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SYSTEMS AND METHODS FOR MONITORING CATALYST DEACTIVATION AND CONTROLLING AN AIR/FUEL RATIO

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SYSTEMS AND METHODS FOR MONITORING CATALYST DEACTIVATION AND CONTROLLING AN AIR/FUEL RATIO

ABSTRACT

A system (100) for controlling an air/fuel ratio in an engine (105) based on catalyst deactivation includes an NH_3 detector (120) disposed downstream from the three way catalyst (110), and a subsystem (135) that compares measured values of NH_3 concentration with a nominal value of NH_3 concentration at rich operating conditions. A subsystem (145) adjusts the air/fuel ratio based on the measured value of NH_3 concentration and estimated CO concentration.

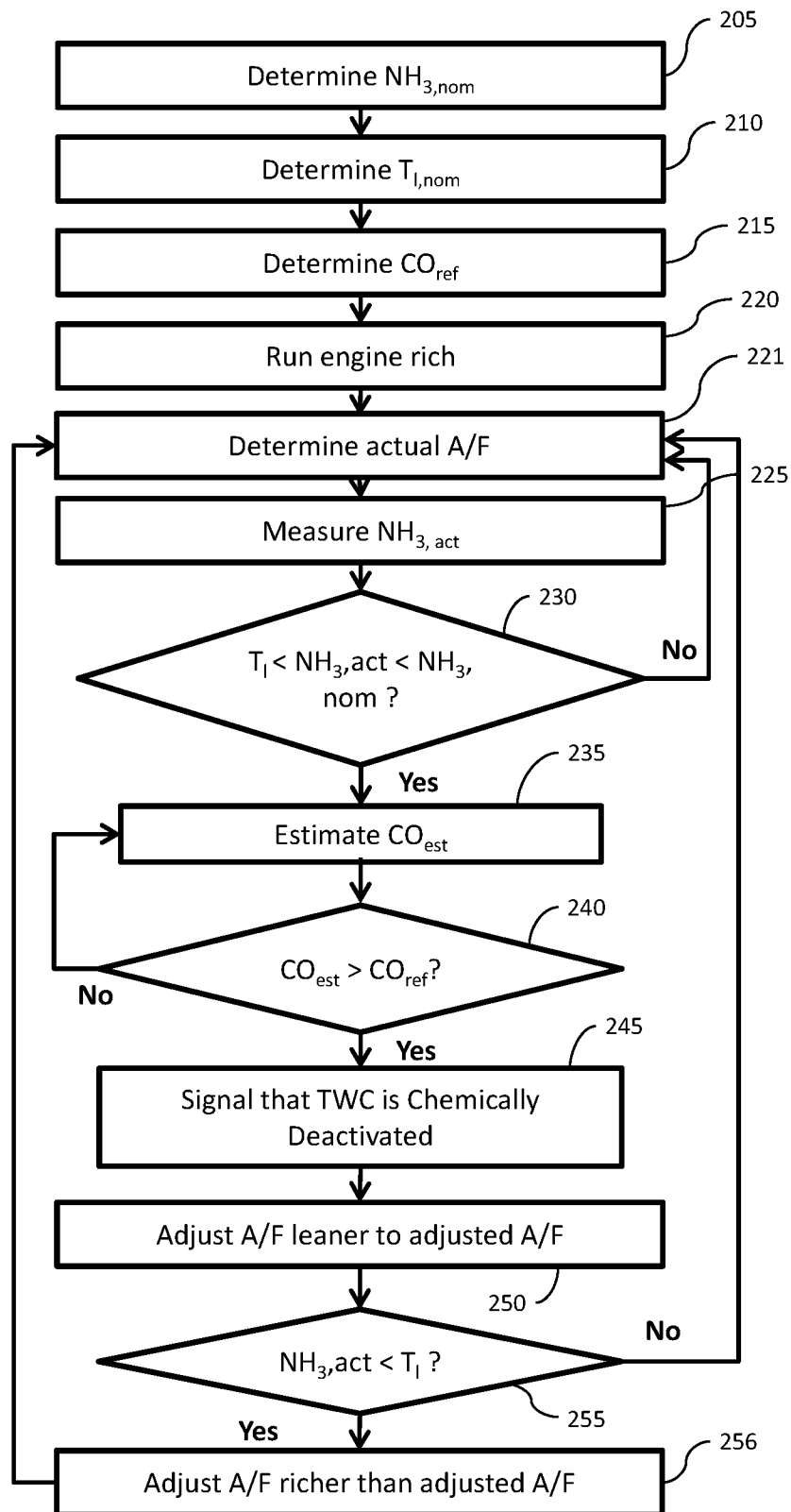


Fig. 2

SYSTEMS AND METHODS FOR MONITORING CATALYST DEACTIVATION AND CONTROLLING AN AIR/FUEL RATIO

[0001] This application claims priority from United States Application No. 14/038,014 filed on 26 September 2013, the contents of which are to be taken as incorporated herein by this reference.

BACKGROUND OF THE INVENTION

[0002] The subject matter disclosed herein generally relates to monitoring a catalyst in an engine system and more particularly to methods and systems for continuously diagnosing a three way catalyst and taking corrective control action in the case of catalyst deactivation.

