SCR REDUCTANT DEPOSIT REMOVAL

Inventors: Matthew Thomas Kiser, Chillicothe, IL (US); Cornelius N. Opris, Peoria, IL (US); Alan R. Stockner, Metamora, IL (US); Jinhui Sun, Bloomington, IL (US); Zhiyong Wei, Chicago, IL (US)

Assignee: Caterpillar Inc., Peoria, IL (US)

Correspondence Address:
Caterpillar Inc.
Intellectual Property Dept.
AH 9510, 100 N.E. Adams Street
PEORIA, IL 61629-9510 (US)

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ABSTRACT

An engine exhaust aftertreatment system including a selective catalytic reduction (SCR) system. The SCR system includes a reductant injection system configured to introduce a reductant into an exhaust stream of an engine, a SCR catalysts configured to reduce NOx in the presence of a reductant, and a SCR monitoring system configured to determine temperatures associated with the SCR system. The SCR system also includes a heat source configured to raise the temperature of the exhaust stream and a controller configured to operate the heat source to reach exhaust stream temperatures in the SCR system of at least about 400 degrees Celsius based on the temperature associated with the SCR system.
SCR REDUCTANT DEPOSIT REMOVAL

TECHNICAL FIELD

[0001] The present disclosure relates to engine exhaust aftertreatment systems, and more particularly to exhaust aftertreatment systems employing reductants for NOx reduction technologies.

BACKGROUND

[0002] A selective catalytic reduction (SCR) system may be included in an exhaust treatment or aftertreatment system for a power system to remove or reduce nitrous oxide (NOx or NO) emissions coming from the exhaust of an engine. SCR systems use reductants, such as urea. These reductants may form deposits in the exhaust system, creating backpressure, reducing efficiency, and potentially corroding components and inhibiting injection of the reductant.

[0003] PCT Patent Application Publication WO 2005/073528 (the ‘528 publin) discloses a heater around the outside of the exhaust conduit to remove solute deposited on the exhaust conduit. The ‘528 publin, however, may not address deposits in other areas of the SCR system and may not be the most efficient solution.

SUMMARY

[0004] In one aspect, the present disclosure provides an engine exhaust aftertreatment system including a selective catalytic reduction (SCR) system. The SCR system includes a reductant injection system configured to introduce a reductant into an exhaust stream of a engine, a SCR catalyst configured to reduce NOx in the presence of a reductant, and a SCR monitoring system configured to determine temperatures associated with the SCR system. The SCR system also includes a heat source configured to raise the temperature of the exhaust stream and a controller configured to operate the heat source to reach temperatures in the SCR system of at least about 400 degrees Celsius.

[0005] In another aspect, a method is provided for removing deposits from a selective catalytic reduction (SCR) system. The method includes determining temperatures associated with the SCR system, activating a heat source to increase exhaust stream temperatures to reach temperatures in the SCR system of at least about 400 degrees Celsius, and controlling the heat source based on temperatures in the SCR system.

[0006] In yet another aspect, a selective catalytic reduction (SCR) system is provided including an injector, SCR catalyst, and an injector heater. The injector introduces a reductant into the exhaust stream of the engine. The injector heater is associated with the injector to prevent or remove deposits.

[0007] Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a diagrammatic view of a power system including an engine and an aftertreatment system.

[0009] FIG. 2 is a cross-sectional view of an exhaust conduit from FIG. 1, showing a reductant deposit upstream from a mixer.

[0010] FIG. 3 is a cross-sectional view of an exhaust conduit from FIG. 1, showing a reductant deposit upstream in the exhaust conduit.

[0011] FIG. 4 is a cross-sectional view of a SCR canister from FIG. 1, showing a reductant deposit on a face of a SCR catalyst.

DETAILED DESCRIPTION

[0012] As seen in FIG. 1, a power system includes an engine 12 and an aftertreatment system 14 to treat an exhaust stream 16 produced by the engine 12. The engine 12 may include other features not shown, such as controllers, fuel systems, air systems, cooling systems, peripherals, drivetrain components, turbochargers, exhaust gas recirculation systems, etc. The engine 12 may be any type of engine (internal combustion, gas, diesel, gaseous fuel, natural gas, propane, etc.), may be of any size, with any number of cylinders, and in any configuration (“V,” in-line, radial, etc.). The engine 12 may be used to power any machine or other device, including on-highway trucks or vehicles, off-highway trucks or machines, earth moving equipment, generators, aerospace applications, locomotive applications, marine applications, pumps, stationary equipment, or other engine powered applications.

