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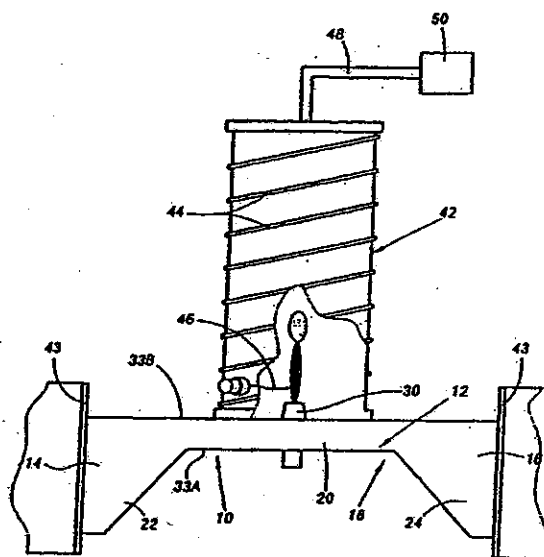
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(54) Title: DEVICE FOR TREATING GAS WITH PLASMA

(54) Titre : DISPOSITIF DE TRAITEMENT DE GAZ PAR PLASMA



(57) Abstract: The invention concerns a device for treating gas with plasma, maintained by microwaves comprising a hollow structure (12) forming a waveguide designed to be connected to a microwave generator, and means (29) for circulating the gas to be treated through said structure in a zone (20) wherein the amplitude of the electric field associated with the incident wave is high. The gas circulating means comprise a plasma torch (30) made of electrically conductive material mounted on a first large surface (33A) of said structure (12) and projecting through an orifice provided in a second large surface (33B) opposite said first large surface. An interstice allowing through the incident waves extends around the injector.

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For an explanation of the two-letter codes and the other abbreviations, reference is made to the explanations ("Guidance Notes on Codes and Abbreviations") at the beginning of each regular edition of the PCT Gazette.

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(57) Abrégé : Ce dispositif de traitement de gaz par plasma, entretenu par micro-ondes comprend une structure creuse (12) formant guide d'ondes destinée à être raccordée à un générateur de micro-ondes, et des moyens (29) pour faire circuler le gaz à traiter à travers ladite structure dans une zone (20) dans laquelle l'amplitude du champ électrique associé à l'onde incidente est élevée. Les moyens pour faire circuler le gaz comportent une torche (29) à plasma pour la production d'un plasma dans le gaz. La torche comprend un injecteur (30) en matériau conducteur électrique monté sur une première grande face (33A) de ladite structure (12) et s'étendant en saillie à travers un orifice ménagé dans une deuxième grande face (33B) opposée à ladite première grande face. Un interstice de passage des ondes incidentes s'étend autour de l'injecteur.

Device for treating gas with plasma

The present invention relates to a device for treating gas with plasma, in which method the gas for treatment
5 is excited by the plasma.

Devices for treating gas with plasma, particularly sustained by microwaves of this type generally comprise a waveguide-forming hollow structure intended to be
10 connected to a microwave generator and means for causing the gas for treatment to circulate through said structure in a region in which the amplitude of the electric field associated with the incident wave is high, and is preferably at a maximum.

15 The principle of these gas treatment techniques consists in creating, by means of an electrical discharge in a predominantly plasma-generating gas (argon, nitrogen, krypton, xenon, etc.) containing
20 impurities or gaseous effluent, a plasma within which the initial molecules are excited, ionized and split up into smaller fragments, atoms and radicals. These smaller fragments then recombine and react with each other and/or with auxiliary gases to yield new species
25 which can be removed from the gas by conventional methods such as reactive adsorption for example. The molecules of the background gas for purifying or decontaminating reach the outlet of the installation unchanged and in their fundamental state. For further
30 details on the various devices that allow the creation of excited plasmas, reference can be made in greater detail to the work entitled "Microwave Excited Plasmas" by M. Moisan and J. Pelletier, Elsevier, 1992.

35 Document US-A-5,750,823 describes a device for treating gas with plasma which allows the gas to be excited by sustaining therein an electrical discharge by means of an electric field associated with incident

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electromagnetic waves. These waves are excited by an applicator of a field, formed by the hollow structure forming a waveguide, and which is itself fed with microwave power from a conventional waveguide, also
5 formed by the hollow structure.

When the plasma is sustained by a surface electromagnetic wave, the field applicators used are of surfatron guide or surfaguide type.

10

The means used for causing the gas to circulate consist of a tube made of dielectric material, in which the discharge is created.

15 Other examples of such gas treatment systems are described in documents DE-A-44 28 418 and US-A-5,300,202. These systems are used at low pressure. Document EP-A-0 295 083 describes a device for treating gas with plasma comprising a resonant cavity operating
20 at atmospheric pressure.

These gas treatment devices, although advantageous in terms of conversion yield, energy efficiency, and low operating sensitivity to variable operating conditions,
25 do have a major disadvantage in that they are poorly- or ill-suited to the treatment of gas the breakdown of which yields appreciable amounts of solids, generally in the form of powder.

