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(54) **METHOD TO REDUCE THE IGNITION TEMPERATURE OF SOOT BEING ACCUMULATED ON A PARTICULATE TRAP**

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(57) **ABSTRACT**

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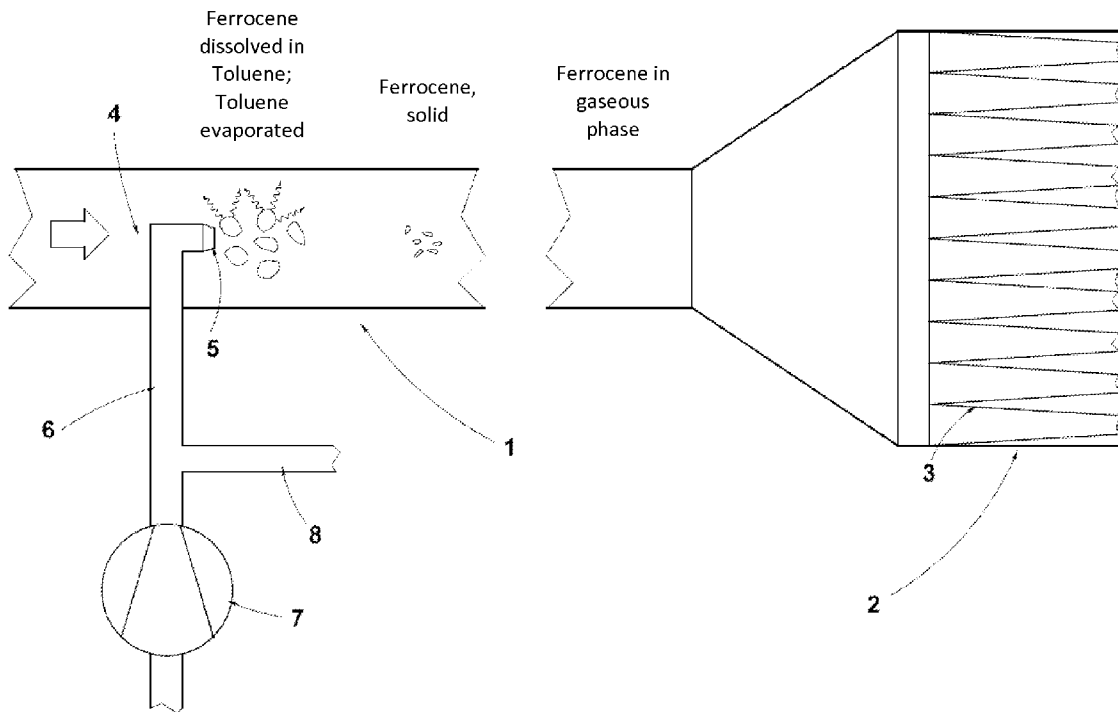
A method for lowering the ignition temperature of soot accumulated on a particulate filter 2 installed in exhaust tract 1 of an internal combustion engine is described. In this method, a precursor of a catalyst which lowers the oxidation temperature of soot is introduced into exhaust tract 1 downstream from the internal combustion engine and upstream from particulate filter 2. The precursor introduced into exhaust tract 1 is converted to its gaseous phase within exhaust tract 1 prior to contacting the soot accumulated on particulate filter 2. The gaseous catalyst precursor is adsorbed by the soot accumulated on particulate filter 2. Subsequently the catalyst responsible for lowering the ignition temperature is formed from the gaseous precursor in a reaction with at least one other component contained in the exhaust gas flow.

