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(54) **EXHAUST PROCESSING SYSTEM, USE THEREOF AND VEHICLE COMPRISING THE SAME**

(57) The present invention relates to an exhaust processing system for processing exhaust particles comprising at least one catalytic converter; at least one plasma apparatus comprising at least one first electrode structure and at least one second electrode structure. The exhaust processing system further comprises at least one voltage source connected to the first and/or second electrode structures. The voltage source is configured to create a potential difference between the first and second electrode structures such that at least one electrical discharge occurs in a discharge region between the first and second electrode structures, each electrical discharge having a discharge path. The catalytic converter and the plasma apparatus provide a passage configured to accommodate the flow of exhaust particles therethrough such that the exhaust particles pass through the discharge region of the plasma apparatus.

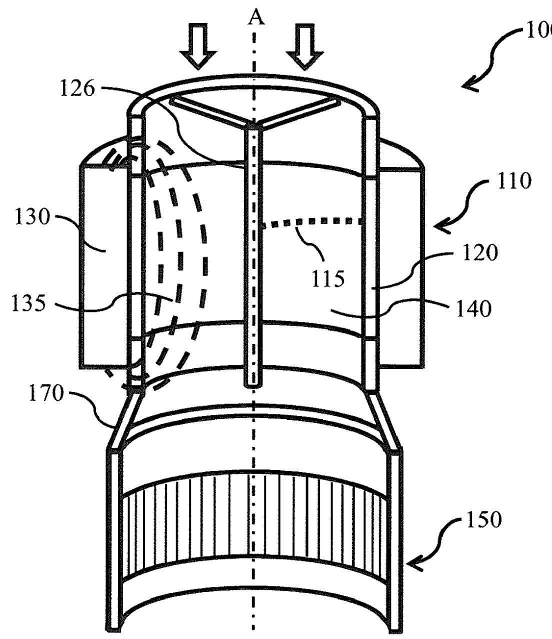

Fig. 2

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Description

Background

[0001] The invention relates to a plasma apparatus for the processing of exhaust molecules produced by combustion engines or other devices. In particular, the invention relates to a plasma apparatus for the processing of exhaust molecules in combination with a catalytic converter.

[0002] The exhaust produced in a combustion engine may include a variety of particles which are hazardous or deleterious to the environment, such as NOx, SOx, HC, CO, CO_2. The standard method for processing said exhaust molecules in, for instance, automobiles, is to pass the exhaust gases through a catalytic converter.

[0003] Although a catalytic converter may effectively reduce unwanted emissions under certain circumstances, said efficacy is not reached under all circumstances. Notably, catalytic efficiency can only be reached within a certain temperature zone, generally at around 800 K and above. Consequently, during the "cold start" phase of an engine beginning to run, the exhaust is processed by the catalytic converter with markedly reduced efficacy. Consequently, the cold start phase of engine operation contributes disproportionally to the overall amount of environmentally damaging emissions released by combustion engine systems.

[0004] Thus, one problem present in the known technology is the limited exhaust handling of a combustion engine under certain conditions.

[0005] WO 2017/021194 A1, incorporated herein by reference, describes methods and devices for producing plasma. The apparatus for producing plasma requires at least a first electrode and a second electrode with a potential difference existing between them. The potential difference produces a discharge path between said electrodes in a discharge region between them. A magnetic field device is arranged such that a magnetic field vector is oriented at an angle to the discharge path. The magnetic field sets the discharge path into motion within the discharge region.

[0006] It is an object of the present invention to provide a plasma apparatus together with a catalytic converter, which together are particularly suited for processing exhaust from combustion engines and provide an improvement over known exhaust processing methods.

Summary

[0007] This object is achieved with the features of the independent claims. Dependent claims refer to preferred embodiments.

[0008] As discussed herein the term "plasma" refers to an ionized gas comprising positive ions and free electrons. A plasma apparatus is understood to be an apparatus capable of producing plasma.

[0009] According to a first aspect, the invention relates to an exhaust processing system for processing exhaust particles. The exhaust processing system comprises at least one catalytic converter and at least one plasma apparatus, the plasma apparatus comprising at least one first electrode structure and at least one second electrode structure. The plasma apparatus further comprises at least one voltage source connected to the first and/or second electrode structures, the voltage source being configured to create a potential difference between the first and second electrode structures such that at least one electrical discharge occurs in a discharge region between the first and second electrode structures, each electrical discharge having a discharge path. The catalytic converter and the plasma apparatus provide a passage configured to accommodate the flow of exhaust particles therethrough such that the exhaust particles pass through the discharge region of the plasma apparatus. The discharge region may be defined as a volume between the first and second electrode structures that is traversable by the electrical discharge and/or the exhaust particles.

[0010] Preferably the exhaust processing system is configured such that the plasma apparatus is positioned upstream of the catalytic converter. This may allow for the exhaust particles to be imparted with excitational energy by passing through the electrical discharge of the plasma apparatus. The excitational energy may subsequently be deposited in an active material of the catalytic converter, thus improving catalytic efficiency even when the exhaust is being supplied at sub-optimal temperatures.

