be described in regard to FIGS. **1-2**.

At process **602**, the controller **150** acquires NOx data (e.g., the engine outlet NOx data **172**, etc.) from a first NOx sensor (e.g., the inlet NOx sensor **12**, a virtual NOx sensor, etc.) indicative of an inlet amount of NOx of an exhaust flow exiting an engine (e.g., the engine **20**, etc.) and entering an exhaust aftertreatment system (e.g., the exhaust aftertreatment system **22**, etc.). At process **604**, the controller **150** acquires NOx data (e.g., the aftertreatment outlet NOx data **174**, etc.) from a second NOx sensor (e.g., the outlet NOx sensor **14**, a virtual NOx sensor, etc.) indicative of an outlet amount of NOx of the exhaust flow exiting the exhaust aftertreatment system. At process **606**, the controller interprets the NOx data to determine whether a NOx conversion efficiency fault is present based on the inlet amount of NOx and the outlet amount of NOx.

At process **608**, the controller **150** provides a command to a doser (e.g., the second doser **88**, etc.) to inject reductant into the exhaust flow within the exhaust aftertreatment system downstream of a DPF-SCR (e.g., the DPF-SCR **70**, etc.) and upstream of a SCR catalyst (e.g., the SCR catalyst **90**, etc.). In one embodiment, the controller **150** passively provides the dosing command according to typical operation (e.g., when the inlet temperature at the DPF-SCR **70** reaches the temperature threshold, etc.). In other embodiments, the controller **150** actively provides the dosing command atypically (e.g., when the first doser **84** would typically provide the reductant injection, etc.).

At process **610**, the controller **150** acquires NOx data from the second NOx sensor indicative of an actual amount of NOx downstream of the SCR catalyst. At process **612**, the controller **150** determines an expected amount of NOx downstream of the SCR catalyst. The expected amount of NOx may be determined based on at least one of operating characteristics of the engine and operating characteristics of the exhaust aftertreatment system. As described above, the operating characteristics of the engine may include at least one of an engine speed, an engine torque, and an exhaust flow characteristics (e.g., volume flow rate, mass flow rate, etc.). The operating characteristics of the exhaust aftertreatment system may include at least one of a temperature of the exhaust flow, the amount of reductant injected into the exhaust flow, the inlet amount of NOx exiting the engine, and the outlet amount of NOx exiting the exhaust aftertreatment system.

At process **614**, the controller **150** determines a difference between the actual amount of NOx and the expected amount of NOx. At process **616**, the controller **150** compares the difference between the actual amount of NOx and the expected amount of NOx to a threshold NOx difference. In other embodiments, the controller **150** is structured to compare the actual amount of NOx to a threshold NOx value. At process **618**, the controller **150** determines the SCR catalyst is faulty responsive to the difference between the actual amount of NOx and the expected amount of NOx being greater than the threshold NOx difference. In other embodiments, the controller **150** determines the SCR catalyst is faulty responsive to the actual amount of NOx exceeding the threshold NOx value.

In some embodiments, the controller **150** is further structured to determine that a diesel particulate filter including a coating of a selective catalytic reduction reaction catalyst (DPF-SCR) is faulty responsive to at least one of the actual amount of NOx differing from the expected amount of NOx by less than the threshold NOx difference and the actual amount of NOx being less than the threshold NOx value (i.e., Method **600** indicating that the SCR catalyst is not faulty). In some embodiments, the controller **150** is further structured to verify that the DPF-SCR catalyst is faulty (see, e.g., FIG. **7**).

Referring now to FIG. **7**, a method **700** of diagnosing a DPF-SCR of an exhaust aftertreatment system is shown according to an example embodiment. In one example embodiment, method **700** may be implemented with the controller **150** of FIGS. **1**-**2**. Accordingly, method **700** may be described in regard to FIGS. **1**-**2**. Method **700** may implemented by the controller **150** to determine whether the DPF-SCR is faulty (i.e., independent of method **600**) or to verify that the DPF-SCR is faulty as determined by the controller **150** (e.g., using the method **600**, etc.).

