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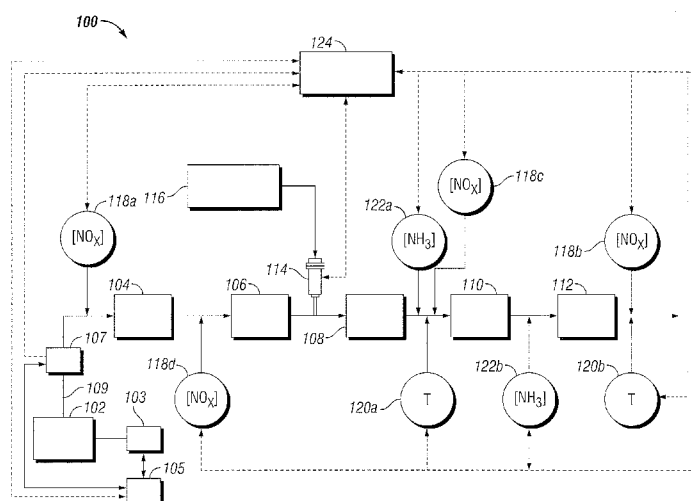


FIG. 1

(57) Abstract: A system includes an internal combustion engine, an exhaust conduit fluidly coupled to the internal combustion engine and an SCR catalyst, and a reductant doser operationally coupled to the exhaust conduit at a position upstream of the SCR catalyst. Certain embodiments include an electrical device to assist in providing motive power and an energy storage device. The system includes a controller configured to anticipate a temperature excursion event associated with the SCR catalyst and control operations to mitigate ammonia slip from the SCR catalyst as a result of the temperature excursion event.

SCR AFTERTREATMENT MANAGEMENT TO MITIGATE SLIP EVENTS

Cross-Reference to Related application:

[0001] The present application claims the benefit of the filing of Provisional Application No. 61/882,115 filed on September 25, 2013, which is incorporated herein by reference in its entirety for all purposes.

BACKGROUND

[0002] Many modern engines utilize selective catalytic reduction (SCR) catalysts to reduce NO_x emissions from the system. An SCR catalyst is a dynamic component that adsorbs reductant (e.g. NH₃) and NO_x from the exhaust gas, and reacts the reductant with the NO_x to reduce the NO_x. The amount of NH₃ storage depends upon the temperature of the catalyst, and the NO_x conversion capacity of the catalyst depends upon the temperature, the amount of NH₃ stored on the catalyst, and/or the flow rate of NO_x and exhaust gases through the catalyst. Under certain operating conditions, rapid temperature excursions of the exhaust gas can cause undesirable operations of the SCR catalyst, such as slip of ammonia or NO_x through the tail pipe. Accordingly, further improvements in this technology area are needed.

SUMMARY

[0003] Systems, apparatus and methods are disclosed to mitigate a slip event associated with the release of ammonia from an SCR catalyst in response to a thermal event. The thermal event indication includes an expected temperature excursion that is anticipated based on an analysis of at least one of operating conditions, operator inputs, and route conditions. An estimate of the amount of ammonia to be released from the SCR catalyst in response to the anticipated temperature excursion is determined from an ammonia storage condition of the SCR catalyst. Appropriate mitigation measures are taken in response to the anticipated temperature excursion and ammonia amount to be released to minimize the slip of ammonia and/or NO_x from the tailpipe, thus improving SCR conversion efficiency.

[0004] This summary is provided to introduce a selection of concepts that are further described below in the illustrative embodiments. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter. Further embodiments, forms, objects, features, advantages, aspects, and benefits shall become apparent from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Fig. 1 is an exemplary system for slip control of an SCR aftertreatment system.

[0006] Fig. 2 is an exemplary controller for executing operations for mitigating slip events in an SCR aftertreatment system.

[0007] Fig. 3 is a flow diagram of a procedure to mitigate slip events associated with an SCR catalyst.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

[0008] For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, any alterations and further modifications in the illustrated embodiments, and any further applications of the principles of the invention as illustrated therein as would normally occur to one skilled in the art to which the invention relates are contemplated herein.

[0009] Referencing Fig. 1, an exemplary system 100 for control of an SCR aftertreatment system is shown. The system 100 includes an internal combustion engine 102 that drives an output shaft to, for example, propel a vehicle. Engine 102 produces exhaust gases including NO_x, and provides the exhaust gases to an exhaust conduit 109. In certain embodiments, the exhaust gases may be provided by any type of internal combustion engine, including a diesel engine.

[0010] In addition, in certain embodiments one or more electrical devices 103, such as a motor or combined motor/generator, are provided with system 100. Electrical device 103 can be connected to the output shaft of the engine 102 and to a drive shaft (not shown) connected to the wheels of the vehicle, or separately connected to the drive shaft with a second output shaft, to propel the vehicle, either alone or in combination with power output from engine 102. Electrical device 103 can receive power from an energy storage device 105, which may include one or more batteries. In certain embodiments, the vehicle is operable to generate electricity that is stored by energy storage device 105 under certain operating conditions, and to use energy from energy storage device 105 to propel or assist

in propelling the vehicle under certain other operating conditions. Typically, the energy storage device 105 is maintained above a minimum state-of-charge (SOC) and below a maximum SOC, or within a fixed or dynamic range of a target SOC, to maintain energy storage device 105 within desired operating and/or protective limits.

[0011] The system 100 further includes a first SCR catalyst 108 fluidly coupled to the exhaust conduit 109. The first SCR catalyst 108 is illustrated downstream of a diesel oxidation catalyst (DOC) 104 and a diesel particulate filter (DPF) 106. Any of these components may be present or missing, catalyzed or not catalyzed, and may be arranged in alternate order. Further, certain components or all components may be provided in the same or separate housings.

