



US 20230038263A1

(19) **United States**(12) **Patent Application Publication**
Quinet et al.(10) **Pub. No.: US 2023/0038263 A1**(43) **Pub. Date: Feb. 9, 2023**(54) **SCR CATALYST****Publication Classification**(71) Applicant: **Umicore AG & Co. KG,**
Hanau-Wolfgang (DE)(72) Inventors: **Elodie Quinet,** Hanau (DE); **Stephan Malmberg,** Frankfurt (DE); **Nicola Soeger,** Nidderau (DE)(21) Appl. No.: **17/958,963**(22) Filed: **Oct. 3, 2022**(51) **Int. Cl.****F01N 3/20** (2006.01)**B01J 21/06** (2006.01)**B01J 23/00** (2006.01)**F01N 3/035** (2006.01)**F01N 3/10** (2006.01)(52) **U.S. Cl.****CPC** **F01N 3/2066** (2013.01); **B01J 21/063**(2013.01); **B01J 23/002** (2013.01); **F01N****3/035** (2013.01); **F01N 3/106** (2013.01); **B01J****21/08** (2013.01)**Related U.S. Application Data**

(63) Continuation of application No. 16/763,608, filed on May 13, 2020, now Pat. No. 11,492,945, filed as application No. PCT/EP2018/081077 on Nov. 13, 2018.

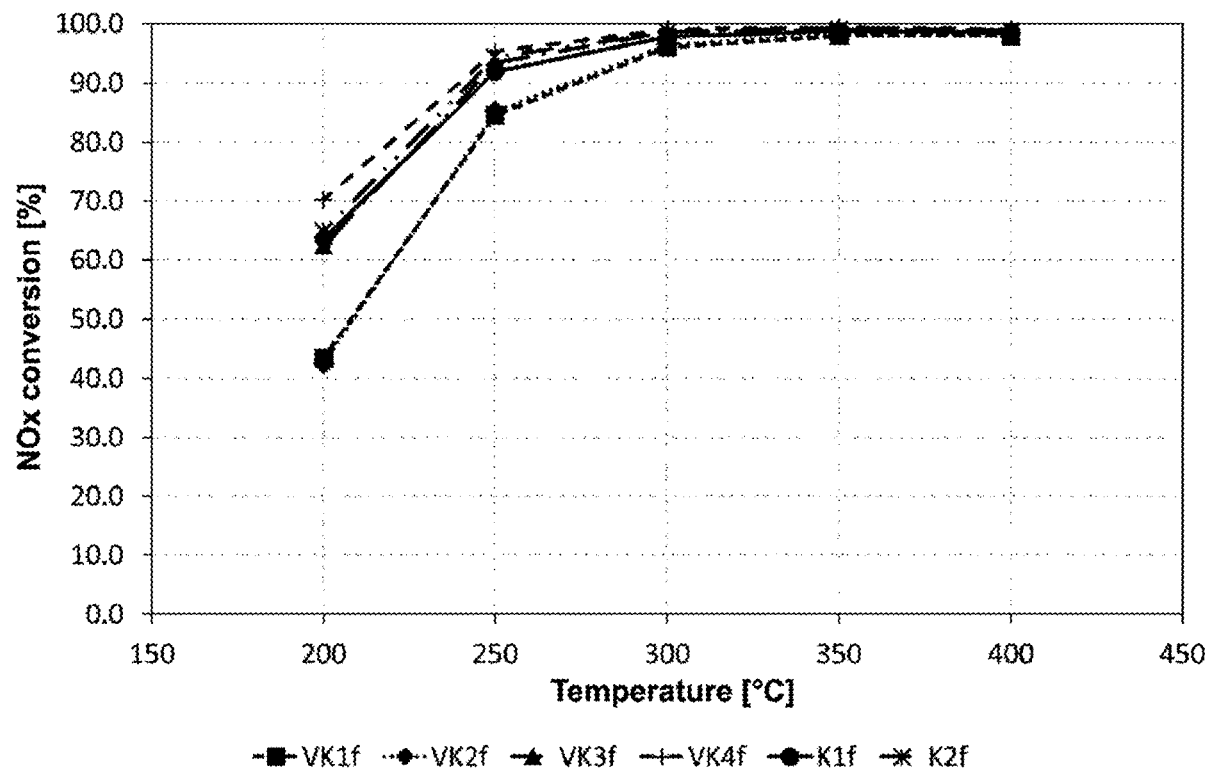
(30) **Foreign Application Priority Data**

Nov. 14, 2017 (EP) 17201482.1

(57)

ABSTRACT

The present invention relates to a catalyst comprising at least one oxide of vanadium, at least one oxide of tungsten, at least one oxide of cerium, at least one oxide of titanium and at least one oxide of niobium, and an exhaust system containing said oxides.



