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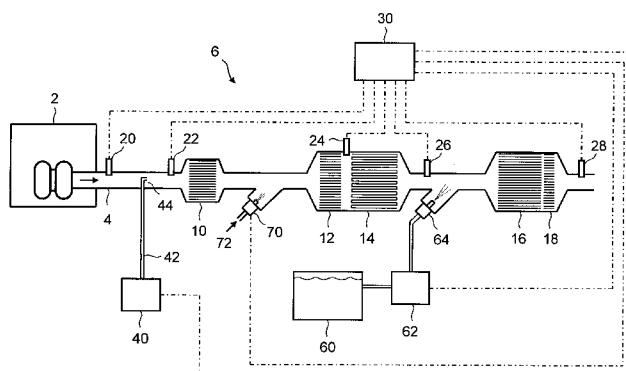


FIG.1

(57) **Abstract:** The object of the present invention is to provide an inventive exhaust system (6) for receiving an exhaust gas. The exhaust system (6) comprising a first SCR catalyst (10) and a second SCR catalyst (16) positioned downstream of said first SCR catalyst (10). A first injector (44) is provided upstream of said first SCR catalyst (10), and a second injector (64) is provided upstream of said second SCR catalyst (16). The exhaust system (6) further comprising a gaseous ammonia supply device (40) being fluidly connected to said first injector (44) for supplying gaseous ammonia to said exhaust gas by said first injector (44), and an ammonia-containing reductant reservoir (60) being fluidly connected to said second injector (64) for supplying a fluid ammonia-containing reductant, such as urea, to said exhaust gas by said second injector (64). The first SCR catalyst (10) having a smaller volume than said second SCR catalyst (16) for a fast warm-up of said first SCR catalyst (10).



## TITLE

Exhaust aftertreatment system and method for operating the system

## TECHNICAL FIELD

- 5 The present invention relates to an exhaust system for receiving an exhaust gas, wherein the exhaust system comprising a first SCR catalyst, a second SCR catalyst positioned downstream of said first SCR catalyst, a first injector provided upstream of said first SCR catalyst, and a second injector provided upstream of said second SCR catalyst.

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## BACKGROUND ART

- Engines, in particular diesel-powered combustion engines but also other engines known in the art, produce exhaust gases which contain several air pollutants, including carbon monoxide (CO), hydrocarbons (HC), nitrogen
- 15 oxides NO and NO<sub>2</sub> (NO<sub>x</sub>) as well as particulate matter (PM) containing carbonaceous matter, or soot.

- With increased attention to environmental problems and health hazard prevention, exhaust emission regulations are becoming more and more
- 20 stringent.

- To reduce the amount of NO<sub>x</sub> in the exhaust gases, some engines are equipped with Selective Catalytic Reduction (SCR) systems that convert a mixture of NO<sub>x</sub> and ammonia (**NH<sub>3</sub>**) into nitrogen gas (**N<sub>2</sub>**) and water (**H<sub>2</sub>O**).
- 25 For example, document US 2008/0060348 A 1 shows an exhaust system for reducing NO<sub>x</sub> comprising a first SCR catalyst, a second SCR catalyst, and a particulate filter positioned between said first and second SCR catalyst. This system however exhibits a limited efficiency for removal of the above mentioned pollutants during low-temperature exhaust conditions, such as
- 30 after cold start of the engine, or during low-temperature operation, e.g. low-speed urban driving conditions. Consequently, in order to combine an efficient **NO<sub>2</sub>**-based oxidation of stored PM in the particulate filter with a

maximum efficiency for removal of the above mentioned NO<sub>x</sub> pollutants during low-temperature exhaust conditions, further improvement in reductant dosing definition and a dedicated operating strategy according to the present invention is beneficial.

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Another problem with efficient exhaust treatment systems in general is relatively short refill-intervals of the ammonia-source that is required for operation of the SCR catalyst.

10 Still another problem with efficient exhaust treatment systems is the physical size of the system and the limited space available in modern vehicles, rendering packaging of the exhaust aftertreatment system difficult.

There is thus a need for an improved exhaust aftertreatment system that  
15 removes the above mentioned disadvantage.

#### SUMMARY

The object of the present invention is to provide an inventive exhaust system for receiving an exhaust gas and a method for operating the system where  
20 the previously mentioned problems are avoided. Said exhaust system comprising a first SCR catalyst, a second SCR catalyst positioned downstream of said first SCR catalyst, a first injector provided upstream of said first SCR catalyst, and a second injector provided upstream of said second SCR catalyst.

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The object of the present invention object is at least partly achieved by the features of the characterising portion of claim 1, wherein said exhaust system further comprising a gaseous ammonia supply device being fluidly connected to said first injector for supplying gaseous ammonia to said exhaust gas by  
30 said first injector, and an ammonia-containing reductant reservoir being fluidly connected to said second injector for supplying a fluid ammonia-containing reductant, such as urea, to said exhaust gas by said second

injector. Said first SCR catalyst has a smaller volume than said second SCR catalyst for a fast warm-up of said first SCR catalyst.

The inventive arrangement has preferably two clear operating modes: low-  
5 temperature exhaust gas operating mode and high-temperature exhaust gas  
operating mode. During the low-temperature exhaust gas operating mode,  
gaseous ammonia is injected upstream of the first SCR catalyst, which  
efficiently reduces NOx of the exhaust gases. In general, no ammonia-  
containing reductant is injected by the second injector in this operating mode.  
10 During the high-temperature exhaust gas operating mode, ammonia-  
containing reductant is injected upstream of the second SCR catalyst, which  
efficiently reduces NOx of the exhaust gases. Generally, no gaseous  
ammonia is injected by the first injector in this operating mode. The inventive  
arrangement results not only in significantly improved NOx emissions control  
15 during cold start and low-temperature exhaust operating conditions in  
general, but also in maintained long service intervals of the exhaust  
aftertreatment system, as well as improved exhaust system packaging.

The inventive exhaust system is designed to perform efficient NOx reduction  
20 by means of the first SCR catalyst also at a reduced exhaust temperature  
level compared with the prior art, such that catalytic NOx reduction can be  
performed at an earlier stage upon engine cold-start. There are a number of  
underlying reasons behind this technical effect:

25 The first SCR catalyst exhibits a smaller volume than the second SCR  
catalyst. For any given substance, the heat capacity of a body is directly  
proportional to the amount of substance it contains. As a consequence, the  
temperature of a smaller volume SCR catalyst may be more rapidly  
increased than a larger volume SCR catalyst due to the smaller heat capacity  
30 of the smaller SCR catalyst compared with the larger SCR catalyst.

The SCR catalyst requires ammonia for the catalytic removal of NO<sub>x</sub> emissions in the exhaust gases. When injecting a fluid ammonia-containing reductant, such as urea, the decomposition reaction of said reductant to active reagent gaseous ammonia within the exhaust passage requires a certain temperature level of the exhaust gases at the injection position for substantially complete decomposition, e.g. normally around 200°C. Injection of the ammonia-containing reductant can thus not be initiated much below said temperature level, thereby strongly limiting the NO<sub>x</sub> emission abatement efficiency. However, by supplying gaseous ammonia instead of a fluid ammonia-containing reductant, there is no requirement to wait with injection until the exhaust gases have reached said temperature level. Consequently, the NO<sub>x</sub> emission abatement can be initiated at a lower temperature, allowing the full active temperature window of the SCR catalyst to be employed, e.g. down to temperatures around 150°C.

Moreover, the inventive arrangement as a consequence also results in improved NO<sub>x</sub> emissions control upon entering a low-temperature exhaust operating conditions, such as traffic jams, low-speed urban driving conditions, or the like, because the system may always go back from the high temperature exhaust gas operating mode to the low temperature exhaust gas operating mode as described above when necessary.