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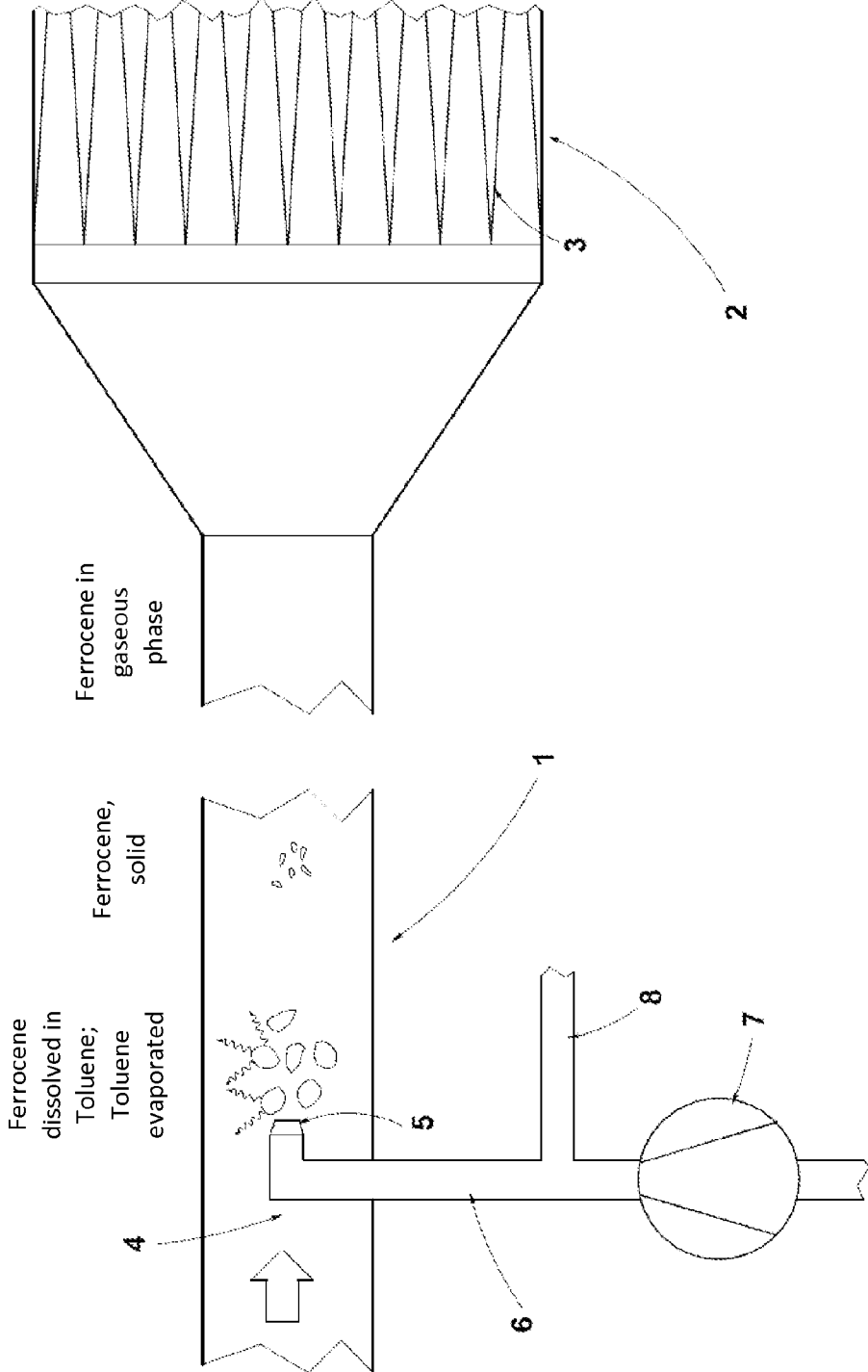


Fig. 1

**METHOD TO REDUCE THE IGNITION
TEMPERATURE OF SOOT BEING
ACCUMULATED ON A PARTICULATE TRAP**

CROSS REFERENCE APPLICATIONS

[0001] This application claims priority from German application number 10 2010 038 148.8 filed Oct. 13, 2010, which is hereby incorporated in its entirety for all purposes.

BACKGROUND

[0002] To purify the exhaust gases emitted from an internal combustion engine such as a diesel engine, it is sometimes necessary that the exhaust gas or the exhaust gas purification unit must have a certain minimum temperature. The exhaust gas is sometimes heated using additional measures such as connecting an exhaust gas burner so that the exhaust gas treatment operation can be preformed even if the exhaust gas and thus the exhaust gas purification unit is not yet at the minimum temperature.