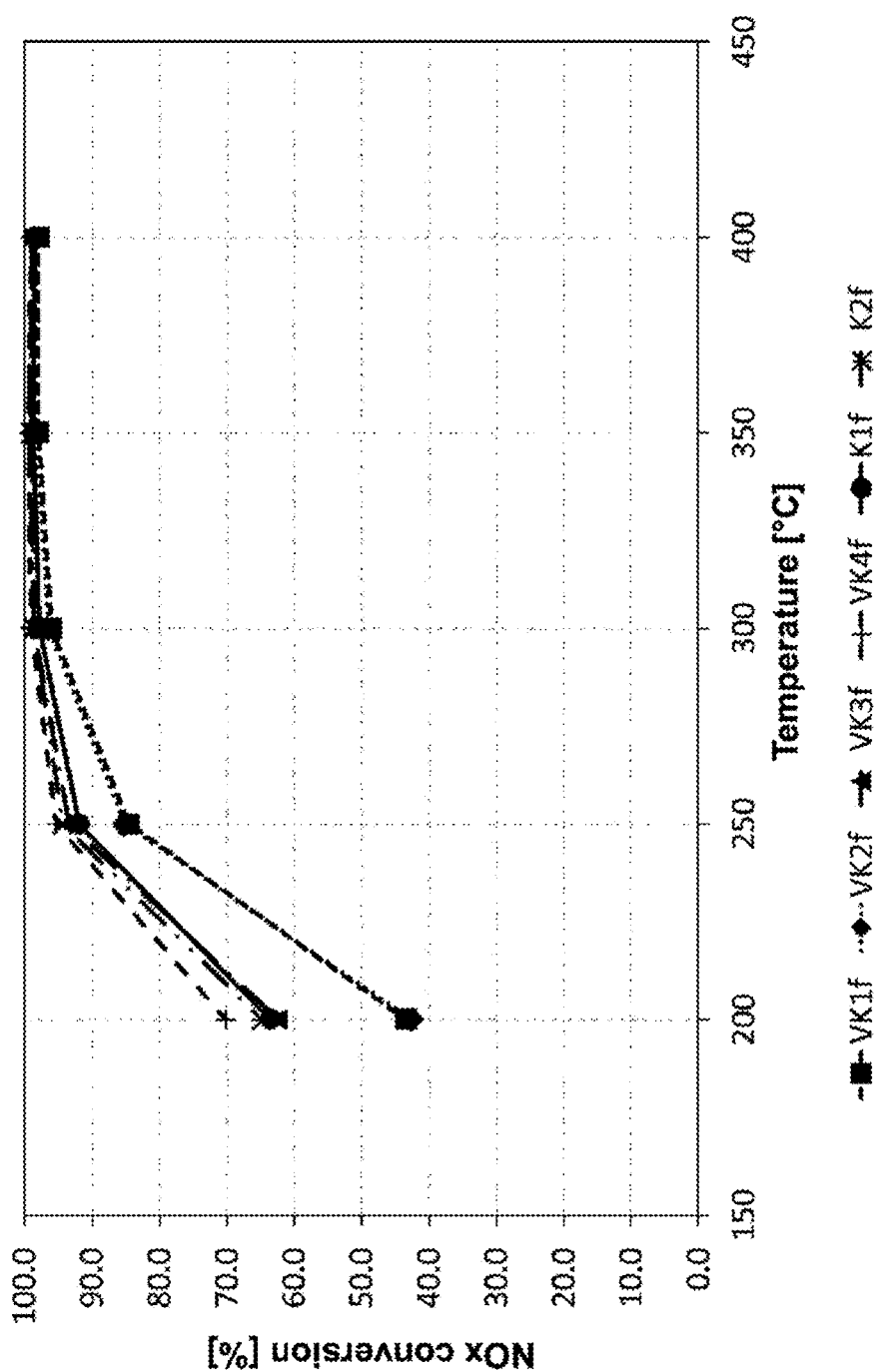


Figure 1

Figure 2

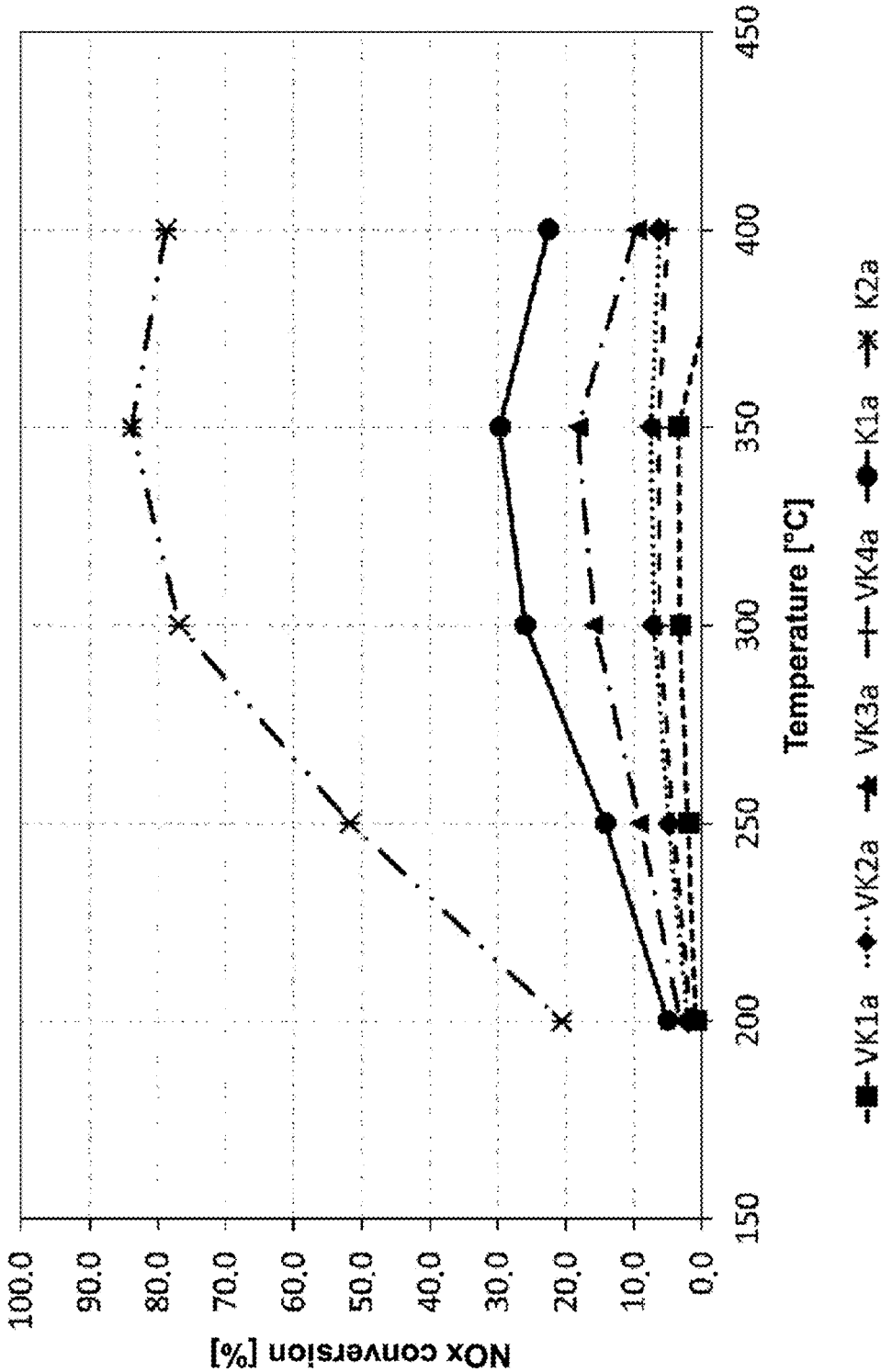


Figure 3