[0011] Alternatively, the exhaust processing system is configured such that the plasma apparatus is positioned downstream of the catalytic converter. Preferably the exhaust processing system is configured such that the plasma apparatus is downstream of a first catalytic converter and upstream of a second catalytic converter.

[0012] Preferably, the plasma apparatus excites the exhaust particles, wherein the excitation energy of the exhaust particles is larger than 0.1 eV (electronvolts). The excitation energy may be defined as $k \cdot T$, wherein k is the Boltzmann constant and T the temperature of the respective particle. The exhaust processing system is then configured such that the excited exhaust particles reach the catalytic converter with an effective particle temperature that is equal to or higher than an operating temperature of the catalytic converter. Preferably, the operating temperature is equal to or higher than an optimal operating temperature of the catalytic converter at which the rate of catalytic conversion of the exhaust particles in the catalytic converter is greatest. Alternatively, the operating temperature may be defined as a temperature at which the rate of catalytic conversion of the exhaust particles in the catalytic converter is at least 70%, at least 80%, or at least 90% of the rate of catalytic conversion of the exhaust particles at the optimal operating temperature of the catalytic converter. In either case, the temperature dependent catalytic conversion rate for any one of the following particles may be used as a basis for assessing the optimal operating temperature of the catalytic converter and/or the operating temperature: NOx, SOx, HC, CO, CO_2. The type of particle considered may depend on the composition of the exhaust and the type of catalytic converter employed.

[0013] Preferably, the exhaust processing system is configured such that the exhaust particles are received by the plasma apparatus at a temperature of less than 800 K, preferably less than 700 K, more preferably less than 600 K, for example during a cold start phase of a combustion engine. In other words, the exhaust processing system may be configured such that the exhaust gas can be received by the plasma apparatus at a temperature of less than 800 K, preferably less than 700 K, more preferably less than 600 K. Meanwhile, the exhaust processing system is preferably configured to emit the exhaust particles from the plasma apparatus at an effective temperature of at least 800 K or at least 1000 K. During the "cold start" phase of an exhaust producing operation this allows catalytic conversion to take place at heightened efficiency than would happen with only a catalytic converter.

[0014] Preferably the exhaust processing system is configured to have a distance between the discharge region and the catalytic converter which is 50 cm or less, 30 cm or less, 20 cm or less, or 15 cm or less. Without wanting to be bound by theory, it is believed by the inventors that with smaller separation distances a greater portion of excitation energy of the exhaust particles is retained at the time of entry into the catalytic converter.

[0015] Optionally, the catalytic converter and the plasma apparatus are directly connected to each other. For example, the catalytic converter(s) and the plasma apparatus may be directly connected to each other without any further devices and/or tubing between them.

[0016] Preferably, the plasma apparatus is configured such that the exhaust flows parallel to a longitudinal axis thereof. A portion of the passage comprised within the plasma apparatus may be cylindrically or conically shaped, e.g. as a hollow cylinder or as a hollow cone. Such a configuration may allow the exhaust processing system to be easily integrated within existing exhaust line pathways, for example, in exhaust lines of automobiles. While the base of the cylinder or cone could have any polygonal shape, a circular or annular shape is generally preferred. The first electrode structure and/or the second electrode structure preferably extend along said longitudinal axis. At least one of the first and second electrode structures may extend around the longitudinal axis.

[0017] The plasma apparatus preferably further comprises at least one magnetic field generating means for generating a magnetic field in the discharge region such that a magnetic field vector of the magnetic field is oriented at an angle to the discharge path, enabling the discharge path to be set into motion within the discharge region. Optionally, the electrical discharge path of the electrical discharge rotates around the longitudinal axis of the plasma apparatus.

[0018] Preferably the magnetic field generating means is not interposed between the first and second electrode structure. Alternatively or additionally, the magnetic field generating means may surround the first electrode structure and/or at least a portion of the second electrode structure. This configuration may allow for a substantially uniform magnetic field within the discharge region.

[0019] Preferably the magnetic field system is configured to provide a magnetic field strength of at least 0.5 Tesla, preferably at least 1.0 Tesla, and more preferably at least 2.0 Tesla. Optionally the voltage source is configured to provide a current greater than 20 mA, preferably greater than 50 mA, and more preferably greater than 100 mA. The strength of the magnetic field influences the speed of progression/rotation of the electrical discharge through the discharge region. The current provided by the voltage source influences the distance between the first electrode and second electrode structure that can be spanned by an electrical discharge. Without wanting to be bound to these values, it is believed that these field and/or current strengths are suitable for the intended applications.

[0020] Preferably the exhaust particles delivered to the exhaust processing system are produced by an exhaust producing mechanism and the plasma apparatus is operated during a cold start phase of said exhaust producing mechanism.

[0021] Catalysts used in the catalytic converter may include platinum, palladium and/or rhodium, as generally known in the art.

[0022] According to a further aspect, the invention is directed to a combustion engine being provided with an exhaust processing system as described herein, wherein the combustion engine is configured to produce exhaust during operation and the exhaust processing system is configured to receive exhaust therethrough.

[0023] According to a further aspect, the invention is also directed to the use of an exhaust processing system with an exhaust producing mechanism. Use of the system comprises the steps of providing an exhaust processing system as described herein which is coupled to the exhaust producing mechanism, flowing exhaust through the plasma apparatus, and flowing exhaust through the catalytic converter. Use of the system may improve the output of exhaust producing mechanisms by processing environmentally damaging particles before they are emitted.