[0012] The system 100 may further include a second SCR catalyst 110 fluidly coupled to the exhaust conduit 109 at a position downstream of the first SCR catalyst 108. The system 100 includes a mid-bed ammonia sensor 122a operationally coupled to the exhaust stream at a position between the first SCR catalyst 108 and the second SCR catalyst 110. The first SCR catalyst 108 and the second SCR catalyst 110 may occur within the same catalyst brick, with the position of the ammonia sensor 122a defining the separation point or mid-bed between the first SCR catalyst 108 and the second SCR catalyst 110. In additional or alternatively, an SCR-out ammonia sensor 122b may be provided downstream of second SCR catalyst 110 to provide an indication of an NH_3 amount exiting the SCR catalysts 108, 110. The ammonia sensors 122a, 122b may be any type understood in the art, including virtual sensors.

[0013] In addition, system 100 may include an exhaust heater 107 upstream of SCR catalyst 108, 110 that is operable to increase a temperature of the exhaust gas from engine

102. In another embodiment, exhaust heater 107 is integrated with SCR catalyst 108, 110 to heat the catalyst material or the exhaust in the SCR catalyst 108, 110. Exhaust heater 107 can be connected to energy storage device 105 to receive electrical power for heating of the exhaust gases or catalyst. Exhaust heater 107 may also be connected to electrical device 103 if electrical device 103 is also a generating device, or to a separate electrical energy generator device (not shown.)

[0014] While the illustrative system 100 includes two SCR catalysts 108, 110 and a mid-bed ammonia sensor 122a positioned therebetween, the slip control operations of the controller 124 may be present in any system 100 having NO_x aftertreatment and a NO_x treatment catalyst. Without limitation, the NO_x treatment catalyst may include a single element, multiple elements, and/or one or more branches or bypasses of the exhaust gases.

[0015] The system 100 further includes a reductant doser 114 operationally coupled to the exhaust conduit at a position upstream of the first SCR catalyst 108. The reductant doser 114 is fluidly coupled to a reductant source such as a reductant storage tank 116. The reductant is any type of reductant utilized in an SCR aftertreatment system that results in ammonia being utilized as the final reductant – including at least ammonia (gaseous or aqueous) and urea. Certain operations described herein apply to NO_x reduction generally and are not specific to SCR systems. Where the NO_x reduction operations are not specific to SCR systems, hydrocarbon or other reductants may be utilized. Further, in some SCR systems, other reductants may be utilized during certain operating conditions, and the slip control operations described herein may be utilized with reductants other than ammonia producing reductants in SCR systems.

[0016] The system 100 may include an ammonia oxidation (AMOX) catalyst 112 downstream of the second SCR catalyst 110, or after a last one of the SCR catalysts 108, 110. In certain embodiments, the AMOX catalyst 112 may not be present, or the AMOX catalyst 112 may be commingled with the second SCR catalyst 110 (or the last SCR catalyst, where multiple SCR catalysts are present), for example with a washcoat applied toward the rear portion of the second SCR catalyst 110 that is responsive to at least partially oxidize ammonia. Ammonia sensor 122b is shown upstream of AMOX catalyst 122b, but alternatively may be provided downstream of AMOX catalyst 122b.

[0017] The exemplary system 100 may further include various other sensors. The illustrated sensors include a first NO_x sensor 118a positioned upstream of the first SCR catalyst 108, a second NO_x sensor 118b positioned downstream of the second SCR catalyst 110, a first temperature sensor 120a positioned between the SCR catalysts 108, 110, and a second temperature sensor 120b positioned downstream of the AMOX catalyst 112. The illustrated sensors are exemplary only, and may be re-positioned, removed, substituted, and other sensors may be present that are not illustrated in Fig. 1. Certain embodiments of the system do not include either a NO_x sensor 118a upstream of the first SCR catalyst 108 or a second NO_x sensor 118b downstream of the second SCR catalyst 110, or do not include either of these NO_x sensors. In other embodiments, a mid-bed NO_x sensor 118c can be provided between catalysts 108, 110 and/or a DOC-out NO_x sensor 118d can be provided at the outlet of DOC 104. Further, certain NO_x and/or temperature sensors may be virtual sensors that are calculated from other parameters available to the system, or certain sensors may be values that would be indicated by sensors but that are supplied to a computer readable memory location, via a datalink or network communication, or otherwise made

available to the system where the sensor providing the sensed parameter is not a part of the defined system 100.

[0018] In certain embodiments, the system 100 further includes a controller 124 structured to perform certain operations to provide slip control of ammonia and NO_x in from SCR catalyst 108, 110. In certain embodiments, the controller 124 forms a portion of a processing subsystem including one or more computing devices having memory, processing, and communication hardware. The controller 124 may be a single device or a distributed device, and the functions of the controller may be performed by hardware or software. The controller 124 may be in communication with any sensor, actuator, datalink, and/or network in the system 100.

[0019] In certain embodiments, the controller 124 includes one or more modules structured to functionally execute the operations of the controller 124. In certain embodiments, the controller 124 includes an NH_3 target module, a dosing control module, an NH_3 storage module, a thermal event anticipation module, and a slip mitigation module. The description herein including modules emphasizes the structural independence of the aspects of the controller, and illustrates one grouping of operations and responsibilities of the controller. Other groupings that execute similar overall operations are understood within the scope of the present application. Modules may be implemented in hardware and/or software on computer readable medium, and modules may be distributed across various hardware or software components. More specific descriptions of certain embodiments of controller operations are included in the section referencing Fig. 2.

[0020] The control operations of the controller 124 in Fig. 2 include operations that adjust nominal control operations for a NO_x aftertreatment system utilizing a reductant. Nominal

control operations for a NO_x aftertreatment system, including an SCR aftertreatment system, are understood in the art and are not described further herein. Any nominal NO_x aftertreatment control operations may be utilized.

[0021] Referencing Fig. 2, controller 124 includes an NH₃ target module 200 that interprets a reductant amount target 202 that is a target amount of reductant in the exhaust conduit 109 at a position upstream of a NO_x reduction catalyst. In one example, the NO_x reduction catalyst is SCR catalyst 108, 110 and the reductant is NH₃ or a precursor (e.g. urea). The NH₃ target module 200, in one example, interprets the reductant amount target 202 in response to an ANR target 204 and an incoming NO_x amount 206 to SCR catalyst 108, 110. The incoming NO_x amount 206 may be determined from a NO_x sensor as discussed above in system 100, a model, or brought in as a data parameter from another system or controller. The NH₃ target module 200 may further interpret the reductant amount target 202 in response to an exhaust mass flow rate 208, a catalyst space velocity 210, and/or a catalyst temperature 212.