[0003] Environmental regulations require the use of catalysts to treat engine exhaust in order to reduce air pollution. A catalytic converter uses two types of catalysts, a reduction catalyst and an oxidation catalyst. The catalytic converter consists of a ceramic structure coated with a metal catalyst incorporated within a housing. The catalytic converter provides a structure that exposes the maximum surface area of catalyst to the exhaust stream.

[0004] A three-way catalytic converter has the capacity to store oxygen (O_2). When the air/fuel ratio of the exhaust is lean (oxidizing atmosphere), it stores O_2 and thereby suppresses the production of mono-nitrogen oxides (NO_x). When the air/fuel ratio of the exhaust is rich, it releases the stored O_2 thereby accelerating the oxidation of hydrocarbons (HC) and carbon monoxide (CO).

[0005] In many applications, it is desirable to monitor the performance of the catalytic converter. Failure to detect catalyst deactivation on gas engines might result in severe financial penalties for the end-user. Monitoring may involve sensing the exhaust gases to determine whether the catalyst is performing adequately. Among the sensors used are O_2 sensors and NO_x sensors. In the case of O_2 , the sensors may be located upstream and downstream of the catalyst. Signals from the sensors are compared and correlated to the emissions to determine whether the catalyst is performing adequately.

[0006] Another approach to monitoring the performance of a catalytic converter is to sense the temperature of the catalytic converter. Usually two sensors will be fitted. One sensor is disposed upstream from the catalyst and the other sensor is disposed downstream

from the catalyst. The sensors monitor the temperature rise over the catalytic converter core. When the temperature difference between the sensors is greatest, the catalytic converter is thought to be working optimally.

[0007] For a system having a three way catalyst combined with an ammonia slip catalyst and mid bed air injection, the engine is typically run with a rich air/fuel ratio. Running the engine rich achieves the benefit of reducing NO_x in the three way catalyst and oxidizing CO and NH₃ in the ammonia slip catalyst. Three way catalysts lose performance when chemically deactivated. For example, oil exposure for a 4000 hour duration may chemically deactivate a three way catalyst. Such deactivation could result in CO and methane (CH₄) emissions increasing while NH₃ emissions decrease which could result in the engines being out of compliance with environmental regulations. Prior methodologies for monitoring catalytic converter performance are typically based on catalyst temperature and O₂ storage based diagnosis. As the engine is typically run rich in a mid-bed air injection scenario, O₂ storage based diagnosis will not be valid and hence, there is a need for an alternate way of monitoring the catalyst health.

[0008] The discussion of the background to the invention included herein including reference to documents, acts, materials, devices, articles and the like is included to explain the context of the present invention. This is not to be taken as an admission or a suggestion that any of the material referred to was published, known or part of the common general knowledge in Australia or in any other country as at the priority date of any of the claims.

BRIEF DESCRIPTION OF THE INVENTION

[0009] The disclosure provides a methodology for continuously diagnosing a three way catalyst and for taking corrective control action in the case of catalyst deactivation.

[0010] In accordance with one aspect of the present invention, there is provided a method for controlling an air/fuel ratio in an engine. The method includes determining whether an actual value of NH₃ concentration downstream from a three way catalyst is lower than a nominal value for NH₃ concentrations produced at rich operating conditions. If the actual value of the NH₃ concentration is lower than the nominal value for the NH₃ concentrations produced at rich operating conditions, then the air/fuel ratio is adjusted based on estimated CO concentrations.

[0011] In accordance with another aspect of the present invention, a method for detecting deactivation of a catalyst is provided. The method includes determining whether an actual value of NH₃ concentration downstream from a three way catalyst is lower than a

nominal value for NH_3 concentrations produced at rich operating conditions. If the actual value of NH_3 concentration is lower than the nominal value for NH_3 concentrations produced at rich operating conditions then the method determines an estimated CO concentration value. The estimated CO concentration value is then compared to a reference CO concentration value.

[0012] In another aspect of the present invention, a system for controlling an air/fuel ratio in an engine is provided. The system includes a three way catalyst, an NH_3 detector disposed downstream from the three way catalyst, and a subsystem that compares a measured values of NH_3 concentration with a nominal value of the NH_3 concentration at rich operating conditions. The system also includes a subsystem that adjusts the air/fuel ratio based on the measured value of NH_3 concentration and estimated CO concentrations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Other features and advantages of the present invention will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of certain aspects of the invention.

[0014] Figure 1 is a schematic diagram of an embodiment of a system for diagnosing catalyst deactivation.

[0015] Figure 2 is a flow chart of an embodiment of a method for controlling an air/fuel ratio based on catalyst deactivation.

[0016] Figure 3 is a block diagram of a general purpose computer.

DETAILED DESCRIPTION OF THE INVENTION

[0017] The disclosure provides a methodology for continuously diagnosing a three way catalyst and for taking corrective control action in the case of catalyst deactivation. The technical effect is the ability to diagnose catalyst deactivation with a minimal number of sensors and to adjust the air/fuel ratio based on the catalyst deactivation.

