

Dielectric Barrier Gas Reactors with Non-Axial Flow

The present invention relates to reactors for the processing of gaseous media, in which an electric
5 discharge, more particularly in the form of a non-thermal plasma, is established in a gaseous medium to be processed between two electrodes at least one of which is in intimate contact with a dielectric medium exposed to the gaseous medium. Such reactors are known as
10 dielectric barrier reactors.

A problem which arises in the practical design of dielectric barrier gas processing reactors is ensuring that the residence time of the gaseous medium in the
15 reactor is sufficient to ensure that sufficient exposure of the gaseous medium to the electric discharge occurs for the desired processing reactions to take place. This problem is particularly challenging when the reactor is used for the processing of the exhaust gases from
20 internal combustion engines to remove noxious components such as one or more of nitrogenous oxides, particulate including carbonaceous particulate, hydrocarbons including polyaromatic hydrocarbons, carbon monoxide and other regulated or unregulated combustion products
25 therefrom, because the space envelope available for the reactor is limited. There is a general requirement for simple, compact reactor designs with appropriate gas space velocity and residence times which also satisfy requirements such as electromagnetic compatibility
30 regulations (see for example 'Electromagnetic Compatibility: Guidance Notes on UK Regulations', published by Department of Trade and Industry, May 1995, publication number URN 95/683).

35 The practicality of using such dielectric barrier reactors on vehicles has not been generally discussed.

US patent 5,711,147 describes a corona reactor in which a pulsed power supply is connected to a corona wire positioned along the central axis of a reactor housing between a pair of insulating bulkheads. The corona wire or inside walls of the reactor can be coated with a dielectric layer to prevent arcing whereby the pulsed corona reactor operates as a dielectric barrier reactor. The configuration of this reactor is such that gas flow is axially through it and the reactor comprises two stages, the first in which the plasma can carry out oxidative reactions in the gas and a second non-plasma stage comprising a catalyst in which reduction reactions take place in the gaseous medium. Publication WO99/12638 also describes plasma reactors that consist of several stages for treatment of the emissions from internal combustion engines.

US Patent 5,254,231 describes a continuous flow fluid reactor for chemically altering fluids in which an annular electrode circles a ceramic or glass chamber and an inner electrode extends along the central axis of the reactor. Dielectric packing material with a dielectric constant less than 33 is placed inside the chamber and a non-thermal plasma is generated in the chamber from using standard voltage electricity supplies (90 to 130 volts) and standard frequency (50 to 60 Hz) after passing through a transformer. Fluid flow is axial through the plasma in the chamber and although not described as such the reactor in US Patent 5,254,231 is an embodiment of a dielectric barrier reactor.

US Patent 5,746,984 also describes the configuration of a dielectric barrier reactor which is a preferred embodiment of that invention in which two parallel electrodes are positioned on the outside of two parallel dielectric plates and in which gaseous medium flows in a

parallel direction between the plates although the detailed description of the dielectric barrier reactor is not disclosed or its applicability to vehicle based systems.

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In corona reactors consisting of a central wire electrode and a concentric outer cylindrical electrode, for example as described in US Patents 5,711,147 and 5,254,231 the radii of curvature of the electrodes
10 ensures a non-uniform electric field in the plasma reactor. To produce a uniform electric field, flat parallel plate electrodes can be used as shown diagrammatically in US Patent 5,746,984.

15 A configuration which has been adopted for use in so-called pellet-bed plasma-assisted gas processing reactors, in which a plasma is established in the gaseous medium in the interstices in a bed of gas-permeable dielectric material, is one in which the bed of gas-
20 permeable active material is contained between two concentric perforated metal electrodes and the gaseous medium is constrained to enter and leave the reactor axially, but to pass through the bed of active material radially. Such a reactor is described in Figure 5 of
25 publication WO99/12638. In this reactor, the electrodes are in direct contact with the active material, which usually is in the form of pellets, beads or extrudates of a dielectric material that can also be a ferroelectric material.