[0022] The controller 124 further includes a dosing control module 214 that provides a reductant doser command 216 in response to the reductant amount target 202. Dosing control module 214 further interprets an injected NH₃ amount 218 from the reductant amount target 202 that is injected into the exhaust conduit in response to reductant doser command 216.

[0023] The controller 124 further includes an NH₃ storage module 220 that provides a determination and/or estimate of the NH₃ storage amount 224 stored on the SCR catalyst 108, 110. In one embodiment, SCR-out ammonia sensor 122b tracks an NH₃ amount 222 leaving SCR catalyst 108, 110 and determines an estimate of the NH₃ storage amount 224

stored on SCR catalyst 108, 110 from the difference between an ammonia release amount indicated by SCR-out ammonia sensor 122b and mid-bed ammonia sensor 122a. In another embodiment NH₃ storage module 220 interprets the injected NH₃ amount 218 entering SCR catalyst 108, 110 and determines an NH₃ storage amount 224 in response to SCR catalyst temperature 212, incoming NO_x amount 206, NH₃ concentration and other parameters. Based on the NH₃ storage amount 224, an NH₃ release estimate 226 in response to a temperature excursion of SCR catalyst 108, 110 can be determined.

[0024] NH₃ release estimate 226 corresponds to an amount of ammonia that is estimated to be released from SCR catalyst 108, 110 but not measured by mid-bed ammonia sensor 122a in response to a thermal event. It has been observed by the inventors in testing data that ammonia stored in an SCR catalyst can shift in location on the SCR catalyst during a thermal event, such as when an engine rapidly shifts from a low load condition to a high load condition. During such a thermal event, which indicates a rapid temperature excursion of the SCR catalyst, the ammonia stored on SCR catalyst 108 upstream of mid-bed ammonia sensor 122a is released at a rate that depends on a start temperature and an end temperature of the SCR catalyst. At lower operating temperatures, such as the 200-250 degree Celsius range, the SCR catalyst 108, 110 can be saturated with ammonia. When the engine load increases by, for example, increasing speed and torque, the temperature of SCR catalyst 108, 110 also rises. At high temperatures, such as around 350 degrees Celsius and higher, the ammonia storage capability of SCR catalyst 108, 110 is limited. Therefore, a significant amount of ammonia is released from SCR catalyst 108, 110 during the temperature excursion.

[0025] While mid-bed ammonia sensor 122a can be used to provide feedback control of the reductant amount target 202 based on the ammonia released from the front SCR catalyst 108, such feedback control may not be effective in mitigating ammonia slip during rapid temperature excursions of SCR catalyst 108, 110. The inventors have observed a phase lag between the ammonia amount at the mid-bed location of SCR catalyst 108, 110 and the ammonia amount at the outlet of SCR catalyst 110. The phase lag is caused by the front or upstream side of the catalyst 108 increasing in temperature before the rear or downstream side of SCR catalyst 110. As a result, a fraction of the ammonia released by the front side SCR catalyst 108 is stored again by the rear side SCR catalyst 110. When the rear side SCR catalyst 110 “catches up” in temperature with the front side SCR catalyst 108, the fraction of the ammonia that was re-stored on the rear side SCR catalyst 110 is released again, which is not measured by mid-bed ammonia sensor 122a. As a result, mid-bed ammonia sensor 122a does not provide an accurate indication of the ammonia storage amount of the SCR catalyst 108, 110 during the temperature excursion event. The feedback control provided by NH₃ target module 200 based on the incoming NO_x amount 206 and ammonia sensor reading from mid-bed ammonia sensor 122a that determines reductant amount target 202 in response to the ANR target 204 can thus result in excess ammonia being injected into the exhaust stream during the temperature excursion event. Furthermore, in systems with an AMOX catalyst 112, the slipped ammonia could be converted back to NO_x and increase the severity of NO_x slip.

[0026] The controller 124 further includes a thermal event anticipation module 228 that detects a thermal event that indicates an expected temperature excursion of SCR catalyst 108, 110 and provides a thermal event indicator 230. Thermal event anticipation module

228 interprets one or more of a throttle position 232, GPS data 234, engine operating conditions 236, and catalyst temperature 212. In one embodiment, data related to the catalyst temperature 212 can be analyzed to provide a catalyst temperature trend analysis 238 that indicates a temperature trend associated with the catalyst temperature. Thermal event anticipation module 228 interprets the catalyst temperature trend analysis 238 and provides thermal event indicator 230 in response to an anticipated temperature excursion for SCR catalyst 108, 110 indicated by the analysis, such as rapidly increasing catalyst temperature from a low temperature range toward a high temperature range.

[0027] In another embodiment, data related to engine operating conditions 236 can be used to provide an operator behavior trend analysis 240 and/or an engine operating conditions analysis 242 that indicate trends associated with the operator behavior and/or operating conditions. Thermal event anticipation module 228 interprets the operator behavior trend analysis 240 and/or engine operating conditions analysis 242 and provides thermal event indicator 230 in response to an anticipated temperature excursion for SCR catalyst 108, 110 indicated by the analysis, such as rapidly increasing torque requests or torque demands or other behaviors or operating conditions that are expected to increase exhaust temperature rapidly.

[0028] In another embodiment, data related to throttle position 232 can be used to provide a throttle position trend analysis 244 that indicates trends associated with throttle positioning. Thermal event anticipation module 228 interprets the throttle position trend analysis and provides thermal event indicator 230 in response to an anticipated temperature excursion for SCR catalyst 108, 110 indicated by the analysis, such as throttle positions

that indicate rapidly increasing torque requests or torque demands that increase exhaust temperature rapidly.

[0029] In another embodiment, GPS data 236 can be used to provide a route conditions analysis 246 that indicates conditions of the route of the vehicle. Thermal event anticipation module 228 interprets the route conditions analysis 246 and provides thermal event indicator 230 in response to an anticipated temperature excursion for SCR catalyst 108, 110 indicated by the analysis, such as an upcoming road grade increase.