[0018] Illustrated in Figure 1 is a schematic of a catalyst monitoring and control system (CMCS 100). As shown in Figure 1, an engine 105 is provided with a three way catalyst 110. An O_2 sensor 115 may be provided downstream from the engine 105 and upstream from the three way catalyst 110. The O_2 sensor 115 measures the proportion of O_2 downstream from the engine 105. When information from the O_2 sensor 115 is coupled with information from other sources, it can be used to determine indirectly the air/fuel ratio and to

estimate the CO content downstream of the three way catalyst 110. The CMCS 100 also may include an NH_3 sensor 120 disposed downstream from the three way catalyst 110 and upstream from an ammonia slip catalyst 125. The NH_3 sensor 120 may be an optical sensor such as an IR detector or an optic-fiber-based sensor. Alternately, the NH_3 sensor 120 may be a semiconductor sensor that measures the change in resistance or capacitance of a coating as a function of adsorbed species. The ammonia slip catalyst 125 selectively oxidizes NH_3 to elemental N_2 and H_2O in a certain catalyst operating window. The CMCS 100 includes a control subsystem 130 having a catalyst monitoring module 135, and a model based CO estimator 140. The model based CO estimator 140 may be a linear or non-linear observer estimator based on a physical model of the three way catalyst 110. Inputs to the model based CO estimator 140 include the gas flow rate, the catalyst inlet temperature and the inlet CO concentration. The output of the model based CO estimator 140 is the CO concentration downstream of the three way catalyst 110. Inlet CO concentration may be obtained through a map of engine out CO (for example, as a function of the air/fuel equivalence ratio, λ) or through a simple empirical correlation. The CMCS 100 also may include an air/fuel control subsystem 145 that adjusts the air/fuel ratio in response to control signals from the control subsystem 130.

[0019] In operation, the NH_3 sensor of the CMCS 100 senses a drop in the NH_3 content of the gas stream from the three way catalyst 110. The catalyst monitoring module 135 determines if the actual NH_3 content ($\text{NH}_{3,\text{act}}$) is less than a nominal value at rich operating conditions ($\text{NH}_{3,\text{nom}}$). Once a certain time averaged signal from the NH_3 sensor 120 shows consistent drop in the NH_3 concentration, the estimated CO concentration (CO_{est}) is determined from the model based CO estimator 140. CO_{est} is compared to a reference CO concentration (CO_{ref}) derived from a map or a correlation to check for an increase in CO emissions. Once the rise in CO concentration is ascertained for a certain time duration, the air/fuel control subsystem 145 adjusts air/fuel ratio slightly leaner and the process is repeated until $\text{NH}_{3,\text{act}}$ is less than a threshold value T_1 . The threshold value T_1 may be 10% of $\text{NH}_{3,\text{nom}}$. A leaner air/fuel ratio contains more air than a rich air/fuel ratio. A 'Stoichiometric' air/fuel ratio has the exact amount of air and fuel necessary to produce a chemically complete combustion. For gasoline engines, the stoichiometric, air/fuel ratio is 14.7:1, which corresponds to 14.7 parts of air to one part of fuel. The stoichiometric air/fuel ratio depends on fuel type-- for alcohol it is 6.4:1 and 14.5:1 for diesel. A lower air/fuel ratio number contains less air than the 14.7:1 stoichiometric air/fuel ratio, therefore it is a richer mixture. Conversely, a higher AFR number contains more air and therefore it is a leaner mixture.

[0020] Illustrated in Figure 2 is a flow chart of a method 200 for controlling the air/fuel ratio of an engine 105 based on catalyst deactivation.

[0021] In step 205, the method 200 determines $\text{NH}_{3,\text{nom}}$.

[0022] In step 210, the method 200 determines a threshold NH_3 concentration T_1 . The threshold NH_3 concentration may be set at a percentage of $\text{NH}_{3,\text{nom}}$. For example, $T_1 = 0.1 * \text{NH}_{3,\text{nom}}$.

[0023] In step 215, the method 200 determines CO_{ref} . CO_{ref} may be derived from a map or correlation.

[0024] In step 220, the engine 105 is run at rich operating conditions.

[0025] In step 221, the method 200 determines an initial air fuel ratio.

[0026] In step 225, the method 200 measures and determines $\text{NH}_{3,\text{act}}$. This may be accomplished through the NH_3 sensor 120.

[0027] In step 230, the method 200 may determine whether $\text{NH}_{3,\text{act}}$ is less than $\text{NH}_{3,\text{nom}}$. A drop in the NH_3 sensor signal $\text{NH}_{3,\text{act}}$ when compared to $\text{NH}_{3,\text{nom}}$ could be a first indicator of the degradation of the three way catalyst 110.

[0028] If $\text{NH}_{3,\text{act}}$ is greater than $\text{NH}_{3,\text{nom}}$ then the method 200 returns to step 220 where the method 200 measures and determines $\text{NH}_{3,\text{act}}$.