[0003] Diesel engines are equipped with exhaust gas purification systems for reducing harmful emissions. The exhaust gas expelled from such a diesel engine is passed through an exhaust gas purification system for this purpose. The exhaust gas purification system includes an exhaust tract in which one or more exhaust gas purification units are installed. A particulate filter may be installed in the exhaust tract to remove the soot in the exhaust gas. The soot in the exhaust gas accumulates on the inflow-side surface of the particulate filter. The soot is burned off when the soot load on the filter is sufficiently high to clog the filter to prevent the exhaust gas counterpressure from increasing excessively during the successive soot accumulation. The particulate filter is regenerated when a soot burn-off is completed. A non-combustible ash residue remains on the filter. For the soot burn-off to occur the soot must have a specific temperature, called soot ignition temperature. The required temperature for triggering soot burn-off is not always attained by the inflowing exhaust gas depending on the operation of the diesel engine. Additional measures must be taken for triggering a regeneration process in these circumstances. This can be done by heating the filter body or its inflow-side surface with the aid of electrical heating elements or by heating the exhaust gas flowing to the filter by using burners and/or oxidation catalysts, which are brought into contact with fuel to increase the exhaust gas temperature.

[0004] It is also known to lower the soot ignition temperature is by supplying a catalyst. Such catalysts are used in the form of an additive containing a precursor of the catalyst. Additives of this type are typically mixed into the fuel. The additive is supplied to the internal combustion engine with the fuel. The catalyst is formed from the precursor during the combustion process and deposited on the soot being formed at the same time. The catalyst flows with the soot through the exhaust tract until the soot particles are captured by a particulate filter.

[0005] Ferrocene is used in many cases as additive. In addition to supplying ferrocene as additive and the iron oxide Fe_xO_y , for example Fe_2O_3 , formed therefrom during the conversion in the internal combustion engine, it is known from EP 0 543 477 B1 to supply ferrocene in the gaseous form to the combustion chamber of the internal combustion engine. In these methods, the catalyst is also formed together with the soot during the process of combustion of the fuel by the

internal combustion engine. In the two above-described methods, the soot emitted by the internal combustion engine already has a lowered ignition temperature. Accordingly, the soot accumulated in a particulate filter installed in the exhaust tract has a lowered ignition temperature within the entire filter cake.

[0006] In the above methods, a known problem is that the additive introduced into the combustion chamber can have a disadvantageous impact at the time of the injection or in the units used for fuel injection when supplying the catalyst to the soot by converting the catalyst precursor in the engine compartment of the internal combustion engine. Against this background, methods have been developed in which the catalyst precursor is introduced into the exhaust tract downstream from the internal combustion engine. Such a method is known, for example, from EP 1 741 886 A1. In this method, a dissolved metal colloid is injected into the exhaust tract as catalytic precursor for the purpose of evaporating the solvent and then depositing the catalyst contained therein on the soot particles entrained in the exhaust gas flow before these are deposited from the exhaust gas flow on the surface of the particulate filter.

[0007] In addition to this previously known method, it is also known to introduce a catalyst precursor into the exhaust tract so it contacts the soot already deposited on the particulate filter. Metal colloids in solutions are also used as catalyst precursor in this method. The disadvantage of these methods is that the catalyst precursor must be supplied continuously or quasi-continuously for the entire quantity of the soot accumulated on the particulate filter to have a lowered ignition temperature. Yet EP 1 741 886 A1 also refers to a discontinuous operation of supplying the catalyst precursor. However, such an operation as described in this document is only possible when switching between operating states of the internal combustion engine at a higher load and lower or no load takes place or is possible at all. If the internal combustion engine is operated in such states, which are very different regarding their load, the catalyst precursor is supplied only in the high load range against the background that most of the soot to accumulate on the filter is formed in that case.

[0008] Of course, an effort is made to keep the quantity of additive to be supplied (catalyst or catalyst precursor) which is used for the purposes mentioned as low as possible. Since the quantities of catalyst precursor are rather small anyway, it requires a non-negligible effort to meter the catalyst precursor sufficiently accurately and not provide too great an excess amount. It must also be kept in mind in this context that metering takes place in a hot environment.

[0009] Based on this above-discussed prior art, an aspect of the present disclosure is to refine an above-described method such that the metering of a catalyst precursor into the exhaust tract simplified and an effort is made for all, or at least a predominant portion of the soot accumulated on a particulate filter to have an ignition temperature lowered by the catalyst.