[0030] Controller 124 further includes a slip mitigation module 248 that interprets the thermal event indicator 230 and NH_3 release estimate 226, and outputs a slip mitigation command 250 that mitigates the slip of ammonia from SCR catalyst 108, 110 in response to the anticipated temperature excursion. In one embodiment, slip mitigation module 248 interprets the reductant dosing command 216 and outputs a slip mitigation command 250 that provides a modified reductant doser command 216 that reduces the amount of reductant to be injected into the exhaust stream before the temperature excursion begins or is completed. The modified reductant doser command 216 provides a reduced amount of reductant that is offset by the excess ammonia that is re-stored and re-released by rear SCR catalyst 110 during the temperature excursion.

[0031] In another embodiment, slip mitigation module 248 interprets the reductant injection timing 252 and outputs a slip mitigation command 250 that delays the reductant injection timing before and during the temperature excursion to delay the timing of the reductant amount supplied to the SCR catalyst. In another embodiment, slip mitigation module 248 interprets a variable geometry turbine (VGT) position 254 and outputs a slip mitigation command 250 that modulates the VGT position to decrease the rate of

temperature increase of the exhaust gas, and thus slows the expected rate of the expected temperature excursion. The reduction in the rate of the temperature excursion reduces the differential between the temperatures of front SCR catalyst 108 and rear SCR catalyst 110 during the temperature excursion, thus reducing the ammonia amount that is released but not detected by mid-bed ammonia sensor 122a. Other embodiments contemplate other control commands to reduce the rate of the temperature excursion during the thermal event, such as retarding fuel injection timing, modulating intake throttle position, and increasing cooling of the charge flow, for example. The specific magnitudes and adjustment functions of the doser and/or actuators are control selections for a particular system.

[0032] In another embodiment, for a vehicle equipped with a hybrid power train including an electrical device 103 that propels the vehicle, at least a part of the increase in load creating the thermal event can be met by satisfying at least a part of the torque request or load with electrical device 103. As a result, the temperature increase of SCR catalyst 108, 110 can be reduced or avoided by satisfying the increase in load with a non-exhaust gas producing electrical device 103. Accordingly, slip mitigation command 250 can include operating an electrical device 103 in response to a thermal event indicator 230 and NH_3 release estimate 226 to satisfy at least a part of the torque demand until the thermal event is concluded or the SCR catalyst 108, 110 temperature has increased sufficiently to mitigate ammonia slip due to the temperature excursion.

[0033] In a further refinement of this embodiment, slip mitigation module 248 interprets a battery SOC 256 and determines a slip mitigation command 250 that can include a command to temporarily modify the SOC target or SOC limits of energy storage device 105 in response to a thermal event indicator 230 so that electrical device 103 can operate to

reduce the rate of the temperature excursion or control the rate of increase in temperature of SCR catalyst 108, 110 during the thermal event even if, under other operating conditions, the SOC target or limits would otherwise prevent operation of electrical device 103 with power from energy storage device 105.

[0034] In yet another embodiment, slip mitigation command 250 can include a command to activate exhaust heater 107, which can also receive power from energy storage device 105 and/or electrical device 103, in response to a thermal event indicator 230 to modulate the exhaust temperature in a more direct manner before the thermal event to avoid a rapid increase in the temperature of SCR catalyst 108, 110. The exhaust heater 107 can heat the exhaust upstream of SCR catalyst 108, 110 or heat the catalyst directly.

[0035] The descriptions which follow provide an illustrative embodiment of procedures for thermal event anticipation and control in a NO_x reduction aftertreatment system to avoid or mitigate slip of ammonia and/or NO_x. Operations illustrated are understood to be exemplary only, and operations may be combined or divided, and added or removed, as well as re-ordered in whole or part, unless stated explicitly to the contrary herein. Certain operations illustrated may be implemented by a computer executing a computer program product on a computer readable medium, where the computer program product comprises instructions causing the computer to execute one or more of the operations, or to issue commands to other devices to execute one or more of the operations.

[0036] Referring to Fig. 3, an exemplary procedure 300 includes an operation 302 to interpret or determine an NH₃ storage amount on the SCR catalyst 108, 110. The NH₃ storage amount can be determined by a virtual sensor or any estimation technique.

Procedure 300 continues at operation 304 to determine a thermal event indicator. The

thermal event indicator provides an anticipator of a thermal event associated with the SCR catalyst 108, 110 in which a temperature excursion will result that releases NH_3 in a manner that is not accounted for by mid-bed ammonia sensor 122a. In response to the thermal event indicator, procedure 300 includes an operation 306 to determine an NH_3 release estimate. The NH_3 release estimate is determined from the amount of NH_3 stored on SCR catalyst 108, 110 and the fraction of NH_3 that will be released from the front of SCR catalyst 108, 110 and re-stored on the rear of SCR catalyst 108, 110 and subsequently released during the thermal event. The NH_3 release estimate can be based on, for example, look-up tables, operating maps or algorithms developed during testing. In response to the thermal event indicator and NH_3 release estimate, procedure 300 includes an operation 308 to mitigate NH_3 slip. Mitigation of NH_3 slip can include any one or combination of a modification in the amount and timing of reductant injection before the temperature excursion to offset the release of NH_3 , the operation of actuators that control operating parameters of the engine or exhaust system to reduce the rate of the temperature excursion and resulting increase in catalyst temperature, and operations that provide a more stable increase in the temperature of the SCR catalyst.

[0037] In systems that include an electrical device 103 that propels the vehicle, mitigation of NH_3 slip can include operating the electrical device to satisfy at least part of the torque request before the temperature excursion to reduce the expected rate of the temperature excursion, and modifying SOC targets or limits of an energy storage device that powers the electrical device during the thermal event to reduce the expected rate of the temperature excursion. In still other embodiments, an exhaust heater can be provided that is operated by the energy storage device and/or an electrical generating device to modulate the SCR

catalyst temperature in a controlled manner and reduce the rate of the temperature excursion.