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Application PCT/GB00/00108 discloses a reactor having a layer of dielectric material deposited on the facing surfaces of the electrodes, such that it is a reactor of the dielectric barrier type. The layer of
35 dielectric material is shown as a coating on the inner surfaces of the perforations on the electrodes as well as

the surfaces of the electrodes which face each other. In practice, a uniform coating of this layer is difficult to achieve, particularly at the lips or edges of the perforations. If the inter-electrode spacing is
5 relatively small, or the applied voltage is relatively high then there is a risk of electrical breakdown through the gas between exposed metal at the lips or edges of the perforations in the inner electrode and the outer electrode.

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EP 0 366 876 discloses a reactor consisting of two co-axial cylindrical electrodes which are perforated and which has a perforated glass cylinder in contact with the inner surface of the outer electrode. The gaseous medium
15 being treated in the reactor flows radially through the space between the electrodes.

It is an object of the present invention to provide an improved dielectric barrier reactor for the processing
20 of gaseous media.

According to the present invention there is provided a reactor for the plasma assisted processing of a gaseous medium, which may include particulate emissions such as
25 are present in the exhaust from internal combustion engines, the reactor comprising a chamber having inlet and outlet ports and two concentric cylindrical electrodes at least one of the facing surfaces of which is in intimate contact with a layer of dielectric
30 material, at least one of the electrodes is provided with perforations or apertures through which a gaseous medium may pass, but such that no path is provided between any exposed electrically conducting surfaces of the electrodes along any part of which path, for a given
35 potential applied in use across the electrodes, the electric field strength exceeds the breakdown potential

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of the gaseous medium, and the electrodes are configured to constrain the gaseous medium to pass through the region between the electrodes so that the flow of the gaseous medium between entering and leaving the chamber
5 has a combination of at least two of axial, radial and circumferential components. Preferably the said flow of gaseous medium in the space between the electrodes has axial, radial and circumferential components. Combinations of the axial, radial and circumferential gas
10 flow components can result in gas flow which has partially or fully helical and/or spiral form.

By arranging for the difference in the radii of the concentric electrodes to be as small as is practicable
15 for given gas flow requirements, the uniformity of the electric field between the electrodes can be improved. Preferably the difference in radii is not greater than 80%, more preferably not greater than 60% and most preferably not greater than 40%, of the radius of the
20 outer electrode. Reducing the difference in radii of the electrodes in this way can also result in lower applied voltages being required to generate the appropriate discharge conditions. This in itself impacts upon the simplicity of design and the cost of the reactor and
25 power supply, which are key considerations for a vehicle based exhaust gas processing system.

Preferably the reactor chamber is adapted to be connected into the exhaust system of an internal
30 combustion engine.

By intimate contact we mean that the dielectric layer is either chemically bonded to the, usually metal, electrode or that the dielectric layer, which may be in
35 the form of a tube, plate or sheet of dielectric material, is in physical contact with the electrode. This

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intimate contact reduces any losses due to discharges or corona in any gaps between the electrode and barrier. This means that the power applied to the reactor is more efficiently coupled for generating a discharge, such as a plasma for processing of the gaseous media. Reducing these losses increases the efficiency of the dielectric barrier reactor and power supply system for a vehicle application and so reduces the power requirement and possible fuel penalty which are key considerations for any design. Reducing such losses also helps minimise electromagnetic emissions improving electromagnetic compatibility for vehicle applications. The physical contact between the electrode and dielectric material may be enhanced by depositing a metallised layer as a coating onto the dielectric material. The layer can be deposited electrolytically and can be made of, but is not restricted to, a suitable conducting material such as silver, nickel or copper. The metallised layer can also constitute the electrode. By way of an example an intermediate layer of molybdenum/manganese can first be deposited on the dielectric material and fired on at around 1400°C causing some of the metal to diffuse into the dielectric material surface. A conducting layer, for example nickel is then deposited onto the molybdenum/manganese so that the nickel makes a uniform contact with the diffused metal layer on the dielectric material. In this way a strong, intimately bonded, metallised layer on the dielectric material is achieved between the nickel-metal electrode and the dielectric material.