A further inventive advantage of having a small first SCR catalyst is the simplified arrangement of said catalyst close to the outlet of the engine or turbocharger, where the space is very limited. The relatively small size of the first SCR catalyst allows closer arrangement thereof to the engine. Hence, the limitation in size of the first SCR catalyst is a factor supporting the improved NO<sub>x</sub> emission reduction of the present invention. The addition of gaseous ammonia upstream the first SCR catalyst enables a very short mixing distance, utilizing the turbulence created directly downstream the turbocharger outlet, further enabling a compact packaging solution.

Another inventive advantage of the present invention results from the specific supply arrangement of the active reagent ammonia to the first and second SCR catalyst of the invention. The combination of supplying gaseous ammonia to the first SCR catalyst and fluid ammonia-containing reductant, such as urea, to the second SCR catalyst allows, by means of intelligent dosing strategy of said first and second ammonia source, extended service intervals of the exhaust aftertreatment system, rendering said system more efficient, reliable and cost effective. For example, by supplying gaseous ammonia via the first injector to the first SCR catalyst only during the low-temperature exhaust gas operating mode, such as cold-start and certain urban driving conditions, and upon reaching a certain exhaust gas temperature at the second SCR catalyst, supplying ammonia-containing reductant via the second injector to the second SCR catalyst while stopping the supply of gaseous ammonia, the first and second SCR catalyst are operated more or less non-simultaneously. This type of dosing strategy, which is possible by means of the inventive arrangement, does not only enable a very high NO<sub>x</sub> conversion efficiency without any penalty to fuel economy but also results in significantly extended service intervals of the exhaust aftertreatment system, i.e. longer time periods between refill or exchange of the ammonia sources. It is of course possible to have a less distinct transition between injection at the first or the second injector, and catalytic operation of the first or second SCR catalyst and both SCR catalysts may be configured to be simultaneously catalytically active during a transition period.

An advantage of having a substantially non-simultaneous dosing strategy is more efficient NO<sub>2</sub>-based PM regeneration process of a particulate filter when such is provided in the exhaust system, because the NO<sub>2</sub>-based PM regeneration process, which is essentially only possible when dosing of gaseous ammonia to the first SCR catalyst has been stopped, results in less thermal degradation of the catalytic components and a lower fuel economy penalty, as described more in detail in the detailed description below. In the temperature range where the NO<sub>2</sub>-based PM regeneration process is active,

e.g. 250-450°C, the dosing of ammonia-containing reductant, e.g. urea, to the second SCR catalyst is fully active so that the emissions compliance is maintained even if the dosing of gaseous ammonia to the first SCR catalyst has been stopped.

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Further advantages are achieved by implementing one or several of the features of the dependent claims. According to the invention, the volume of said first SCR catalyst is within a range of 5% to 60% of the volume of said second SCR catalyst, specifically within a range of 5% to 40% of the volume  
10 of said second SCR catalyst, and more specifically within a range of 10% to 25% of the volume of said second SCR catalyst. Typical values of said volumes in a diesel engine for a heavy truck is about 5 - 10 litres for the first SCR catalyst, and about 40 litres for the second SCR catalyst. The limited volume of the first SCR catalyst results in faster warm-up and simplified  
15 positioning thereof close to the engine or turbocharger outlet. Due to the limited volume, the first SCR catalyst may not have the capacity to alone provide sufficient catalytic removal of NO<sub>x</sub> emission in the upper operating load region of the engine, i.e. upon high power demand, but the capacity is sufficient in the engine operating conditions normally associated with cold-  
20 start and low-temperature exhaust gas urban driving, i.e. a relatively low operating engine load.

According to the invention, said exhaust system further comprises an ammonia oxidation catalyst located downstream of said second SCR  
25 catalyst. An ammonia oxidation catalyst at the end of the exhaust aftertreatment system can remove any residual ammonia in the exhaust gas that did not react in the second SCR catalyst, by means of oxidation of residual ammonia

30 According to the invention, said exhaust system further comprising a particulate filter positioned between said first and second SCR catalyst. Depending on the type of fuel used, more or less soot and particulate matter

is produced. Diesel fuel for example produces more soot and requires thus often a particulate filter for fulfilling legal emission requirements, whereas fuel such as natural gas or dimethyl ether produces generally small amounts of soot, thereby often eliminating the need of a particulate filter.

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According to the invention, said exhaust system further comprising an oxidation catalyst located downstream of said first SCR catalyst and upstream of said particulate filter. The oxidation catalyst serves to oxidise hydrocarbons and carbon monoxide into carbon dioxide and water. The  
10 oxidation catalyst also increases the exhaust temperature. The oxidation catalyst is arranged upstream of the second SCR catalyst, which is configured to be used as sole SCR catalyst during normal highway driving and other normal and high-temperature exhaust operating conditions.

15 According to the invention, the first SCR catalyst is a vanadia-based (e.g.  $V_2O_5/TiO_2/WO_3$ ) catalyst, and said second SCR catalyst is a zeolite-based catalyst. Using a vanadia-based catalyst as first SCR catalyst is advantageous because this type of catalyst does not require  $NO_2$  for efficient selective catalytic reduction of  $NO_x$  emissions. There is essentially no  $NO_2$   
20 available in the exhaust gas directly after the engine or turbocharger outlet port. Furthermore, in the case of misfueling with high-sulphur fuel (e.g. >300 ppm S), some zeolite-based SCR catalysts require elevated temperatures, e.g. 600°C, for removal of adsorbed sulphur species to regain the SCR catalyst performance. A vanadia-based SCR catalyst is generally very  
25 sulphur tolerant and does not require elevated temperatures for removal of adsorbed sulphur species.

The second SCR catalyst is preferably implemented by a zeolite-based catalyst because of its wide active temperature window, good heat-resistance  
30 and effective  $NO_x$  reduction, but the second SCR catalyst may alternatively also be implemented by a vanadia-based catalyst.



According to the invention, the gaseous ammonia supply device can be implemented in several ways. For example, one or more gas bottles holding pressurised ammonia gas can be provided and coupled to the first injector, such that gaseous ammonia may be injected upstream of the first SCR

5 catalyst immediately upon a cold-start, or similar conditions. Replacement and handling of the gas bottles is also relatively easy. According to an alternative embodiment, a storage container may be provided that is configured to store an alkaline earth metal chloride salt, which functions as a source of said gaseous ammonia. The container is preferably heated by

10 electrical wires or the like, thereby facilitating release of gaseous ammonia. Transporting ammonia in a solid storage medium, such as alkaline earth metal chloride salt, results in satisfactory safety and handling of the ammonia source, and only a small amount of heat is required to release the gaseous ammonia. According to yet another alternative, the gaseous ammonia supply

15 device may comprise a storage container holding a solution of ammonia dissolved in a solvent, such as water.

According to the invention, said first injector is formed by metal pipe that passes through a side wall of an exhaust passage of said exhaust system,

20 and exhibits an discharge opening within said exhaust passage, such that gaseous ammonia from said gaseous ammonia supply device can be supplied to an exhaust gas flow within said exhaust passage by means of said metal pipe. As previously mentioned, the first SCR catalyst is preferably positioned very close to the engine or turbocharger outlet for rapid heat-up.

25 However, the first injector, which is configured to supply the first SCR catalyst with gaseous ammonia and is arranged upstream of the first SCR catalyst, must consequently be positioned even closer to said outlet. There is thus a problem of extremely high heat at the position of the first injector. By forming the first injector merely by metal pipe that is arranged to receive gaseous

30 ammonia from the ammonia supply device and release the gaseous ammonia within the exhaust passage by means of a discharge opening, the

first injector is extremely heat resistant, leading to a reliable and cost-effective design and implementation of the first injector.