[0024] Preferably the use of the exhaust processing system further includes use of the system with a combustion engine, e.g. an internal combustion engine. Use with combustion engines, for example, within generators, airplanes, tractors, automobiles, ships and other vehicles is envisioned. Applications may also include the use of the exhaust processing system to treat exhaust of a turbine, e.g. a gas turbine or a turbine of an airplane.

[0025] Preferably the exhaust is first flowed through the plasma apparatus and then flowed through the catalytic converter. Use in this manner may excite exhaust particles to bring activation energy with them into the catalytic converter. This may result in catalytic conversion taking place even during phases of engine operation which are unfavorable to catalytic conversion processes, such as, at low temperatures during a cold start phase. Without wanting to be bound by theory, it is believed that the use of such plasma apparatus may be particularly advantageous during a cold start phase of the engine, while it may be less advantageous when the engine is a warm. It is thus also envisioned, that the plasma apparatus is only operated during the cold start phase.

[0026] Preferably the exhaust particles are excited, dissociated, and/or ionized by the plasma apparatus such that the exhaust particles have a higher energy level upon leaving the plasma apparatus than upon entering the plasma apparatus. An energy level of exhaust particles may be expressed in electron volts (eV) or in effective temperature (Kelvin).

[0027] Preferably the catalytic converter of the exhaust processing system has an optimal operating temperature at which the rate of catalytic conversion of the exhaust particles is greatest. Passing exhaust particles through the plasma apparatus may provide an increased catalytic conversion rate of the exhaust particles compared to when the exhaust particles are emitted from the exhaust producing mechanism with a temperature below the optimal operating temperature. Operation of the exhaust processing system at exhaust intake temperatures below optimal operating temperature of the catalytic converter may also be known as the "cold start" phase. Preferably at least one electrical discharge is produced in the plasma apparatus during a cold start phase of the exhaust producing mechanism. Optionally, no electrical discharge is produced in the plasma apparatus when the exhaust producing mechanism reaches a determined operation temperature. If the plasma apparatus is configured to only operate during the cold start phase of the exhaust producing mechanism, energy and therefore fuel can be conserved when the exhaust producing mechanism is operating at temperatures sufficient for optimal catalytic conversion.

[0028] As optionally applicable to all aspects described herein, the voltage source may be configured to provide a pulsed electrical current. The pulsed electrical current may have a period between 10 and 1000 milliseconds, preferably between 100 and 500 milliseconds, or a period of at least 10 milliseconds, at least 50 milliseconds, or at least 100 milliseconds. Alternatively or additionally, the voltage source may be configured to provide a pulsed electrical current having a duty cycle of at most 0.7 or at most 0.5. For example, the duty cycle may be between 0.7 and 0.05, preferably between 0.5 and 0.1.

[0029] According to a further aspect, the invention is also directed to a vehicle with an exhaust processing system as described herein. Preferably, the vehicle further comprises a turbine or a combustion engine, e.g. an internal combustion engine. A vehicle equipped with an exhaust processing system as described herein may help to reduce overall vehicle emissions of environmentally damaging exhaust particles.

[0030] According to a further aspect, alternate exhaust processing systems are envisioned in which the plasma apparatus does not comprise a magnetic field generating means. In such a configuration the electrical discharge is not set into motion within in the discharge region.

Brief Description of the Drawings

[0031] The subject matter of the invention will be explained in more detail in the following text with reference to preferred exemplary and non-limiting embodiments which are illustrated in the attached drawings. These figures disclose embodiments of the invention for illustrational purposes only. In particular, the disclosure provided by the figures and description is not meant to limit the scope of protection conferred by the invention.

Fig. 1 schematically shows a perspective view of an example of the exhaust processing system;

Fig. 2 schematically shows a cross-sectional view of one example of the exhaust handling system including plasma apparatus and catalytic converter;

Fig. 3 schematically shows a cross-sectional view of one example of the exhaust handling system.

Detailed Description

[0032] Fig. 1 schematically depicts an exhaust processing system 100 including a plasma apparatus 110 in connection with a catalytic converter 150. The arrows indicate the direction of exhaust flow through the exhaust processing system 100. The exhaust may be arriving at the exhaust processing system directly from a combustion engine or may optionally undergo other processes before arriving at the exhaust processing system 100.

[0033] In preferred examples of the system 100, the plasma apparatus 110 may be directly connected to the catalytic converter 150, as shown in Fig. 1. The plasma apparatus 110 and the catalytic converter 150 may be of a similar size and/or may be adapted to fit within the exhaust line of an automobile. In an alternative arrangement, the plasma apparatus 110 may be placed downstream from the catalytic converter 150.

[0034] Fig. 2 provides a cross-sectional view of an example of the exhaust processing system. Arrows indicate the direction of exhaust flow through the exhaust processing system 100. In this example the exhaust first flows through the plasma apparatus 110 and then through the catalytic converter 150, as also indicated in Fig. 1. The plasma apparatus 110 and the catalytic converter 150 may be separate elements as depicted in Fig. 2, which are joined by an intermediate section 170.