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In the case where both electrodes have a layer of dielectric material on their facing surfaces, and both the electrodes and the dielectric material are provided with perforations or apertures, such as holes or slits, so as to provide a gas flow path therethrough, then it is necessary in accordance with the invention to so arrange

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the separation between the perforations or apertures in the layer of dielectric material on one electrode relative to the perforations or apertures in the dielectric material on the other electrode that, for a
5 given operating potential difference between the electrodes in use, the electric field strength between any exposed electrically conducting surfaces on the electrodes nowhere exceeds the breakdown voltage of the gaseous medium.

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The gas flow components described according to the present invention are best defined in the context of an example comprising a regular cylindrical type reactor.

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By axial component of the gas flow we mean that component of gas flow which is parallel to or along the longitudinal axis of the cylinder. By radial component of the gas flow we mean that component of the gas flow which is parallel to a radius of the cylinder. By

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circumferential component of the gas flow we mean that component of the gas flow which follows a path concentric with the circumference of the cylinder.

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Combinations of two or more of these gas flow components can result in gas flow which is at least partially or fully helical and/or spiral.

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The space between the electrodes may be packed with a gas permeable bed of an active material. This may be
30 selected to act as a catalyst with respect to the treatment of the gaseous medium that passes through the reactor with axial, radial and circumferential flow components. The material of the packing or coating may be selected to be catalytic to increase the efficiency of
35 oxidation of particulates and/or the reduction of

nitrogenous oxides to nitrogen present in the exhaust from internal combustion engines.

It should be appreciated that a packing material or
5 coating that is not catalytic for the oxidation of carbonaceous particulate or reduction of nitrogenous oxides, for example by thermal mechanisms, may develop catalytic properties for these processes when exposed to a plasma. This may be due, for example to activation by
10 oxygen atoms or other plasma-generated free radicals or activation by plasma generated species such as activated hydrocarbons, organo nitrogen or activated organo nitrogen species and or nitrogen dioxide. Catalytic or non-catalytic material properties can be further
15 augmented by the electric field or by other charged species present in or adjacent to the plasma region.

The packing material can also serve to act as a selective filter for the selective modification of
20 residence times of adsorbed and trapped species on the filter material as described in patent applications GB 99 24999.7 and GB 99 29771.5 & GB 00 08351.9. In this way the residence time of adsorbed and trapped species is increased relative to species in the gas phase that are
25 not adsorbed or trapped on the filter and thus increase the time for the desired processing reactions to take place. This effect may be further enhanced by the axial, radial and circumferential gas flow components for the dielectric barrier reactors for the processing of gaseous
30 media described herein.

The reactor can be separated into sections so that the gaseous medium can be contacted with the active material before entering the plasma region of the
35 reactor, or can be excited in the plasma region and be contacted with the active material housed in the plasma

region or can be excited in the plasma region and then pass through the active material that is housed outside of the plasma region of the reactor. It should also be appreciated that the dielectric packing material can also
5 be placed outside the plasma reactor with a multiplicity of additive injection ports to improve process efficiency if a reductant is required for the process as described in WO99/12638.

- 10 The gas permeable bed of active packing material, can be in the form of spheres, pellets, extrudates, fibres, sheets, wafers, frits, meshes, coils, foams, membrane, ceramic honeycomb monolith or granules or as a
15 dielectric, polymeric or metallic material in any of the above shapes or as a combination of more than one of the aforementioned forms of packing material.

- The packing material may be selected to enhance the
20 oxidation or combustion of particulates such as carbonaceous carbon from internal combustion engines. Examples of oxidation catalysts such as carbon combustion catalysts for use in the gas permeable bed are alkali-metal salts such as lithium nitrate described in GB 2 232
25 613 B, cerium oxide, alkali-metal doped lanthanum oxide-vanadium oxide such as lanthanum-caesium-vanadium pentoxide in addition to the active materials, alkali metal metavanadates, alkali metal pyrovanadates, perovskites including layered perovskites and
30 combinations of these materials. Some of these combustion catalysts such as perovskites can simultaneously remove both nitrogen oxides and carbonaceous particulates. Examples of perovskites are
35 La_2CuO_4 , $\text{La}_{1.9}\text{K}_{0.1}\text{Cu}_{0.95}\text{V}_{0.05}\text{O}_4$ and $\text{La}_{0.9}\text{K}_{0.1}\text{CoO}_3$. The mode of operation of such catalysts is described in our

specification PCT/GB00/00079. The use of a carbon combustion catalyst can reduce the power requirements to the plasma reactor for treating carbonaceous particulate material and reduce the volume of active material
5 required.