[0029] If $\text{NH}_{3,\text{act}}$ is less than $\text{NH}_{3,\text{nom}}$ and greater than T_1 , then in step 235 the method 200 estimates CO_{est} . This may be accomplished with a model based CO estimator 140. The estimator can be a linear or non-linear observer based on a physical model of the three way catalyst 110. The observer or estimator is created by constructing a dynamical system associated with the system under consideration, in this case the three way catalyst 110. The role of the observer is to produce valid estimates of the state space variables of the original system, for example, CO concentrations downstream from the three way catalyst 110.

[0030] Once a certain time averaged signal from the NH_3 sensor 120 shows consistent drop, CO_{est} is compared to CO_{ref} to check for an increase in CO emissions. In step 240, the method 200 determines whether CO_{est} is greater than CO_{ref} .

[0031] If CO_{est} is less than or equal to CO_{ref} then the method 200 returns to step 225 to determine whether $\text{NH}_{3,\text{act}}$ is less than $\text{NH}_{3,\text{nom}}$.

[0032] A value of CO_{est} that is greater than CO_{ref} is an indication that the three way catalyst 110 has been degraded (step 245).

[0033] In step 250, the method 200 adjusts the air/fuel ratio to an adjusted air/fuel ratio that is leaner than the initial air/fuel ratio.

[0034] In step 255, the method 200 determines whether $\text{NH}_{3,\text{act}}$ is less than T_1 .

[0035] If $\text{NH}_{3,\text{act}}$ is less than T_1 the method 200 adjusts the air/fuel ratio to richer than the adjusted air/fuel ratio and returns to step 221 where the actual air/fuel ratio is determined. If $\text{NH}_{3,\text{act}}$ is greater than or equal to T_1 then the method 200 returns to step 221 where the actual air/fuel ratio is determined.

[0036] This invention provides a diagnosis method to detect chemical deactivation of a three way catalyst 110 in a mid-bed air injection system, and provides a corrective air/fuel ratio control action. A technical advantage includes the ability to diagnose catalyst deactivation with minimal number of sensors. Commercially, the approach could result in a reduction of costs associated with frequent emissions monitoring and avoidance of financial penalties which otherwise could be incurred due to catalyst deactivation.

[0037] Figure 3 is a block diagram of a computer 1020 in which the control subsystem 130 may be incorporated. Computer 1020 includes a processing unit 1021, a system memory 1022, and a system bus 1023 that couples various system components including the system memory to the processing unit 1021. The system bus 1023 may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. The system memory includes read-only memory (ROM) 1024 and random access memory (RAM) 1025. A basic input/output system 1026 (BIOS), containing the basic routines that help to transfer information between elements within the computer 1020, such as during start-up, is stored in ROM 1024.

[0038] The computer 1020 may further include a hard disk drive 1027 for reading from and writing to a hard disk (not shown), a magnetic disk drive 1028 for reading from or writing to a removable magnetic disk 1029, and an optical disk drive 1030 for reading from or writing to a removable optical disk 1031 such as a CD-ROM or other optical media. The hard disk drive 1027, magnetic disk drive 1028, and optical disk drive 1030 are connected to the system bus 1023 by a hard disk drive interface 1032, a magnetic disk drive interface 1033, and an optical drive interface 1034, respectively. The drives and their associated computer-readable media provide non-volatile storage of computer readable instructions, data structures, program modules and other data for the computer 1020. As described herein, computer-readable media is an article of manufacture and thus not a transient signal.

[0039] Although the exemplary environment described herein employs a hard disk, a removable magnetic disk 1029, and a removable optical disk 1031, it should be appreciated that other types of computer readable media, which can store data that are accessible by a

computer, may also be used in the exemplary operating environment. Such other types of media include, but are not limited to, a magnetic cassette, a flash memory card, a digital video or versatile disk, a Bernoulli cartridge, a random access memory (RAM), a read-only memory (ROM), and the like.

[0040] A number of program modules may be stored on the hard disk, removable magnetic disk 1029, removable optical disk 1031, ROM 1024 or RAM 1025, including an operating system 1035, one or more application programs 1036, other program modules 1037 and program data 1038. A user may enter commands and information into the computer 1020 through input devices such as a keyboard 1040 and pointing device 1042. Other input devices (not shown) may include a microphone, joystick, game pad, satellite disk, scanner, or the like. These and other input devices are often connected to the processing unit 1021 through a serial port interface 1046 that is coupled to the system bus 1023, but may be connected by other interfaces, such as a parallel port, game port, or universal serial bus (USB). A monitor 1047 or other type of display device is also connected to the system bus 1023 via an interface, such as a video adapter 1048. In addition to the monitor 1047, a computer may include other peripheral output devices (not shown), such as speakers and printers. The exemplary system of Figure 3 also includes a host adapter 1055, a Small Computer System Interface (SCSI) bus 1056, and an external storage device 1062 connected to the SCSI bus 1056.

[0041] The computer 1020 may operate in a networked environment using logical connections to one or more remote computers, such as a remote computer 1049. The remote computer 1049 may be a personal computer, a server, a router, a network PC, a peer device or other common network node, and may include many or all of the elements described above relative to the computer 1020, although only a memory storage device 1050 has been illustrated in Figure 3. The logical connections depicted in Figure 3 include a local area network (LAN) 1051 and a wide area network (WAN) 1052. Such networking environments are commonplace in offices, enterprise-wide computer networks, intranets, and the Internet.