[0035] Alternatively, other configurations of the exhaust processing system 100 are foreseen in which multiple plasma apparatuses 110 may be positioned upstream of the catalytic converter 150. Said multiple plasma apparatuses 110 may be positioned to process the exhaust gas either in series or in parallel. Different configurations of plasma apparatuses 110 are described in WO 2017/021194 A1, the disclosure of which is hereby incorporated by reference in its entirety.

[0036] In preferred examples of the exhaust processing system 100, a portion of a passage comprised within the exhaust processing system 100 is cylindrically shaped and configured such that the exhaust flows parallel to a longitudinal axis A of the exhaust processing system 100, as also shown in Fig. 2.

[0037] The plasma apparatus 110 comprises at least one first electrode structure 120 and at least one second electrode structure 126. The at least one first electrode structure 120 may be structured as a ring or open cylinder electrode. The at least one second electrode structure 126 may be structured as a wire electrode, a cylinder electrode, or a pin electrode and is preferably aligned along the longitudinal axis A. Further structures for the first electrode structure 120 and the second electrode structure 126 are possible, in which the distance between the first electrode structure 120 and the second electrode structure 126 is constant throughout the plasma apparatus 110.

[0038] At least one voltage source (not shown) supplies a voltage to the plasma apparatus 110 such that a potential difference is formed between the at least one first electrode structure 120 and the at least one second electrode structure 126. The voltage provided by the voltage source is high enough to overcome the electrical resistance of the gases interposed between the first and second electrode structures 120, 126 such that an electrical discharge 115 is formed therebetween. The voltage source may be configured to provide a current greater than 20 mA, greater than 50 mA or even greater than 100 mA. The amount of current provided may be increased with increasing distance between the at least one first electrode structure 120 and the at least one second electrode structure 126. Alternatively, the voltage source may be a car battery or other automobile voltage source and the dimensions of the first and second electrode structures 120, 126 may be adapted to suit the current and voltage available from these sources. In some configurations the voltage source may be configured to provide a pulsed or intermittent potential difference. In some circumstances the plasma discharge may continue to provide an ionizing/dissociating effect within the discharge region for a time after being terminated. Thus, this plasma "afterglow" can potentially be utilized to reduce overall power requirements of the plasma apparatus and the temperature of gases flowing through the plasma apparatus could potentially be lowered. The voltage source may then be configured to provide a pulsed electrical current having a period between 10 and 1000 milliseconds, or preferably between 50 and 800 milliseconds. The voltage source may also be configured to provide a pulsed electrical current having a duty cycle between 0.7 and 0.05, preferably between 0.5 and 0.1.

[0039] The electrical discharge 115 may follow a relatively straight path between the at least one first electrode structure 120 and the at least one second electrode structure 126. Alternatively, the discharge path of the electrical discharge 115 may be curved or elongated. The electrical discharge 115 occurs in a discharge region 140 which exists principally between the at least one first electrode structure 120 and the at least one second electrode structure 126. In one example shown in Fig. 2, the discharge region 140 is cylindrical with the second electrode structure 126 disposed through the center along the longitudinal axis A (thus forming a hollow cylinder). However, the discharge region 140 may take on many complex forms, including a disc-shape, a rectangular form, an arctuate section of a ring, etc.

[0040] The plasma apparatus 110 may also form multiple electrical discharges 115 simultaneously during operation. The formation and cessation of electrical discharges 115 may take place continuously during operation of the plasma apparatus 110.

[0041] Preferably, at least one magnetic field generating means 130 is positioned so as to generate a magnetic field 135 within the discharge region 140. The magnetic field generating means 130 may be a permanent magnet or an electromagnet. In the example shown in Fig. 2 the magnetic field generating means 130 is a permanent ring magnet encompassing the first electrode structure 120, the second electrode structure 126, and the discharge region 140. In the illustrated example, the magnetic field generating means 130 is positioned outside of the discharge region 140 and/or not interposed between the first and second electrode structures 120, 126. As also shown in Fig. 2, it is preferred that the magnetic field generating means 130 at least partially overlaps with the discharge region 140. More specifically, it is preferred that the magnetic field generating means 130, when considering the position along the longitudinal axis A, at least partially overlaps with the first electrode structure 120 and/or the second electrode structure 126.

[0042] The at least one magnetic field generating means 130 may be configured to provide a magnetic field strength of at least 0.5 Tesla, preferably at least 1.0 Tesla, and even more preferably, a magnetic field strength of at least 2.0 Tesla. As the speed of progression of the electrical discharge 115 is directly related to the strength of the magnetic field 135, the magnetic field generating means' 130 magnetic field strength may be tuned to the size of the discharge region 140 and the speed of the exhaust particles.

[0043] The magnetic field generating means 130 generates a magnetic field 135 within the discharge region 140 which is at an angle with respect to the electrical discharge 115. The magnetic field 135 may be principally oriented perpendicular to the electrical discharge 115.

Alternatively, the magnetic field 135 may take on any angle with respect to the electrical discharge 115 that is non-zero. As the magnetic field 135 forms an angle relative to the electrical discharge 115, the magnetic field 135 generates Lorentz Force acting on the electrical discharge 115. This force will set the electrical discharge 115 into motion within the discharge region 140.