The exhaust may also contain a chemical additive acting as a carbon combustion catalyst that is either present initially in the fuel or added separately to the
10 exhaust and whose function is to lower the combustion temperature and/or increase the rate of removal of carbonaceous material. Carbon combustion catalyst can be encapsulated within or bound to a fugitive additive that chemically decomposes during or shortly after fuel
15 combustion thus releasing the additive into the fuel or exhaust.

The packing material may be chosen to be a catalyst for the reduction of nitrogenous oxides. The gas
20 permeable bed of dielectric material can be an activated alumina such as gamma alumina, or alpha alumina or zirconium dioxide or titanium dioxide, silver aluminate, silver doped alumina, spinels, vanadium pentoxide, metal-doped and metal oxide-doped or exchanged inorganic oxides
25 such as cobalt oxide-doped alumina, and metal-doped zeolites. Zeolites are particularly useful materials for the reduction of nitrogenous oxides. Examples of zeolites are those known as ZSM-5, Y, beta, mordenite all of which may contain iron, cobalt or copper with or without
30 additional catalyst promoting cations such as cerium and lanthanum. Other examples of zeolites are alkali metal containing zeolites in particular sodium-Y zeolites that are particularly useful for treatment of nitrogenous
oxides. Another zeolite especially useful for removal of
35 nitrogenous oxides is ferrierite with silica to alumina mole ratios up to thirty and containing up to 10

percentage by weight of silver. It should be appreciated that zeolites, depending on their chemical composition, can also exhibit oxidative properties towards the gaseous and particulate processing reactions.

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Mixtures of these materials and mixtures of these materials with oxidation catalysts such as carbon combustion catalysts can also be used to oxidise carbonaceous particulates and/or reduce nitrogenous
10 oxides to nitrogen present in the gaseous exhaust from internal combustion engines.

An additive may be required to improve the process of oxidation and/or reduction of the gaseous media
15 constituents in combination with the packing material. For example when a nitrogen containing species such as ammonia, urea or cyanuric acid is used for nitrogenous oxide reduction, a particularly useful catalyst is vanadium pentoxide-titanium dioxide. When using a
20 nitrogen containing additive species, addition and mixing with the exhaust can also be made after the exhaust has passed through the plasma zone of the reactor before contact with the catalyst. Other examples of suitable additives may be added such as hydrocarbons either added
25 separately or residually derived from combustion fuel to promote processes such as selective catalytic reduction of nitrogenous oxides.

The packing material type is not restricted to those
30 described herein for the particular embodiments described in the present invention. Modifications and changes will no doubt become apparent to those skilled in the art.

When the reactor is for use in the treatment of the
35 exhaust gases from internal combustion engines the dielectric barrier material can be, for example, alumina,

glass, glass-ceramic, a micaceous glass such as MICATHERM as described in our publication WO99/20373. The dielectric barrier shape/geometry is not restricted to the particular embodiments described in the present invention. Modifications and changes will no doubt become apparent to those skilled in the art. For example the barriers could be in the form of tubes, plates or sheets. The dielectric barrier material in intimate contact with the electrode can also have catalytic properties with respect to the oxidation of carbonaceous particulates and/or reduction of nitrogenous oxides to nitrogen present in the gaseous exhaust from internal combustion engines. The dielectric barrier can be manufactured from a catalytic material, or contain a catalytic coating in or on its surface for such treatment wherein the catalytic material can be produced by ion-exchange, doping, deposited by wet chemical techniques such as sol-gel processing, by sputtering or by thermal spraying for example by plasma spraying or by physical and chemical vapour deposition. The type of dielectric barrier material or coating, be it catalytic or non-catalytic can be, but is not restricted to, those described for the packing material.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which

Figure 1 is a longitudinal section of a reactor embodying the invention for the plasma assisted treatment of the exhaust gases from an internal combustion engine,

Figure 2 is a schematic view showing the gas flow path through the reactor of Figure 1,

Figure 3 is a longitudinal section of a second reactor embodying the invention for the plasma assisted treatment of the exhaust gas from an internal combustion engine,