[0038] The exemplary procedure further includes an operation to anticipate a thermal event as an event that is expected to cause a change in an ammonia storage capacity of the SCR catalyst and provide a thermal event indicator. In certain embodiments, anticipating the thermal event includes determining an imminent temperature change event in the SCR catalyst. Determining an imminent temperature change event can include analyzing catalyst temperature trends, analyzing operator behavior and/or throttle position in conjunction with current operating conditions, analyzing engine operating conditions, and analyzing route conditions from GPS data.

[0039] An exemplary system includes an internal combustion engine, an exhaust conduit fluidly coupled to the internal combustion engine, and an SCR catalyst fluidly coupled to the exhaust conduit. The system further includes a reductant doser operationally coupled to the exhaust conduit at a position upstream of the SCR catalyst, and a controller configured to determine a thermal event indicator that anticipates a temperature excursion of the SCR catalyst and an estimate of an NH_3 amount to be released from the SCR catalyst as a result of the temperature excursion. The controller is further configured to mitigate slip of NH_3 from the SCR catalyst by controlling operations to reduce at least one or the reductant amount supplied to the SCR catalyst and the rate of the temperature excursion of the SCR catalyst in response to the thermal event.

[0040] Exemplary and non-limiting examples of anticipating a thermal event and providing a thermal event indicator in response thereto include detecting a temperature increase in an exhaust stream, in an SCR catalyst, and/or in a component or temperature

sensor positioned upstream of the SCR catalyst. Another example includes detecting a parameter indicative of an imminent temperature increase in the SCR catalyst, including a temperature change upstream of the SCR catalyst, a change in a torque or power request input to an engine (e.g. an accelerator pedal position change, governor switch, and/or engine controls torque reference value), a system load increase determination, and/or a determination that a vehicle including the SCR catalyst has entered or is approaching an increased grade. Another example includes detecting that an exhaust mass flow rate is increasing, that an imminent increase in the exhaust mass flow rate is present due to a change in a torque or power request input to an engine, a vehicle launch indication (e.g. according to a clutch pedal position or engine speed to vehicle speed correlation), an engine speed change, and/or a turbocharger operating conditions change (speed, bypass or wastegate position, and/or variable geometry position).

[0041] As is evident from the figures and text presented above, a variety of embodiments according to the present invention are contemplated.

[0042] According to one aspect, a method includes receiving an exhaust flow into an exhaust conduit; interpreting a reductant storage amount of a reductant stored by a SCR catalyst in an exhaust conduit; detecting a thermal event indicator of an expected temperature excursion of the SCR catalyst, the temperature excursion being an event that is expected to release at least part of the reductant stored by the SCR catalyst by reducing a reductant storage capacity of the SCR catalyst; and in response to the thermal event indicator, initiating reductant slip mitigation measures before the temperature excursion begins to mitigate a slip of the reductant from the catalyst.

[0043] In one embodiment, the method further includes estimating an amount of reductant to be released from the reductant stored by the SCR catalyst in response to the expected temperature excursion and initiating the reductant slip mitigation measures in response to the estimated amount. In a refinement of this embodiment, the method includes interpreting a reductant amount target comprising a target amount of reductant in the exhaust conduit at a position upstream of the SCR catalyst and providing a reductant doser command in response to the reductant amount target before detecting the thermal event indicator. Initiating reductant slip mitigation measures includes modifying the reductant dosing command in response to the amount of reductant to be released in response to the expected temperature excursion.

[0044] In another embodiment of the method, detecting the thermal event indicator includes analyzing SCR catalyst temperature trend data. In another embodiment, detecting the thermal event indicator includes. In yet another embodiment, detecting the thermal event indicator includes analyzing throttle position trend data; analyzing route conditions data; and analyzing operating conditions data.

[0045] In a further embodiment, initiating reductant slip mitigation measures includes operating an electrical device to reduce a load on an engine producing an exhaust gas that is delivered to the SCR catalyst by the exhaust conduit and operating the electrical device decreases a rate of the expected temperature excursion. In one refinement, operating the electrical device includes supplying energy to the electrical device from an electrical energy storage device. In a further refinement, the method includes modifying a state of charge target of the electrical energy storage device to maintain operation of the electrical

device until the expected amount of reductant to be released is less than a threshold amount.

[0046] In another embodiment of the method, initiating reductant slip mitigation measures includes operating an exhaust heater to decrease a rate of the expected temperature excursion. In one refinement, operating the exhaust heater includes supplying electrical energy to the exhaust heater from an energy storage device.

[0047] According to another aspect, a method includes operating an engine to produce an exhaust flow in an exhaust conduit; interpreting a reductant amount target comprising a target amount of reductant in an exhaust conduit at a position upstream of an SCR catalyst; interpreting a reductant storage amount of the SCR catalyst; detecting a thermal event associated with an expected temperature excursion of the SCR catalyst; and, in response to the thermal event and the reductant storage amount, decreasing a rate of the expected temperature excursion associated with the SCR catalyst.

[0048] In embodiment, the expected temperature excursion causes a change in reductant storage capacity of the SCR catalyst. In another embodiment, detecting the thermal event comprises determining an imminent temperature change event of the SCR catalyst. In yet another embodiment, decreasing the rate of the expected temperature excursion includes decreasing a temperature of an exhaust flow into the exhaust conduit. In still another embodiment, decreasing the rate of the expected temperature excursion includes operating an electrical motor device to satisfy at least part of a torque request of the engine. In another embodiment, decreasing the rate of the expected temperature excursion includes operating an electrical heating device to heat the SCR catalyst.

[0049] According to another aspect, a system includes an internal combustion engine and an exhaust conduit fluidly coupled to the internal combustion engine. The system further includes an SCR catalyst fluidly coupled to the exhaust conduit and a reductant doser operationally coupled to the exhaust conduit at a position upstream of the SCR catalyst. The reductant doser responsive to a reductant doser command to provide reductant into the exhaust conduit. The system also includes a controller that includes an ammonia storage module structured to interpret an ammonia storage amount of the SCR catalyst, a thermal event anticipation module structured to detect an expected temperature excursion of the SCR catalyst and to provide a thermal event indicator in response to the expected temperature excursion and the ammonia storage amount, and a slip mitigation module structured to provide a slip mitigation command in response to the thermal event indicator.