[0042] When used in a LAN networking environment, the computer 1020 is connected to the LAN 1051 through a network interface or adapter 1053. When used in a WAN networking environment, the computer 1020 may include a modem 1054 or other means for establishing communication over the wide area network 1052, such as the Internet. The modem 1054, which may be internal or external, is connected to the system bus 1023 via the serial port interface 1046. In a networked environment, program modules depicted relative to the computer 1020, or portions thereof, may be stored in the remote memory

storage device. It will be appreciated that the network connections shown are exemplary and other means of establishing a communication link between the computers may be used.

[0043] Computer 1020 may include a variety of computer readable storage media. Computer readable storage media may be any available media that can be accessed by computer 1020 and includes both volatile and nonvolatile media, removable and non-removable media. By way of example, and not limitation, computer readable media may comprise computer storage media and communication media. Computer storage media include both volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Computer storage media include, but are not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by computer 1020. Combinations of any of the above should also be included within the scope of computer readable media that may be used to store source code for implementing the methods and systems described herein. Any combination of the features or elements disclosed herein may be used in one or more embodiments.

[0044] Where the definition of terms departs from the commonly used meaning of the term, applicant intends to utilize the definitions provided below, unless specifically indicated.

[0045] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. Where the definition of terms departs from the commonly used meaning of the term, applicant intends to utilize the definitions provided herein, unless specifically indicated. The singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be understood that, although the terms first, second, etc. may be used to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. The term "and/or" includes any, and all, combinations of one or more of the associated listed items. The phrases “coupled to” and “coupled with” contemplates direct or indirect coupling.

[0046] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated

methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements.

[0047] Where the terms “comprise”, “comprises”, “comprised” or “comprising” are used in this specification (including the claims) they are to be interpreted as specifying the presence of the stated features, integers, steps or components, but not precluding the presence of one or more other features, integers, steps or components, or group thereto.

PARTS LIST

Number Part Name

100	cmcs
105	engine
110	way catalyst
115	oxygen sensor
120	NH ₃ sensor
125	ammonia slip catalyst
130	control subsystem
135	catalyst monitoring module
140	model based CO estimator
145	air/fuel control subsystem
200	method -for controlling the air/fuel ratio of an engine
205	step - determines a nominal value of NH ₃ (NH _{3,nom}) concentration at rich operating conditions
210	step - determines a threshold NH ₃ concentration Tl
215	step - determines a reference value for CO concentration (CO _{ref})
220	step - engine 105 is run at rich operating conditions
225	step - measures and determines an actual post catalyst NH ₃ concentration (NH _{3,act}).
230	step - determine whether NH _{3,act} is less than NH _{3,nom} .
235	step estimates the CO concentration (CO _{est})
240	step determines whether CO _{est} is greater than CO _{ref} .
245	step - indication that the three way catalyst 110 has been deactivated
250	step - adjusts the air/fuel mixture to slightly leaner than rich
255	step - determines whether NH _{3, act} is less than the Tl

The claims defining the invention are as follows:

1. A method for controlling an air/fuel ratio in an engine, the method comprising:
determining whether an actual value of NH_3 concentration downstream from a
three way catalyst is lower than a nominal value for NH_3
concentrations produced at rich operating conditions;
if the actual value of NH_3 concentration is lower than the nominal value for
 NH_3 concentrations produced at rich operating conditions then
adjusting the air/fuel ratio based on estimated CO concentrations.
2. The method for controlling an air/fuel ratio in an engine of claim 1, wherein
determining whether an actual value of NH_3 concentration is lower than a nominal value for
 NH_3 concentrations produced at rich operating conditions comprises:
establishing a nominal value for NH_3 concentrations produced at rich
operating conditions;
detecting an actual value of NH_3 concentration downstream from a three way
catalyst; and
comparing the actual value of NH_3 concentration downstream from a three
way catalyst with the nominal value for NH_3 concentrations produced
at rich operating conditions.
3. The method for controlling an air/fuel ratio in an engine of claim 1 or claim 2,
wherein adjusting the air/fuel ratio based on estimated CO concentrations comprises:
determining an actual air/fuel ratio;
determining whether an actual CO concentration is greater than a reference
CO concentration; and
if the actual CO concentration is greater than the reference CO concentration
then changing the air/fuel ratio.
4. The method for controlling an air/fuel ratio in an engine of claim 3, wherein
determining whether an actual CO concentration is greater than a reference CO concentration
comprises:
establishing a reference CO concentration value;

estimating an actual CO concentration value; and
comparing the actual CO concentration value to the reference CO
concentration value.

5. The method for controlling an air/fuel ratio in an engine of claim 3 or claim 4, wherein changing the air/fuel ratio comprises:

adjusting the air/fuel ratio to an adjusted air/fuel ratio that is leaner than the
actual air/fuel ratio.