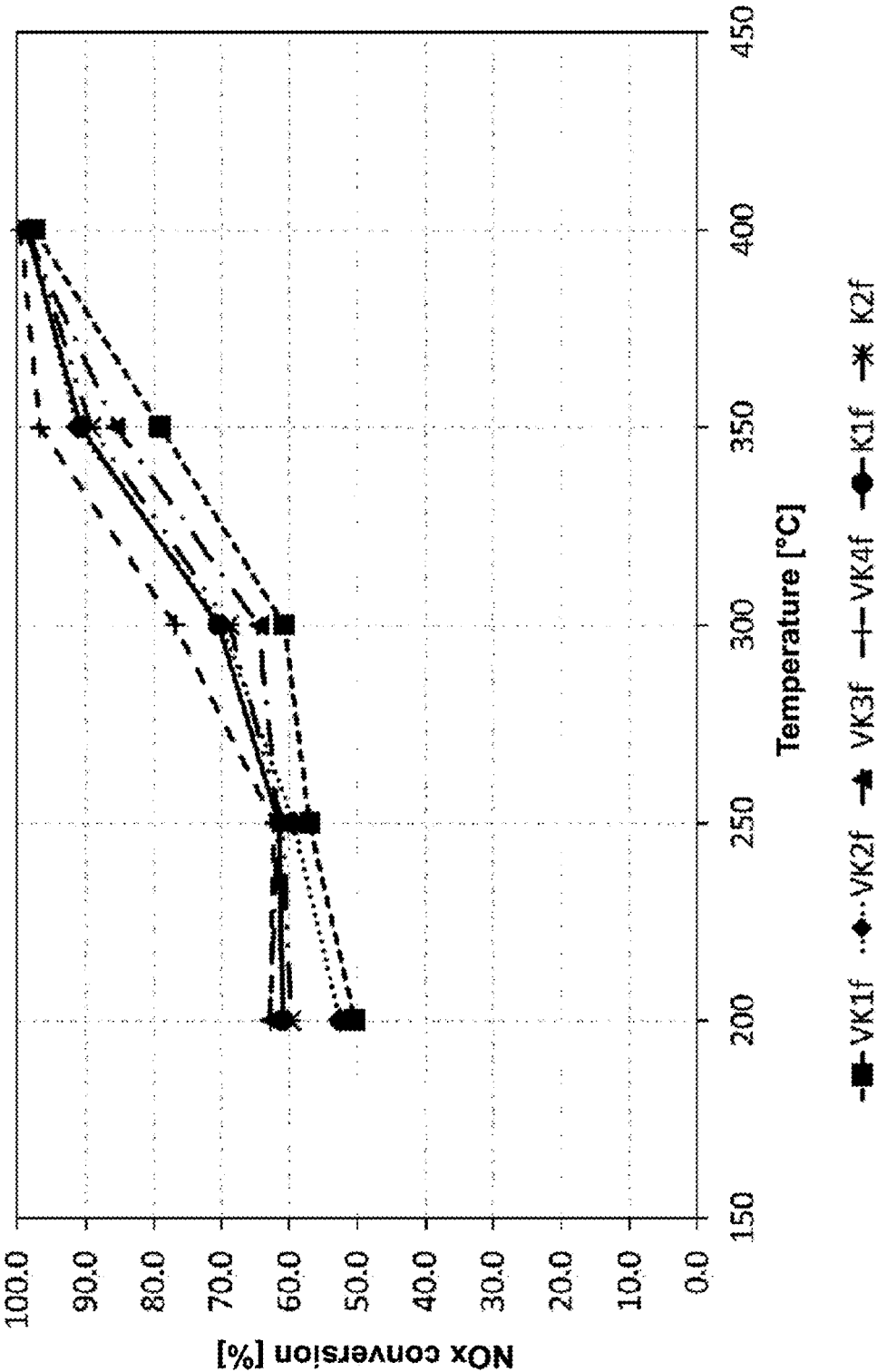


Figure 4

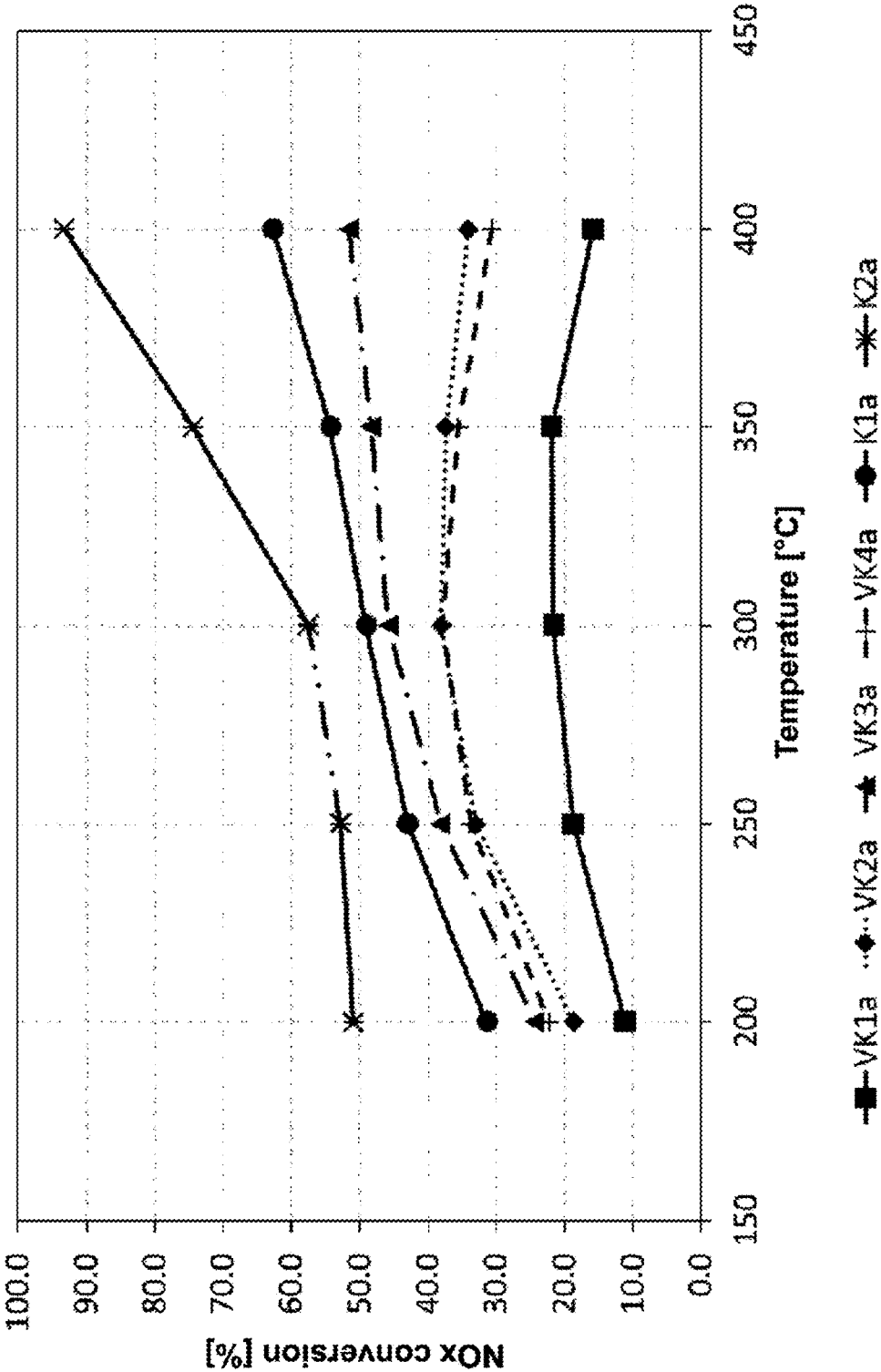
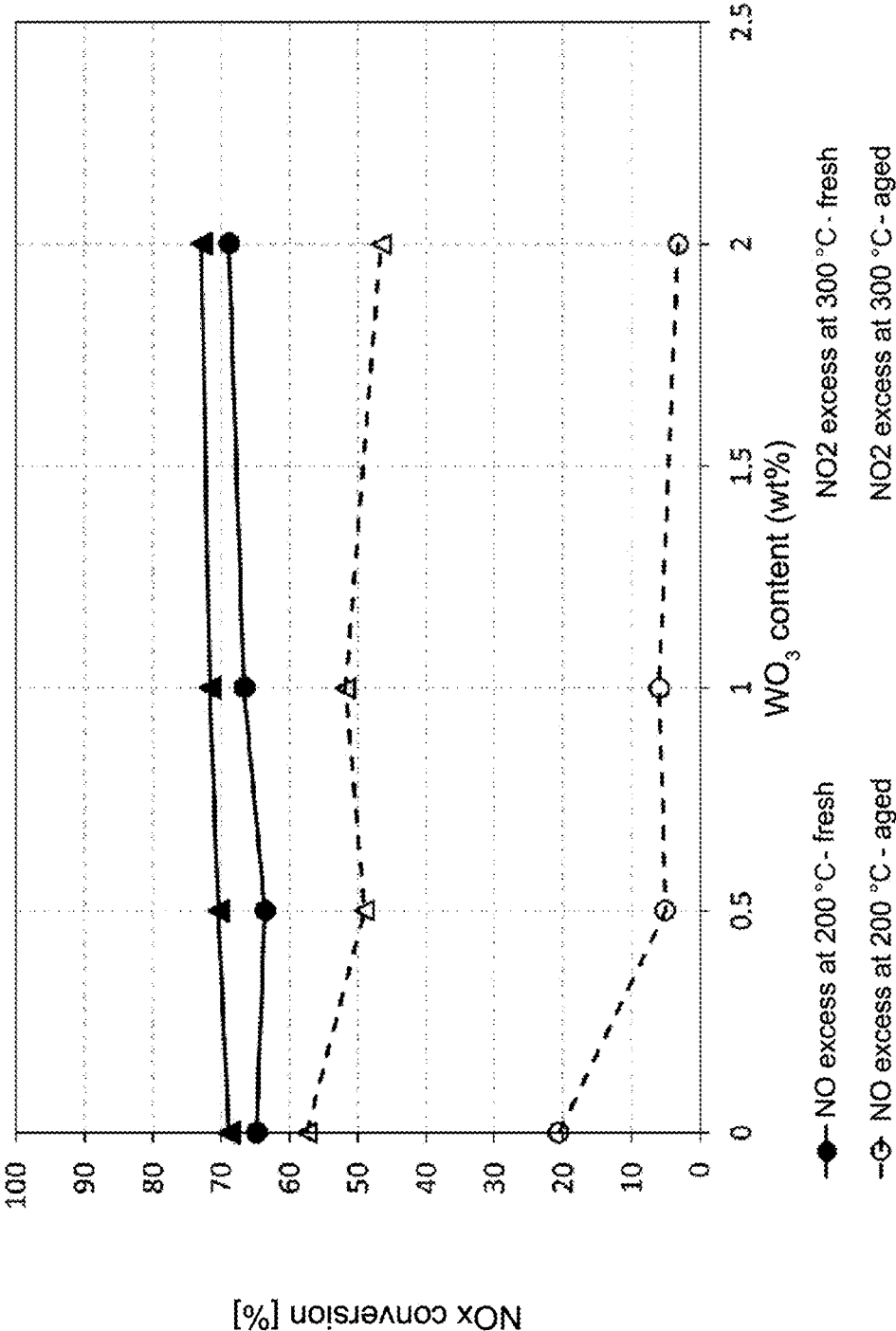