5 According to the invention, said first injector is free from parts made of thermo-plastic material, or other heat sensitive materials. As mentioned, providing a heat-resistant first injector improves system reliability and reduces costs. The addition of gaseous ammonia upstream the first SCR catalyst also enables a very short mixing distance compared to the corresponding injection of ammonia-containing fluid, such as urea.

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According to the invention, an electronic controller is configured to control injection of gaseous ammonia by said first injector, such that supply of gaseous ammonia to said exhaust gas by said first injector is limited to a operation mode where a temperature  $T_{SCR1}$  associated with said first SCR catalyst is above a first value  $T_1$ , and a temperature  $T_{SCR2}$  associated with said second SCR catalyst is below a second value  $T_2$ , thereby at least partly facilitating high NOx conversion efficiency of said exhaust gas at temperatures when NOx conversion efficiency of said exhaust gas by said second SCR catalyst is low. The lower end of the active temperature window of the first SCR catalyst is defined by said first value  $T_1$ , below which temperature level efficient NOx reduction is no longer accomplished. Furthermore, as previously described, the system is configured to stop injection of gaseous ammonia upstream of the first SCR catalyst when the temperature  $T_{SCR2}$  associated with said second SCR catalyst has reached a second value  $T_2$ .

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Another inventive advantage of the present invention results from the specific supply arrangement of the active reagent ammonia to the first and second SCR catalyst of the invention. The combination of gaseous ammonia supply to the first SCR catalyst and fluid ammonia-containing reductant supply, such as supply of urea, to the second SCR catalyst allows by means of intelligent dosing strategy of said ammonia sources, extended service intervals of the

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exhaust aftertreatment system, rendering said system more efficient, reliable and cost effective. For example, by supplying gaseous ammonia via the first injector to the first SCR catalyst only during low-temperature exhaust gas operating conditions, such as cold-start and certain urban driving conditions, and upon reaching a certain exhaust gas temperature at the second SCR catalyst, supplying ammonia-containing reductant via the second injector to the second SCR catalyst while stopping the supply of gaseous ammonia, the first and second SCR catalysts are operated more or less non-simultaneously. This type of dosing strategy, which is possible by means of the inventive arrangement, does not only enable a very high NO<sub>x</sub> conversion efficiency without any penalty to fuel economy but also result in significantly extended service intervals of the exhaust aftertreatment system, i.e. longer time periods between refill or exchange of the ammonia sources. More specifically, the exchange of ammonia-containing storage containers can be performed during normal vehicle service intervals for e.g. engine oil.

According to the invention, the temperature  $T_{SCR1}$  associated with said first SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said first SCR catalyst, and the temperature  $T_{SCR2}$  associated with said second SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said second SCR catalyst, and said first value  $T_1$  is about 120 °C, preferably about 150 °C, and said second value  $T_2$  is about 270 °C, preferably about 250 °C.

According to the invention, an electronic controller is configured to control injection of fluid ammonia-containing reductant by said second injector, such that supply of ammonia-containing reductant to said exhaust gas by said second injector is limited to an operation mode where a temperature level  $T_{SCR2}$  associated with said second SCR catalyst is above a third value  $T_3$ , which corresponds to a lower end of the active temperature window of the second SCR catalyst. The second value  $T_2$  may be set equal to  $T_3$ , such that injection at the first injector ends when injection at the second injector begins.

Alternatively, the second value may be arranged a certain level above the third value  $\tau_3$ , such that a certain injection overlap occurs by the first and second injectors. In other words, the overlapping temperature range, which is defined by the second value  $T_2$  and third value  $\tau_3$ , signifies that both the first and second SCR catalysts are temporarily in a simultaneous operating mode during a hand over and start-up of NOx catalytic reduction from one SCR catalyst to the other SCR catalyst. The electronic controller allows fast and economical control of the exhaust aftertreatment system in general, especially with respect to the particular dosing strategy used by the inventive system.

According to the invention, said temperature  $T_{SCR2}$  associated with said second SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said second SCR catalyst, and said third value  $\tau_3$  is 200 °C, preferably 250 °C.

According to the invention, said first SCR catalyst is arranged less than 0.6 metres downstream from an exhaust manifold outlet or turbo exhaust outlet of said engine, preferably less than 0.4 metres downstream from an exhaust manifold outlet or turbo exhaust outlet, and more preferably less than 0.25 metres downstream from an exhaust manifold outlet or turbo exhaust outlet. By arranging the first SCR catalyst more close to the exhaust manifold outlet, or turbo exhaust outlet if a turbocharger is provided, the exhaust gases passing through the first SCR catalyst will be warmer, thereby facilitating a more rapid warm-up of said catalyst.

According to the invention, an electronic controller is configured to control injection of fluid ammonia-containing reductant by said second injector. The electronic controller allows fast and economical control of the exhaust aftertreatment system in general, especially with respect to the particular dosing strategy used by the inventive system.

According to the invention, said second injector is provided downstream of said particulate filter. This arrangement prevents ammonia-containing reductant from entering the DPF.

- 5 The object of the present invention object is at least partly achieved by the features of claim 17, more specifically by a method of operating an exhaust system comprising a first SCR catalyst; a second SCR catalyst positioned downstream of said first SCR catalyst; a first injector provided upstream of said first SCR catalyst; and a second injector provided upstream of said
- 10 second SCR catalyst, wherein the method comprises the steps of controlling injection of gaseous ammonia by a first injector, such that supply of gaseous ammonia to said exhaust gas by said first injector is limited to a operation mode where a temperature ( $T_{SCR1}$ ) associated with said first SCR catalyst is above a first value ( $T_1$ ), and a temperature ( $T_{SCR2}$ ) associated with said
- 15 second SCR catalyst is below a second value ( $T_2$ ), thereby at least partly facilitating high NOx conversion efficiency of said exhaust gas at temperatures when NOx conversion efficiency of said exhaust gas by said second SCR catalyst is low.
- 20 According to a first embodiment of the method, the temperature ( $T_{SCR1}$ ) associated with said first SCR catalyst (10) is the temperature of the exhaust gas in the region directly upstream of said first SCR catalyst (10), and said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst (16) is the temperature of the exhaust gas in the region directly upstream of said second
- 25 SCR catalyst (16), and said first value ( $T_1$ ) is 120 °C, preferably 150 °C, and said second value ( $T_2$ ) is 270 °C, preferably 250 °C.

According to a second embodiment, the method comprises the step of controlling injection of fluid ammonia-containing reductant by said second

30 injector, such that supply of ammonia-containing reductant to said exhaust gas by said second injector is limited to an operation mode where a

temperature level ( $T_{SCR2}$ ) associated with said second SCR catalyst is above a third value ( $T_3$ ).

5 According to a first embodiment of the method, said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said second SCR catalyst, and said third value ( $T_3$ ) is 200 °C, preferably 250 °C.

## 10 BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in detail with reference to the figures, wherein:

15 Figure 1 shows a schematic structure of the exhaust system according to the invention; and

Figure 2 shows a typical dosage strategy according to the invention.

## DETAILED DESCRIPTION

20 Various aspects of the invention will hereinafter be described in conjunction with the appended drawings provided to illustrate and not to limit the invention.