6. The method for controlling an air/fuel ratio in an engine of claim 5, further comprising:

establishing a lower threshold value for NH_3 concentrations;

comparing the actual value of NH_3 concentration downstream from a three
way catalyst with the lower threshold value for NH_3 concentrations;

if the actual value of NH_3 concentration downstream from a three way catalyst
is lower than the lower threshold value for NH_3 concentrations then
adjusting the air/fuel ratio to an air/fuel ratio that is richer than the
adjusted air/fuel ratio;

if the actual value of NH_3 concentration downstream from a three way catalyst
is greater than the lower threshold value for NH_3 concentrations then
detecting actual value of NH_3 concentration downstream from a three
way catalyst.

7. The method for controlling an air/fuel ratio in an engine of claim 4, wherein
estimating an actual CO concentration value comprises calculating an actual CO
concentration using a model based estimator.

8. A method for detecting deactivation of a catalyst, the method comprising:
determining whether an actual value of NH_3 concentration downstream from a
three way catalyst is lower than a nominal value for NH_3
concentrations produced at rich operating conditions;
if the actual value of NH_3 concentration is lower than the nominal value for
 NH_3 concentrations produced at rich operating conditions then
determining an estimated CO concentration value; and

comparing the estimated CO concentration value to a reference CO concentration value.

9. The method for detecting deactivation of a catalyst of claim 8, wherein determining an estimated CO concentration value comprises determining an estimated CO concentration value using a model-based estimator.
10. The method for detecting deactivation of a catalyst of claim 8 or claim 9, wherein determining whether an actual value of NH_3 concentration downstream from a three way catalyst is lower than a nominal value for NH_3 concentrations produced at rich operating conditions comprises determining whether a time averaged value of NH_3 concentration downstream from a three way catalyst is lower than a nominal value for NH_3 concentrations produced at rich operating conditions.
11. The method for detecting deactivation of a catalyst of any one of claims 8 to 10, further comprising providing a signal that the three way catalyst is deactivated if the estimated CO concentration value is greater than the reference CO concentration value.
12. The method for detecting deactivation of a catalyst of claim 9, wherein the model based estimator comprises an observer based on a physical model of the three way catalyst.
13. The method for detecting deactivation of a catalyst of claim 12, wherein the observer based on a physical model of the three way catalyst is a linear observer.
14. The method for detecting deactivation of a catalyst of claim 12, wherein the observer based on a physical model of the three way catalyst is a non-linear observer.
15. A system for controlling an air/fuel ratio in an engine, the system comprising:
 - a three way catalyst;
 - an NH_3 detector disposed downstream from the three way catalyst;
 - a subsystem that compares a measured value of NH_3 concentration with a nominal value of NH_3 concentration at rich operating conditions; and

a subsystem that adjusts the air/fuel ratio based on the measured value of NH_3 concentration and estimated CO concentrations.

16. The system for controlling an air/fuel ratio in an engine of claim 15, wherein the subsystem that adjusts the air/fuel ratio comprises:

a subsystem that estimates a CO concentration downstream of the three way catalyst.

17. The system for controlling an air/fuel ratio in an engine of claim 15 or claim 16, wherein the subsystem that adjusts the air/fuel ratio comprises:

a subsystem that compares an estimated value of CO concentration to a reference value of CO concentration.

18. The system for controlling an air/fuel ratio in an engine of claim 16 wherein the subsystem that estimates a CO concentration comprises an observer based on a physical model of the three way catalyst.