[0044] In an example, such as in Fig. 2, wherein the discharge region 140 is substantially cylindrical, with the second electrode structure 126 being positioned along the longitudinal axis A of the cylinder, and wherein the magnetic field 135 is principally perpendicular to the electrical discharge 115, the electrical discharge 115 will progress in a circular motion around the second electrode structure 126. In other words, the electrical discharge path will rotate around the longitudinal axis A of the plasma apparatus 110. Other configurations are also envisioned in which the electrical discharge 115 may progress along a more complex path, based on the placement of the magnetic field generating means 130. In some instances the progression of the electrical discharge 115 may even be periodically reversed. It is also envisioned that the plasma apparatus 110 may not comprise a magnetic field generating means and that the electrical discharge(s) 115 may be stationary.

[0045] As previously mentioned, the plasma apparatus 110 may be joined directly to the catalytic converter 150, or an intervening section 170 may be placed in between the plasma apparatus 110 and the catalytic converter 150. In either case, the plasma apparatus 110 and the catalytic converter 150 may be arranged such that a distance between the discharge region 140 and the catalytic converter 150 is 50 cm or less, 30 cm or less, 20 cm or less, or 15 cm or less in order to reduce loses in particle excitation energy.

[0046] Alternatively, an exhaust processing system 100 is envisioned comprising two catalytic converters. The additional catalytic converter may, in this configuration be placed in a location of the exhaust flow that has lower temperatures, which may in some cases be further away from the combustion apparatus.

[0047] Fig. 3 depicts an alternative example of the exhaust processing system 100. In this example the exhaust processing system 100 may comprise all of the features described with regard to Fig. 2, above. In addition, the plasma apparatus 110 and the catalytic converter 150 are combined within a tubular passage of a certain diameter and are within close proximity of one another.

[0048] In this configuration the plasma apparatus 110 is positioned in close proximity to the catalytic converter 150, wherein a distance B between the discharge region and the catalytic converter 150 is 50 cm or less. The distance B between the discharge region and the catalytic converter 150 may be even smaller, such as 30 cm or less, 20 cm or less, or 15 cm or less. Such a relatively small separation between the plasma apparatus and the catalytic converter 150 ensures that the exhaust molecules which are excited or otherwise imparted with energy by passing through the discharge region of the plasma apparatus retain as much energy as possible at the time they enter the catalytic converter 150.

[0049] The described configurations of the exhaust processing system 100 may be particularly useful during the "cold start" phase of an engine. During this phase of engine operation the exhaust particles entering the plasma apparatus 110 may be at a temperature of less than 800 K, less than 700 K, or less than 600 K. As the exhaust particles pass through the discharge region 140 of the plasma apparatus 110, the exhaust particles come into contact with the electrical discharge 115 as it sweeps through the discharge region 140. The electrical discharge 115 transfers energy to the exhaust molecules flowing through the discharge region 140, such that the particles are excited with an excitation energy greater than 0.05 eV, preferably greater than 0.1 eV, and more preferably greater than 0.2 eV. The excitation energy of the particle is further understood using the equation $E = kT$, where k is Boltzmann's constant and T is a temperature. Thus, with an excitation energy of 0.1 eV, for instance, this results in a corresponding effective particle temperature of around 1000 K. Said transfer of energy to the exhaust particles raises the effective temperature of the exhaust particles such that as they leave the plasma apparatus 110, the particles have an effective temperature of at least 800 K, preferably at least 1000 K.

[0050] After exiting the plasma apparatus 110, the exhaust particles (e.g. after travelling the distance B) enter the catalytic converter 150. Over the travel distance, the exhaust particles should retain much of the energy imparted by the plasma apparatus 110. Thus, the exhaust particles with said heightened effective temperatures are able to interact with the material of the catalytic converter 150 and deposit their excitation energy onto the surface of the active components of the catalytic converter 150. Thus, the localized region contact between the excited exhaust particle and the active components of the catalytic converter 150 is a local "hot spot" which consequently allows the exhaust particles to be reduced to less environmentally damaging particulates at faster rates. In other words, the present invention allows for catalytic processing of exhaust particles even at low exhaust temperatures. Without wanting to be bound by theory, it is believed that the excited exhaust particles are catalytically converted to less harmful species in the catalytic converter even at these low exhaust temperatures because each particle, due to the excitation energy received in the plasma apparatus, forms a local hot spot on the surface of the catalytic converter. At this hot spot, the temperature required for a successful catalysis is locally achieved, even when the overall temperature of the exhaust gas and/or of the overall temperature of the catalytic converter is lower.

[0051] It should also be noted that the act of passing exhaust through the plasma apparatus 110 alone may also help reduce environmentally damaging emissions, as the exhaust particles may dissociate and/or ionize upon passing through the electrical discharge 115, thus rendering the exhaust particles into a less environmentally damaging configuration.

[0052] Consequently, it is understood that the exhaust processing system 100 may reduce the emission of environmentally damaging exhaust particles as both the plasma apparatus 110 and the catalytic converter 150 may process particles independently. Additionally, the plasma apparatus 110 and the catalytic converter 150 may work together to provide a synergistic exhaust processing effect.