25 The use of selective catalytic reduction (SCR) for reducing NO<sub>x</sub> emissions is widespread within the automotive industry, with the most common technology using urea ( $NH_2CONH_2$ ) as a precursor to ammonia ( $NH_3$ ) for the catalytic removal of NO<sub>x</sub> emissions. The invention is not limited to urea as ammonia-containing reductant, and other reductant types currently used in SCR applications may alternatively be used, such as aqueous ammonia. The NO<sub>x</sub> abatement efficiency of an SCR catalyst has a two-fold temperature  
30 dependence, limiting the efficiency during low-temperature exhaust conditions. The reaction rates of the catalytic reactions for NO<sub>x</sub> removal are dependent on temperature, with an active temperature window generally

starting at a catalyst temperature of e.g. 150°C, depending also on the **NO:NO<sub>2</sub>** ratio of the feedgas NO<sub>x</sub> emissions.

5 In the case where urea is employed as reductant for SCR, the decomposition reactions, i.e. thermolysis and hydrolysis of urea to produce gaseous ammonia and carbon dioxide, are highly dependent on temperature. If the exhaust temperature upstream the SCR catalyst is below a certain level, e.g. 200°C, there is a risk for incomplete urea decomposition, thus limiting the NO<sub>x</sub> removal efficiency. There is also a risk for formation of unwanted solid  
10 by-products through polymerization reactions, causing clogging of the SCR catalyst and an increased back pressure of the exhaust aftertreatment system.

In combined exhaust aftertreatment systems with multiple types of catalysts,  
15 it is beneficial to position a diesel oxidation catalyst (DOC) and diesel particulate filter (DPF) upstream the SCR catalyst. One of the reasons is that for a DOC, the temperature needs to be above a certain threshold level, generally called the light-off temperature, to attain activation with respect to conversion of CO and HC as well as the oxidation of NO to **NO<sub>2</sub>**.

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For the DPF, a process commonly known as regeneration is performed to oxidize and remove carbonaceous PM collected in the particulate filter, and there are two well-known major oxidation mechanisms. For relatively rapid regeneration with residual oxygen in the exhaust gas stream, the  
25 temperature of the particulate filter needs to be elevated to levels considerably higher than exhaust temperatures normally encountered during diesel engine operation, e.g. 550-650°C. The regeneration of a DPF may be performed at significantly lower temperatures (e.g. 250-450°C) if NO<sub>2</sub> is used as oxidant rather than oxygen. Whereas the NO<sub>2</sub>-based PM regeneration  
30 process is slower than oxygen-based regeneration, the advantages include less thermal degradation of the catalytic components and a lower fuel economy penalty. In addition, the lower exhaust temperature enables a

greater efficiency for the downstream selective catalytic reduction of NOx emissions.

5 An  $\text{NO}_2$ -based regeneration process is greatly enhanced by positioning the DPF downstream the DOC. If the SCR catalyst would be located upstream the DPF, the  $\text{NO}_2$ -based regeneration becomes ineffective due to the absence of NOx emissions downstream the SCR catalyst. As a consequence, the best solution is generally to position the SCR catalyst downstream both the DOC and DPF.

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While this configuration is advantageous for the efficient regeneration of PM in the DPF, a drawback of such an exhaust aftertreatment system definition is that the cold start properties of the SCR catalyst and thus also for NOx emissions control are far from ideal. A significant amount of heat is required to raise the temperature of the DOC and DPF units so as to attain a sufficiently high working temperature for the SCR catalyst and enable dosing of ammonia-containing reductant, e.g. urea. In addition, temperature losses may occur in the exhaust aftertreatment prior to the SCR catalyst. For the reasons described above, the NOx abatement efficiency of the SCR catalyst can be limited by its position relatively far from the engine in the chosen exhaust aftertreatment system definition.

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Positioning the SCR catalyst upstream of the DPF results in other problems. An ammonia reductant injector must be positioned upstream of the SCR catalyst, and thus very close to the turbocharger. The ammonia reductant injector is however generally sensitive to high-temperature exposure and have a bulky design which may cause packaging issues in the normally very limited packaging space available close to the turbocharger outlet. In addition, a certain mixing length, e.g. minimum 0.50 m, is generally required for the decomposition of ammonia reductant, such as urea, prior to the SCR catalyst, placing further geometric packaging demands on the installation. In addition, for the complete decomposition of urea prior to the SCR catalyst, an

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exhaust temperature should be approximately 200°C. The NO<sub>x</sub> abatement efficiency at low temperatures or shortly after cold start is thus primarily limited by the urea decomposition rate, not the SCR reaction rates of the SCR catalyst.

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In the present invention, the active temperature range of SCR is dramatically enhanced, both by improving the temperature conditions for the SCR catalyst and by removing the temperature limitation of urea decomposition to the active reagent ammonia. Regeneration of the DPF may further be mainly  
10 NO<sub>2</sub>-based, assuring an efficient, less harmful and more economical regeneration.

An inventive exhaust system according to the invention is shown in fig. 1 For a compression ignition engine 2, an exhaust stream 4 contains an exhaust  
15 system 6, which consists of, in said order, a smaller first selective catalytic reduction catalyst 10, an oxidation catalyst 12 also referred to a diesel oxidation catalyst (DOC), a particulate filter 14 for the collection of particulate matter from the engine and a larger second selective catalytic reduction catalyst 16 for the abatement of NO<sub>x</sub> emissions. An ammonia oxidation  
20 catalyst 18 may be positioned downstream second selective catalytic reduction catalyst 16 for conversion of excess ammonia.

A supply of gaseous ammonia is positioned upstream the first selective catalytic reduction catalyst 10. A controlled dosing rate of ammonia gas from  
25 an ammonia supply device 40 is led through a pipe 42 and through a first injector 44 into the exhaust gas stream 4 upstream the first selective catalytic reduction catalyst 10. The first injector 44 is positioned directly upstream the first selective catalytic reduction catalyst 10.

30 The ammonia supply device 40 may be constituted in different ways. According to a first preferred example, the ammonia supply device 40 is formed by a gas container holding pressurized ammonia gas. The feeding

rate of ammonia gas may be controlled by an electronic control unit 30 through e.g. a mass flow control device.

5 According to second example, the ammonia supply device 40 is formed by a container with an alkaline earth metal chloride salt ( $\text{SrCl}_2$ ,  $\text{CaCl}_2$  or  $\text{MgCl}_2$ ) which readily stores ammonia in the form of an alkaline earth metal chloride chemical complex with ammonia, e.g.  $\text{Sr}(\text{NH}_3)_6\text{Cl}_2$ ,  $\text{Ca}(\text{NH}_3)_8\text{Cl}_2$  or  $\text{Mg}(\text{NH}_3)_6\text{Cl}_2$ . The ammonia-containing container may be equipped with a heating device to initiate the decomposition of the complex into the alkaline  
10 earth metal chloride salt and ammonia, thus raising the partial pressure of gaseous ammonia. The dosing rate of ammonia gas may also here be controlled by an electronic control unit 30 through e.g. a mass flow control device.

15 According to third example, the ammonia supply device 40 is formed by a container holding a solution of ammonia dissolved in a solvent, e.g. water. The feeding rate of ammonia gas may be controlled by the electronic control unit 30 through e.g. a pump unit.

20 A reservoir 60 containing ammonia-containing reductant, such as urea, is connected to a pumping unit 62. The electronic control unit 30 controls the pumping unit 62 and the flow rate of fluid to a second injector 64 positioned upstream the second selective catalytic reduction catalyst 16. The second injector 64 is positioned directly upstream the second selective catalytic  
25 reduction catalyst 16. The second injector 64 is positioned downstream the oxidation catalyst 12. The second injector 64 is positioned downstream the particulate filter 14.