[0050] In one embodiment, the thermal event anticipation module is structured to interpret at least one of an SCR catalyst temperature trend, a throttle position trend, an operator behavior trend, and a route condition to detect the expected temperature excursion. In another embodiment, the ammonia storage module is structured to interpret the ammonia storage amount in response to at least one of an injected ammonia amount into the exhaust conduit and an ammonia amount outlet from the SCR catalyst.

[0051] In another embodiment, the slip mitigation command reduces a reductant amount supplied by the reductant doser command in response to the thermal event indicator. In yet another embodiment, the slip mitigation command reduces a rate of the expected temperature excursion in response to the thermal event indicator.

[0052] In another embodiment, the system includes an electrical device operable to produce a drive torque, and the slip mitigation command operates the electrical device in

conjunction with the internal combustion engine to reduce the rate of the expected temperature excursion. In a refinement of this embodiment, the electrical device is connected to an energy storage device, and the slip mitigation command further modifies a target state of charge of the energy storage device in response to the thermal event indicator.

[0053] In another embodiment, the system includes an electrical heating device operable to heat the SCR catalyst, and the slip mitigation command operates the electrical heating device to reduce the rate of the expected temperature excursion. In a refinement of this embodiment, the electrical device is connected to an energy storage device that powers the electrical heating device during the temperature excursion event.

[0054] While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only certain exemplary embodiments have been shown and described and that all changes and modifications that come within the spirit of the inventions are desired to be protected. In reading the claims, it is intended that when words such as “a,” “an,” “at least one,” or “at least one portion” are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. When the language “at least a portion” and/or “a portion” is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

WHAT IS CLAIMED IS:

1. A method, comprising:
 - receiving an exhaust flow into an exhaust conduit;
 - interpreting a reductant storage amount of a reductant stored by a selective catalytic reduction (SCR) catalyst in the exhaust conduit;
 - detecting a thermal event indicator of an expected temperature excursion of the SCR catalyst, the temperature excursion being an event that is expected to release at least part of the reductant stored by the SCR catalyst by reducing a reductant storage capacity of the SCR catalyst; and
 - in response to the thermal event indicator, initiating reductant slip mitigation measures before the temperature excursion begins to mitigate a slip of the reductant from the catalyst.
2. The method of claim 1, further comprising:
 - estimating an amount of reductant to be released from the reductant stored by the SCR catalyst in response to the expected temperature excursion; and
 - initiating the reductant slip mitigation measures in response to the estimated amount.
3. The method of claim 2, further comprising:
 - interpreting a reductant amount target comprising a target amount of reductant in the exhaust conduit at a position upstream of the SCR catalyst;
 - providing a reductant doser command in response to the reductant amount target before detecting the thermal event indicator; and

wherein initiating reductant slip mitigation measures includes modifying the reductant dosing command in response to the amount of reductant to be released in response to the expected temperature excursion.

4. The method of claim 2, wherein initiating reductant slip mitigation measures includes operating an electrical device to reduce a load on an engine producing an exhaust gas that is delivered to the SCR catalyst by the exhaust conduit, wherein operating the electrical device decreases a rate of the expected temperature excursion.

5. The method of claim 4, wherein operating the electrical device includes supplying energy to the electrical device from an electrical energy storage device.

6. The method of claim 5, further comprising modifying a state of charge target of the electrical energy storage device to maintain operation of the electrical device until the expected amount of reductant to be released is less than a threshold amount.

7. The method of claim 2, wherein initiating reductant slip mitigation measures includes operating an exhaust heater to decrease a rate of the expected temperature excursion.

8. The method of claim 7, wherein operating the exhaust heater includes supplying electrical energy to the exhaust heater from an energy storage device.

9. The method of claim 1, wherein detecting the thermal event indicator includes at least one of analyzing SCR catalyst temperature trend data; analyzing throttle position trend data; analyzing route conditions data; and analyzing operating conditions data.

10. A method, comprising:

operating an engine to produce an exhaust flow in an exhaust conduit;

interpreting a reductant amount target comprising a target amount of reductant in the exhaust conduit at a position upstream of a selective catalyst reduction (SCR) catalyst;

interpreting a reductant storage amount of the SCR catalyst;

detecting a thermal event associated with an expected temperature excursion of the SCR catalyst; and

in response to the thermal event and the reductant storage amount, decreasing a rate of the expected temperature excursion associated with the SCR catalyst.

11. The method of claim 10, wherein the expected temperature excursion is expected to cause a change in reductant storage capacity of the SCR catalyst.

12. The method of claim 10, wherein detecting the thermal event comprises determining an imminent temperature change event of the SCR catalyst.

13. The method of claim 10, wherein decreasing the rate of the expected temperature excursion includes decreasing a temperature of the exhaust flow into the exhaust conduit.

14. The method of claim 10, wherein the decreasing the rate of the expected temperature excursion includes operating an electrical motor device to satisfy at least part of a torque request.

15. The method of claim 10, wherein the decreasing the rate of the expected temperature excursion includes operating an electrical heating device to heat the SCR catalyst.

16. A system, comprising:

an internal combustion engine;

an exhaust conduit fluidly coupled to the internal combustion engine;

a selective catalyst reduction (SCR) catalyst fluidly coupled to the exhaust conduit;
a reductant doser operationally coupled to the exhaust conduit at a position upstream of the SCR catalyst, the reductant doser responsive to a reductant doser command to provide a reductant into the exhaust conduit;

a controller, comprising:

an ammonia storage module structured to interpret an ammonia storage amount of the SCR catalyst;

a thermal event anticipation module structured to detect an expected temperature excursion of the SCR catalyst and to provide a thermal event indicator in response to the expected temperature excursion and the ammonia storage amount; and

a slip mitigation module structured to provide a slip mitigation command in response to the thermal event indicator.