[0013] The aftertreatment system 14 includes an exhaust conduit 18, a heat source 20, a Selective Catalytic Reduction (SCR) system 22, and a control system 24. The aftertreatment system 14 may also include a diesel oxidation catalyst (DOC) 26, a diesel particulate filter (DPF) 28, and a clean up catalyst 29 or other exhaust treatment devices upstream, downstream, or within the SCR system 22.

[0014] The exhaust stream 16 exits the engine 12, passes by or through the heat source 20, passes through the DOC 26, DPF 28, then passes through the SCR system 22, and then passes through the clean up catalyst 29 via the exhaust conduit 18. During operation, the DOC 26 oxidizes NOx into Nitrogen dioxide (NO2). The DPF 28 collects particulate matter or soot. The DOC 26 and DPF 28 may be in the same canister, as shown, or separate.

[0015] The heat source 20 may embody a burner 30 including a combustion head 32 and a housing 33. The housing 33 may contain a flame 35 generated by the combustion head 32. The housing 33 may also route the exhaust stream 16 to be heated by the burner 30. The burner 30 may receive a supply of fuel and may also include an ignition source and air supply to generate the flame 35. In alternative embodiments the heat source 20 may not employ a fuel-fired burner 30. The heat source 20 may embody an electric heating element, microwave device, or other heat source. The heat source 20 may also embody operating the engine 12 under conditions to generate elevated exhaust stream 16 temperatures.

[0016] The SCR system 22 may include a reductant system 34, mixer 36, diffuser 38, SCR canister 40, and SCR catalyst 42. The SCR system 22 may also include one or more changes of direction or bends 43 in the exhaust conduit 18.

[0017] The reductant system 34 may include a reductant source 44, pump 46, valve 48, and injector 50. Reductant 52 is drawn from the reductant source 44 via the pump 46 and delivery to the injector 50 is controlled via the valve 48. The reductant 52 comes from a nozzle or injector tip 54 of the injector 50 to form a reductant spray 56 or is otherwise introduced into the exhaust stream 16 or SCR catalyst 42. Components of the reductant system 34 may be cooled or insulated to prevent overheating of the reductant 52.

[0018] The mixer 36 may be added to aid mixing of the reductant 52 with the exhaust stream 16. The diffuser 38 may be added to aid in distributing the exhaust stream 16 evenly
into the SCR catalyst 42. The diffuser 38 may be disposed in the SCR canister upstream of the SCR catalyst 42 and may include a plurality of diffuser openings 55 that the exhaust stream 16 exits from.

The SCR catalyst 42 includes a catalyst material disposed on a substrate. The catalyst is configured to reduce an amount of NOx in the exhaust stream 16 by using the reductant 52. The substrate may consist of cordierite, silicon carbide, other ceramic, or metal. The substrate may include a plurality of throughgoing channels 57. The channels 57 may form a honeycomb structure. A face 58 of the SCR catalyst 42 is exposed to the oncoming exhaust stream 16.

While other reductants 52 are possible, urea is the most common source of reductant 52. Urea reductant 52 decomposes into ammonia (NH3) and is then adsorbed or stored in the SCR catalyst 42. The length of the SCR system 22 between the injector tip 54 and SCR catalyst 42 may be sufficiently long to achieve the mixing of reductant 52 into the exhaust stream 16 and provide the dwell time for the urea reductant 52 to convert into NH3.

The dosing of urea reductant 52 may only occur above an injection threshold temperature, which may be about 180 degrees Celsius. Below about 180 degrees Celsius sulfates are formed from the urea reductant 52 that may deactivate the SCR catalyst 42.

The NH3 is consumed in the SCR Catalyst 42 through a reduction of NOx into nitrogen gas (N2). Desorption of NH3 from the SCR catalyst 42 also occurs at temperatures in excess of about 200 degrees Celsius and continues to accelerate as temperatures increase. Some NH3 oxidation also occurs above about 500 degrees Celsius. However, the rates of NH3 desorption and oxidation do not exceed the rate of adsorption and NOx reduction, making the dosing of urea still effective for emission reductions.