A fuel dosing unit 70 is fed with a fuel supply 72 from a fuel container (not  
30 shown), and may dose fuel into said exhaust aftertreatment system 6 upstream the oxidation catalyst 12. The fuel dosing unit 70 is controlled by the electronic control unit 30 and operated with the purpose of elevating the

exhaust temperature to a level where the oxidation efficiency of the carbonaceous PM loaded onto the particulate filter 14 is enhanced so as to oxidize the PM in a rapid manner without damaging the integrity of neither the oxidation catalyst 12 nor the particulate filter 14. Unburned fuel may  
5 alternatively be temporarily supplied to the exhaust system by the fuel injectors of the combustion engine upon appropriate injection timing.

The control of the exhaust aftertreatment system 6 is performed with the help of multiple gas sensing devices. A first NO<sub>x</sub> emission sensor 20 may be fitted  
10 directly downstream the engine 2 for assessing the feedgas NO<sub>x</sub> emission level. A second NO<sub>x</sub> emissions sensor 28 is fitted directly downstream the ammonia oxidation catalyst 18 for assessing the NO<sub>x</sub> emission level of the exhaust gas released to the ambient environment. A first temperature sensor  
15 22 is positioned upstream the smaller first selective catalytic reduction catalyst 10. A second temperature sensor 24 is positioned upstream the particulate filter 14, and a third temperature sensor 26 is positioned downstream the particulate filter 14.

The respective measurement signals of sensing units 20, 22, 24, 26 and 28  
20 are fed to the electronic control unit 30, from which the first and second injector 44, 64 and fuel dosing unit 70 are controlled as previously described. The measurement signals from NO<sub>x</sub> sensors 20 and 28 are led to the electronic control unit 30 as inputs to the reductant dosing strategy.

25 In fig. 2, the dosing strategy during a typical engine cold-start is illustrated. In the upper chart, time is plotted along the x-axis and temperature of the respective SCR catalyst is plotted up the y-axis, the centre chart illustrates very schematically the corresponding dosage activity of the first injector 44 plotted up the y-axis with time being plotted along the x-axis, and the lower  
30 chart illustrates equally schematic the corresponding dosage activity of the second injector 64 plotted up the y-axis with time being plotted along the x-axis. Said dosage activity of each injector 44, 64 being controlled by the

electronic control unit 30, and is here illustrated by two states only: on or off. Initially, at time  $t_0$ , immediately at engine cold-start, the temperature  $T_{SCR1}$ ,  $T_{SCR2}$ , of the first and second SCR catalyst 10, 16 are close to ambient temperature  $T_A$ , and no injection is performed by the first or second injectors 44, 64. With the engine running, warm exhaust gases quickly heats up the first SCR catalyst 10 due to its position close to the engine or turbocharger outlet, as well as the relatively small thermal capacity thereof. As clearly illustrated, the first SCR catalyst 10 heats up much quicker than the second SCR catalyst 16.

10

At time  $t_i$ , the temperature associated with the first SCR catalyst has reached a first value  $T_i$ , for example  $150^\circ\text{C}$ , representing the lower end of the active temperature window of the first SCR catalyst 10, and injection of gaseous ammonia by the first injector 44 is initiated, as illustrated in the centre chart. In the disclosed embodiment, the electronic control unit 30 determines the temperature of the first SCR catalyst based on temperature of the exhaust gas as measured by the first temperature sensor 22. Time  $t_1$  depends on many factors such as type of SCR catalyst, engine size, power output, etc, and may typically be about 1 minute.

20

At time  $t_2$ , the temperature associated with the second SCR catalyst has reached a second value  $T_2$ , for example  $250^\circ\text{C}$ , representing the lowest temperature at which efficient NOx reduction may be realised by the second SCR catalyst 16, and efficient decomposition of the ammonia-containing reductant by thermolysis and hydrolysis to produce gaseous ammonia may be realised. Time  $t_2$  depends on many factors such as type of SCR catalyst, engine size, power output, ammonia-containing reductant, etc, and may typically be about 10 minutes. At this time point, injection of gaseous ammonia by the first injector 44 is discontinued and injection of fluid ammonia-containing reductant by the second injector 64 is initiated instead, as illustrated in the centre and lower chart of fig. 2. The transition from the injection by the first injector 44 to injection by the second injector 64 may be

realised instantaneous, or have a certain overlap, in which both the first and second injector 44, 64 is operated simultaneously to assure efficient reduction of NO<sub>x</sub> emissions at all times. In the disclosed embodiment, the electronic control unit 30 determines the temperature of the second SCR catalyst based on the temperature of the exhaust gas as measured by the second temperature sensor 26.

If, during the subsequent operation, the engine is used in low-temperature operating conditions and the exhaust temperature drops below the aforementioned threshold value of the second SCR catalyst (e.g. 250°C), injection of gaseous ammonia at the first injector 44 may be restarted again, and the injection of ammonia-containing reductant at the second injector 64 may be stopped or limited to avoid incomplete decomposition of urea and the formation of solid by-products in the exhaust line upstream the second SCR catalyst.

This type of dynamic dosing strategy enables a very high NO<sub>x</sub> conversion efficiency without any penalty to fuel economy. Furthermore, the strategy can be tuned to allow for efficient NO<sub>2</sub>-based PM regeneration process of the particulate filter 14 by stopping ammonia dosing to the first SCR catalyst 10 at temperatures where the NO<sub>2</sub>-based PM regeneration process starts to become active, e.g. 250°C.

In addition, the consumption of gaseous ammonia can be limited in order to prolong the time before the ammonia supply device 40 is emptied of its entire ammonia content.

The refilling of ammonia into the ammonia supply device 40 when emptied of its entire ammonia content needs to be performed by replacing the entire unit by one saturated with ammonia. For many vehicle applications, this replacement would have to be made on a relatively frequent basis, especially for vehicles operated at high loads and with large mass flow rates of feedgas

NOx emissions. Practical problems for such servicing arise due to the lack of an infrastructure for the widespread distribution of such units. In contrast, an infrastructure for the widespread distribution of commercial urea solutions under the commercial names AdBlue® or DEF is established on many  
5 markets and is becoming established on even more markets worldwide.

A significant advantage of the present invention is that the dimensioning of the ammonia supply device 40 and the dynamic dosing strategy involving both gaseous ammonia and ammonia-containing reductant, e.g. urea, can be  
10 controlled in such a way that the ammonia supply device 40 only needs to be replaced at the normal vehicle service intervals. The distribution of the ammonia supply device 40 only needs to be extended to the conventional workshops, making an infrastructure for the widespread distribution of such ammonia supply devices 40 redundant. The refilling of ammonia-containing  
15 reductant, e.g. urea to the reservoir 60 can be performed utilizing the widespread distribution of commercial urea solutions, e.g. AdBlue® or DEF.

An advantage of the present invention compared to the concept described above, is that the first dosing arrangement consists of a metallic pipe 42 and  
20 first injector 44 with a very simple design which can easily withstand high temperatures and has a minimum space claim. The first injector 44 preferably being formed by an opening at the end of the metallic pipe. Mass flow control devices are generally temperature-sensitive and can in the present invention be positioned away from the hot surfaces close to the turbocharger. For  
25 ammonia gas dosing, a relatively short mixing length, e.g. 0.25 m, is required to achieve a uniform ammonia gas distribution over the cross section of the first SCR catalyst 10. In contrast to the use of urea as reductant, the NOx abatement efficiency at low temperatures is not limited by the urea decomposition rate in the present invention, since the reductant is added in  
30 the form of the desired reactant ammonia. The full active temperature window of the first SCR catalyst 10 may thus be employed.

The term volume of the SCR catalyst is herein considered to define the geometrical volume as derived from the outer geometrical dimensions of the catalyst substrate.