17. The system of claim 16, wherein the thermal event anticipation module is structured to interpret at least one of an SCR catalyst temperature trend, a throttle position trend, an operator behavior trend, and a route condition to detect the expected temperature excursion.

18. The system of claim 16, wherein the ammonia storage module is structured to interpret the ammonia storage amount in response to at least one of an injected ammonia amount into the exhaust conduit and an ammonia amount outlet from the SCR catalyst.

19. The system of claim 16, wherein the slip mitigation command reduces a reductant amount supplied by the reductant doser in response to the reductant doser command.

20. The system of claim 16, wherein the slip mitigation command reduces a rate of the expected temperature excursion.

21. The system of claim 20, further comprising an electrical device operable to produce a drive torque, and the slip mitigation command operates the electrical device in conjunction with the internal combustion engine to reduce the rate of the expected temperature excursion in response to the thermal event indicator.

22. The system of claim 21, wherein the electrical device is connected to an energy storage device, and the slip mitigation command further modifies a target state of charge of the energy storage device in response the thermal event indicator.

23. The system of claim 20, further comprising an electrical heating device operable to heat the SCR catalyst, and the slip mitigation command operates the electrical heating device to reduce the rate of the expected temperature excursion in response to the thermal event indicator.

24. The system of claim 23, wherein the electrical device is connected to an energy storage device that powers the electrical heating device during the temperature excursion event.

