An exhaust system (1) for an internal combustion engine (2), especially for a diesel engine, includes an exhaust manifold (3) inside which at least one exhaust aftertreatment device is disposed, and at least one DeNOx unit that is arranged downstream from a first oxidizing catalyst (4). In order to reduce the NOx emissions a second oxidizing catalyst (5) is disposed upstream of the DeNOx unit.
EXHAUST SYSTEM FOR AN INTERNAL COMBUSTION ENGINE

[0001] The invention relates to an exhaust system for an internal combustion engine, especially for a diesel engine, comprising an exhaust manifold inside which at least one exhaust aftertreatment device is disposed, and at least one DeNOx unit that is arranged downstream from a first oxidizing catalyst. The invention further relates to a method for operating an exhaust aftertreatment system for reducing the nitrogen oxide emissions of an internal combustion engine, preferably an SCR catalyst, with a sensor for determining the NOx concentration in the exhaust manifold being arranged downstream of the exhaust aftertreatment system, and with a reducing agent, especially NH3 or an aqueous urea solution, being dosed to the exhaust gas preferably at a stoichiometric ratio to the NOx emissions upstream of the exhaust aftertreatment system, and with the NOx emissions of the internal combustion engine being determined by means of a characteristic map of the engine or an exhaust gas model.

[0002] NOx and NO are components of the raw exhaust gases of diesel engines. NO is partly converted into NO2 in the oxidation catalyst whose primary task is the combustion of CO and HC residues. The thus obtained ratio of NO2 to NO is a function of the noble metal concentration in the oxidation catalyst, the space velocity, the partial pressure of NOx and the temperature in the oxidation catalyst. NO2 is used in the diesel particulate filter, which is typically blown through after the oxidation catalyst, as an oxidation agent for permanent oxidation of the exhaust particulate stored thereon. As a further component of a diesel exhaust system, a DeNOx unit can be used for reducing the NOx emissions which is formed by an SCR catalyst (Selective Catalytic Reduction) for example, in which NOx is reduced with the help of dosed NH3. Both the NO and NO2 components of the exhaust gas should be reduced in this stage to N2 to the highest possible extent.

[0003] For the following reasons, the highest possible activity of the oxidation catalyst is desirable (corresponds to high mass of noble metal):

[0004] Light-off begins earlier;

[0005] a complete conversion of CO and HC, even when upstream additional HC is dosed for combustion in the oxidation catalyst (increasing the temperature of the exhaust gas);

[0006] complete conversion even in case of aging of the oxidation catalyst;

[0007] high NOx partial pressure after the oxidation catalyst in order to improve the combustion of particulates in the diesel particle filter;

[0008] This is counteracted in such a way however that for catalytic activity or the complete conversion of NOx in the DeNOx unit, a molar ratio of NOx/NO of 1 is advantageous. Moreover, a ratio of NOx/NO=1 might lead to the formation of laughing gas (N2O) in the DeNOX unit. In the case of a high catalyst mass however, NOx/NO=1 is exceeded in relevant operating points, which means that too much NOx is converted into NO2 in the oxidation catalyst.

[0009] JP 2005-002968 A discloses an internal combustion engine with an exhaust manifold in which a powerful oxidation catalyst and an SCR catalyst are arranged. The oxidation catalyst can be bypassed via a bypass line. Once the exhaust temperature has reached a value in which the inversion rate of the oxidation catalyst is at least 50%, the exhaust gases are moved past the oxidation catalyst in order to prevent excessive generation of NO2 which would reduce the NOx conversion rate in the SCR catalyst.

[0010] EP 1 357 267 A2 describes an exhaust system for a diesel engine, comprising an SCR catalyst in the exhaust manifold, upstream of which an oxidation catalyst and a hydrolysis catalyst are arranged in parallel flow paths. Hydrolysis catalyst and oxidation catalyst are flowed through simultaneously by separate partial exhaust gas flows. This allows a compact arrangement and a reduced exhaust back-pressure.