- 5 Reference signs mentioned in the claims should not be seen as limiting the extent of the matter protected by the claims. As will be realised, the invention is capable of modification in various obvious respects, all without departing from the scope of the appended claims. Accordingly, the drawings and the description thereto are to be regarded as illustrative in nature, and not
- 10 restrictive.

## CLAIMS

1. An exhaust system (6) for receiving an exhaust gas, said exhaust system (6) comprising:  
5 a first SCR catalyst (10);  
a second SCR catalyst (16) positioned downstream of said first SCR catalyst (10);  
a first injector (44) provided upstream of said first SCR catalyst (10);  
and  
10 a second injector (64) provided upstream of said second SCR catalyst (16), characterised in that said exhaust system (6) further comprising:  
a gaseous ammonia supply device (40) being fluidly connected to said first injector (44) for supplying gaseous ammonia to said exhaust gas  
15 by said first injector (44);  
an ammonia-containing reductant reservoir (60) being fluidly connected to said second injector (64) for supplying a fluid ammonia-containing reductant, such as urea, to said exhaust gas by said second injector (64); wherein said first SCR catalyst (10) has a smaller  
20 volume than said second SCR catalyst (16) for a fast warm-up of said first SCR catalyst (10).
2. The exhaust system (6) according to claim 1, characterised in that  
25 the volume of said first SCR catalyst (10) is within a range of 5% to 60% of the volume of said second SCR catalyst (16), preferably within a range of 5% to 40% of the volume of said second SCR catalyst (16), and more preferably within a range of 10% to 25% of the volume of said second SCR catalyst (16).
- 30 3. The exhaust system (6) according to any of the preceding claims, characterised in that said exhaust system (6) further comprising an



ammonia oxidation catalyst (18) located downstream of said second SCR catalyst (16).

4. The exhaust system (6) according to any of the preceding claims,  
5 **characterised in that** a particulate filter (14) is positioned between said first and second SCR catalyst (10, 16).
5. The exhaust system (6) according to claim 4, **characterised in that**  
10 said exhaust system (6) further comprising an oxidation catalyst (12) located downstream of said first SCR catalyst (10) and upstream of said particulate filter (14).
6. The exhaust system (6) according to any of the preceding claims,  
15 **characterised in that** said first SCR catalyst (10) is a vanadia-based catalyst, and said second SCR catalyst (16) is a zeolite-based catalyst.
7. The exhaust system (6) according to any of the preceding claims,  
20 **characterised in that** said gaseous ammonia supply device (40) comprises:  
a storage container, which is configured to store an alkaline earth metal chloride salt that is the source of said gaseous ammonia;  
or  
a storage container holding a solution of ammonia dissolved in a  
25 solvent, such as water; or  
a gas bottle holding pressurised ammonia gas.
8. The exhaust system (6) according to any of the preceding claims,  
30 **characterised in that** said first injector (44) is formed by a metal pipe (42) that passes through a side wall of an exhaust passage of said exhaust system (6), and exhibits an discharge opening within said exhaust passage, such that gaseous ammonia from said gaseous

ammonia supply device (40) can be supplied to an exhaust gas flow within said exhaust passage by means of said metal pipe (42).

9. The exhaust system (6) according to claim 8, **characterised in that**  
5 said first injector (44) is free from parts made of thermo-plastic material, or other heat sensitive materials.
10. The exhaust system (6) according to any of the preceding claims,  
10 **characterised in that** an electronic controller (30) is configured to control injection of gaseous ammonia by said first injector (44), such that supply of gaseous ammonia to said exhaust gas by said first injector (44) is limited to a operation mode where a temperature ( $T_{SCR1}$ ) associated with said first SCR catalyst (10) is above a first value ( $T_1$ ), and a temperature ( $T_{SCR2}$ ) associated with said second  
15 SCR catalyst (16) is below a second value ( $T_2$ ), thereby at least partly facilitating high NOx conversion efficiency of said exhaust gas at temperatures when NOx conversion efficiency of said exhaust gas by said second SCR catalyst (16) is low.
- 20 11. The exhaust system (6) according to claim 10, **characterised in that** said temperature ( $T_{SCR1}$ ) associated with said first SCR catalyst (10) is the temperature of the exhaust gas in the region directly upstream of said first SCR catalyst (10), and said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst (16) is the temperature of the exhaust  
25 gas in the region directly upstream of said second SCR catalyst (16), and said first value ( $T_1$ ) is 120 °C, preferably 150 °C, and said second value ( $T_2$ ) is 270 °C, preferably 250 °C.
- 30 12. The exhaust system (6) according to any of the preceding claims, **characterised in that** an electronic controller (30) is configured to control injection of fluid ammonia-containing reductant by said second injector (64), such that supply of ammonia-containing reductant to said

exhaust gas by said second injector (64) is limited to an operation mode where a temperature level ( $T_{SCR2}$ ) associated with said second SCR catalyst (16) is above a third value ( $T_3$ ).

- 5 13. The exhaust system (6) according to claim 12, **characterised in that** said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst (16) is the temperature of the exhaust gas in the region directly upstream of said second SCR catalyst (16), and said third value ( $T_3$ ) is 200 °C, preferably 250 °C.
- 10 14. The exhaust system (6) according to any of the preceding claims, **characterised in that** said first SCR catalyst (10) is arranged less than 0.6 metres downstream from an exhaust manifold outlet or turbo exhaust outlet of said engine (2), preferably less than 0.4 metres
- 15 downstream from an exhaust manifold outlet or turbo exhaust outlet, and more preferably less than 0.25 metres downstream from an exhaust manifold outlet or turbo exhaust outlet.
- 20 15. The exhaust system (6) according to any of the preceding claims, **characterised in that** an electronic controller (30) is configured to control injection of fluid ammonia-containing reductant by said second injector (64).
- 25 16. The exhaust system (6) according to any of claims 4 or 5, **characterised in that** said second injector (46) is provided downstream of said particulate filter (14).
- 30 17. Method of operating an exhaust system (6) comprising a first SCR catalyst (10);  
a second SCR catalyst (16) positioned downstream of said first SCR catalyst (10);

a first injector (44) provided upstream of said first SCR catalyst (10); and a second injector (64) provided upstream of said second SCR catalyst (16), wherein the method comprises the steps of controlling injection of gaseous ammonia by a first injector (44), such that supply  
5 of gaseous ammonia to said exhaust gas by said first injector (44) is limited to a operation mode where a temperature ( $T_{SCR1}$ ) associated with said first SCR catalyst (10) is above a first value ( $T_1$ ), and a temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst (16) is below a second value ( $T_2$ ), thereby at least partly facilitating high NOx  
10 conversion efficiency of said exhaust gas at temperatures when NOx conversion efficiency of said exhaust gas by said second SCR catalyst (16) is low.

18. Method according to claim 17, wherein temperature ( $T_{scm}$ ) associated  
15 with said first SCR catalyst (10) is the temperature of the exhaust gas in the region directly upstream of said first SCR catalyst (10), and said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst (16) is the temperature of the exhaust gas in the region directly upstream of said second SCR catalyst (16), and said first value ( $T_1$ ) is 120 °C,  
20 preferably 150 °C, and said second value ( $T_2$ ) is 270 °C, preferably 250 °C.

19. Method according to claim 17 or 18, comprising the step of controlling  
25 injection of fluid ammonia-containing reductant by said second injector (64), such that supply of ammonia-containing reductant to said exhaust gas by said second injector (64) is limited to an operation mode where a temperature level ( $T_{SCFS}$ ) associated with said second SCR catalyst (16) is above a third value ( $T_3$ ).

30 20. Method according to claim 19, wherein said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst (16) is the temperature of

the exhaust gas in the region directly upstream of said second SCR catalyst (16), and said third value ( $T_3$ ) is 200 °C, preferably 250 °C.