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Figure 4 is a schematic view showing the gas flow path through the reactor of Figure 3,

Figure 5 is a longitudinal section of a third reactor embodying the invention for the plasma assisted treatment of the exhaust gases from an internal combustion engine,

Figure 6 is a schematic view showing the gas flow path through the reactor of Figure 5,

Figure 7 is a schematic longitudinal section of a modified version of the reactor shown in Figure 3,

Figure 8 is a longitudinal section of a component for a modification of the reactor shown in Figure 7, and

Figure 9 is a longitudinal section of a component for an alternative modification of the reactor shown in Figure 7.

Referring to Figure 1, a reactor for the treatment of the exhaust emissions from an internal combustion engine to remove noxious components therefrom consists of a reactor chamber 100 for example made out of stainless steel which has inlet and outlet stubs 101, 102 respectively, by means of which it can be incorporated into the exhaust system of an internal combustion engine.

Inside the reactor chamber 100 are an inner electrode 103 and an outer electrode 104. A high voltage input terminal 105 enables voltages of the order of kilovolts

to tens of kilovolts and repetition frequencies in the range 50 to 5000 Hz to be applied to the inner electrode 103 although higher frequencies of the order of tens of kilohertz can be used. Pulsed direct current is
5 convenient for automotive use, but alternating potentials for example triangular or sine waves of the same or similar characteristics can be used. The outer electrode 104 is grounded, allowing establishment of a non-thermal plasma in the exhaust gases in the space between the
10 electrodes 103, 104. The electrodes 103 and 104 are made of perforated conducting material such as stainless steel and are supported in the reactor chamber 100 by insulating supports 106, 107. The electrode support 106, at the inlet end of the reactor chamber 100 has a row of
15 holes 108 around its periphery so as to admit incoming exhaust gases to the space 109 between the outer electrode 104 and the reactor chamber 100 wall. The electrode support 107 at the outlet end of the reactor chamber 100 has an axial outlet hole 110. In contact
20 with the opposing surfaces of the electrodes 103, 104 are layers 111, 112, respectively, of a dielectric medium for example α -alumina, glass, glass-ceramic or micaceous glass such as MICATHERM. The layers 111, 112 of dielectric have circumferential gaps 113, 114,
25 respectively, in them. The gaps 113, 114 in the layers 111, 112 of dielectric are staggered so that one series of gaps is opposite the centre of the opposing region of dielectric, as is clearly shown in Figure 2. As can be seen from Figure 2, the gaps 113, 114 in the layers 111,
30 112, respectively, of dielectric also are staggered circumferentially so as to cause a helical gas flow in the region between the electrodes 103, 104.

Referring to Figure 2, the incoming exhaust gases
35 pass initially axially into the space 109 and then radially down through the perforations on the outer

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electrode 104 and gaps 114 in the dielectric layer 112 into the space 115 between the electrodes 103 and 104 where it may flow circumferentially before passing through the gaps 113 in the dielectric layer 111 and the perforations in the inner electrode 103 and then passing out of the reactor chamber 100 via the central hole 110 in the electrode support 107. Thus the gas flow path through the gap between the electrodes 103, 104 has axial, radial and circumferential components. The radial component of flow results from the transfer of the gas flow from outside the outer electrode 104 to exit from inside the inner electrode 103. There is also a circumferential component imposed by the circumferential staggering of the gaps 113 and 114, so that the flow is at least partially helical. The distances between the gaps 113 and 114 in the layers 111, 112 of dielectric are made to be such that the electric field strength between the exposed surfaces of the electrodes 103, 104 is nowhere sufficient to cause electrical breakdown in the exhaust gases passing through the space between the electrodes 103, 104 with the consequent occurrence of arcing instead of a plasma discharge in the exhaust gases.

Referring to Figure 3, a second reactor for the plasma assisted processing of the exhaust emissions from internal combustion engines to remove noxious components therefrom consists of a reactor chamber 300 which has inlet and outlet stubs 301, 302, respectively, by means of which it can be incorporated into the exhaust system of an internal combustion engine, as before.