The clean-up catalyst 29 may embody an ammonium oxidation catalyst (AMOX) and may be included downstream of the SCR system 22. The clean-up catalyst 29 and SCR catalyst 42 may be in the same canister, as shown, or separate. The clean-up catalyst 29 is configured to capture, store, oxidize, reduce, and/or convert NH3 that may slip past or break-through the SCR catalyst 42. The clean-up catalyst 29 may also be configured to capture, store, oxidize, reduce, and/or convert other constituents present.

Control system 24 includes a controller 60, engine connection 62, heat source connection 64, DPF sensor system 66, reductant system connection 68, and SCR monitoring system 70. The engine connection 62 receives data from the engine 12 and machine and may provide control signals to the engine 12. The heat source connection 64 activates the heat source 20 when ordered by the controller 60.

The DPF sensor system 66 may include upstream sensors 72 and a soot sensor 74. The upstream sensors 72 may include temperature and or pressure sensors. The soot sensor 74 provides an indication of soot levels in the DPF 28 and may be based on pressure differential or attenuated radio frequencies (RF) or another sensor system.

The reductant system connection 68 activates the reductant system 34 when ordered by the controller 60. The SCR monitoring system 70 determines a temperature associated with the SCR system 22. The SCR monitoring system 70 may include upstream sensors 76, inside sensors 78, and downstream sensors 80. The SCR monitoring system 70 may also determine the temperature of the SCR system 22 directly from these sensors or may calculate or predict the temperature based on temperatures sensed elsewhere in the power system 10, operating or ambient conditions, or any combination thereof. The upstream sensors 76, inside sensors 78, and downstream sensors 80 may also include any of NOx, NH3, temperature, signal frequency, and pressure sensors and may include more than one. One or more of the upstream sensors 76, inside sensors 78, and downstream sensors 80 may not be needed.

The upstream sensors 76 are located in the exhaust stream 16 upstream of the reductant system 34. The inside sensors 78 are located in the exhaust stream 16 downstream of the reductant system 34 and upstream of the SCR catalyst 42. The downstream sensors 80 are located in the exhaust stream 16 downstream of the SCR catalyst 42. The location of the sensors may be changed or moved with appropriate compensations made to any measurements.

INDUSTRIAL APPLICATION

An unintended consequence of urea reductant 52 injections may be the formation of deposits 82. While the reductant system 34 may or may not be air-assisted, deposits more readily develop in airless reductant systems 34. Airless reductant systems 34 tend to produce reductant sprays 56 with larger droplet sizes than air-assisted reductant systems 34. The larger droplet size in the reductant spray 56 may cause deposit 82 formations.

As seen in FIGS. 2 and 3, the deposits 82 may form as settlements 83 on an inside wall 84 of the exhaust conduit 18. The settlements 83 may form in areas where the reductant spray 56 impinges or settles. For example, the deposits 82 may form opposite the injector 50 before the mixer 36, as seen in FIG. 2, or on the far wall of a bend 43 as seen in FIG. 3. The deposits 82 may also form on or in other components of the exhaust system, such as the injector 50, mixer 36, diffuser 38, or face 58 of the SCR catalyst 42.

The deposits 82 may also break away as flakes 86. As seen in FIG. 4, these flakes 86 may land or be blown onto the face 58 of the SCR catalyst 42. The flakes 86 may also come to rest in other locations, such as in the mixer 36, in the exhaust conduit 18, in the diffuser 38, the diffuser openings 55, or in the canister 40.

The deposits 82 may form under a number of different conditions and through a number of different mechanisms. Deposits 82 may form when the urea reductant 52 is not quickly decomposed into NH3 and thick layers of urea reductant 52 collect. These layers may build as more and more urea reductant 52 is sprayed or collected, which may have a cooling effect that prevents decomposition into NH3. As a result, the urea reductant 52 sublimes into crystals or otherwise transforms into a solid composition to form the deposit 82. This composition may consist of biuret (NH2CONHCONH2) or cyanuric acid (NH2CO3) or another composition depending on temperatures and other conditions.