[0053] Optionally, the plasma apparatus 110 may be configured to only operate during the "cold start" phase of engine operation. That is to say, the plasma apparatus 110 may be operated for a period of time together with the catalytic converter 150 and during another period of time the catalytic converter 150 may operate alone.

[0054] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and non-restrictive; the invention is thus not limited to the disclosed embodiments. Variations to the disclosed embodiments can be understood and effected by those skilled in the art and practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality and may mean "at least one".

[0055] The following are preferred aspects of the invention:

1. An exhaust processing system for processing exhaust particles comprising
at least one catalytic converter;
at least one plasma apparatus, the plasma apparatus comprising

   at least one first electrode structure;

   at least one second electrode structure;

   at least one voltage source connected to the first and/or second electrode structures, the voltage source being configured to create a potential difference between the first and second electrode structures such that at least one electrical discharge occurs in a discharge region between the first and second electrode structures, each electrical discharge having a discharge path;

   wherein the catalytic converter and the plasma apparatus provide a passage configured to accommodate the flow of exhaust particles therethrough such that the exhaust particles pass through the discharge region of the plasma apparatus.

2. The exhaust processing system of aspect 1, wherein the plasma apparatus is positioned upstream of the catalytic converter.

3. The exhaust processing system of aspect 2,
wherein the plasma apparatus excites the exhaust particles;
wherein the excitation energy of the exhaust particles, kT (where k is Boltzmann's constant and T a temperature), is larger than 0.1 eV (corresponding to an effective temperature of around 1000 deg)
wherein the system is configured such that the excited exhaust particles reach the catalytic converter with an effective particle temperature that is equal to or higher than an operating temperature of the catalytic converter, preferably equal to or higher than an optimal operating temperature of the catalytic converter at which the rate of catalytic conversion of the exhaust particles in the catalytic converter is greatest.

4. The exhaust processing system of any of the preceding aspects,
wherein the exhaust particles are received by the plasma apparatus at a temperature of less than 800 K, less than 700 K, or less than 600 K; and/or
wherein exhaust particles are emitted from the plasma apparatus at an effective temperature of at least 800 K or at least 1000 K

5. The exhaust processing system of any of the preceding aspects, wherein a distance between the discharge region and the catalytic converter is 50 cm or less, 30 cm or less, 20 cm or less, or 15 cm or less.

6. The exhaust processing system of any of the preceding aspects, wherein the catalytic converter and the plasma apparatus are directly connected.

7. The exhaust processing system of any of the preceding aspects, wherein a portion of the passage comprised within the plasma apparatus is cylindrically shaped and configured such that the exhaust flows parallel to a longitudinal axis of the plasma apparatus.

8. The exhaust processing system of any of the preceding aspects, wherein the electrical discharge path rotates around a longitudinal axis of the plasma apparatus.

9. The exhaust processing system of any of the preceding aspects, wherein the plasma apparatus further comprises at least one magnetic field generating means for generating a magnetic field in the discharge region such that a magnetic field vector of the magnetic field is oriented at an angle to the discharge path enabling the discharge path to be set

into motion within the discharge region.

10. The exhaust processing system of aspect 9, wherein the magnetic field generating means is not interposed between the first and second electrode structures; and/or
wherein the magnetic field generating means surrounds the first electrode structure and at least a portion of the second electrode structure.

11. The exhaust processing system of any of aspect 9 or aspect 10,
wherein the magnetic field generating means is configured to provide a magnetic field strength of at least 0.5 Tesla, preferably at least 1.0 Tesla, and more preferably at least 2.0 Tesla.

12. The exhaust processing system of any of the preceding aspects, wherein the voltage source is configured to provide a current greater than 20 mA, preferably greater than 50 mA, and more preferably greater than 100 mA.

13. The plasma apparatus of any of the previous aspects, wherein the voltage source is configured to provide a pulsed electrical current, wherein the pulsed electrical current preferably has
a period between 10 and 1000 milliseconds, preferably between 100 and 500 milliseconds; or
a period of at least 10 milliseconds, at least 50 milliseconds, or at least 100 milliseconds.

14. The plasma apparatus of any of the previous aspects, wherein the voltage source is configured to provide a pulsed electrical current having a duty cycle of:

between 0.7 and 0.05, preferably between 0.5 and 0.1; or

at most 0.7 or at most 0.5.

15. The exhaust processing system of any of the preceding aspects, wherein the exhaust particles are produced by an exhaust producing mechanism and the plasma apparatus is operated during a cold start phase of said exhaust producing mechanism.

16. A combustion engine comprising an exhaust processing system according to any of the preceding aspects, wherein the combustion engine is configured to produce exhaust during operation and the exhaust processing system is configured to receive the exhaust therethrough.

17. Use of an exhaust processing system with an exhaust producing mechanism, comprising the steps of
providing an exhaust processing system according to any of aspects 1 to 15 coupled to the exhaust producing mechanism;
flowing exhaust through the plasma apparatus;
flowing exhaust through the catalytic converter.

18. Use of the exhaust processing system according to aspect 17, wherein the exhaust producing mechanism is a combustion engine.