Figure 5



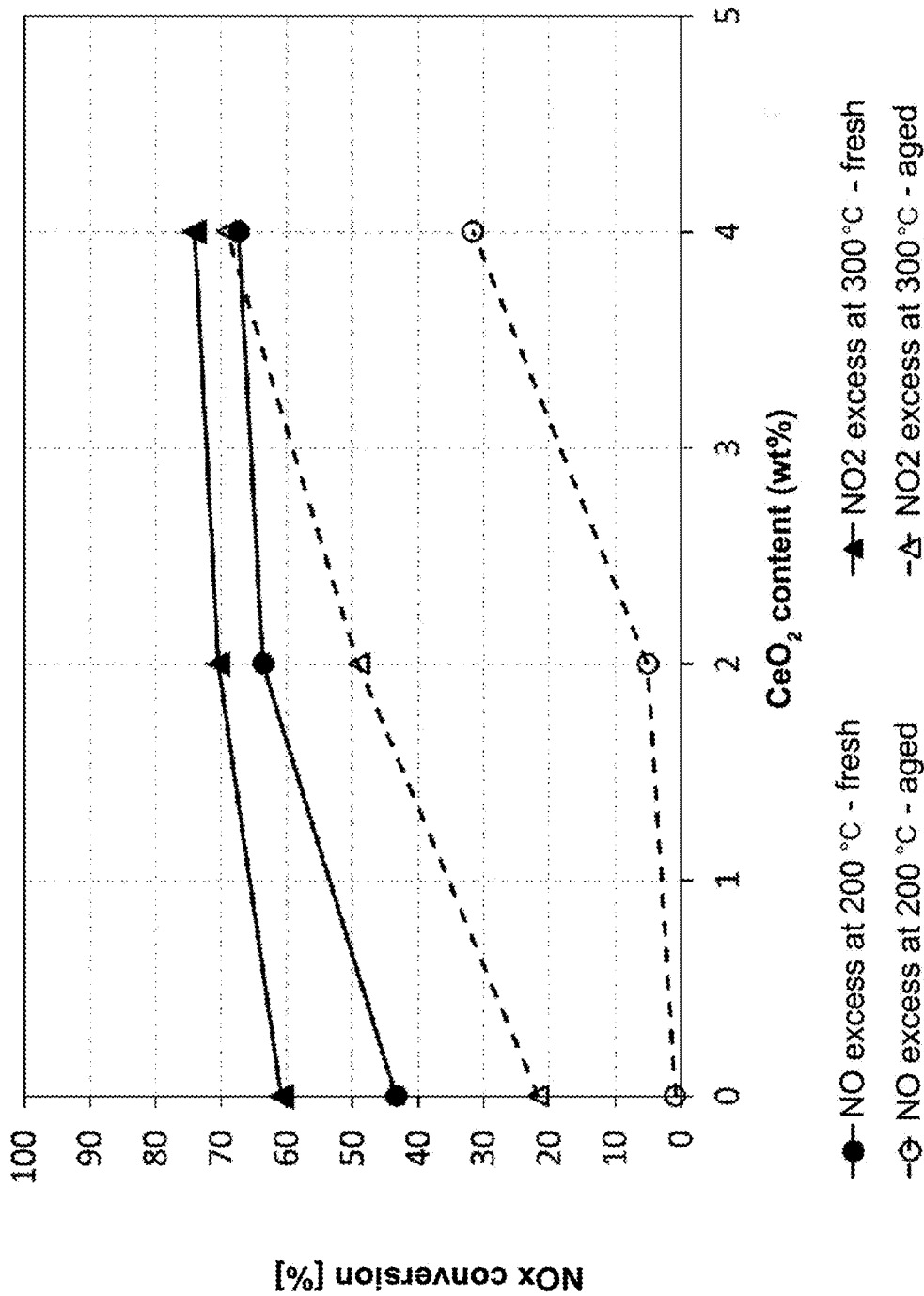
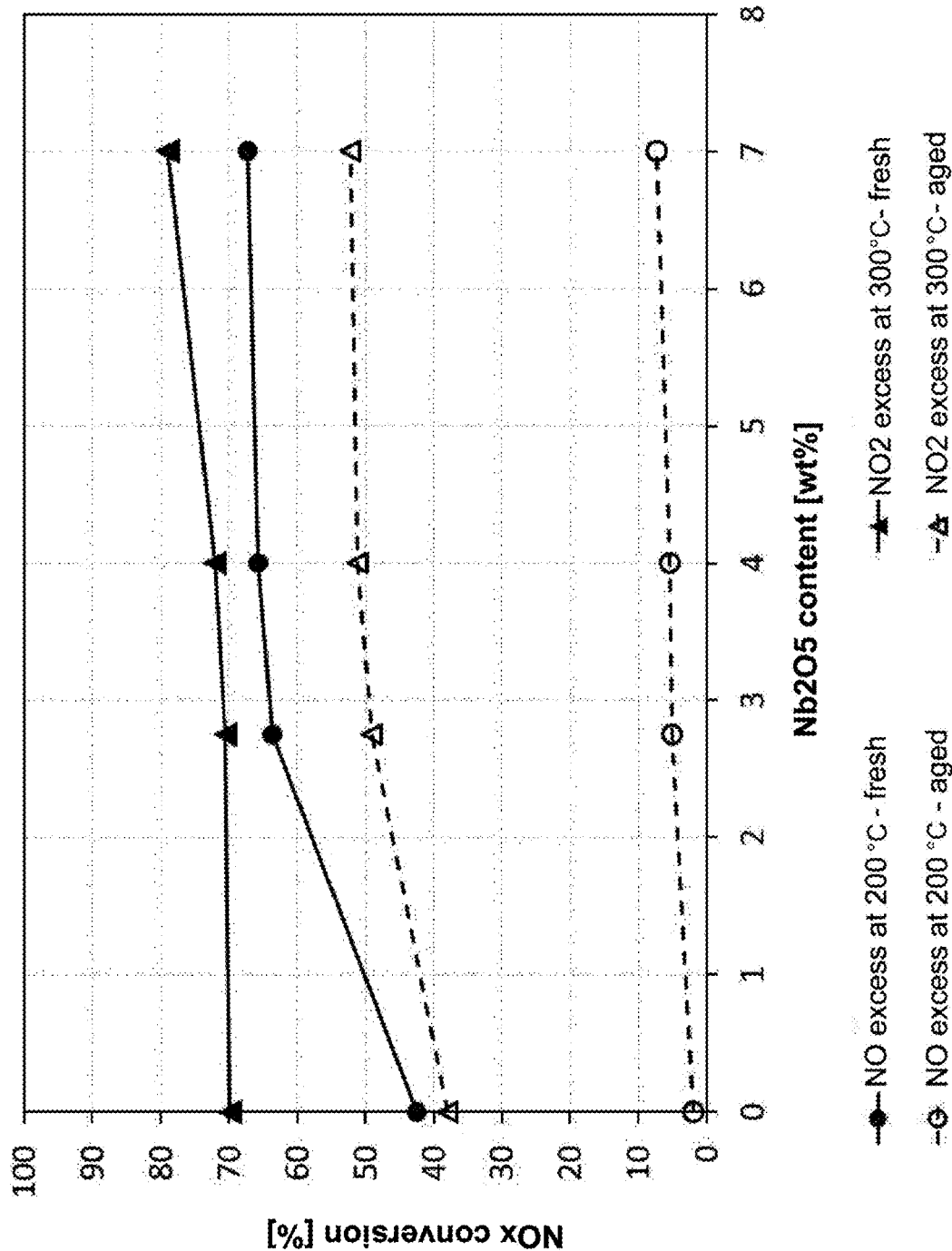


Figure 6

Figure 7



SCR CATALYST

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 16/763,608, which is a national phase entry of PCT/EP2018/081077, filed Nov. 13, 2018, which is herein incorporated by reference in its entirety, and claims priority to EP 17201482.1 filed Nov. 14, 2017.

[0002] The present invention relates to an SCR catalyst, based upon vanadium oxide, containing niobium oxide and cerium oxide.

[0003] The exhaust gas of motor vehicles that are operated with lean-burn combustion engines, such as diesel engines, also contains, in addition to carbon monoxide (CO) and nitrogen oxides (NO_x), components that result from the incomplete combustion of the fuel in the combustion chamber of the cylinder. In addition to residual hydrocarbons (HC), which are usually also predominantly present in gaseous form, these also include particle emissions. These are complex agglomerates from predominantly carbonaceous particulate matter and an adhering liquid phase, which usually preponderantly consists of longer-chained hydrocarbon condensates. The liquid phase adhering to the solid components is also referred to as "Soluble Organic Fraction SOF" or "Volatile Organic Fraction VOF."

[0004] To clean these exhaust gases, the aforementioned components must be converted to harmless compounds as completely as possible, which is only possible with the use of suitable catalysts.

[0005] A well-known process for removing nitrogen oxides from exhaust gases in the presence of oxygen is selective catalytic reduction using ammonia on a suitable catalyst (SCR process). With this process, the nitrogen oxides to be removed from the exhaust gas are converted into nitrogen and water using ammonia as a reducing agent.

[0006] The so-called "standard SCR reaction" according to equation (I)



and the so-called "fast SCR reaction" according to equation (II)



were identified as significant reaction pathways of the SCR reaction.

[0007] Since the exhaust gas from lean-burn internal combustion engines usually comprises NO₂ only in amounts of approximately 10% of the total proportion of nitrogen oxide, it is normally desired to increase its amount in order to benefit from the fast SCR reaction. This is done, for example, by means of an upstream oxidation catalytic converter. However, depending upon the exhaust system used in the specific case, an SCR catalyst may nevertheless be confronted with quite different NO₂/NO_x ratios, which may range from an excess of NO to an excess of NO₂.

[0008] The ammonia used as a reducing agent can be made available by dosing an ammonia precursor compound such as urea, ammonium carbamate, or ammonium formate into the exhaust tract, and subsequent hydrolysis.

[0009] So-called mixed oxide catalysts, which are based upon oxides of vanadium and which generally also contain oxides of titanium and of further metals, e.g., of tungsten (see Isabella Nova and Enrico Tronconi (eds.), Urea-SCR

Technology for deNO_x After Treatment of Diesel Exhausts, chapter 3, Springer Verlag, 2014), may also be used as SCR catalysts.

[0010] If the nitrogen oxide contained in the exhaust gas is present or at least predominantly present in the form of NO, SCR catalysts based upon vanadium oxide are characterized by good activity and stability. However, in the case of NO₂ excess, they show a clear loss in activity. Although the addition of cerium oxide to the vanadium oxide-based SCR catalysts improves activity in case of NO₂ excess, it also impairs low-temperature activity (T<250° C.) in case of NO excess.

[0011] Accordingly, there is a need for vanadium oxide-based SCR catalysts which have both good activity for NO₂ excess and NO excess and low temperatures (T<250° C.). Furthermore, there is also a need to improve the thermal stability of vanadium-based SCR catalysts.