[0010] The foregoing example of the related art and limitations related therewith are intended to be illustrative and not exclusive. Other limitations of the related art will become apparent to those of skill in the art upon a reading of the specification and a study of the drawings.

SUMMARY

[0011] The present disclosure relates to a method for lowering the ignition temperature of soot accumulated on a particulate filter installed in the exhaust tract of an internal com-

bustion engine. The disclosed method uses a precursor of a catalyst which lowers the ignition temperature of the soot is introduced into the exhaust tract downstream from the internal combustion engine and upstream from the particulate filter.

[0012] The following embodiments and aspects thereof are described and illustrated in conjunction with systems, tool and methods which are meant to be exemplary and illustrative, not limiting in scope. In various embodiments, one or more of the above described problems have been reduced or eliminated, while other embodiments are directed to other improvements.

[0013] Disclosed is a method in which the precursor introduced into the exhaust tract is converted into its gaseous phase within the exhaust tract prior to impinging on the soot accumulated on the particulate filter. The gaseous catalyst precursor adsorbs the soot accumulated on the particulate filter. The catalyst responsible for lowering the ignition temperature is subsequently formed from the catalyst precursor in a reaction with at least one other gaseous component contained in the exhaust gas flow.

[0014] In contrast with the previously known methods, in this method the catalyst is formed from a catalyst precursor in its gaseous phase. The catalyst is formed with the participation of at least one other gaseous component contained in the exhaust gas flow. This reaction for forming the catalyst takes place in or on the soot, and thus in situ, i.e.: directly at the one place where the catalyst is needed. In the above-described concept, use is made of the adsorbing characteristics of the soot accumulated on the particulate filter, which has adsorption characteristics like activated carbon. The gaseous catalyst precursor is adsorbed by the soot due to its above-described characteristics. The catalyst needed for lowering the ignition temperature is thus formed from the accumulated gaseous catalyst precursor by combining with at least one other gaseous component contained in the exhaust gas flow.

[0015] Furthermore, the gaseous characteristic of the catalyst precursor is used for distributing same within the soot accumulated on the particulate filter. The catalyst precursor penetrates into the soot layer due to its gaseous aggregate state and may thus be supplied to all the soot. It is assumed that this describes, for the first time, the active percolation of a catalyst precursor through a soot cake. In contrast to previously known methods, in which the catalyst is continuously deposited together with the soot particles on the inflow side surface of the particulate filter, with the subject matter of the claimed method this allows the supply of the catalyst precursor be carried out discontinuously. Due to the above-described characteristics of the claimed method, the catalyst precursor may be introduced into the exhaust tract only when a particulate filter regeneration is to be triggered. This has advantages in metering, as it is described below, as well as in monitoring and control of a particulate filter regeneration. The point in time of a particulate filter regeneration is also better determined and unintended regeneration processes are avoided because in this operation the soot ignition temperature is lowered only directly before a regeneration process. This is true mainly when soot oxidation and thus soot burn-off is to be avoided when the accumulated quantity of soot is not yet sufficiently large for performing an optimum soot burn-off.

[0016] The catalyst precursor is introduced into the exhaust tract downstream from the internal combustion engine and upstream from the particulate filter. Use is made of the cir-

cumstance that the catalyst precursor is in the exhaust tract for a certain dwell time and changes its aggregate state into the gaseous phase during this dwell time. The supplied gaseous catalyst precursor is brought into contact with all, or nearly all, soot particles which then adsorb the catalyst due to the permeability of the soot cake accumulated on the particulate filter. It is not required that the soot particles have a lowered ignition temperature during the process of deposition from the exhaust gas flow. Rather, in this method the catalyst precursor may be supplied discontinuously. Typically the precursor is supplied in connection with a regeneration process of the particulate filter. The catalyst precursor is supplied in advance of the actual regeneration process being started or triggered. The advance timing is chosen such that sufficient time is available for the catalyst to be formed from the gaseous catalyst precursor adsorbed by the soot particles. This reaction may take several minutes.