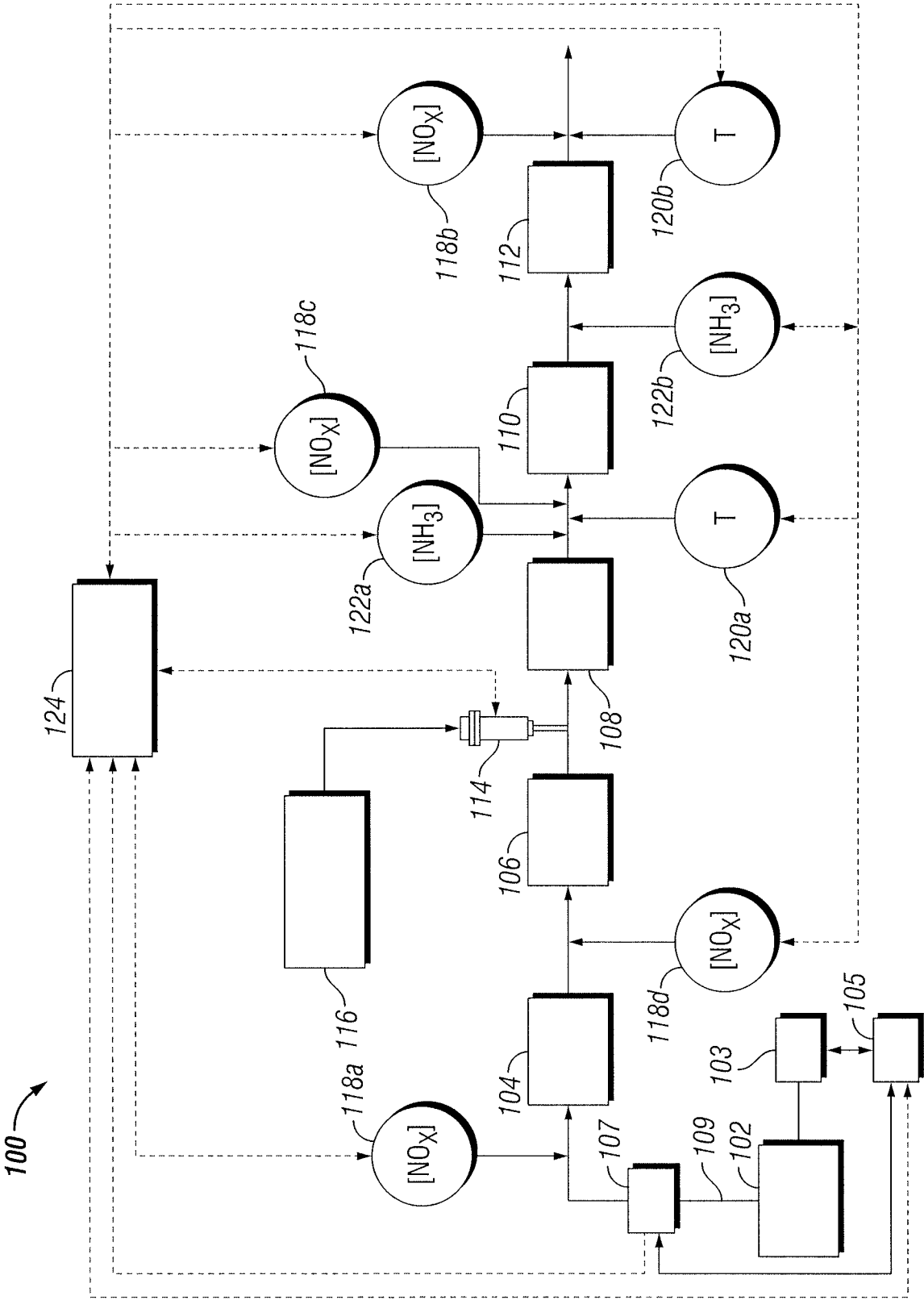


FIG. 1

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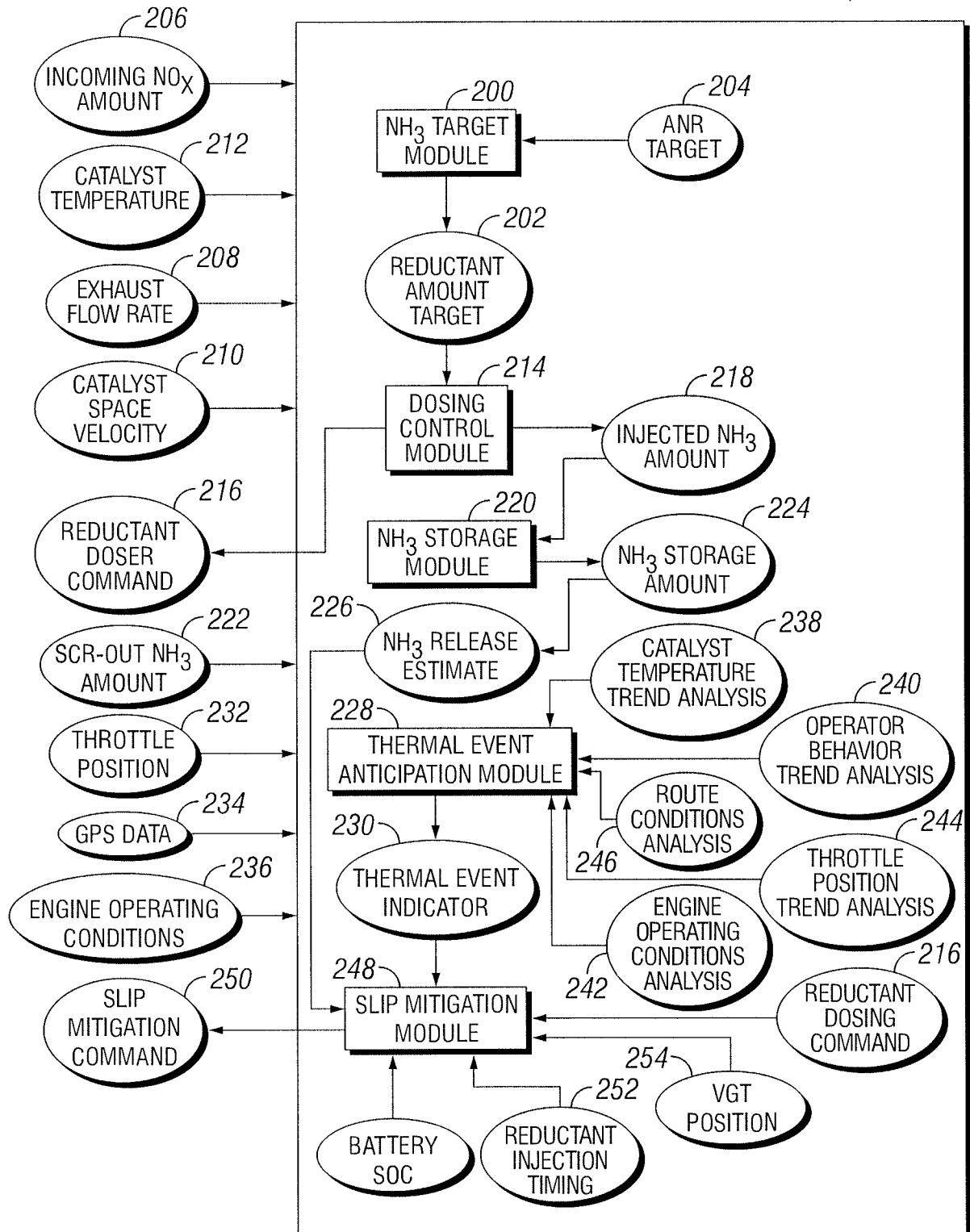
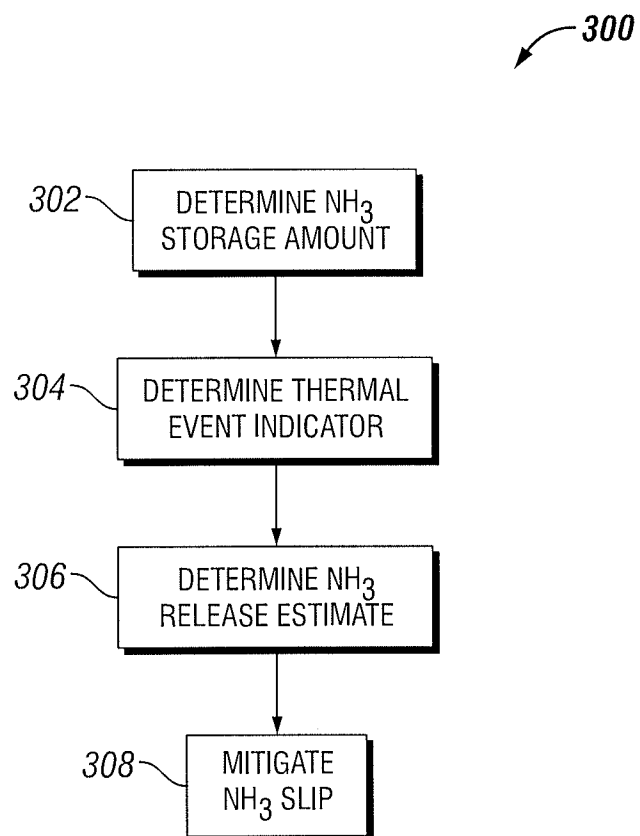


FIG. 2

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2014/057167

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F01N 3/10 (2014.01)

CPC - F01N 3/10 (2014.12)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - B01D 53/92, 53/94; F01N 3/08, 3/10, 3/18 (2014.01)

CPC - B01D 53/92, 53/94; F01N 3/08, 3/10, 3/18 (2014.12)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 60/274, 276, 282, 286, 287, 294, 299, 301, 302; 701/101, 102 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Orbit, Google Patents, Google

Search terms used: selective catalytic reduction, SCR, reductant, reductant slip, storage

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/0058740 A1 (KURTZ) 11 March 2010 (11.03.2010) entire document	1-3, 9-13, 16, 19, 20
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Y		7, 8, 15, 18
Y	US 2013/0152553 A1 (GONZE et al) 20 June 2013 (20.06.2013) entire document	7, 8, 15
Y	US 2010/0101214 A1 (HERMAN et al) 29 April 2010 (29.04.2010) entire document	18
A	US 2010/0107609 A1 (PARMENTIER et al) 06 May 2010 (06.05.2010) entire document	1-24
A	US 2012/0017568 A1 (GEVECI et al) 26 January 2012 (26.01.2012) entire document	1-24
A	US 2013/0232958 A1 (CUMMINS INC) 12 September 2013 (12.09.2013) entire document	1-24

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

08 December 2014

Date of mailing of the international search report

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Name and mailing address of the ISA/US

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