At process **702**, the controller **150** acquires NOx data (e.g., the engine outlet NOx data **172**, etc.) from a first NOx sensor (e.g., the inlet NOx sensor **12**, a virtual NOx sensor, etc.) indicative of an inlet amount of NOx of an exhaust flow exiting an engine (e.g., the engine **20**, etc.) and entering an exhaust aftertreatment system (e.g., the exhaust aftertreatment system **22**, etc.). At process **704**, the controller **150** acquires NOx data (e.g., the aftertreatment outlet NOx data **174**, etc.) from a second NOx sensor (e.g., the outlet NOx sensor **14**, a virtual NOx sensor, etc.) indicative of an outlet amount of NOx of the exhaust flow exiting the exhaust aftertreatment system. At process **706**, the controller interprets the NOx data to determine whether a NOx conversion efficiency fault is present. The NOx conversion efficiency is based on the inlet amount of NOx and the outlet amount of NOx.

At process **708**, the controller **150** provides a command to a doser (e.g., the first doser **84**, switches from the second doser **88** to the first doser **84**, etc.) to inject reductant into the exhaust flow within the exhaust aftertreatment system upstream of a DPF-SCR (e.g., the DPF-SCR **70**, etc.). In one embodiment, the controller **150** passively provides the dosing command according to typical operation (e.g., when the inlet temperature at the DPF-SCR **70** is below the temperature threshold, etc.). In other embodiments, the controller **150** actively provides the dosing command atypically (e.g., when the second doser **88** would typically provide the reductant injection, the temperature is above the temperature threshold, etc.).

At process **710**, the controller **150** acquires reductant data (e.g., the reductant data **176**, etc.) from a reductant sensor (e.g., the reductant sensor **76**, a virtual reductant sensor, etc.) indicative of an actual amount of reductant downstream of the DPF-SCR. At process **712**, the controller **150** determines an expected amount of reductant downstream of the DPF-SCR. The expected amount of reductant may be determined based on at least one of operating characteristics of the engine and operating characteristics of the exhaust aftertreatment system. At process **714**, the controller **150** compares the actual amount of reductant to at least one of the expected amount of reductant and a threshold value of reductant. At process **716**, the controller **150** either determines (e.g., if method **700** is run independent of method **600**, etc.) or verifies (e.g., if method **700** is run subsequent method **600** and the SCR catalyst was determined to not be faulty, etc.) that the DPF-SCR is faulty responsive to at least one of the actual amount of reductant being greater than the expected amount of reductant and the actual amount of reductant being greater than a threshold reductant value (i.e., the DPF-SCR allowing for a greater than expected amount of reductant slip, etc.). In other embodiments, the controller **150** compares a difference between the actual amount of reductant and the expected amount of reductant to a threshold reductant difference.

The schematic flow chart diagrams and method schematic diagrams described above are generally set forth as logical flow chart diagrams. As such, the depicted order and labeled steps are indicative of representative embodiments. Other steps, orderings and methods may be conceived that are equivalent in function, logic, or effect to one or more steps, or portions thereof, of the methods illustrated in the schematic diagrams.

Additionally, the format and symbols employed are provided to explain the logical steps of the schematic diagrams and are understood not to limit the scope of the methods illustrated by the diagrams. Although various arrow types and line types may be employed in the schematic diagrams, they are understood not to limit the scope of the corresponding methods. Indeed, some arrows or other connectors may be used to indicate only the logical flow of a method. For instance, an arrow may indicate a waiting or monitoring period of unspecified duration between enumerated steps of a depicted method. Additionally, the order in which a particular method occurs may or may not strictly adhere to the order of the corresponding steps shown. It will also be noted that each block of the block diagrams and/or flowchart diagrams, and combinations of blocks in the block diagrams and/or flowchart diagrams, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and program code.

Many of the functional units described in this specification have been labeled as modules, in order to more particularly emphasize their implementation independence. For example, a module may be implemented as a hardware circuit comprising custom VLSI circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

Modules may also be implemented in machine-readable medium for execution by various types of processors. An identified module of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions, which may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module need not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose for the module.

Indeed, a module of computer readable program code may be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network. Where a module or portions of a module are implemented in machine-readable medium (or computer-readable medium), the computer readable program code may be stored and/or propagated on in one or more computer readable medium(s).

The computer readable medium may be a tangible computer readable storage medium storing the computer readable program code. The computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, holographic, micromechanical, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing.