[0012] It is already known to also use niobium oxide in SCR catalysts that are based upon metal oxide. For example, U.S. Pat. No. 9,555,371 discloses an SCR catalyst containing at least 91 wt % cerium oxide and 0.1 to 9 wt % niobium oxide or tantalum oxide. WO 2012/004263 A1 also describes a catalyst containing cerium oxide and 2 to 20 wt % niobium oxide. Zirconium oxide and further metal oxides may also be present.

[0013] U.S. Pat. No. 4,378,338 describes a catalyst containing titanium, vanadium, magnesium, and another metal component, which may also be niobium. US 2012/308459 describes a catalyst containing vanadium, tungsten, and titanium, as well as another component selected from molybdenum, cobalt, and niobium.

[0014] Finally, WO 2011/032020 A2 discloses an SCR catalyst having a carrier layer and a catalytic layer. While the carrier layer contains, for example, TiO₂, Al₂O₃, SiO₂, TiO₂—Al₂O₃, TiO₂—SiO₂, CeO₂, Al₂O₃—SiO₂, or TiO₂—Al₂O₃—SiO₂, the catalytic layer may also contain niobium.

[0015] It has now surprisingly been found that, starting from vanadium oxide-based SCR catalysts containing cerium oxide, the above-mentioned technical problem can be solved by adding an oxide of niobium to the catalyst.

[0016] The present invention thus relates to a catalyst containing

[0017] at least one oxide of vanadium in an amount of 2 to 6 wt %,

[0018] at least one oxide of cerium in an amount of 2 to 4 wt %,

[0019] at least one oxide of niobium in an amount of 1 to 7 wt %, and

[0020] at least one oxide of titanium in an amount measured so as to result in a total of 100 wt %,

[0021] in each case relative to the total weight of the catalyst and calculated as V₂O₅, CeO₂, Nb₂O₅ or TiO₂.

[0022] Here, the at least one oxide of titanium acts as carrier material, the at least one oxide of vanadium as active catalyst component, and the at least one of the oxides of tungsten, of cerium, and of niobium as promoters. Promoters are understood to mean substances which maintain or increase the activity of a catalyst.

[0023] In one embodiment of the catalyst according to the invention, it additionally contains at least one oxide of silicon.

[0024] In a further embodiment, the catalyst according to the invention further contains at least one oxide of tungsten

in an amount of 0.001 to 2 wt %. A catalyst according to the invention containing at least one oxide of tungsten thus has the composition of

- [0025] at least one oxide of vanadium in an amount of 2 to 6 wt %,
 - [0026] at least one oxide of tungsten in an amount of 0.001 to 2 wt %,
 - [0027] at least one oxide of cerium in an amount of 2 to 4 wt %,
 - [0028] at least one oxide of niobium in an amount of 1 to 7 wt %, and
 - [0029] at least one oxide of titanium in an amount measured so as to result in a total of 100 wt %,
- [0030] in each case relative to the total weight of the catalyst and calculated as V_2O_5 , WO_3 , CeO_2 , Nb_2O_5 or TiO_2 .
- [0031] In further embodiments of the catalyst according to the invention, it additionally contains at least one oxide of molybdenum, antimony, zirconium, tantalum, and/or hafnium.
- [0032] In preferred embodiments of the catalyst according to the invention, it contains at least one oxide of cerium in an amount of 2 to 4 wt %, relative to the weight of the catalyst and calculated as CeO_2 . In further preferred embodiments of the catalyst according to the invention, it contains at least one oxide of niobium in an amount of 1 to 7 wt %, relative to the weight of the catalyst and calculated as Nb_2O_5 . In addition, preference is given to embodiments of the catalyst according to the invention containing at least one oxide of cerium in an amount of 2 to 4 wt % and calculated as CeO_2 , and at least one oxide of niobium in amounts of 1 to 7 wt %, in each case based on the weight of the catalyst and calculated as Nb_2O_5 .
- [0033] In further preferred embodiments of the catalyst according to the invention, it contains
- [0034] at least one oxide of vanadium in an amount of 2 to 6 wt %,
 - [0035] at least one oxide of tungsten in an amount of 0.5 to 2 wt %,
 - [0036] at least one oxide of cerium in an amount of 2 to 4 wt %,
 - [0037] at least one oxide of niobium in an amount of 1 to 7 wt %, and
 - [0038] at least one oxide of titanium in an amount measured so as to result in a total of 100 wt %,
- [0039] in each case based on the weight of the catalyst and calculated as V_2O_5 , WO_3 , CeO_2 or Nb_2O_5 .
- [0040] If the catalyst according to the invention contains at least one oxide of silicon, it is preferably present in amounts of 2 to 7 wt %, based the weight of the catalyst and calculated as SiO_2 .
- [0041] If the catalyst according to the invention comprises at least one oxide of molybdenum, antimony, zirconium, tantalum, and/or hafnium, then the total amount of these oxides is preferably 0.5 to 20 wt %, based on the weight of the catalyst and calculated as MoO_3 , Sb_2O_5 , ZrO_2 , Ta_2O_5 or HfO_2 .
- [0042] The catalyst according to the invention is preferably free of magnesium or compounds of magnesium.
- [0043] In further embodiments, the catalyst according to the invention is also free of zirconium or compounds of zirconium.
- [0044] Within the context of the present invention, the term oxide of vanadium, comprises all oxides which arise or

may be present under the conditions of the preparation, storage, and use of the catalyst according to the invention. It thus comprises, for example, V_2O_5 , but also all other oxides of vanadium.

[0045] Analogously, the term oxide of tungsten, comprises, for example, WO_3 , but also all other oxides of tungsten, the term oxide of cerium comprises, for example, CeO_2 , but also all other oxides of cerium, the term oxide of niobium comprises, for example, Nb_2O_5 , but also all other oxides of niobium, the term oxide of titanium comprises, for example, TiO_2 , but also all other oxides of titanium, and oxide of silicon comprises, for example, SiO_2 , but also all other oxides of silicon. The same applies to the terms oxide of molybdenum, antimony, zirconium, tantalum, and hafnium.

[0046] The catalyst according to the invention can be produced in a simple manner. Thus, for example, oxides of vanadium, tungsten, cerium, niobium, and titanium, and, optionally, of the further metal oxides, may be closely mixed in powder form in the desired amounts and then calcined. However, it is generally advantageous for the aforementioned oxides to be slurried in water and then dried and calcined.

[0047] In one variant of this method, only a portion of the metal oxides as such is initially charged, while the remaining metals are added in the form of water-soluble metal salts. For example, oxides of tungsten, cerium, niobium, and titanium can be initially charged, and then impregnated with the aqueous solution of a water-soluble vanadium compound and subsequently dried and calcined. Suitable water-soluble vanadium compounds are, in particular, vanadyl oxalate, which can be obtained by dissolving vanadium pentoxide in oxalic acid (see, for example, EP 0 345 695 A2) or reaction products of vanadium pentoxide with amines or ethanalamines (see, for example, WO89/03366 A1 and WO2011/013006)—especially, ammonium metavanadate. DE 11 2007 000 814 T5 also describes the use of vanadium oxytrichloride.

[0048] Alternatively, oxides of vanadium, cerium, niobium, and titanium can also be initially charged, and then impregnated with the aqueous solution of a water-soluble tungsten compound and subsequently dried and calcined. A suitable water-soluble tungsten compound for this purpose is ammonium metatungstate.

[0049] Instead of using the individual oxides, one may also use two or more metal oxides also in the form of the corresponding mixed oxides or in the form of metal oxides doped with one or more other metal oxides. For example, a titanium dioxide doped with silicon dioxide and tungsten trioxide may be impregnated with water-soluble compounds of vanadium and niobium and then dried and calcined.

[0050] Depending in particular upon the production method, the catalyst according to the invention may be present as a mixture of metal oxides, as mixed oxide, but, in particular, in the form of intermediates between a mixture of metal oxides and mixed oxide. For example, two or three metals may be present in the form of a mixed oxide impregnated with the remaining metals.

[0051] The starting compounds required for preparing the catalyst according to the invention, such as metal oxides, mixed oxides, or water-soluble metal salts, are known to the person skilled in the art and are commercially available.

[0052] In preferred embodiments, the catalyst according to the invention is present as a coating on a carrier body, which may be present as a flow-through honeycomb body or wall flow filter.

[0053] In embodiments of the present invention, the carrier body is catalytically inert and consists of ceramic or metallic material—for example, silicon carbide, aluminum titanate, or cordierite. In these embodiments, all components of the catalyst according to the invention are present in one coating.

[0054] Coated carrier bodies can be produced according to methods familiar to the person skilled in the art, e.g., according to common dip coating methods or pump and suction coating methods with subsequent thermal post-treatment (calcination).