Inside the reactor chamber 300 there is an inner electrode 303 which is supported within a dielectric tube 304, made for example out of α -alumina which has its upstream end closed by a spherical dome 305 to facilitate

the flow of exhaust gases through the reactor. The inner electrode 303 is supported in the dielectric tube 304 by two spider supports 306, 307. The inner surface of the dielectric tube can be metallised with a metal coating in order to increase the physical contact between the electrode and dielectric tube. The support 307 is connected to a high voltage input terminal 308 via a ceramic insulated feed 309 so that a potential of the order of kilovolts to tens of kilovolts and repetition frequencies in the range 50 to 5000 Hz can be applied to the inner electrode 303. Concentric with the inner electrode 303 and dielectric tube 304 is a grounded outer electrode 310 made for example of stainless steel. The dielectric tube 304 and outer electrode 310 are supported within the reactor chamber 300 by disks 311, 312 made of an insulating ceramic material, such as alumina. A compliant heat resistant material 313 is interposed between the electrode support 311 and the dielectric tube 304.

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As shown in Figure 4, the outer electrode 310 has a series of baffles 314 and slots 315 315a. The baffles 314 extend from the outer electrode 310 to the inner surface of the wall of the reactor chamber 300 and act as grounding connections as well as causing the exhaust gases to follow a convoluted path which has both axial, and circumferential components and being at least partially helical. There is also a radial component of flow, initially inwardly as the gas transfers from outside the outer electrode 310 to the space between the electrodes 310 and 303 and then outwardly as the gas returns to exit from outside the outer electrode 310. Thus there is also a spiral component in the flow.

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The baffle 314 is arranged to divide the space between the electrode 310 and the reactor chamber 300

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into six segments. At the gas inlet end three of these segments are closed off at 314a, 314b and 314c to axial gas flow and the remaining three segments are open to axial gas flow into the space between the electrode 310 and the reactor chamber 300. These latter three segments are closed off by the baffle 314 at the gas outlet end of the reactor. Consequently the gas is forced to pass via slot 315 radially into the space between the electrodes 303 and 310 then passing in at least a partially helical manner before passing radially via the next slot 315a into the next segment of space between electrode 310 and reactor chamber 300. The baffle 314 leaves open this segment at the gas outlet end, allowing exhaust of the treated gas. Thus it will be seen that the exhaust gases both enter and leave the main part of the reactor 300 along the surface of the outer electrode 310 and the electrode supports 311, 312 have reliefs at their circumferences which are so positioned as to permit this to happen. Thus for a given gas velocity, the residence time of the exhaust gases in the electric field is increased compared with either purely axial or radial flow. Note that in Figure 4 part of the electrode 310 has been shown cut away at 316. This cut away is shown in the Figure only to illustrate the flow of the exhaust gases as they pass between the electrodes 303 and 310 and does not represent a structural feature of the reactor.

Referring to Figures 5 and 6, there is illustrated a third form of reactor for the plasma assisted processing of the exhaust emissions from internal combustion engines to remove noxious components therefrom. The reactor consists of a cylindrical chamber 500 which can be stainless steel, and which has inlet and exhaust stubs 501, 502, respectively, by means of which it can be connected into the exhaust system of an internal combustion engine. Within the reactor chamber 500 is a cylindrical inner electrode 503 to which there is

connected a high voltage input terminal 504 by means of which there can be applied to the inner electrode 503 a voltage sufficient to create a non-thermal plasma in the exhaust gases as they pass through a space 505 between the inner electrode 503 and a layer 506 of a dielectric material such as α -alumina or MICATHERM which is deposited on the inner surface of a grounded outer electrode 507 which is in the reactor chamber also. The electrodes 503, 507 are held in place in the reactor chamber 300 by means of annular ceramic insulating supports 508, 509.