These deposits 82 may have negative impacts on the operation of the power system 10. The deposits 82 may block flow of the exhaust stream 16, causing higher back-pressure and reducing engine 12 and aftertreatment system 14 performance and efficiency. The deposits 82 may also disrupt the flow and mixing of the urea reductant 52 into the exhaust stream 16, thereby reducing the decomposition into NH3 and reducing NOx reduction efficiency. The deposits 82 may also block the injector tip 54 or disrupt the reductant spray 56. The formation of the deposits 82 also consumes urea reductant 52,
making control of injection harder and potentially reducing NOx reduction efficiency. The deposits 82 may also corrode components of the aftertreatment system 14 materials and degrade the structural and thermal properties of the SCR catalyst 42. The deposits 82 may also block channels 57 of the SCR catalyst 42, again reducing NOx reduction efficiency.

The heat source 20 is upstream of the SCR system 22 for heating the exhaust stream 16. By heating the exhaust stream 16, the heat source 20 is able to decompose or remove any deposits 82 present in the SCR system 22. The heat source 20 may also be upstream of the DPF 28 for the regeneration or soot removal of the DPF 28.

The deposits 82 have been found to decompose into ammonia and carbon dioxide (CO2) at SCR system 22 temperatures in excess of about 400 degrees Celsius. The SCR system 22 temperatures may be the temperature of the exhaust stream 16 entering the SCR system 22 as measured by the upstream sensors 76. Tests have shown that deposits 82 are removed in the SCR system 22 when exposed to about 450 degree Celsius for between about 15 and 30 minutes or about 650 degrees Celsius for between about 5 and 10 minutes.

Only heating the outside of the exhaust conduit 18 and not significantly heating the exhaust stream 16 would not be effective in removing the deposits 82 that may be inside the exhaust conduit 18, such as those on the face 58 of the SCR catalyst 42, in the mixer 36, or in the diffuser 38. Heating the outside of the exhaust conduit 18 may also require a large and complex heating system to apply heat to all the needed areas of the aftertreatment system 14 as compared to a single heat source 20 that heats the exhaust stream 16. A robust heat source 20, such as a burner 30, may be needed to reach the temperatures needed for decomposition in the SCR system, especially if the heat source 20 is upstream of the DPF 28 or otherwise far away from the SCR system 22 and given the length and number or mass of components in the SCR system 22.

Controller 60 receives data from SCR monitoring system 70 and controls the operation of the heat source 20. When the controller 60 orders the heat source 20 to activate, temperatures associated with the SCR monitoring system 70 are reported to the controller 60 from the SCR monitoring system 70. The controller 60 calculates or determines whether a sufficient temperature has been reached in the SCR system 22 for a sufficient amount of time to decompose any deposits 82 that may be present. If not, the controller 60 will order the heat source 20 to provide more heat for longer.

The controller 60 may control the heat source 20 for deposit 82 removal in conjunction with regeneration or soot removal of the DPF 28. Removal of deposits 82 in the SCR system 22 may also be needed at times when additional heat is not needed for regeneration of the DPF 28. Under certain engine 12 operating conditions passive regeneration of the DPF 28 may occur or the amount of soot produced may be reduced, extending the time between active DPF 28 regenerations that require activation of the heat source 20. During these periods, however, deposits 82 may continue to form in the SCR system 22, requiring activation of the heat source 20 for deposit 82 removal even when not needed for DPF 28 regeneration.

The controller 60 may be configured to activate the heat source 20 for deposit 82 removal under a number of different conditions. The activation of the heat source 20 may be based on a time period during which deposits 82 are known to normally accumulate to a limit threshold. The activation of the heat source 20 may also be a function of several parameters. Those parameters may include time, engine 12 operating conditions, reductant 52 dosing rates, or SCR system 22 temperatures. The controller 60 may include a map or algorithm or combination thereof to calculate or predict a time based on those parameters when deposits 82 will be expected to accumulate beyond the threshold limit and the heat source 20 will need to be activated to remove the deposits 82.

The controller 60 may also use the SCR monitoring system 70 to measure that deposits 82 have formed beyond the threshold limit and the heat source 20 will need to be activated to remove the deposits 82. This measurement from the SCR monitoring system 70 may be changes in back pressure, changes in a signal frequency attenuation, changes in NOx reduction efficiency, changes in ammonia conversion, or changes in temperature distributions.

The controller 60 may also slow, stop, or inhibit the injection of reductant 52 when activating the heat source 20 to remove deposits 82. The injection of the reductant 52 may have a cooling effect on the deposits 82, preventing their decomposition, which is a function of temperature. Accordingly, inhibiting the injection of reductant 52 when activating the heat source 20 may aid in the removal of deposits 82. The inhibiting of reductant 52 injection may represent short delays between injection events or may last a longer period of time while the heat source 20 is activated.