30 This is because such materials can clog the tube in which the gas for treatment circulates and in which the discharge is created or, at the very least, can alter its initially optimized internal geometry, disrupt heat exchange and impede the cooling of the tube, or
35 alternatively may have an adverse effect on the dielectric properties of this tube and disrupt the propagation of the surface wave.

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To alleviate this disadvantage it is possible to use a gas treatment device in which the gas is converted into plasma not in a confined tubular space but in a relatively open volume, spatially separated from the waveguide. In this case, one of the possible arrangements is that of a plasma torch supported and fed by the waveguide.

What happens is that a torch does not suffer any of the aforementioned disadvantages generated by the potential formation of solid deposits, in that the plasma is not formed in the gas feed pipe of the torch but downstream of the latter, at the end of the torch nozzle.

To produce such a gas treatment device, the free end of the torch, where the plasma forms, opens into a chamber whose main function is to imperviously collect the gases after treatment in the plasma and to receive the solid deposits generated by the treatment. The gases thus collected are then directed toward an outlet duct. They can then be used as they are, or alternatively undergo a post treatment, or alternatively still may be discharged into the atmosphere.

A known example of such a microwave plasma torch is the axial injection torch (AIT). Such a torch is described for example in the article "An atmospheric pressure waveguide-fed microwave plasma torch" (Plasma Sources Sci. Technol. 3 (1994) p. 584 to 592) or in the addition certificate application FR-A-2 533 397. The AIT torch was applied to the destruction of SF_6 and C_2F_6 . However, its architecture is relatively sophisticated and its construction is fairly complicated and expensive. In addition, it is intrinsically difficult to seal the gas circuit well, and this represents a very serious disadvantage when treating gases containing impurities or effluent whose conversion yields dangerous gases (for example corrosive halogenated compounds), or alternatively

gases of high added value (krypton and xenon). Finally, the length of the AIT nozzle feed pipe is quite long, and this may pose problems of recondensation of impurities.

The object of the invention is to alleviate these disadvantages.

In accordance with an aspect of the present invention, there is provided a device for treating gas with plasma, particularly sustained by microwaves, of the type comprising a hollow structure forming a waveguide intended to be connected to a microwave generator and means for causing the gas for treatment to circulate through said structure in a region in which the amplitude of the electrical field associated with the incident wave is high and preferably at a maximum, characterized in that the means for causing the gas for treatment to circulate comprise at least one plasma torch for producing, at its outlet, a plasma in the gas for treatment, the torch comprising an injector made of electrically conducting material mounted on a first large face of the waveguide-forming structure and projecting through an orifice made in a second large face opposite said first large face, a gap for the passage of the incident waves extending around the injector.

This device may also have one or more of the following characteristics, taken in isolation or in any technically feasible combination:

- the device comprises means of adjusting the axial position of the injector with respect to the waveguide forming structure;

- the adjusting means are designed in the form of a screwthread formed on the external surface of the injector and collaborating with a tapping borne by the waveguide-forming structure;
- the injector has a roughly cylindrical outer part, the adjusting means are designed in the form of a double-ring coupling device fixed to said first large face of the structure, the double ring coupling device having the injector passing through it, and said cylindrical part is tightened radially onto said coupling device;

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- the waveguide-forming hollow structure has a first end intended to be connected to a microwave generator, an opposite second end intended to be equipped with impedance adjusting means forming a short circuit, and
5 a region in which the means for causing the gas to circulate and for conveying the microwave power to the end of the injector are provided;
- said region is a region of narrowed cross section;
- said region of narrowed cross section comprises a
10 part of constant cross section in which the means for causing the gas to circulate are provided, and said region of narrowed cross section extends between two parts the cross section of which increases linearly toward the first and second ends;
- 15 - said region is a region of constant cross section which extends between said two ends, and the device further comprises an impedance matcher which converts the electromagnetic impedance of the plasma injector system into the characteristic electromagnetic
20 impedance of the waveguide-forming structure;
- the impedance matcher is a hollow cylinder made of a material that is a good conductor of electricity, particularly of copper or brass, arranged coaxially around the injector, and extending from the second
25 large face of the structure toward said first large face;
- the microwaves have a frequency of roughly 2.45 GHz, and the hollow cylinder has a length of between 25 mm and 40 mm, preferably roughly equal to
30 33 mm and an outside diameter of between 20 and 30 mm, preferably roughly equal to 25 mm;
- the gap is delimited by the orifice formed in said large face and the outline of the injector;
- the device comprises an annular disk mounted on
35 said second large face and having a central orifice which has a diameter smaller than the diameter of the orifice of said second large face, the gap is delimited by the central orifice, and a spacer piece is placed

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between the annular disk and said second large face spaced away from the edge of the central orifice;