- 5 21. An exhaust system for receiving an exhaust gas, said exhaust system comprising:
- a first SCR catalyst;
  - a second SCR catalyst positioned downstream of said first SCR catalyst;
  - a first injector provided upstream of said first SCR catalyst; and
  - 10 a second injector provided upstream of said second SCR catalyst, wherein said exhaust system further comprising:
    - a gaseous ammonia supply device being fluidly connected to said first injector for supplying gaseous ammonia to said exhaust gas by said first injector;
    - 15 an ammonia-containing reductant reservoir being fluidly connected to said second injector for supplying a fluid ammonia-containing reductant, such as urea, to said exhaust gas by said second injector; wherein said first SCR catalyst has a smaller volume than said second SCR catalyst for a fast warm-up of said first SCR catalyst.
- 20 22. The exhaust system according to claim 21, the volume of said first SCR catalyst is within a range of 5% to 60% of the volume of said second SCR catalyst, preferably within a range of 5% to 40% of the volume of said second SCR catalyst, and more preferably within a
- 25 range of 10% to 25% of the volume of said second SCR catalyst.
23. The exhaust system according to claim 21 or 22, wherein said exhaust system further comprising an ammonia oxidation catalyst located downstream of said second SCR catalyst.
- 30

24. The exhaust system according to any of claims 21-23, wherein a particulate filter is positioned between said first and second SCR catalyst.
- 5 25. The exhaust system according to claim 24, wherein said exhaust system further comprising an oxidation catalyst located downstream of said first SCR catalyst and upstream of said particulate filter.
- 10 26. The exhaust system according to any of claims 21-25, wherein said first SCR catalyst is a vanadia-based catalyst, and said second SCR catalyst is a zeolite-based catalyst.
27. The exhaust system according to any of claims 21-26, wherein said gaseous ammonia supply device comprises:
- 15 a storage container, which is configured to store an alkaline earth metal chloride salt that is the source of said gaseous ammonia; or
- a storage container holding a solution of ammonia dissolved in a solvent, such as water; or
- 20 a gas bottle holding pressurised ammonia gas.
28. The exhaust system according to any of claims 21-27, wherein said first injector is formed by a metal pipe that passes through a side wall of an exhaust passage of said exhaust system, and exhibits an
- 25 discharge opening within said exhaust passage, such that gaseous ammonia from said gaseous ammonia supply device can be supplied to an exhaust gas flow within said exhaust passage by means of said metal pipe.
- 30 29. The exhaust system according to claim 28, wherein said first injector is free from parts made of thermo-plastic material, or other heat sensitive materials.

30. The exhaust system according to any of claims 21-29, wherein an electronic controller is configured to control injection of gaseous ammonia by said first injector, such that supply of gaseous ammonia to said exhaust gas by said first injector is limited to a operation mode where a temperature ( $T_{SCR1}$ ) associated with said first SCR catalyst is above a first value ( $T_1$ ), and a temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst is below a second value ( $T_2$ ), thereby at least partly facilitating high NOx conversion efficiency of said exhaust gas at temperatures when NOx conversion efficiency of said exhaust gas by said second SCR catalyst (16) is low.
31. The exhaust system according to claim 30, wherein said temperature ( $T_{SCR1}$ ) associated with said first SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said first SCR catalyst, and said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said second SCR catalyst, and said first value ( $T_1$ ) is 120 °C, preferably 150 °C, and said second value ( $T_2$ ) is 270 °C, preferably 250 °C.
32. The exhaust system according to any of claims 21-31 wherein an electronic controller is configured to control injection of fluid ammonia-containing reductant by said second injector, such that supply of ammonia-containing reductant to said exhaust gas by said second injector is limited to an operation mode where a temperature level ( $T_{SCR2}$ ) associated with said second SCR catalyst is above a third value ( $T_3$ ).
33. The exhaust system according to claim 32, wherein said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst is the temperature

of the exhaust gas in the region directly upstream of said second SCR catalyst (16), and said third value ( $T_3$ ) is 200 °C, preferably 250 °C.

5 34. The exhaust system according to any of claims 21-33, wherein said first SCR catalyst is arranged less than 0.6 metres downstream from an exhaust manifold outlet or turbo exhaust outlet of said engine, preferably less than 0.4 metres downstream from an exhaust manifold outlet or turbo exhaust outlet, and more preferably less than 0.25 metres downstream from an exhaust manifold outlet or turbo exhaust outlet.  
10

35. The exhaust system according to any of claims 21-34, wherein an electronic controller (30) is configured to control injection of fluid ammonia-containing reductant by said second injector (64).  
15

36. The exhaust system according to any of claims 34 or 35, wherein said second injector is provided downstream of said particulate filter.

20 37. Method of operating an exhaust system comprising a first SCR catalyst;  
a second SCR catalyst positioned downstream of said first SCR catalyst;  
a first injector provided upstream of said first SCR catalyst; and a second injector provided upstream of said second SCR catalyst,  
25 wherein the method comprises the steps of controlling injection of gaseous ammonia by a first injector, such that supply of gaseous ammonia to said exhaust gas by said first injector is limited to a operation mode where a temperature ( $T_{SCR1}$ ) associated with said first SCR catalyst is above a first value ( $T^1$ , and a temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst is below a second value ( $T_2$ ), thereby at least partly facilitating high NOx conversion efficiency  
30



of said exhaust gas at temperatures when NO<sub>x</sub> conversion efficiency of said exhaust gas by said second SCR catalyst (16) is low.

5 38. Method according to claim 37, wherein temperature ( $T_{scm}$ ) associated with said first SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said first SCR catalyst, and said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said second SCR catalyst, and said first value ( $T_1$ ) is 120 °C, preferably 10 150 °C, and said second value ( $T_2$ ) is 270 °C, preferably 250 °C.

15 39. Method according to claim 37 or 38, comprising the step of controlling injection of fluid ammonia-containing reductant by said second injector, such that supply of ammonia-containing reductant to said exhaust gas by said second injector is limited to an operation mode where a temperature level ( $T_{SCR2}$ ) associated with said second SCR catalyst is above a third value ( $T_3$ ).

20 40. Method according to claim 39, wherein said temperature ( $T_{SCR2}$ ) associated with said second SCR catalyst is the temperature of the exhaust gas in the region directly upstream of said second SCR catalyst, and said third value ( $T_3$ ) is 200 °C, preferably 250 °C.