19. Use of the exhaust processing system according to aspect 17 or aspect 18, wherein the exhaust is first flowed through the plasma apparatus and then flowed through the catalytic converter.

20. Use of the exhaust processing system according to any of aspects 17 to 19, wherein the exhaust particles are excited, dissociated and/or ionized by the plasma apparatus such that the exhaust particles have a higher energy level upon leaving the plasma apparatus than upon entering the plasma apparatus.

21. Use of the exhaust processing system according to any of aspects 17 to 20, wherein the catalytic converter has an optimal operating temperature at which the rate of catalytic conversion of the exhaust particles is greatest, and wherein passing exhaust particles through the plasma apparatus provides an increased catalytic conversion rate of the exhaust particles compared to when the exhaust particles are emitted from the exhaust producing mechanism with a temperature below the optimal operating temperature.

22. Use of the exhaust processing system according to any of aspects 17 to 21, wherein the at least one electrical discharge is produced in the plasma apparatus during a cold start phase of the exhaust producing mechanism, optionally wherein no electrical discharge is produced in the plasma apparatus when the exhaust producing mechanism reaches a determined operating temperature.

23. Vehicle with an exhaust processing system according to any of aspects 1 to 15 and/or performing the use according to any of aspects 17 to 22.

Claims

1. An exhaust processing system for processing exhaust particles comprising at least one catalytic converter;
at least one plasma apparatus, the plasma apparatus comprising

at least one first electrode structure;
at least one second electrode structure; and

at least one voltage source connected to the first and/or second electrode structures, the voltage source being configured to create a potential difference between the first and second electrode structures such that at least one electrical discharge occurs in a discharge region between the first and second electrode structures, each electrical discharge having a discharge path;

wherein the catalytic converter and the plasma apparatus provide a passage configured to accommodate the flow of exhaust particles therethrough such that the exhaust particles pass through the discharge region of the plasma apparatus.

2. The exhaust processing system of claim 1, wherein the plasma apparatus is positioned upstream of the catalytic converter.

3. The exhaust processing system of claim 2,
wherein the plasma apparatus excites the exhaust particles;
wherein the excitation energy of the exhaust particles is larger than 0.1 eV;
wherein the system is configured such that the excited exhaust particles reach the catalytic converter with an effective particle temperature that is equal to or higher than an operating temperature of the catalytic converter, preferably equal to or higher than an optimal operating temperature of the catalytic converter at which the rate of catalytic conversion of the exhaust particles in the catalytic converter is greatest.

4. The exhaust processing system of any of the preceding claims, wherein a distance between the discharge region and the catalytic converter is 50 cm or less, 30 cm or less, 20 cm or less, or 15 cm or less.

5. The exhaust processing system of any of the preceding claims, wherein a portion of the passage comprised within the plasma apparatus is cylindrically shaped and configured such that the exhaust flows parallel to a longitudinal axis of the plasma apparatus, and wherein the electrical discharge path rotates around a longitudinal axis of the plasma apparatus.

6. The exhaust processing system of any one of the preceding claims, wherein the at least one plasma apparatus further comprises at least one magnetic field generating means for generating a magnetic field in the discharge region such that a magnetic field vector of the magnetic field is oriented at an angle to the discharge path enabling the discharge path to be set into motion within the discharge region.

7. The exhaust processing system of claim 6,
wherein the magnetic field generating means is not interposed between the first and second electrode structures; and/or
wherein the magnetic field generating means surrounds the first electrode structure and at least a portion of the second electrode structure; and/or
wherein the magnetic field generating means is configured to provide a magnetic field strength of at least 0.5 Tesla, preferably at least 1.0 Tesla, and more preferably at least 2.0 Tesla.

8. The exhaust processing system of any of the preceding claims,
wherein the voltage source is configured to provide a current greater than 20 mA, preferably greater than 50 mA, and more preferably greater than 100 mA; and/or
wherein the voltage source is configured to provide a pulsed electrical current having a period between 10 and 1000 milliseconds, preferably between 50 and 800 milliseconds; and/or
wherein the voltage source is configured to provide a pulsed electrical current having a duty cycle between 0.7 and 0.05, preferably between 0.5 and 0.1.

9. A combustion engine comprising an exhaust processing system according to any of the preceding claims, wherein the combustion engine is configured to produce exhaust during operation and the exhaust processing system is configured to receive the exhaust therethrough.

10. Use of an exhaust processing system with an exhaust producing mechanism, comprising the steps of providing an exhaust processing system according to any of claims 1 to 8 coupled to the exhaust producing mechanism;
flowing exhaust through the plasma apparatus;
flowing exhaust through the catalytic converter.

11. Use of the exhaust processing system according to claim 10, wherein the exhaust producing mechanism is a combustion engine and wherein the exhaust is first flowed through the plasma apparatus and then flowed through the catalytic converter, preferably wherein the catalytic converter has an optimal operating temperature at which the rate of catalytic conversion of the exhaust particles is greatest, and wherein passing exhaust particles through the plasma apparatus provides an increased catalytic conversion rate of the exhaust particles compared to when the exhaust particles are emitted from the exhaust producing mechanism with a temperature below the optimal operating temperature.