[0055] In another embodiment of the present invention, the catalyst according to the invention itself is a component of the carrier body, which in this case is formed from the catalyst according to the invention and a matrix component.

[0056] Carrier bodies, flow-through substrates, and wall flow substrates, which do not just consist of inert material, such as cordierite, but additionally contain a catalytically-active material, are known to the person skilled in the art. To produce them, a mixture consisting of, for example, 10 to 95 wt % of an inert matrix component and 5 to 90 wt % of catalytically-active material is extruded according to a method known per se. All of the inert materials that are also otherwise used to produce catalyst substrates can be used as matrix components in this case. These are, for example, silicates, oxides, nitrides, or carbides, wherein, in particular, magnesium aluminum silicates are preferred.

[0057] The catalyst according to the invention is particularly well suited to the reduction of nitrogen oxides in exhaust gases of lean-burn internal combustion engines—in particular, diesel engines.

[0058] The present invention, therefore, also relates to a method for the reduction of nitrogen oxides in exhaust gases of lean-burn internal combustion engines, comprising the following method steps:

[0059] adding a reducing agent to the exhaust-gas-containing nitrogen oxides, and

[0060] passing the resulting mixture from the exhaust-gas-containing nitrogen oxides and reducing agent over a catalyst according to the invention.

[0061] As a reducing agent, ammonia comes especially into consideration, whereby, with particular advantage, not ammonia itself, but an ammonia precursor—in particular, urea—is added to the nitrogen oxide containing exhaust gas.

[0062] In particular, the catalyst according to the invention is used as a component of an exhaust gas purification system which, for example, comprises an oxidation catalyst and a diesel particle filter arranged on the inflow side, in addition to the catalyst according to the invention. In so doing, the catalyst according to the invention can also be present as a coating on the diesel particle filter.

[0063] The present invention therefore relates also to an exhaust gas cleaning system for treating diesel exhaust gas, comprising, in the flow direction of the exhaust gas,

[0064] an oxidation catalyst,

[0065] a diesel particle filter, and

[0066] a catalyst according to the invention,

or

[0067] an oxidation catalyst, and

[0068] a diesel particle filter on which a catalyst according to the invention is present as a coating.

[0069] Oxidation catalysts suitable for the exhaust gas cleaning system according to the invention—in particular, platinum, palladium, or platinum and palladium carried on, for example, aluminum oxide—and diesel particle filters are known to the person skilled in the art and are commercially available.

[0070] The exhaust gas purification system of the present invention generally comprises a device for metering in the reducing agent that is arranged upstream of the catalyst according to the invention.

[0071] The injection device can be chosen at will by the person skilled in the art, wherein suitable devices can be taken from the literature (see, for example, T. Mayer, Feststoff-SCR-System auf Basis von Ammonium-carbamat, Dissertation, TU Kaiserslautern, 2005). The reducing agent introduced into the exhaust gas stream via the injection device may be, in particular, ammonia as such or in the form of a compound from which ammonia is formed under the ambient conditions. Examples of suitable compounds are aqueous solutions of urea or ammonium formate, as well as solid ammonium carbamate. As a rule, the reducing agent or a precursor thereof is kept in stock in a container that is carried along with and connected to the injection device.

[0072] The invention is explained below in more detail by means of figures and examples. The following are shown:

[0073] FIG. 1: Nitrogen oxide conversions in the standard SCR reaction, measured at catalysts K1 and K2 according to the present invention in comparison to the comparative catalysts VK1, VK2, VK3, and VK4 in the fresh state (K1f, K2f, VK1f, VK2f, VK3f, VK4f).

[0074] FIG. 2: Nitrogen oxide conversions in the standard SCR reaction, measured at catalysts K1 and K2 according to the present invention in comparison to the comparative catalysts VK1, VK2, VK3, and VK4 in the aged state (K1a, K2a, VK1a, VK2a, VK3a, VK4a).

[0075] FIG. 3: Nitrogen oxide conversions in the fast SCR reaction, measured at catalysts K1 and K2 according to the present invention in comparison to the comparative catalysts VK1, VK2, VK3, and VK4 in the fresh state (K1f, K2f, VK1f, VK2f, VK3f, and VK4f).

[0076] FIG. 4: Nitrogen oxide conversions in the fast SCR reaction, measured at catalyst K1 and K2 according to the present invention in comparison to the comparative catalysts VK1, VK2, VK3, and VK4 in the aged state (K1a, K2a, VK1a, VK2a, VK3a, VK4a).

[0077] FIG. 5: Nitrogen oxide conversions in the standard SCR reaction at 200° C. and fast SCR reaction at 300° C. versus the WO₃ content, measured at catalysts K1 and K2 according to the present invention in comparison to the comparative catalysts VK5 and VK6 in the fresh and aged states.

[0078] FIG. 6: Nitrogen oxide conversions in the standard SCR reaction at 200° C. and fast SCR reaction at 300° C. versus the CeO₂ content, measured at catalyst K1 according to the present invention in comparison to the comparative catalysts VK3 and VK7 in the fresh and aged states.

[0079] FIG. 7: Nitrogen oxide conversions in the standard SCR reaction at 200° C. and fast SCR reaction at 300° C. versus the Nb₂O₅ content, measured at catalyst K1 according to the present invention in comparison to the comparative catalysts VK2, VK8, and VK9 in the fresh and aged states.

EXAMPLE 1

[0080] a) A commercially available titanium dioxide in the anatase form doped with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2), tungsten trioxide (WO_3), cerium dioxide (CeO_2), and ammonium niobium oxalate were added in amounts so as to result in a catalyst of the composition 85.98 wt % TiO_2 , 4.53 wt % SiO_2 , 3.75 wt % V_2O_5 , 1.00 wt % WO_3 , 2.00 wt % CeO_2 , and 2.75 wt % Nb_2O_5 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0081] b) The dispersion obtained according to a) was coated in a conventional manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. The powder thus obtained was dried at 90° C. and then calcined at 600° C. for 2 hours. The catalyst K1 thus obtained is present in the fresh state and is therefore referred to hereinafter as K1f.

[0082] c) The catalyst K1 obtained according to b) was subjected to hydrothermal aging for 48 hours in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. Catalyst K1 is then present in the aged state and is referred to hereinafter as K1a.

EXAMPLE 2

[0083] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2), cerium dioxide (CeO_2), and ammonium niobium oxalate were added in amounts so as to result in a catalyst of the composition 86.93 wt % TiO_2 , 4.58 wt % SiO_2 , 3.75 wt % V_2O_5 , 2.00 wt % CeO_2 , and 2.75 wt % Nb_2O_5 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0084] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst K2 thus obtained is present in the fresh state and is therefore referred to hereinafter as K2f.

[0085] c) Catalyst K2 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst K2 is then present in the aged state and is referred to hereinafter as K2a.

Comparative Example 1

[0086] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2) and tungsten trioxide (WO_3) were added in amounts so as to result in a catalyst of the composition 90.49 wt % TiO_2 , 4.76 wt % SiO_2 , 3.75 wt % V_2O_5 , 1.00 wt % WO_3 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0087] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a

cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK1 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK1f.

[0088] c) Catalyst VK1 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst VK1 is then present in the aged state and is referred to hereinafter as VK1a.

Comparative Example 2

[0089] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2), tungsten trioxide (WO_3), and cerium dioxide (CeO_2) were added in amounts so as to result in a catalyst of the composition 88.59 wt % TiO_2 , 4.66 wt % SiO_2 , 3.75 wt % V_2O_5 , 1.00 wt % WO_3 , and 2.00 wt % CeO_2 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0090] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK2 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK2f.

[0091] c) Catalyst VK2 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst VK2 is then present in the aged state and is referred to hereinafter as VK2a.

Comparative Example 3

[0092] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2), tungsten trioxide (WO_3), and ammonium niobium oxalate were added in amounts such as to result in a catalyst of the composition 87.88 wt % TiO_2 , 4.63 wt % SiO_2 , 3.75 wt % V_2O_5 , 1.00 wt % WO_3 , and 2.75 wt % Nb_2O_5 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0093] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK3 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK3f.

[0094] c) Catalyst VK3 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst VK3 is then present in the aged state and is referred to hereinafter as VK3a.

Comparative Example 4

[0095] a) A commercially available titanium dioxide in the anatase form was dispersed in water, and then vanadium dioxide (VO_2), tungsten trioxide (WO_3), cerium dioxide (CeO_2), and ammonium niobium oxalate were added in amounts so as to result in a catalyst of the composition 90.50 wt % TiO_2 , 3.75 wt % V_2O_5 , 1.00 wt % WO_3 , 2.00 wt % CeO_2 , and 2.75 wt % Nb_2O_5 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0096] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK4 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK4f.