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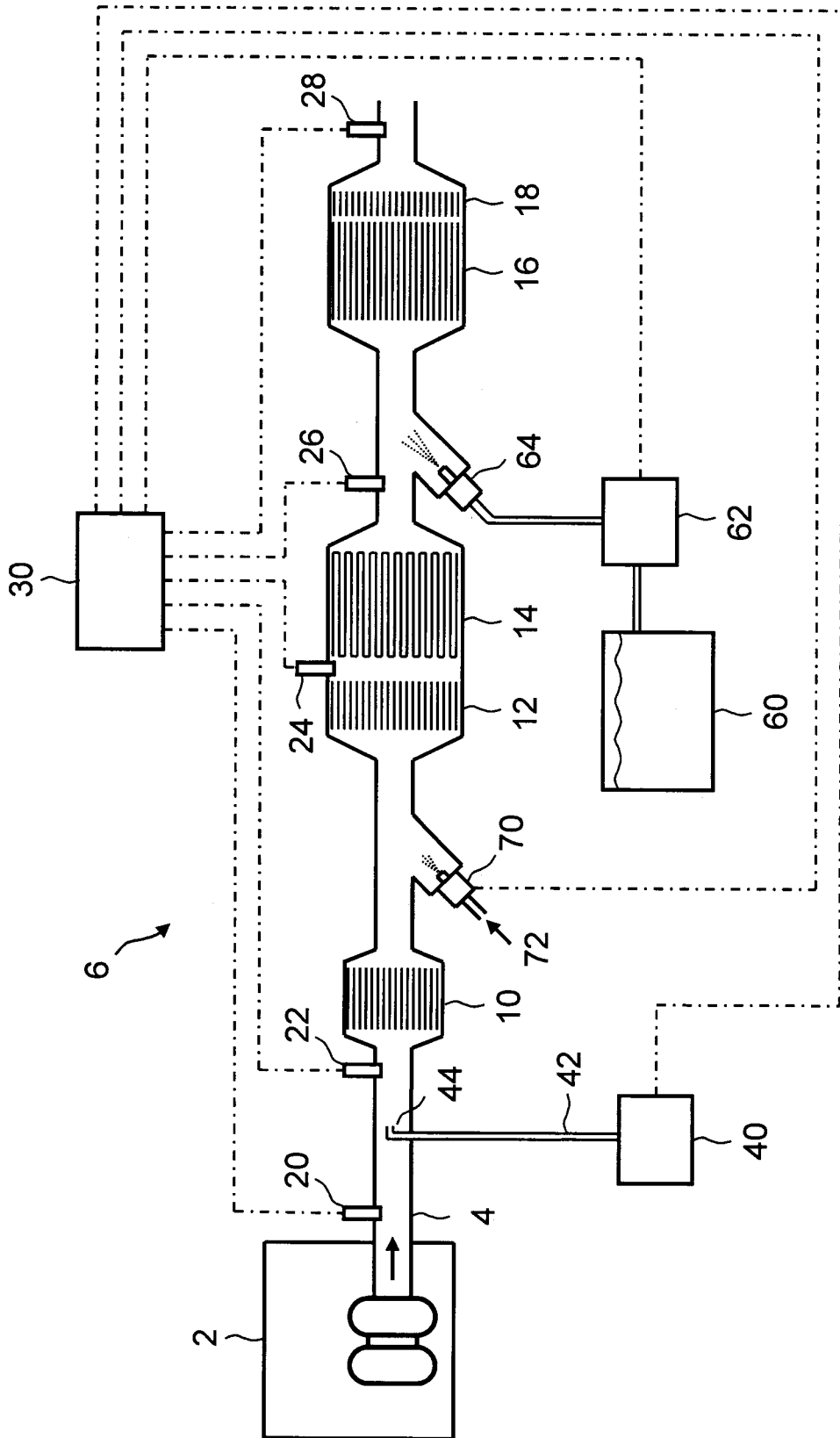


FIG.1

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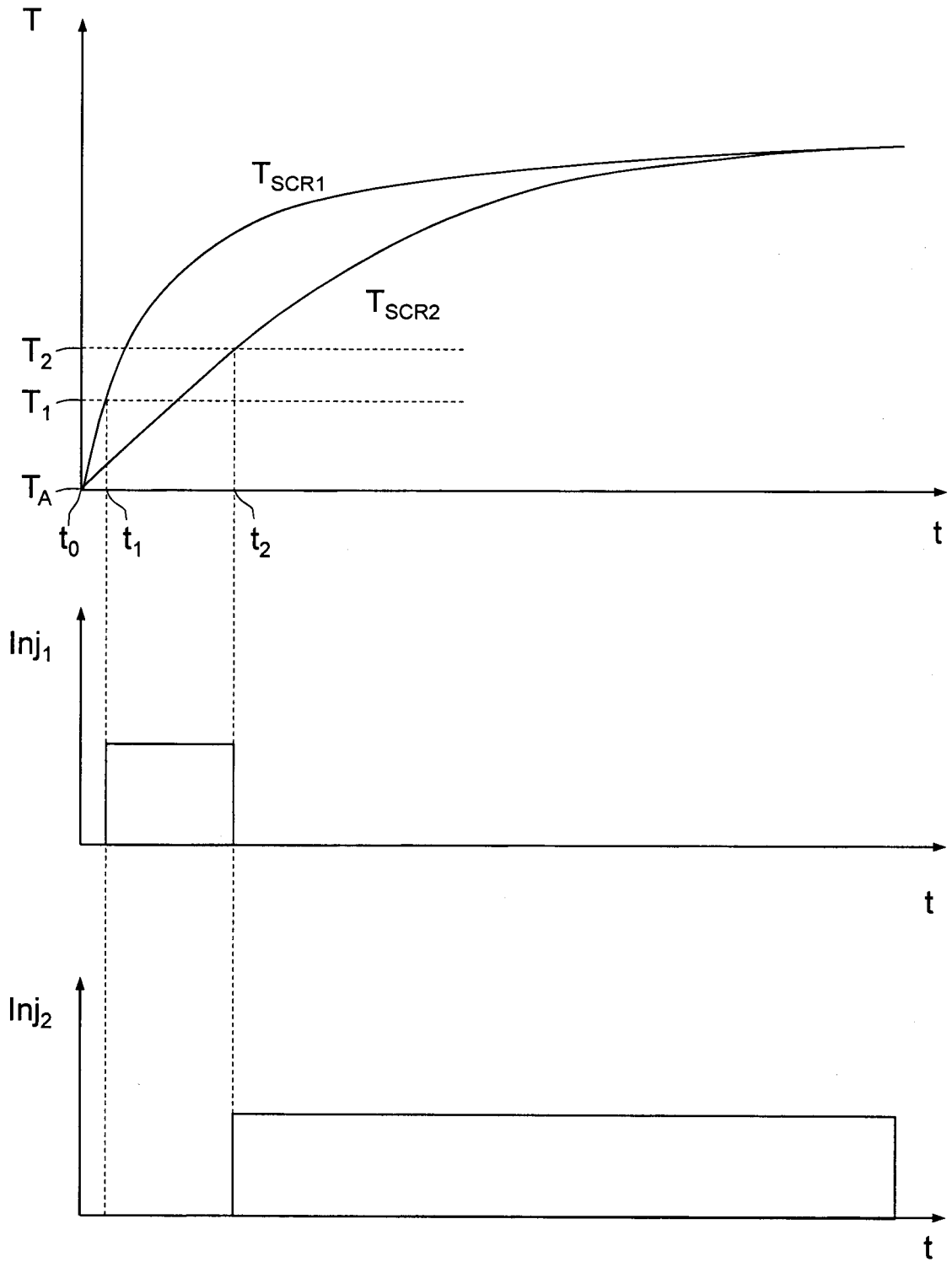


FIG.2

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/SE201 1/000248

A. CLASSIFICATION OF SUBJECT MATTER IPC: see extra sheet According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC: F01 N Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched SE, DK, FI, NO classes as above Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, PAJ, WPI data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 20070051 096 A 1 (PFEIFER MARKUS ET AL), 8 March 2007 (2007-03-08); paragraphs [001 0]-[001 7], [0021 ], [0037]; figure 1 --	1-40
A	WO 9956858 A2 (SIEMENS AG ET AL), 11 November 1999 (1999-11-11); page 2, line 6 - line 12; page 6, line 12 - line 34; figure 1 --	1-40
A	US 201 10283680 A 1 (GEKAS IOANNIS ET AL), 24 November 201 1 (201 1-11-24); paragraph [0048] --	1, 17, 21, 37
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
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## INTERNATIONAL SEARCH REPORT

 International application No.  
 PCT/SE201 1/000248

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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**Continuation of:** second sheet

**International Patent Classification (IPC)**

**F01N 3/20** (2006.01 )

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Information on patent family members

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PCT/SE201 1/000248

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