12. Use of the exhaust processing system according to any claim 10 or 11, wherein the exhaust particles are excited, dissociated and/or ionized by the plasma apparatus such that the exhaust particles have a higher energy level upon leaving the plasma apparatus than upon entering the plasma apparatus.

13. Use of the exhaust processing system according to any of claims 10 to 12, wherein the at least one electrical discharge is produced in the plasma apparatus during a cold start phase of the exhaust producing mechanism, optionally wherein no electrical discharge is produced in the plasma apparatus when the exhaust producing mechanism reaches a determined operating temperature.

14. Use of the exhaust processing system according to any of claims 10 to 13,
wherein the exhaust particles are received by the plasma apparatus at a temperature of less than 800 K, less than 700 K, or less than 600 K; and/or
wherein exhaust particles are emitted from the plasma apparatus at an effective temperature of at least 800 K or at least 1000 K.

15. Vehicle with an exhaust processing system according to any of claims 1 to 8 and/or performing the use according to any of claims 10 to 14.

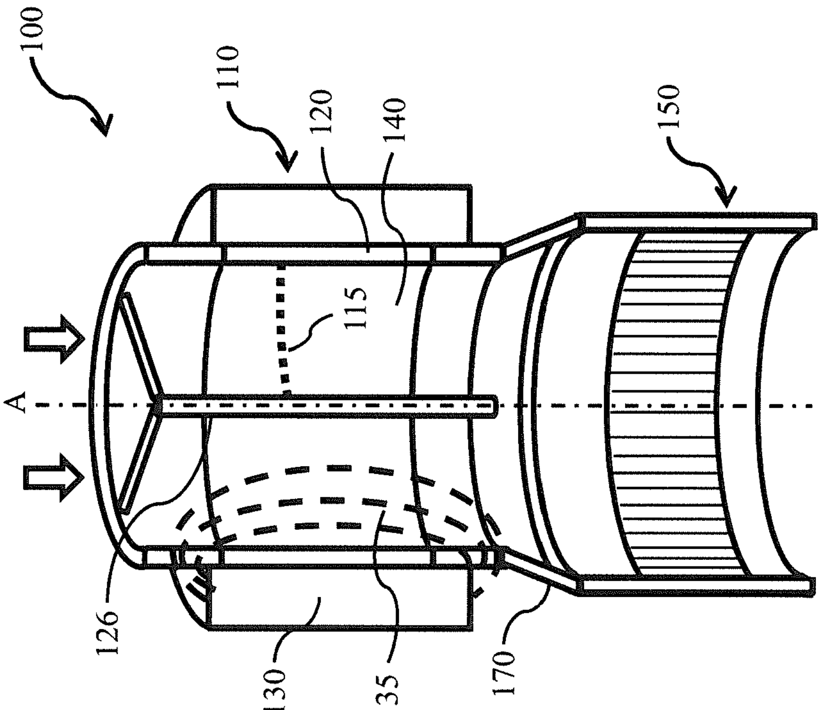

Fig. 2

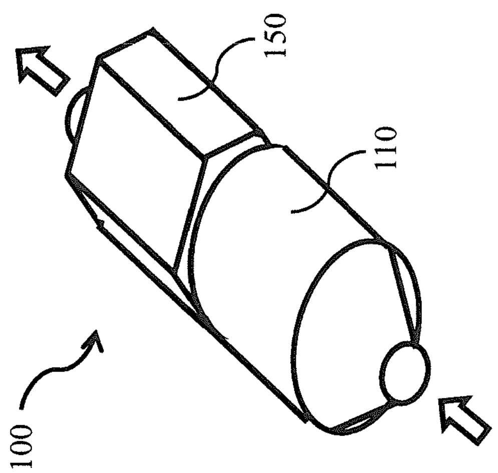

Fig. 1

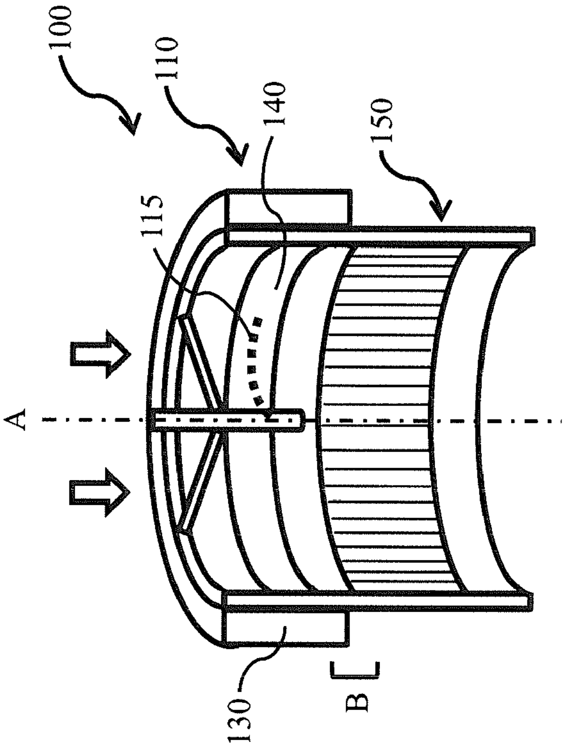

Fig. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 20 15 0876

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1

Place of search	Date of completion of the search	Examiner
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