[0097] c) Catalyst VK4 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst VK4 is then present in the aged state and is referred to hereinafter as VK4a.

Comparative Example 5

[0098] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2), tungsten trioxide (WO_3), cerium dioxide (CeO_2), and ammonium niobium oxalate were added in amounts so as to result in a catalyst of the composition 86.45 wt % TiO_2 , 4.55 wt % SiO_2 , 3.75 wt % V_2O_5 , 0.50 wt % WO_3 , 2.00 wt % CeO_2 , and 2.75 wt % Nb_2O_5 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0099] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK5 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK5f.

[0100] c) Catalyst VK5 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst VK5 is then present in the aged state and is referred to hereinafter as VK5a.

Comparative Example 6

[0101] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2), tungsten trioxide (WO_3), cerium dioxide (CeO_2), and ammonium niobium oxalate were added in amounts so as to result in a catalyst of the composition 85.03 wt % TiO_2 , 4.48 wt % SiO_2 , 3.75 wt % V_2O_5 , 2.00 wt % WO_3 , 2.00 wt % CeO_2 , and 2.75 wt % Nb_2O_5 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0102] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK6 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK6f.

[0103] c) Catalyst VK6 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst VK6 is then present in the aged state and is referred to hereinafter as VK6a.

Comparative Example 7

[0104] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2), tungsten trioxide (WO_3), cerium dioxide (CeO_2), and ammonium niobium oxalate were added in amounts so as to result in a catalyst of the composition 84.08 wt % TiO_2 , 4.43 wt % SiO_2 , 3.75 wt % V_2O_5 , 1.00 wt % WO_3 , 4.00 wt % CeO_2 , and 2.75 wt % Nb_2O_5 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0105] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK7 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK7f.

[0106] c) Catalyst VK7 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst VK7 is then present in the aged state and is referred to hereinafter as VK7a.

Comparative Example 8

[0107] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO_2), tungsten trioxide (WO_3), cerium dioxide (CeO_2), and ammonium niobium oxalate were added in amounts so as to result in a catalyst of the composition 84.79 wt % TiO_2 , 4.46 wt % SiO_2 , 3.75 wt % V_2O_5 , 1.00 wt % WO_3 , 2.00 wt % CeO_2 , and 4.00 wt % Nb_2O_5 . The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0108] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK8 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK8f.

[0109] c) Catalyst VK8 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O_2 , 10% H_2O , remainder N_2) at 700° C. for 48 hours. Catalyst VK8 is then present in the aged state and is referred to hereinafter as VK8a.

Comparative Example 9

[0110] a) A commercially available titanium dioxide in the anatase form stabilized with 5 wt % silicon dioxide was dispersed in water, and then vanadium dioxide (VO₂), tungsten trioxide (WO₃), cerium dioxide (CeO₂), and ammonium niobium oxalate were added in amounts so as to result in a catalyst of the composition 81.94 wt % TiO₂, 4.31 wt % SiO₂, 3.75 wt % V₂O₅, 1.00 wt % WO₃, 2.00 wt % CeO₂, and 7.00 wt % Nb₂O₅. The mixture was vigorously stirred and then milled in a commercially available agitator bead mill.

[0111] b) The dispersion obtained according to a) was coated in a customary manner onto a commercially available ceramic flow substrate with a volume of 0.5 L and a cell number of 62 cells per square centimeter at a wall thickness of 0.17 mm over its entire length, with a washcoat loading of 360 g/L. It was then dried at 90° C. and calcined at 600° C. for 2 hours. Catalyst VK9 thus obtained is present in the fresh state and is therefore referred to hereinafter as VK9f.

[0112] c) Catalyst VK9 obtained according to b) was subjected to hydrothermal aging in a gas atmosphere (10% O₂, 10% H₂O, remainder N₂) at 700° C. for 48 hours. Catalyst VK9 is then present in the aged state and is referred to hereinafter as VK9a.

[0113] Table 1 summarizes the compositions of the catalysts of the examples mentioned. The composition of the catalyst according to the invention is not limited to explicitly shown examples.

TABLE 1

Compositions of the Catalysts of the Examples						
Composition						
Example	V ₂ O ₅ (wt %)	WO ₃ (wt %)	CeO ₂ (wt %)	Nb ₂ O ₅ (wt %)	SiO ₂ (wt %)	TiO ₂ (wt %)
K1	3.75	1.00	2.00	2.75	4.53	85.98
K2	3.75		2.00	2.75	4.58	86.93
VK1	3.75	1.00			4.76	90.49
VK2	3.75	1.00	2.00		4.66	88.59
VK3	3.75	1.00		2.75	4.63	87.88
VK4	3.75	1.00	2.00	2.75		90.50
VK5	3.75	0.50	2.00	2.75	4.55	86.45
VK6	3.75	2.00	2.00	2.75	4.48	85.03
VK7	3.75	1.00	4.00	2.75	4.43	84.07
VK8	3.75	1.00	2.00	4.00	4.46	84.79
VK9	3.75	1.00	2.00	7.00	4.31	81.94

Nitrogen Oxide Conversion Assay as a Measure of Scr Activity

[0114] The NO conversions of the catalysts and comparative catalysts prepared according to the examples and comparative examples described above were determined in a quartz glass reactor. Drill cores with L=3" and D=1" were tested between 200 and 400° C. under steady-state conditions. Testing was carried out in a laboratory model gas system under the following conditions.

Composition of the model gas		
	Standard SCR reaction	Fast SCR reaction
NO _x [vol. ppm]:	1,000	1,000
NO ₂ /NO _x [%]:	0	75
NH ₃ [vol. ppm]:	1,100	1,350
O ₂ [vol %]:	10	10
H ₂ O [vol %]:	5	5
N ₂ :	Remainder	Remainder
General test conditions		
Space velocity [h ⁻¹]:	60,000	
Temperature [° C.]:	200; 250; 300; 350; 400	
Conditioning before start of measurement:	Model gas atmosphere; 550° C.; several minutes	

[0115] During measurement, the nitrogen oxide concentrations of the model gas after flowing through the catalyst were recorded using a suitable analysis method. From the known, dosed nitrogen oxide contents that were verified during conditioning at the beginning of the respective test flow with a pre-catalyst exhaust gas analysis, and the nitrogen oxide conversion contents measured after flowing through the catalyst, the nitrogen oxide conversion, relative to the ratio of NH₃ to NO, over the catalyst was calculated for each temperature measuring point as follows:

$$U_{NO_x} [\%] = \left(1 - \frac{C_{output}(NO_x)}{C_{input}(NO_x)} \right) \times 100$$

with

$$C_{input/output}(NO_x) = C_{input/output}(NO) + C_{input/output}(N_2O) + C_{input/output}(N_2O_2)$$

[0116] The resulting nitrogen oxide conversion values $U_{NO_x} [\%]$ were plotted as a function of the temperature measured before to the catalyst, in order to evaluate the SCR activity of the investigated materials.

[0117] Table 2 shows the NO_x conversion in the standard SCR reaction for the examples described above.

TABLE 2

NO _x Conversion in the Standard SCR Reaction										
Nitrogen oxide conversion (%) in standard SCR reaction										
fresh					after hydrothermal aging at 700° C. for 48 h					
	400° C.	350° C.	300° C.	250° C.	200° C.	400° C.	350° C.	300° C.	250° C.	200° C.
K1	98.54	98.78	97.82	91.93	63.64	22.57	29.70	25.94	14.31	5.09
K2	98.78	99.07	98.59	94.36	64.88	78.75	83.91	76.95	51.79	20.65
VK1	97.88	97.98	96.05	84.57	43.45	-3.39	3.43	3.20	2.00	0.91
VK2	98.34	98.28	96.47	85.23	42.56	6.33	7.43	7.15	4.89	2.03
VK3	98.90	99.25	98.55	93.35	62.44	9.62	18.23	15.89	9.17	3.14

TABLE 2-continued

NOx Conversion in the Standard SCR Reaction										
Nitrogen oxide conversion (%) in standard SCR reaction										
fresh					after hydrothermal aging at 700° C. for 48 h					
400° C.	350° C.	300° C.	250° C.	200° C.	400° C.	350° C.	300° C.	250° C.	200° C.	
VK4	98.95	99.39	98.97	95.29	70.15	5.07	6.35	6.30	4.19	1.60
VK5	99.06	99.37	98.87	94.82	66.63	26.39	34.77	30.01	16.70	6.03
VK6	99.46	99.69	99.40	96.20	68.88	12.37	18.49	16.43	9.47	3.22
VK7	98.81	99.21	98.54	93.89	67.28	93.78	95.09	97.77	72.47	31.61
VK8	98.99	99.35	98.76	93.80	65.65	24.57	30.70	27.26	15.09	5.39
VK9	98.94	99.40	98.95	94.38	67.22	36.05	41.96	37.18	20.49	7.30

[0118] The results of the standard SCR reaction of the fresh catalysts are shown in FIG. 1.