[0012] In the case of sufficient temperature of the SCR catalyst (Selective Catalytic Reduction), the reducing agent must be dosed to the exhaust gas in a suitable ratio, e.g. in a stoichiometric one, to the NOx emissions of the internal combustion engine. The NOx emissions of the internal combustion engine are usually estimated through a characteristic map or an exhaust model. Deviations in real engine operations from this characteristic map or exhaust model lead to increased NOx or NH3 emissions after the SCR catalyst. In particular, an NOx emission of the internal combustion engine which is increased over the characteristic map or model will lead to a control of the SCR catalyst for dosing an insufficient quantity of reducing agent to the exhaust gas and thus to increased NOx emissions after the SCR catalyst. An NOx emission reduced over the characteristic map or model on the other hand will lead in conventional methods to the dosing of a large quantity of reducing agent, leading to detrimental emissions of NH3 after the SCR catalyst. Although precision could be improved by a further NOx sensor in the exhaust manifold upstream of the SCR catalyst, these NOx sensors are expensive.

[0013] It is the object of the invention to achieve a high catalytic activity both in the oxidation catalyst as well as in the SCR catalyst. It is a further object of the invention to improve the catalytic reduction of the NOx emissions.

[0014] This is achieved in accordance with the invention in such a way that a second oxidation catalyst is disposed upstream of the DeNOx unit, with preferably the first and second oxidation catalyst being configured for different catalytic activities and/or for different temperature ranges. The oxidation catalysts preferably comprise different quantities of noble metal.

[0015] It is provided in a first preferred embodiment that the first and second oxidation catalyst are arranged in the exhaust manifold as regards flow parallel with respect to each other, with preferably the flow through at least one oxidation catalyst being adjustable by means of an actuator. As an alternative to this, it can also be provided that a first and a second oxidation catalyst are arranged in regard to flow in series in the exhaust manifold, with at least one oxidation catalyst being capable of being bypassed via a bypass line. Preferably, an actuator is arranged in the bypass line. The catalyst with the higher activity can be activated or deactivated or be flowed through with a partial quantity of exhaust gas.

[0016] The two oxidation catalysts can be housed in separate or in a single common housing.

[0017] It can be provided in a further embodiment of the invention that a particulate filter can be disposed upstream of the DeNOx unit, preferably downstream of a dosing device.
for reducing agent. The reducing agent can thus be sprayed into hotter exhaust gas and a more complex mixing section can be realized.

[0018] An especially precise control of the catalytic activity can be achieved when the actuator is adjusted in a model-based way depending on the NO\textsubscript{X} content in the exhaust gas, the temperature of the exhaust gas, the pressure loss of the diesel particulate filter, the air-mass flow, the fuel-mass flow, the crankshaft speed or the like, with at least one NO\textsubscript{X} sensor preferably being disposed downstream of the DeNO\textsubscript{X} unit.

[0019] In order to improve the catalytic reduction of NO\textsubscript{X} emissions, it is provided that the exhaust temperature of the exhaust gas and/or in operating phases where no reducing agent is added the NO\textsubscript{X} emissions are measured with the sensor downstream of the exhaust aftertreatment system and are compared with the values based on the characteristic map or model, and that in the case of deviations between the measures values and those based on the characteristic map or model a correction of the characteristic map or emission model is performed, with preferably the exhaust gas conveying time between the internal combustion engine and the sensor being taken into account preferably in the comparison of the measured values with those based on the characteristic map or model.

[0020] The method utilizes the fact that at temperatures of the SCR catalyst beneath approx. 200° C no reducing agent can be added, because there is no hydrolysis and no reduction. At these operating points, the NO\textsubscript{X} emissions after the SCR catalyst correspond to the raw emissions when the duration of the transport is taken into account. Specifically, the method uses a raw-emission characteristic map of the internal combustion engine. It evaluates whether the gradient in speed and torque is low, i.e. smaller than a defined threshold value. If yes, the range of the characteristic map in which the engine is located is determined and this value and the raw emissions stored there are stored in a ring buffer. When no reducing agent is injected by the exhaust aftertreatment system, the currently measured emissions are compared with the stored values by taking into account the transport period of the exhaust gas. In the case of deviations, the respective range of the characteristic map or the exhaust model is corrected, with only a small change being permitted in each change stop.