[0017] In such a discontinuous operation of the supply of the catalyst precursor the quantity to be metered is exponentially higher compared to metering when the catalyst precursor must be supplied continuously to the exhaust tract during the entire operation of the internal combustion engine. As an example, if a quantity of 60 mL of catalyst precursor is needed for providing sufficient quantity of catalyst for the desired lowering of the ignition temperature of a soot accumulated on a particulate filter, in the claimed method 6 mL/min of the catalyst precursor is introduced into the exhaust tract approximately 10 minutes prior to the regeneration process. In this example, the quantity of soot accumulated on the particulate filter corresponds to the quantity of soot that is accumulated during an operation of the internal combustion engine for 20 hours. In conventional methods, the same quantity of catalyst precursor must be introduced continuously into the exhaust tract over the 20 hours of operation at a metering rate of 0.05 mL/min.

[0018] Advantageously, the method may be carried out if a metal oxide, for example an iron oxide, is used as catalyst for the purpose of lowering the ignition temperature of soot. Ferrocene, which is typically introduced into the exhaust tract in dissolved form, is well suited as catalyst precursor for forming an iron oxide as catalyst. Due to the temperature typically prevailing in the exhaust tract during the operation of the internal combustion engine, the solvent quickly evaporates. Toluene may be used as solvent, for example. Ferrocene, which remains in the solid form after the solvent is evaporated, is then converted into its gaseous form. When using ferrocene, this process is supported by the relatively high vapor pressure of ferrocene. Ferrocene is initially present in the solid form and has changed its aggregate state to the gaseous phase after a relatively short flow path in the exhaust tract. The oxygen contained in the exhaust gas flow is used as a further gaseous component for forming the desired iron oxide catalyst. Research has shown that when ferrocene is used as catalyst precursor, in its gaseous phase it is very effectively adsorbed by the soot accumulated on the particulate filter. In particular before the gaseous ferrocene, together with oxygen, has reacted to form the iron oxide catalyst it is absorbed by the soot. The reaction is slowed down by the typically relatively small oxygen content in the exhaust gas flow. This slow-down is used in the method to ensure that sufficient gaseous ferrocene has been adsorbed by the soot particles before the catalyst is actually formed. Of course, the

process of forming the catalyst from the gaseous catalyst precursor goes hand-in-hand with the supply of the catalyst precursor.

[0019] The description of the method makes it clear that, despite the discontinuous supply of a catalyst precursor, it is ensured that the ignition temperature of all the soot accumulated by a particulate filter, or at least of a sufficient quantity thereof, is lowered to allow controlled and full regeneration (soot burn-off) to be carried out.

[0020] In addition to the exemplary aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the accompanying drawings forming a part of this specification wherein like reference characters designate corresponding parts in the several views.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. 1 is a schematic view of a particulate filter installed in exhaust tract of a diesel engine (not illustrated).

[0022] Before explaining the disclosed embodiment of the present invention in detail, it is to be understood that the invention is not limited in its application to the details of the particular arrangement shown, since the invention is capable of other embodiments. Exemplary embodiments are illustrated in referenced figures of the drawings. It is intended that the embodiments and figures disclosed herein are to be considered illustrative rather than limiting. Also, the terminology used herein is for the purpose of description and not of limitation.

DETAILED DESCRIPTION OF THE DRAWINGS

[0023] In the illustrated exemplary embodiment, particulate filter 2 has a plurality of filter pockets 3 made of sintered metal. Soot is deposited from the exhaust gas flow on the inflow-side top of filter pocket 3 during operation of the internal combustion engine. It accumulates successively during the operation of the diesel engine on the inflow-side surfaces of filter pockets 3. Of course, while the exhaust gas counterpressure increases with the successive accumulation of soot in particulate filter 2, the accumulated soot layer continues to be permeable to the exhaust gas flow.

[0024] Downstream from the diesel engine (not shown) and upstream from particulate filter 2, a port 4 is installed in exhaust tract 1. Material may be introduced into the exhaust tract via port 4. Port 4 includes a nozzle 5 located in the exhaust tract, whose supply line leads out of exhaust tract 1. A metering pump 7 is installed in supply line 6. The inlet side of the metering pump 7 is connected, in a manner not illustrated in detail, to a storage container for storing the material to be injected into the exhaust gas flow. An air supply line 8 opens into supply line 6 downstream in the pumping direction of metering pump 7. A valve may be installed therein if desired (not shown). The material pumped during the operation of metering pump 7 and enriched with air, may thus be introduced into exhaust tract 1.