As best can be seen from Figure 6, the inner electrode 503 has two intersecting longitudinal baffles 510, 511. Two opposite sectors 512, 513 at the inlet end of the inner electrode are blocked off, as are the other two opposite sectors at the outlet end of the inner electrode 503. Four regularly spaced slots 514 extend axially along the inner electrode 503, one to each sector of the inside of the inner electrode 503. The result of this arrangement is that exhaust gases entering the main part of the reactor chamber 500 enter axially into the open two sectors of the inside of the inner electrode 503, pass radially out of the corresponding two slots 514 in the inner electrode 503 and travel circumferentially, axially and at least partially helically through the space 505 between the inner electrode 503 and the outer electrode assembly 506, 507 before radially exiting this space through the other pair of slots 514 in the inner electrode and leaving the inside of the inner electrode 503 via the two open sectors of the inner electrode. Thus, for a given gas velocity again the residence time of the exhaust gases in the electric field between the electrodes is increased compared with either purely axial or radial flow.

Figure 7 shows a modification of the reactor shown in Figure 3. Corresponding components are referenced similarly to those in Figures 3&4, except that the references start at 700 for the reactor chamber
5 (corresponding to 300 in Figure 3), 710 being the outer electrode, and so on.

In this example, the inner electrode 703 is conveniently provided by a deposited electrically
10 conducting layer of silver on the inner surface of the dielectric tube 704. High voltage connection via the high voltage input terminal 708 is made through a spring loaded telescopic tube assembly 720 and spring contacts 721. Load from the sprung telescopic tube assembly 720
15 is received by a load spreader plate 722, which is connected to the conducting layer of silver forming the inner electrode 703. The materials, including the spring are required to operate at elevated temperatures, and the spring must have low creep at such temperatures. A
20 preferred material for the spring is an Inconel alloy such as X750. Alumina end flange 712 is shaped to receive and locate the end of the dielectric tube 704 and is itself located by a sprung metal clip 723.

25 Figure 8 shows a modified dielectric tube 804 for the reactor of Figure 7. In this example, end flange 812 is joined on to the tube 804 during the manufacturing process. The increased wall thickness allows greater load to be placed on it when sealing the tube 804 into
30 the reactor. The inner electrode 803 is formed by a deposition of silver.

Figure 9 shows a further modified version of dielectric tube 904 for the reactor of Figure 7. In
35 this, end flange 912 is formed as an integral part of the tube 904 during its manufacture. The flange portion and a

neighbouring part of the tube has a wall thickness slightly greater than that of the rest of the tube. Again, the inner electrode 903 is formed by a deposition of silver.

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The embodiments of reactor described in these examples may include catalytic components which may require the addition of additives such as oxidant or reductant additives or be installed as part of an
10 emissions control system employing catalysts or other emission control devices for the plasma assisted treatment of the exhaust gases from internal combustion engines. Such other emission control devices may comprise but are not restricted to exhaust gas recirculation
15 (EGR), variations in ignition timing, fuel injection timing and fuel injection pulse rate shaping. The reactor of these examples can be used in conjunction with a power supply and engine management system as described in the specification of application PCT/GB00/00603. An
20 article 'Stop go systems get the green light' in European Automotive Design, April 1998, pages 24-26 describes an example of an integrated starter alternator damper system (ISAD). Such an ISAD can be used as part of a power supply system to power a plasma assisted emissions
25 control system of which a reactor as described herein is part. In addition, other power sources such as but not limited to single/multiple output 12/14V alternator technologies e.g. 14V/42V, fuel cells, gas turbines, solar cells and heat exchangers can be the primary or
30 part-provider of the electrical-generating power source that can also be used to power the power supply system for the reactor.

Claims

1. A reactor for the processing of a gaseous medium,
5 comprising a chamber(100:300;500;700) having inlet
(101;301;501;701) and outlet (102;302;502;702) ports and
two concentric cylindrical electrodes (103,104: 303,310;
503,507;703,710), characterised by the combination of
features that at least one of the facing surfaces of said
10 electrodes (103,104:303,310;503,507;703,710) has a layer
of dielectric material(111,112;304;506;704;804;904) in
intimate contact with it, at least one of the electrodes
(103,104;310;503;710) is provided with perforations or
apertures (113,114;315,315a;514) through which gaseous
15 medium may pass, but such that no path is provided
between any exposed electrically conducting surfaces of
the electrodes (103,104;310;503;710) along any part of
which path, for a given potential applied in use across
the electrodes (103,104;310;503;710), the electric field
20 strength exceeds the breakdown potential of the gaseous
medium, and the electrodes (103,104: 303,310; 503,507;
703,710) and associated structure (106,107; 314,312;
508,509,510,512) are configured to constrain the gaseous
medium to pass through the region between the electrodes
25 (103,104:303,310;503,507;703,710) so that the flow of the
gaseous medium between entering and leaving the reactor
has both axial, radial and circumferential components.