[0021] The invention is now explained in closer detail by reference to the drawings, wherein:

[0022] FIG. 1 shows an exhaust system in accordance with the invention in a first embodiment;

[0023] FIG. 2 shows an exhaust system in accordance with the invention in a second embodiment;

[0024] FIG. 3 shows the nitrogen oxide conversion rate entered over the temperature, and

[0025] FIG. 4 schematically shows an internal combustion engine for performing the method.

[0026] FIG. 1 shows an exhaust system 1 of a diesel engine 2, comprising an exhaust manifold 3 inside which a first oxidation catalyst 4 and a second oxidation catalyst 5 are arranged. Downstream of the two oxidation catalysts 4, 5, a DeNO\textsubscript{X} unit arranged as an SCR catalyst 6 is arranged for selective catalytic reduction of NO\textsubscript{X} with the help of a dosed reducing agent such as urea or NH\textsubscript{3}. A particulate filter 9 can be arranged between the dosing device 10 and the SCR catalyst 6. The first oxidation catalyst 4 has a lower catalytic activity than the second oxidation catalyst 5. The second oxidation catalyst 5 can be activated or deactivated as required by means of an actuator 7.

[0027] The exhaust gas system 1 as shown in FIG. 2 differs from this one in such a way that the first and second oxidation catalysts 4, 5 are switched behind one another in respect of flow, with the second oxidation catalyst 5 being capable of being circumvented via a bypass line 8 in which the actuator 7 is arranged.

[0028] The two oxidation catalysts 4, 5 can be separated from each other or be arranged in a common housing.

[0029] When there is an increased demand for catalytic activity, the second oxidation catalyst 5 is activated by means of the actuator 7, by which exhaust gas is guided through the same. Several actuators can optionally also be provided.

[0030] FIG. 3 shows a diagram in which the NO\textsubscript{X} conversion rate \textit{CONV}_{NO}\textsubscript{X} % is entered over the temperature \textit{T} in °C. The ratio of NO\textsubscript{2}/NO is further shown. Line 20 designates the NO\textsubscript{X} conversion rate for the case of an exhaust aftertreatment system consisting of only one DeNO\textsubscript{X} unit. Line 30 shows the NO\textsubscript{X} conversion rate for an aftertreatment system which comprises a powerful oxidation catalyst and a downstream DeNO\textsubscript{X} unit. Line 35 shows the ratio of NO\textsubscript{2}/NO for this case. Line 40 describes the NO\textsubscript{X} conversion rate for an exhaust aftertreatment system which comprises an oxidation catalyst which is optimized concerning the ratio NO\textsubscript{2}/NO=1 and a DeNO\textsubscript{X} unit. Line 45 describes the ratio of NO\textsubscript{2}/NO for this case. The dotted line 50 shows the optimal ratio of NO\textsubscript{2}/NO=1.

[0031] With the exhaust systems 1 as shown in FIGS. 1 and 2, all NO\textsubscript{2}/NO ratios of the range A shown in FIG. 3 between curves 35 and 45 can be set by continuous setting of the actuator 7. The setting of the actuator 7 which can be arranged as a flap for example can occur in a controlled manner via an NO\textsubscript{X} sensor 10 disposed downstream of the DeNO\textsubscript{X} unit or can be set in a model-based manner on the basis of measured variables such as the temperatures of the exhaust manifold 3, pressure loss of the diesel particulate filter, air-mass flow, fuel-mass flow, engine speed and the like.

[0032] It is also possible to combine the systems shown in FIGS. 1 and 2.

[0033] The first oxidation catalyst 4 contains only so much noble metal that in the temperature range of 200° C to 300° C. there is no drop in the conversion in the SCR catalyst 6. At temperatures beneath 200° C, a large part of the conversion in the SCR catalyst 6 would thus be avoided. It would further not be possible to carry out all advantages gained from high activity of the oxidation catalyst. High activity of the oxidation catalyst has the following advantages:

[0034] Light-off commences earlier;

[0035] a complete conversion of CO and HC, even when upstream additional HC is doused for combustion in the oxidation catalyst (for increasing the temperature of the exhaust gas);

[0036] complete conversion even in case of ageing of the oxidation catalyst;