19. The system for controlling an air/fuel ratio in an engine of claim 18 wherein the observer is a linear observer.

20. The system for controlling an air/fuel ratio in an engine of claim 18 wherein the observer is a non-linear observer.

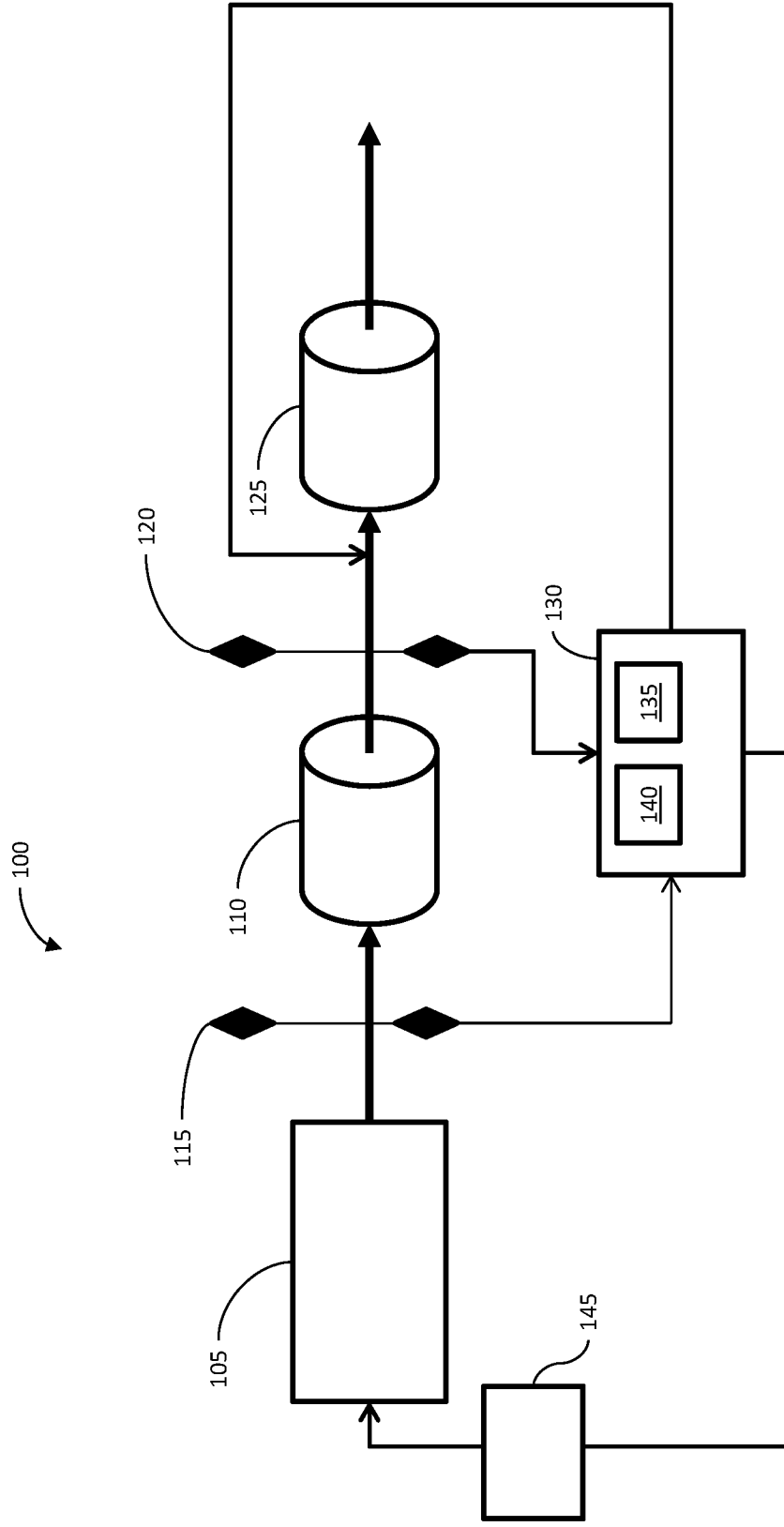


Fig. 1

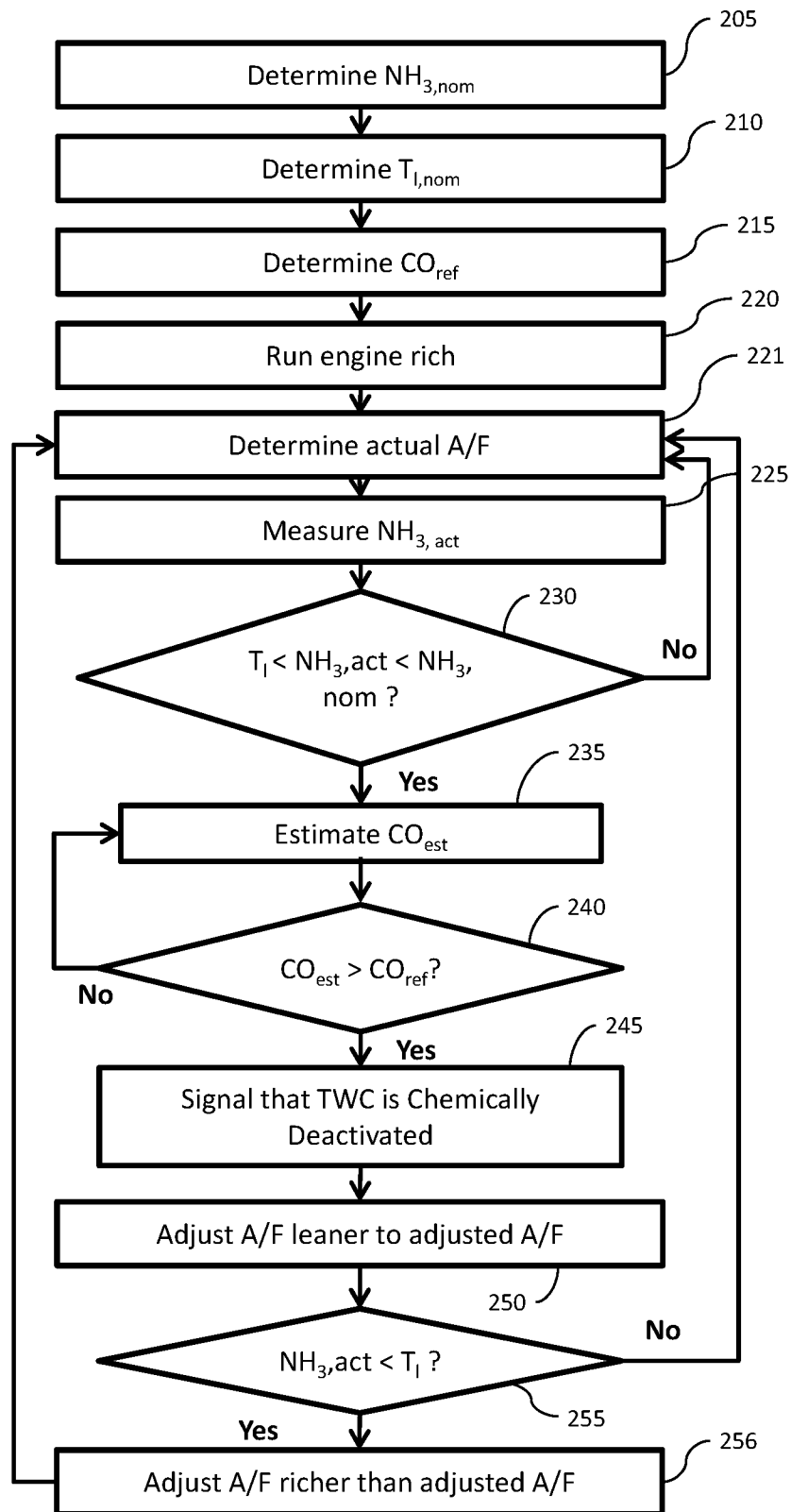


Fig. 2

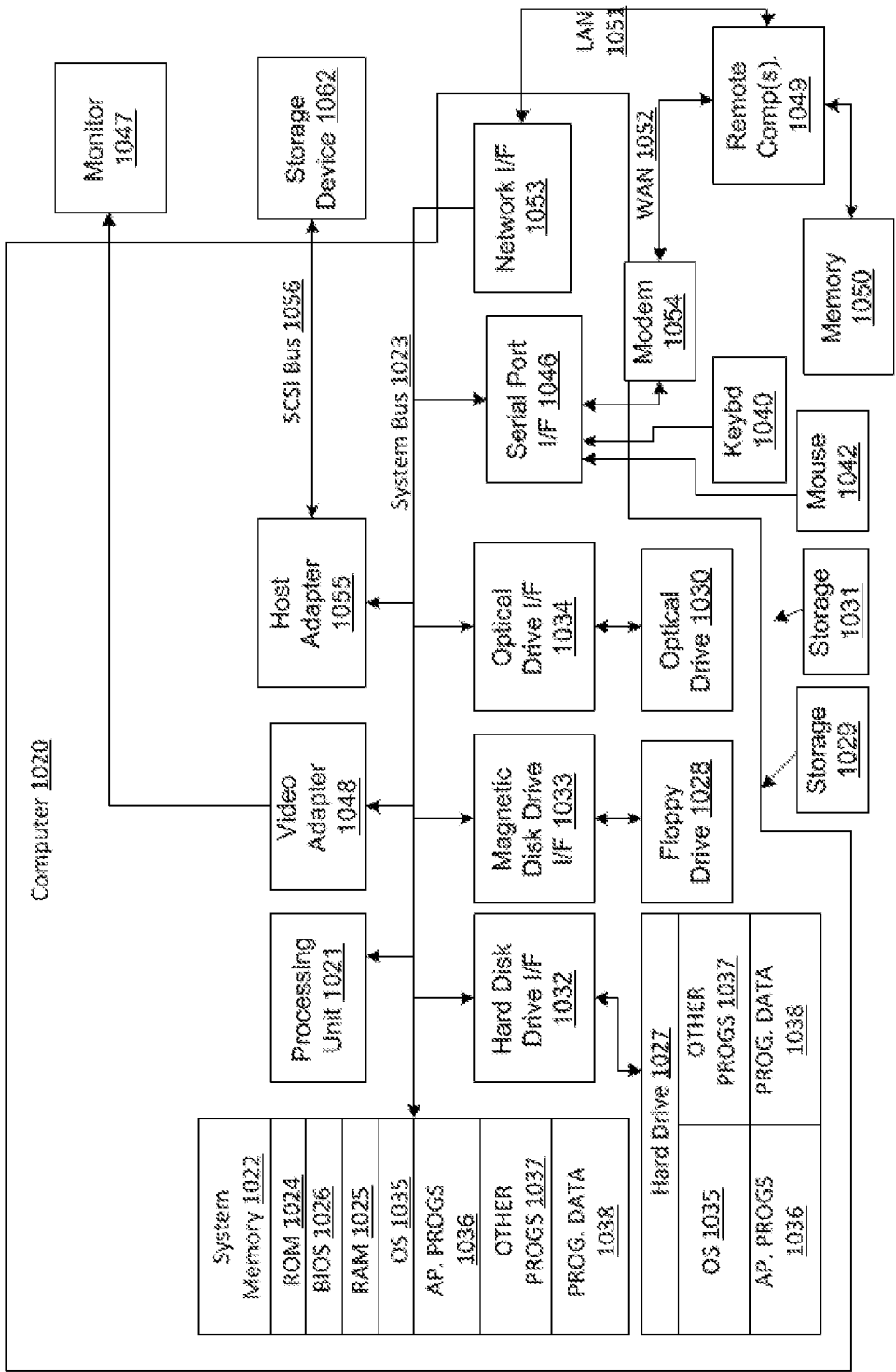


Fig. 3