2. A reactor according to claim 1, further
30 characterised in that the difference in radii of the
concentric electrodes (103,104:303,310; 503,507; 703,710)
is not greater than 80% of the radius of the outer
electrode, to improve the uniformity of electric field
present between the electrodes.

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3. A reactor according to claim 2, further characterised in that the difference in radii of the concentric electrodes (103,104:303,310; 503,507; 703,710) is not greater than 60% of the radius of the outer
5 electrode.

4. A reactor according to claim 2, further characterised in that the difference in radii of the concentric electrodes (103,104:303,310; 503,507; 703,710)
10 is not greater than 40% of the radius of the outer electrode.

5. A reactor according to any preceding claim, further characterised in that the electrodes (103,104: 303,310;
15 503,507;703,710) and associated structure (106,107; 314,312;508,509,510,512) are so configured as to cause the gaseous medium to flow between them in an at least partially helical and/or spiral manner.

20 6. A reactor according to any preceding claim, further characterised in that the or each electrode (103,104; 303;507;703,) having a layer of dielectric material in intimate contact therewith comprises a tube (111,112; 304;506;704;804;904) of dielectric material onto which is
25 deposited metallised layer of a metal coating.

7. A reactor according to any preceding claim, further characterised in that each electrode (103,104) is perforated by apertures and has a layer of dielectric
30 material (111,112) on its said facing surface, the layers of dielectric material (111,112) having circumferential slots (113,114) in them, the slots (113,114) being staggered both axially and in azimuth and associating with the perforations or apertures in the electrode
35 (103,104) to permit gas flow therethrough.



8. A reactor as claimed in claim 7, further characterised in that the separation between the slots (113) in the layer of dielectric material (111) on one electrode (103) relative to the slots (114) in the dielectric material (112) on the other electrode (104) is so arranged that, for a given operating potential difference between the electrodes in use, the electric field strength between any exposed electrically conducting surface of the electrodes nowhere exceeds the breakdown voltage of the gaseous medium.

9. A reactor according to claim 5, further characterised in that the inner electrode (303;703) is coated with a continuous layer of dielectric material (304;704) or is in intimate contact with a continuous layer of dielectric material (304;704) and the outer electrode (310;710) has an arrangement of longitudinal and transverse baffles (314) and longitudinal slots (315) such as to cause an incoming gaseous medium to be treated in the reactor to pass initially over regions of the outer surface of the outer electrode (310;710), through a first group of the slots (315) into the space between the electrodes, through that space in at least a partially helical and/or spiral path before passing through a second group of the slots (315a) and back over the outer surface of the outer electrode (310;710) prior to leaving the reactor chamber (300;700).

10. A reactor according to claim 5, further characterised in that the inner electrode (503) has an arrangement of longitudinal (510,511) and transverse (512,513) baffles and longitudinal slots (514) such that incoming gases to be treated in the reactor are constrained initially to pass into segments of the inside of the inner electrode (503), out of corresponding slots (514) in the inner electrode (503), and pass helically

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through the space between the electrodes (503,507) before
passing through a second group of the slots (514) in the
inner electrode (503) into corresponding segments of the
inside of the inner electrode (503) and thence out of the
5 reactor chamber (500).

11. A reactor according to any preceding claim, further
characterised in that the space between the electrodes
(103,104;303,310;503,507;703,710) is filled with a gas
10 permeable bed of a dielectric medium.

12. A reactor according to claim 11, further
characterised in that the material of the gas permeable
bed is adapted to have catalytic properties in respect of
15 the treatment of the gaseous medium to be carried out in
the reactor.

13. A reactor according to any preceding claim adapted
to form part of an internal combustion engine exhaust
20 system.

14. A reactor according to any preceding claim, further
characterised in that the or each layer of dielectric
material (111,112;304;506;704;804;904) is made of α -
25 alumina, glass, glass-ceramic or micaceous glass.