[0037] high NO\textsubscript{2} partial pressure after the storage catalyst in order to improve the combustion of exhaust particulates in the diesel particle filter;

[0038] This is counteracted in such a way however that for catalytic activity or the complete conversion of NO\textsubscript{X} in the SCR reaction, a molar ratio of NO\textsubscript{2}/NO of 1 is advantageous. Moreover, a ratio of NO\textsubscript{2}/NO=1 might lead to the formation of laughing gas (N\textsubscript{2}O) in the SCR unit. In the case of a high catalyst mass however, NO\textsubscript{2}/NO=1 is exceeded in relevant operating points, which means that too much NO\textsubscript{X} is converted into NO\textsubscript{2} in the catalyst.
Based on the described solution with two oxidation catalysts 4, 5, the use of catalytically coated diesel particulate filters (in which NO\textsubscript{2} would additionally be reproduced in a catalytic way) can be avoided because in all operating ranges the gas flowing in from the storage catalyst already has a sufficiently high NO\textsubscript{2} partial pressure.

In an uncoated diesel particulate filter 9, carbon is incinerated more or less, but not NH\textsubscript{3}, which would be the case in a catalytic diesel particulate filter). That is why as an addition an NH\textsubscript{3} or urea dosing by means of a dosing device 10 can follow before the diesel particulate filter 9, although the SCR catalyst 6 only follows after the diesel particulate filter 9. The reducing agent can thus be sprayed into a hotter exhaust gas and a longer and more complex mixing section can be realized, which thus has an advantageous effect on the dimensions of the exhaust gas system 1. The constructional combination of diesel particulate filters 9 and SCR catalyst 6 is thus possible because no intermediate section is required for dosing the reducing agent.

FIG. 4 schematically shows an internal combustion engine 101 with an exhaust manifold 102 in which an SCR catalyst 103 is disposed. A dosing device 104 for a reducing agent such as NH\textsubscript{3} or an aqueous urea solution opens into the exhaust manifold 102 upstream of the SCR catalyst 103. An NO\textsubscript{2} sensor 105 is provided downstream of the SCR catalyst 103. NO\textsubscript{2} sensors 105 of this kind are used for example in onboard diagnostic systems.

In the case of sufficient temperature of the SCR catalyst 103, reducing agent is dosed to the exhaust gas in a specific, e.g. stoichiometric, ratio to the NO\textsubscript{2} emissions of the internal combustion engine 101. The determination of the quantity of the reducing agent to be dosed occurs on the basis of a characteristic map or an exhaust model. Deviations from this characteristic map or model in real engine operations lead to increased NO\textsubscript{2} or NH\textsubscript{3} emissions after the SCR catalyst 103. The characteristic map preferably contains the NO\textsubscript{2} emissions of the internal combustion engine as a function of speed and torque or a variable proportional to torque such as the quantity of injected fuel.

In order to increase precision in the dosing of the reducing agent, an NO\textsubscript{2} sensor 105 is used according to the method proposed here, which sensor is already present downstream of the SCR catalyst 103 within the scope of an onboard diagnostic system for example. The method makes use of the fact that at temperatures of the SCR catalyst 103 beneath approx. 200° C. no reducing agent can be added because no hydrolysis and no reduction occurs. At these operating points, the NO\textsubscript{2} emissions after the SCR catalyst 103 correspond to the raw emissions when the duration of the transport of the exhaust gas between the internal combustion engine 101 and the NO\textsubscript{2} sensor 105 is also considered. In addition to the NO\textsubscript{2} emissions via the NO\textsubscript{2} sensor 105, speed and/or torque of the internal combustion engine 101 are also detected in order to evaluate whether the amount of the gradient in speed and/or torque lies beneath a predetermined maximum value. If this is the case, the range of the exhaust characteristic map (expressed for example as an interval over speed and torque) is determined in which the internal combustion engine 101 is located, and this value and the raw emissions saved there are stored in a ring buffer. If no reducing agent is injected via the dosing device 104, the NO\textsubscript{2} emissions currently measured via the NO\textsubscript{2} sensor 105 can be compared with the values stored in the ring buffer by taking transport time into account. In the case of deviations, the respective range of the characteristic map and/or the exhaust model is corrected, with only minor changes being permitted in each correction step. The correction performed per correction step must not exceed a defined permissible maximum value. In an especially simple embodiment of the method, the value of the NO\textsubscript{2} emissions calculated from the characteristic map or model is multiplied with a factor which corresponds to the deviation between emissions calculated and those determined from the characteristic map or model, by taking into account the dead time. It is especially advantageous in this respect when the correction factor(s) for the characteristic map or exhaust model are stored in a non-volatile memory so that these corrections are immediately available during the next start of the internal combustion engine.