[0025] In the section of an exhaust gas purification system illustrated in FIG. 1, port 4 and the units related thereto, are used to mix in a catalyst precursor into the exhaust gas flowing through exhaust tract 1. The catalyst forming from the precursor is used for lowering the ignition temperature of the soot accumulated on particulate filter 2. In the depicted embodiment, ferrocene dissolved in toluene is thus mixed into the exhaust gas flowing in exhaust tract 1 through the port 4 during operation of the diesel engine as shown by the block

arrow in FIG. 1. Supported by the temperatures prevailing in exhaust tract 1 (270° C. to 300° C.) during operation of the diesel engine, the toluene atomized from nozzle 5 and introduced into exhaust tract 1 evaporates almost immediately, so that small ferrocene particles are entrained in the exhaust gas flow even after a short flow path of the supplied catalyst precursor. Ferrocene is converted from its solid state into its gaseous phase due to the temperature in exhaust tract 1 and supported by its sublimation, which takes place at relatively low temperatures. Therefore, gaseous ferrocene is subsequently entrained in the exhaust gas flow. The configuration illustrated in FIG. 1 is dimensioned regarding the length of the exhaust gas flow path in such a way that when dissolved ferrocene is injected during operation of the diesel engine, ferrocene is converted into its gaseous state prior to reaching particulate filter 2. The droplets introduced into exhaust tract 1 and the solid particles present after the evaporation of toluene are shown larger than scale only to elucidate the mode of operation. Actually, the liquid is atomized by nozzle 5 into minute droplets. The air introduced through air supply line 8 into the liquid flow pumped by metering pump 7 supports this atomizing process.

[0026] During an operation for supplying the catalyst precursor into the exhaust gas flow via port 4, the soot layer accumulated on the inflow-side surface of particulate filter 2 is exposed to the gaseous ferrocene contained in the exhaust gas flow. The accumulated soot acts as an active carbon filter and adsorbs the gaseous ferrocene. Since in each inflow-side filter pocket 3, the exhaust gas flows through the soot layer on the inflow-side surface of particulate filter 2, in this way gaseous ferrocene is introduced into the entire soot layer, including the soot particles directly on the filter surface of particulate filter 2.

[0027] Oxygen is also transported in the exhaust gas flow. Therefore, an iron oxide is formed from the gaseous ferrocene absorbed by the soot, which is a catalyst for lowering the activation energy of a soot oxidation necessary for filter regeneration. If a sufficient quantity of gaseous ferrocene has been introduced into the accumulated soot and the catalytic iron oxide has been formed, regeneration of particulate filter 2 may be triggered at substantially lower temperatures compared to the ignition temperature of soot without such a catalyst addition.

[0028] A special feature of the above-described method is that the catalyst needed for lowering the oxidation temperature of soot is formed in situ at the location where the catalyst is actually needed. If the catalyst were entrained in the exhaust gas flow in its oxide form, it would deposit only on the uppermost soot layer, but would not be able to penetrate to the soot particles therebelow.

[0029] The above-described mode of operation allows the catalyst precursor to be introduced into exhaust tract 1 via port 4 for the purpose of regenerating particulate filter 2 only shortly before an intended regeneration, for example when sufficient soot accumulation has been detected. The quantity of catalyst precursor introduced into exhaust tract 1 over a certain period of time is such that the catalyst formed therefrom is sufficient for lowering the oxidation temperature of all the soot accumulated on particulate filter 2. Finally, this quantity corresponds to the quantity that would be necessary to add in continuous supply of a catalyst precursor over the same time of operation of the diesel engine between two regeneration periods.

[0030] Due to the special characteristics of the method described with reference to FIG. 1, discontinuous introduction of the catalyst precursor is possible, whereby the needed quantity of catalyst is supplied in the form of the precursor may be metered in much larger quantities due to the short time period in which the quantity of catalyst precursor needed for the entire soot cake is supplied. Metering larger quantities is considerably less demanding regarding the systems needed for metering, making metering much more accurate and therefore more effective.

[0031] Of course, for carrying out the method, the catalyst precursor may be mixed into the exhaust tract also in its solid form instead of the liquid form described in the exemplary embodiment. A catalyst precursor may also be supplied in the gaseous form, for example gaseous ferrocene.