The heat source 20 may be configured to operate during periods of engine 12 idle. As explained before, the urea reductant 52 is injected when the SCR system 22 temperature is above the injection threshold temperature, which may be about 180 degrees Celsius. During periods of extended engine 12 idle, the exhaust stream 16 temperature in the SCR system 22 may fall under this injection threshold temperature. During shorter periods of engine 12 idle the exhaust stream 16 temperature in the SCR system 22 may still exceed this injection threshold temperature and urea reductant 52 injection may ordinarily be occurring.

In other embodiments, the heat source 20 may be configured to also operate at high engine 12 speeds and load or other non-idle engine 12 conditions. At these higher engine 12 speeds and loads, SCR system 22 temperatures will also probably be above the injection threshold temperature and urea reductant 52 injection may ordinarily be occurring.

However, as mentioned above, if the heat source 20 is activated to remove deposits 82, the controller 60 may slow, stop, suspend, or inhibit the injection of urea reductant 52. Especially during engine 12 idle conditions, the injection of urea reductant 52 may be at least partially suspended because lower amounts of reductant 52 are needed as low levels of NOx are probably being produced from engine 12. During non-idle engine 12 conditions, the inhibiting of reductant 52 injection may not be possible or may only represent short delays between injection events because of the higher levels of NOx probably being produced.

The controller 60 controls the injection of urea reductant 52 based on a predicted amount of NH3 stored in the SCR catalyst 42. As mentioned above, desorption of NH3 from the SCR catalyst 42 occurs at temperatures in excess of about 200 degrees Celsius and continues to accelerate as temperatures increase. Therefore, because of the temperatures reached, the SCR catalyst 42 will have nearly zero NH3 remaining after the heat source 20 is activated to remove the deposits 82. The controller may accordingly be configured to
reset the predicted amount of NH3 stored in the SCR catalyst 42 to zero in conjunction with the activation of the heat source 20.

During extended periods of idle, the SCR system 22 temperature may be below the injection threshold temperature. If the heat source 20 is activated during these times, the time period following the deactivation of the heat source 20 may be used as an opportunity to inject reductant 52 before the temperature falls below the injection threshold temperature again. This may provide the ability to inject reductant 52 when not otherwise possible, such as during periods of extended idle or other low temperature conditions. This injection may help store NH3 in the SCR catalyst 42 and provide better response during transient engine 12 conditions following an extended engine 12 idle. The heat source 20 may be activated solely for this purpose of reductant 52 injections or in conjunction with deposit 82 removal, DPF 28 regeneration, or another purpose.

As described above a method for removing deposits from a selective catalytic reduction (SCR) system has been disclosed. The method includes sensing or determining a temperature associated with the SCR system 22, activating a heat source 20 to increase exhaust stream 16 temperatures to reach temperatures in the SCR system 22, as discussed above, and controlling the heat source 20 based on temperatures in the SCR system, as determined by the SCR monitoring system 70. The method may also include at least partially inhibiting an introduction of the reductant 52 and may include assigning a value of about zero for an amount of reductant 52 stored in the SCR catalyst 42 for control of the reductant system 34.

The injector 50 may also include an injector heater 90 to prevent formation of or remove deposits 82 from inside or on the injector 50. The injector heater 90 may be located in, around, or proximate to the injector tip 54 or otherwise located to apply heat to the injector 50. The injector heater 90 may consist of an electric resistance-heating coil connected to a power source. The injector heater 90 may also consist of another heat source. The injector heater 90 may be connected to the controller 60 or otherwise controlled to activate periodically or when predetermined conditions are met.

The injector heater 90 may prevent the formation of deposits 82 in the injector 50 by being activated or otherwise applying heat to the injector 50 and injector tip 54 after an injection. This heat will cause any water or other liquid contained in reductant 52 remaining in the injector 50 to boil and steam. This steam will drive the reductant 52 from critical components in the injector 50 or injector tip 54, such as a check valve. Because the reductant 52 is no longer present, deposits 82 will not form.