As a result of the described simple method, the raw NO\textsubscript{2} emissions of the internal combustion engine 101 can be determined without having to install an expensive second NO\textsubscript{2} sensor. Deviations in the raw NO\textsubscript{2} emissions are independent of the current temperature of the SCR catalyst 103.

1. An exhaust system (1) for an internal combustion engine (2), comprising an exhaust manifold (3) inside which at least one exhaust aftertreatment device is disposed, at least one DeNox unit arranged downstream from a first oxidizing catalyst (4), and a second oxidation catalyst (5) is disposed upstream of the DeNox unit.

2. The exhaust system (1) according to claim 1, wherein the first and second oxidation catalyst (4, 5) are configured for different activities and/or for different temperature ranges.

3. The exhaust system (1) according to claim 1, wherein the first and second oxidation catalyst (4, 5) comprise different masses of noble metal, the second oxidation catalyst (5) having a larger mass of noble metal than the first oxidation catalyst (4).

4. The exhaust system (1) according to claim 1, wherein the first and second oxidation catalyst (4, 5) are arranged parallel with respect to each other in the exhaust manifold (3) as regards flow, with the flow through at least one oxidation catalyst (5) being adjustable by means of an actuator (7).

5. The exhaust system (1) according to claim 1, wherein a first and second oxidation catalyst (4, 5) are arranged in series in regard to flow in the exhaust manifold (3), with at least one oxidation catalyst (5) being capable of being bypassed via a bypass line (8), with an actuator (7) being arranged in the bypass line (8).

6. The exhaust system (1) according to claim 1, wherein a first and second oxidation catalyst (4, 5) are arranged in a single housing.

7. The exhaust system (1) according to claim 1, including a particulate filter (9) upstream of the DeNox unit and downstream of a dosing device (10) for reducing agents.

8. The exhaust system (1) according to claim 5, wherein the actuator (7) is adjustable in a model-based way depending on the NO\textsubscript{2} content in the exhaust gas, the temperature of the exhaust gas, the pressure loss of the diesel particulate filter (9), the air-mass flow, the fuel-mass flow, or the crankshaft speed.

9. The exhaust system (1) according to claim 8, including at least one NO\textsubscript{2} sensor downstream of the DeNox unit.

10. A method for operating an exhaust aftertreatment system for reducing the nitrogen oxide emissions of an internal combustion engine, preferably an SCR catalyst, with a sensor for determining the NO\textsubscript{2} concentration being arranged in the
exhaust manifold downstream of the exhaust aftertreatment system, and with a reducing agent or an aqueous urea solution being dosed to the exhaust gas at a stoichiometric ratio to the NOx emissions upstream of the exhaust aftertreatment system, and with the NOx emissions of the internal combustion engine being determined by means of a characteristic map of the engine or an exhaust gas model, comprising measuring NOx emissions beneath the minimum temperature of the exhaust gas and/or in operating phases where no reducing agent is added with the sensor downstream of the exhaust aftertreatment system and comparing obtained values based on the characteristic map or model, and performing a correction of the characteristic map or emission model in the case of a deviation between the measured values and those based on the characteristic map or model.

11. The method according to claim 10, wherein a correction of the characteristic map or the model only occurs when an amount of the gradient of the speed and/or torque of the internal combustion engine lies beneath a predetermined threshold value.

12. The method according to claim 11, wherein exhaust gas conveying time between the internal combustion engine and the sensor is taken into account in the comparison of the measured values of the NOx emissions with those based on the characteristic map or model.

13. The method according to claim 12, wherein the correction performed per correction step is smaller than a predefined permissible maximum value.