[0032] The present invention was described with reference to an exemplary embodiment. The claimed method may also be used in exhaust gas purification systems in which additional units are provided, for example for increasing the temperature in the exhaust tract or other components used in connection with an exhaust gas purification system.

[0033] While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations therefore. It is therefore intended that the following appended claims hereinafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations are within their true spirit and scope. Each apparatus embodiment described herein has numerous equivalents.

[0034] The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention as defined by the appended claims. Whenever a range is given in the specification, all intermediate ranges and subranges, as well as all individual values included in the ranges given are intended to be included in the disclosure.

LIST OF REFERENCE NUMERALS

[0035]	1 exhaust tract
[0036]	2 particulate filter
[0037]	3 filter pocket
[0038]	4 port
[0039]	5 nozzle
[0040]	6 supply line
[0041]	7 metering pump
[0042]	8 air supply line

What is claimed is:

1. A method for lowering the ignition temperature of soot accumulated in a particulate filter installed in an exhaust tract of an internal combustion engine comprising:

providing a precursor of a catalyst, said catalyst functioning to lower an ignition temperature of the soot;

introducing the catalyst into the exhaust tract downstream from the internal combustion engine and upstream from the particulate filter;

wherein the precursor introduced into the exhaust gas tract is converted within the exhaust gas tract into its gaseous phase before it contacts the soot accumulated on the particulate filter;

said gaseous catalyst precursor being absorbed by the soot accumulated on the particulate filter; and

said catalyst precursor forming the catalyst responsible for lowering the ignition temperature in a reaction with at least one other gaseous component contained in the exhaust gas flow.

2. The method as recited in claim 1, wherein an oxide is used as the catalyst, which is formed from the gaseous precursor and the oxygen contained in the exhaust gas flow.

3. The method as recited in claim 1 wherein to convert the precursor installed in the exhaust tract into its gaseous phase, the precursor is entrained in the exhaust gas flow over a certain dwell time.

4. The method as recited in claim 2 wherein to convert the precursor installed in the exhaust tract into its gaseous phase, the precursor is entrained in the exhaust gas flow over a certain dwell time.

5. The method as recited in claim 1 wherein a material whose vapor pressure favors a change of the aggregate state into the gaseous phase is introduced into the exhaust tract as precursor.

6. The method as recited in claim 2 wherein a material whose vapor pressure favors a change of the aggregate state into the gaseous phase is introduced into the exhaust tract as precursor.

7. The method as recited in claim 3 wherein a material whose vapor pressure favors a change of the aggregate state into the gaseous phase is introduced into the exhaust tract as precursor.

8. The method as recited in claim 4 wherein a material whose vapor pressure favors a change of the aggregate state into the gaseous phase is introduced into the exhaust tract as precursor.

9. The method as recited in claim 1 wherein the precursor is introduced into the exhaust tract in a dissolved form or a gaseous form.

10. The method as recited in claims 2 wherein the precursor is introduced into the exhaust tract in a dissolved form or a gaseous form.

11. The method as recited in claims 5 wherein the precursor is introduced into the exhaust tract (1) in a dissolved form or a gaseous form.

12. The method as recited in claim 7 wherein the precursor is introduced into the exhaust tract (1) in a dissolved form or a gaseous form.

13. The method as recited in claim 1 wherein the precursor is introduced into the exhaust tract as dissolved or gaseous ferrocene.

14. The method as recited in one of claim 3, wherein the precursor is introduced into the exhaust tract as dissolved or gaseous ferrocene.

15. The method as recited in claim 5, wherein the precursor is introduced into the exhaust tract as dissolved or gaseous ferrocene.

16. The method as recited in claim 1 wherein the method is carried out within the scope of a regeneration of the particulate filter with sufficient advance timing before an intended regeneration so that the catalyst may form from the precursor and another gaseous component in the exhaust gas flow.

17. The method as recited in claim **2** wherein the method is carried out within the scope of a regeneration of the particulate filter with sufficient advance timing before an intended regeneration so that the catalyst may form from the precursor and another gaseous component in the exhaust gas flow.

18. The method as recited in claim **16**, wherein the mixing-in of the precursor is terminated before the regeneration process is started or triggered

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