[0119] The results of the standard SCR reaction of the aged catalysts are shown in FIG. 2.

[0120] Table 3 shows the NOx conversion in the fast SCR reaction for the examples described above.

TABLE 3

NOx Conversion in the Fast SCR Reaction										
Nitrogen oxide conversion (%) in fast SCR reaction										
fresh					after hydrothermal aging at 700° C. for 48 h					
400° C.	350° C.	300° C.	250° C.	200° C.	400° C.	350° C.	300° C.	250° C.	200° C.	
K1	98.61	90.75	70.50	61.59	60.92	62.69	54.34	49.10	43.04	31.35
K2	98.32	89.15	68.88	61.01	59.82	93.29	74.46	57.47	52.83	50.97
VK1	97.55	79.12	60.80	57.07	50.40	15.90	21.91	21.69	18.71	11.21
VK2	98.38	91.22	69.91	59.35	52.61	34.02	37.31	38.09	32.95	18.65
VK3	99.07	85.50	64.57	61.54	62.93	51.59	48.35	45.83	38.11	24.33
VK4	99.60	96.66	76.89	62.23	62.86	30.62	35.51	37.83	33.77	22.23
VK5	99.30	92.60	71.73	62.86	63.11	69.13	57.50	51.84	47.09	35.50
VK6	99.76	95.59	72.97	62.51	64.86	51.03	49.07	46.70	39.70	25.94
VK7	98.26	92.87	74.15	62.79	62.71	97.25	88.89	69.05	57.82	56.82
VK8	98.72	93.08	72.22	61.93	63.67	63.89	55.38	51.21	45.98	33.41
VK9	98.95	96.32	79.12	63.80	64.53	70.04	57.62	52.22	48.88	38.15

[0121] The results of the fast SCR reaction of the fresh catalysts are shown in FIG. 3.

[0122] The results of the fast SCR reaction of the aged catalysts are shown in FIG. 4.

[0123] The influence of the WO₃ content of the catalyst on the NOx conversion in the standard SCR reaction at 200° C. and in the fast SCR reaction at 300° C. in the fresh and aged states is shown in Table 4. The amounts of V₂O₅, CeO₂, and Nb₂O₅ were kept constant at 3.75 wt %, 2.00 wt %, and 2.75 wt %, respectively, while the WO₃ content was varied from 0.00 wt % (K2) to 0.50 wt % (VK5), 1.00 wt % (K1), and 2.00 wt % (VK6).

TABLE 4

Influence of WO ₃ Content on the NOx Conversion				
Influence of WO ₃ content on NOx conversion				
WO ₃ content [wt %]	In the standard SCR reaction at 200° C.		In the fast SCR reaction at 300° C.	
	fresh	aged	fresh	aged
0	64.9	20.7	68.9	57.5
0.5	63.6	5.1	70.5	49.1
1	66.6	6.0	71.73	51.8
2	68.9	3.2	73.0	46.7

[0124] The results of the influence of the WO_3 content are shown in FIG. 5.

[0125] The influence of the CeO_2 content of the catalyst on the NOx conversion in the standard SCR reaction at 200° C. and in the fast SCR reaction at 300° C. in the fresh and aged states is shown in Table 5. The amounts of V_2O_5 , WO_3 , and Nb_2O_5 were held constant at 3.75 wt %, 1.00 wt %, and 2.75 wt %, respectively, while the CeO_2 content was varied from 0.00 wt % (VK3) to 2.00 wt % (K1) and 2.00 wt % (VK7).

TABLE 5

Influence of CeO_2 Content on NOx Conversion Influence of CeO_2 content on NOx conversion				
CeO_2 content [wt %]	In the standard SCR reaction at 200° C.		In the fast SCR reaction at 300° C.	
	fresh	aged	fresh	aged
0	43.4	0.9	60.8	21.7
2	63.6	5.1	70.5	49.1
4	67.3	31.6	74.2	69.1

[0126] The results of the influence of the CeO_2 content are shown in FIG. 6.

[0127] The influence of the Nb_2O_5 content of the catalyst on the NOx conversion in the standard SCR reaction at 200° C. and in the fast SCR reaction at 300° C. in the fresh and aged states is shown in Table 6. The amounts of V_2O_5 , WO_3 , and CeO_2 were held constant at 3.75 wt %, 1.00 wt %, and 2.00 wt %, respectively, while the Nb_2O_5 content was varied from 0.00 wt % (VK2) to 2.75 wt % (K1), 4.00 wt % (VK8), and 7.00 wt % (VK9).

TABLE 6

Influence of Nb_2O_5 Content on NOx Conversion Influence of Nb_2O_5 content on NOx conversion				
Nb_2O_5 content [wt %]	In the standard SCR reaction at 200° C.		In the fast SCR reaction at 300° C.	
	fresh	aged	fresh	aged
0	42.6	2.0	69.9	38.1
2.75	63.6	5.1	70.5	49.1
4	65.6	5.4	72.2	51.2
7	67.2	7.3	79.1	52.2

[0128] The results of the influence of the Nb_2O_5 content are shown in FIG. 7.

1-10. (canceled)

11. A method of making a catalyst comprising
at least one oxide of vanadium in an amount of 2 to 6 wt.-%,
at least one oxide of cerium in an amount of 2 to 4 wt.-%,
at least one oxide of niobium in an amount of 1 to 7 wt.-%,
up to 2 wt.-% of at least one oxide of tungsten,
and
at least one oxide of titanium as a carrier material in an amount measured so as to result in a total of 100 wt.-%,

in each case based on the total weight of the catalyst and calculated as V_2O_5 , CeO_2 , Nb_2O_5 , TiO_2 , or, if at least one oxide of tungsten is present, WO_3 , said method comprising:
obtaining oxides of vanadium, cerium, niobium, titanium, and, if present, tungsten, said method comprising:
forming a mixture of the oxides, and
calcining the mixture.

12. The method of claim 11, wherein the mixture contains at least one oxide of silicon.

13. The method of claim 12, wherein the at least one oxide of silicon is present in amounts of 2 to 7 wt.-%, relative to the weight of the catalyst and calculated as SiO_2 .

14. The method of claim 11, wherein the mixture contains at least one oxide of tungsten in an amount of 0.001 to 2 wt.-%, relative to the weight of the catalyst and calculated as WO_3 .

15. The method of claim 11, wherein the mixture further comprises at least one oxide of molybdenum, antimony, zirconium, tantalum, and/or hafnium.

16. The method of claim 11, wherein the mixture further comprises at least one oxide of molybdenum, antimony, zirconium, tantalum, and/or hafnium in a total amount of said oxides of 0.5 to 20 wt.-%, relative to the total weight of the catalyst and calculated as MoO_3 , Sb_2O_5 , ZrO_2 , Ta_2O_5 , of HfO_2 .

17. The method of claim 11, wherein the oxides are provided in powder form.

18. The method of claim 11, wherein the mixture is a slurry of the oxides in water, and the method further comprises drying the slurry before calcining.

19. The method of claim 11, wherein a portion of the oxides are provided in the mixture in the form of an aqueous solution.

20. The method of claim 11, wherein the mixture comprises oxides of tungsten, cerium, niobium, and titanium that have been impregnated with a vanadium oxide.

21. The method of claim 11, wherein the mixture comprises oxides of vanadium, cerium, niobium, and titanium that have been impregnated with a tungsten oxide.

22. The method of claim 11, wherein at least two oxides in the mixtures are provided as one oxide doped with the other oxide.

23. The method of claim 11, wherein the two or more oxides are provided in the mixture as mixed oxide.

24. The method of claim 11, which comprises forming the mixture by dispersing titanium dioxide doped with 5 wt.-% silicon dioxide in water, and adding vanadium dioxide, tungsten trioxide, cerium dioxide, and niobium dioxide thereto.

25. The method of claim 24, wherein the added amounts of vanadium dioxide, tungsten trioxide, cerium dioxide, and niobium pentoxide result in a catalyst composition comprising 85.98 wt.-% TiO_2 , 4.53 wt.-% SiO_2 , 3.75 wt.-% V_2O_5 , 1.00 wt.-% WO_3 , 2.00 wt.-% CeO_2 , and 2.75 wt.-% Nb_2O_5 .

26. The method of claim 24, wherein the added amounts of vanadium dioxide, tungsten trioxide, cerium dioxide, and niobium pentoxide result in a catalyst composition comprising 86.93 wt.-% TiO_2 , 4.58 wt.-% SiO_2 , 3.75 wt.-% V_2O_5 , 2.00 wt.-% CeO_2 , and 2.75 wt.-% Nb_2O_5 .

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