More specific examples of the computer readable medium may include but are not limited to a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a portable compact disc read-only memory (CD-ROM), a digital versatile disc (DVD), an optical storage device, a magnetic storage device, a holographic storage medium, a micromechanical storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, and/or store computer readable program code for use by and/or in connection with an instruction execution system, apparatus, or device.

The computer readable medium may also be a computer readable signal medium. A computer readable signal medium may include a propagated data signal with computer readable program code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electrical, electro-magnetic, magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport computer readable program code for use by or in connection with an instruction execution system, apparatus, or device. Computer readable program code embodied on a computer readable signal medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, Radio Frequency (RF), or the like, or any suitable combination of the foregoing.

In one embodiment, the computer readable medium may comprise a combination of one or more computer readable storage mediums and one or more computer readable signal mediums. For example, computer readable program code may be both propagated as an electro-magnetic signal through a fiber optic cable for execution by a processor and stored on RAM storage device for execution by the processor.

Computer readable program code for carrying out operations for aspects of the present invention may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone computer-readable package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server.

The program code may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the schematic flowchart diagrams and/or schematic block diagrams block or blocks.

Reference throughout this specification to "one embodiment," "an embodiment," or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment," "in an embodiment," and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment.

Accordingly, the present disclosure may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the disclosure is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. An apparatus, comprising:

an exhaust aftertreatment system in exhaust gas receiving communication with an engine, wherein the exhaust aftertreatment system includes a selective catalytic reduction (SCR) system, the SCR system including a SCR catalyst and a diesel particulate filter having a coating of a SCR reaction catalyst (DPF-SCR) positioned upstream of the SCR catalyst;

a nitrogen oxide (NOx) circuit in exhaust gas communication with an exhaust flow of the exhaust aftertreatment system from the engine, the NOx circuit structured to:

interpret NOx data indicative of an amount of NOx exiting the engine and an amount of NOx exiting the exhaust aftertreatment system; and

determine a NOx conversion efficiency fault is present based on the amount of NOx exiting the engine and the amount of NOx exiting the exhaust aftertreatment system; and

a selective catalytic reduction (SCR) diagnostic circuit structured to determine at least one of the SCR catalyst of the exhaust aftertreatment system and the DPF-SCR of the exhaust aftertreatment system are responsible for the NOx conversion efficiency fault based on at least one of a reductant slip amount and a NOx conversion value across at least one of the SCR catalyst and the DPF-SCR.

2. The apparatus of claim **1**, wherein the SCR diagnostic circuit is structured to determine the DPF-SCR is faulty responsive to the reductant slip amount across the DPF-SCR being greater than an expected amount of reductant slip across the DPF-SCR.

3. The apparatus of claim **2**, further comprising a reductant circuit structured to interpret reductant data to determine the reductant slip amount across the DPF-SCR based on an amount of reductant downstream of the DPF-SCR and an amount of reductant injected into the exhaust flow upstream of the DPF-SCR.

4. The apparatus of claim **2**, wherein the SCR diagnostic circuit is structured to determine the expected amount of reductant slip across the DPF-SCR based on an expected amount of reductant downstream of the DPF-SCR and an amount of reductant injected into the exhaust flow upstream of the DPF-SCR, wherein the expected amount of reductant downstream of the DPF-SCR is based on at least one operating characteristic of the engine and the exhaust aftertreatment system.

5. The apparatus of claim **1**, wherein the SCR diagnostic circuit is structured to determine at least one of (i) the SCR catalyst is faulty responsive to a difference between the NOx conversion value across the SCR catalyst and an expected NOx conversion value across the SCR catalyst being greater than or equal to a threshold value and (ii) the DPF-SCR catalyst is faulty responsive to the difference between the NOx conversion value across the SCR catalyst and the expected NOx conversion value across the SCR catalyst being less than the threshold value, wherein the SCR diagnostic circuit is further structured to verify that the DPF-SCR is faulty responsive to the reductant slip amount across the DPF-SCR being greater than an expected amount of reductant slip across the DPF-SCR.

6. The apparatus of claim **5**, wherein the NOx circuit is structured to interpret the NOx data to determine the NOx conversion value across the SCR catalyst based on an actual amount of NOx in the exhaust flow downstream of the SCR catalyst and the amount of NOx exiting the engine when reductant is injected into the exhaust flow downstream of the DPF-SCR and upstream of the SCR catalyst.