The injector heater 90 may also be used to remove urea deposits 82 that may form around or inside the injector 50. The injector heater 90 may be capable of heating the injector 50 or injector tip 54 to the temperatures mentioned above for deposit 82 removal (between about 400 and 650 degrees Celsius and higher).

The use of the injector heater 90 may also eliminate a need to cool the injector or other components of the reductant system 34 because deposits 82 are prevented or removed. The use of the injector heater 90 may or may not be included in the same embodiment as the use of the heat source 20.

Although the embodiments of this disclosure as described herein may be incorporated without departing from the scope of the following claims, it will be apparent to those skilled in the art that various modifications and variations can be made. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosure. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

What is claimed is:

1. An engine exhaust aftertreatment system comprising: a selective catalytic reduction (SCR) system including: a reductant injection system for introducing a reductant into an exhaust stream of an engine; a SCR catalyst configured to reduce NOx in the presence of the reductant; and a SCR monitoring system; a heat source configured to increase the temperature of the exhaust stream; and a controller operating the heat source to reach a temperature associated with the SCR system of at least about 400 degrees Celsius as determined by the SCR monitoring system.

2. The engine exhaust aftertreatment system of claim 1 wherein the controller operates the heat source to reach a temperature associated with the SCR system of at least about 450 degrees Celsius as determined by the SCR monitoring system.

3. The engine exhaust aftertreatment system of claim 1 wherein the controller operates the heat source to reach a temperature associated with the SCR system of at least about 450 degrees Celsius for at least about 15 minutes as determined by the SCR monitoring system.

4. The engine exhaust aftertreatment system of claim 1 wherein the controller operates the heat source to reach a temperature associated with the SCR system of at least about 650 degrees Celsius as determined by the SCR monitoring system.

5. The engine exhaust aftertreatment system of claim 1 wherein the controller operates the heat source to reach a temperature associated with the SCR system of at least about 650 degrees Celsius for at least about 5 minutes as determined by the SCR monitoring system.

6. The engine exhaust aftertreatment system of claim 1 wherein the heat source is a burner.

7. The engine exhaust aftertreatment system of claim 1 further including a diesel particulate filter upstream of the SCR system in the exhaust stream, wherein the heat source is upstream of the diesel particulate filter in the exhaust stream.

8. The engine exhaust aftertreatment system of claim 7 wherein the heat source is upstream of the diesel particulate filter in the exhaust stream.

9. The engine exhaust aftertreatment system of claim 1 wherein the controller activates the operation of the heat source based on parameters measured by the SCR monitoring system.

10. The engine exhaust aftertreatment system of claim 1 wherein the controller activates the operation of the heat source based on an elapsed period of time.

11. The engine exhaust aftertreatment system of claim 1 wherein the controller activates the operation of the heat source at least partially suspends the introduction of the reductant by the reductant injection system.

12. The engine exhaust aftertreatment system of claim 1 wherein following the operation of the heat source, the con-
controller assigns a value of about zero for an amount of reductant stored in the SCR catalyst for control of the reductant injection system.

13. The engine exhaust aftertreatment system of claim 1 wherein following the operation of the heat source and during an engine idle condition, the controller orders the introduction of reductant by the reductant injection system.

14. A method for removing deposits from a selective catalytic reduction (SCR) system comprising:
   determining temperatures associated with the SCR system;
   activating a heat source to increase exhaust stream temperatures to reach temperatures in the SCR system of at least about 400 degrees Celsius; and
   controlling the heat source based on temperatures in the SCR system.

15. The method of claim 14 wherein the heat source is activated to reach temperatures in the SCR system of at least about 450 degrees for at least about 15 minutes.

16. The method of claim 14 wherein the heat source is activated to reach temperatures in the SCR system of at least about 650 degrees.

17. The method of claim 14 wherein the heat source is activated to reach temperatures in the SCR system of at least about 650 degrees for at least about 5 minutes.

18. The method of claim 14 further including at least partially suspending an introduction of a reductant in the SCR system.

19. The method of claim 14 further including assigning a value of about zero for an amount of reductant stored in a SCR catalyst for control of a reductant injection system in the SCR system.

20. A selective catalytic reduction (SCR) system comprising:
   an injector configured to introduce a reductant into an exhaust stream of an engine;
   a SCR catalyst configured to reduce NOx in the presence of the reductant; and
   an injector heater associated with the injector and configured to prevent or remove deposits.

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