7. The apparatus of claim **5**, wherein the SCR diagnostic circuit is structured to determine the expected NOx conversion value across the SCR catalyst based on the amount of NOx exiting the engine and an expected amount of NOx in the exhaust flow downstream of the SCR catalyst when reductant is injected into the exhaust flow downstream of the DPF-SCR and upstream of the SCR catalyst, wherein the expected amount of NOx downstream of the SCR catalyst is based on at least one operating characteristic of at least one of the engine and the exhaust aftertreatment system.

8. The apparatus of claim **7**, wherein the at least one operating characteristic of the engine includes at least one of an engine speed, an engine torque, and an exhaust flow characteristic, and wherein the at least one operating characteristic of the exhaust aftertreatment system includes at least one of a temperature of the exhaust flow, an amount of reductant injected into the exhaust flow, the amount of NOx exiting the engine, and the amount of NOx exiting the exhaust aftertreatment system.

9. The apparatus of claim **1**, further comprising an engine circuit structured to provide at least one command to the engine to modulate the amount of NOx exiting the engine, wherein the at least one command includes actuating an exhaust throttle of an exhaust gas recirculation system in exhaust gas receiving communication with the engine to alter the exhaust flow through the SCR catalyst and affect the amount of NOx in the exhaust flow.

10. The apparatus of claim **1**, further comprising a reductant circuit communicably coupled to a reductant dosing system and structured to control an amount and a location of injection of reductant into the exhaust flow.

11. A system, comprising:

an exhaust aftertreatment system in exhaust gas receiving communication with an engine, wherein the exhaust aftertreatment system includes a selective catalytic reduction (SCR) system, the SCR system including a SCR catalyst and a diesel particulate filter having a coating of a SCR reaction catalyst (DPF-SCR) positioned upstream of the SCR catalyst; and

a controller communicably coupled to the engine and the exhaust aftertreatment system, the controller structured to:

receive first nitrogen oxide (NOx) data indicative of an amount of NOx in an exhaust flow exiting the engine and second NOx data indicative of an amount of NOx in the exhaust flow exiting the exhaust aftertreatment system;

determine a NOx conversion efficiency fault is present based on the first NOx data and the second NOx data; and

determine at least one of the SCR catalyst and the DPF-SCR of the SCR system are faulty responsive to the NOx conversion efficiency fault.

12. The system of claim **11**, further comprising an exhaust throttle of an exhaust gas recirculation system positioned upstream of the SCR catalyst, wherein the controller is further structured to actuate the exhaust throttle to alter the exhaust flow through the SCR catalyst and affect the amount of NOx in the exhaust flow.

13. The system of claim **11**,

wherein the exhaust aftertreatment system includes a first doser positioned upstream of the DPF-SCR, and a second doser positioned downstream of the DPF-SCR and upstream of the SCR catalyst;

wherein the first NOx data is provided by a first NOx sensor and the second NOx data is provided by a second NOx sensor; and

wherein the first NOx sensor and the second NOx sensor are structured as either one of or both of a physical sensor or a virtual sensor.

14. The system of claim **13**, wherein the controller is further structured to:

facilitate injection of reductant into the exhaust flow within the exhaust aftertreatment system downstream of the DPF-SCR and upstream of the SCR catalyst via the second doser;

acquire NOx data from the second NOx sensor indicative of an actual amount of NOx downstream of the SCR catalyst;

determine an expected amount of NOx downstream of the SCR catalyst based on operating characteristics of at least one of the engine and the exhaust aftertreatment system; and

determine the SCR catalyst is faulty responsive to a difference between the actual amount of NOx and the expected amount of NOx being greater than a threshold amount.

15. The system of claim **13**, wherein the controller is further structured to:

facilitate injection of reductant into the exhaust flow within the exhaust aftertreatment system upstream of the DPF-SCR via the first doser;

acquire reductant data from a reductant sensor indicative of an actual amount of reductant downstream of the DPF-SCR;

determine an expected amount of reductant downstream of the DPF-SCR based on operating characteristics of at least one of the engine and the exhaust aftertreatment system; and

determine the DPF-SCR is faulty responsive to the actual amount of reductant being greater than the expected amount of reductant.

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