- the edge of the orifice delimiting the gap is of rounded, particularly semi-toric, shape;
- 5 - the gap is between 1 mm and 3 mm wide;
- the hollow structure has, at least at one of its ends, and preferably at each of these ends, a window made of dielectric material, particularly of Teflon®, transparent to microwave energy and isolating the
- 10 internal volume of the hollow structure in a roughly gastight way from the waveguide sections extending respectively toward the microwave generator and toward the impedance adjusting means;
- the device further comprises a treatment reactor
- 15 mounted on the waveguide-forming hollow structure and capping the free end of the injector;
- the wall of the treatment reactor is cylindrical and equipped with a cooling coil in communication with a source of cooling fluid;
- 20 - the device further comprises means of pumping the atmosphere in the treatment reactor;
- the pumping means constitute means of adjusting the roughly laminar flow of the gases at the site of the plasma;
- 25 - the reactor is equipped with plasma-striking means;
- the striking means comprise a wirelike rod made of electrically conducting material, particularly tungsten, extending toward the free end of the injector
- 30 and connected to a source of low-frequency or radio-frequency high AC voltage, and movement means allowing it to be brought closer to or moved away from the vicinity of the free end;
- the free end of the injector has a cylindrical or
- 35 conical overall exterior shape; and
- the free end of the injector is equipped with a projecting central element for centering the plasma with respect to the outlet of the injector, gas passage orifices extending on each side of this element.

Other features and advantages will become apparent from the following description, given solely by way of example and made with reference to the appended drawings in which:

- Figure 1 is a schematic profile view of a first embodiment of a gas treatment device according to the invention;
- Figure 2 is a view from above of the device of Figure 1;
- Figure 3 is a view in section of part of the device of Figure 1;
- Figures 4 to 13 show various embodiments of the injector of the device of Figure 1;
- Figure 14 is a gas treatment installation using a treatment device according to the invention;
- Figure 15 is a curve showing the change in reflected power in the waveguide as a function of the injector height;
- Figure 16 is a curve showing the level of destruction of a gas by means of the device of Figure 1, as a function of the pressure in the reactor;
- Figure 17 is a curve showing the change in level of destruction of a gas as a function of the incident microwave power for various gas flow rates and a gas dilution of 1%;
- Figure 18 is a schematic profile view of a second embodiment of a gas treatment device according to the invention; and
- Figure 19 is a view in section on XIX-XIX of Figure 18.

Figures 1 and 2 schematically depict a device for treating gas with plasma according to the invention, denoted by the overall numerical reference 10, viewed from the side and viewed from above, respectively.

The device 10 mainly consists of a waveguide-forming hollow structure 12 of longitudinal shape and made of

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an electrically conducting material suited to the envisioned use, particularly of metal. It preferably has a rectangular cross section and has a plane of symmetry situated in the plane of Figure 1, that is to say parallel to the small faces of the structure 12.

The structure 12 has two open ends 14 and 16 respectively, which are intended, one to be connected to a microwave generator (not depicted), and the other to be connected to appropriate means for forming an adjustable short circuit, preferably a conducting plate arranged transversely and longitudinally adjustable so that the impedance can be adjusted.

Between the two ends 14 and 16, the structure 12 comprises a region 18 of narrowed cross section concentrating the incident microwaves, which region 18 comprises a central part 20 of constant cross section extending between two parts 22 and 24 the cross section of which increases linearly toward the end regions 14 and 16.

Referring also to Figure 3, the wall of which the structure 12 is made comprises, at the central part 20, two coaxial orifices 26 and 28 respectively, through which means for causing a gas for treatment to circulate through the structure 12 and, in particular, through the structure in a region in which the amplitude of the electric field associated with the incident wave is high, and is preferably at its maximum, extend.

The expression "high electric field amplitude" is to be understood as meaning an amplitude of the electric field that is high enough to allow the plasma to be struck.

As can be seen in this Figure 3, these means consist of a torch 29 supported by the waveguide and comprising an

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injector 30 comprising a proximal region 32 via which it is fixed to one of the large faces 33A of the structure 12 and a distal free end 34 which passes through the orifice 26 made in the opposite large face 33B of the structure 12 and through which it projects out from this structure 12.

The injector 30 has, in cross section, a cross section that narrows toward its free end 34 so that a gap 26A remains at the orifice 26, between the injector 30 and the constituent wall or face 33 of the structure 12 via which the incident waves are passed along the wall of the injector 30 toward the free end 34.

In the exemplary embodiment depicted in these figures, the waveguide-forming structure 12 has two coaxial orifices 26, 28 for the mounting of a single torch 29. It will be understood that it is possible to provide a higher number of such orifices arranged in pairs of coaxial orifices, for mounting a corresponding number of plasma torches. In this case, the pairs of coaxial orifices will generally be arranged in such a way as, on the one hand, to split the power equally between the gaps so as to create roughly identical plasmas at the ends of each torch and, on the other hand, to allow good impedance matching of the multiple torches structure using adjusting means provided elsewhere (for example a conventional mobile short circuit and a conventional three-screw matcher), with a reflected power preferably less than 1% of the incident power.

Furthermore, the device 10 comprises means of adjusting the axial position of the injector 30 with respect to the structure 12, these being in the form of a screwthread 36 formed in the external peripheral surface of the proximal region 32 of the injector and collaborating with a tapping in a nut 38 borne by the structure 12. It is thus possible to adjust precisely

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the distance between the free end 34 of the torch and the corresponding large face 33B of the structure 12.

5 The injector 30 comprises an internal duct 40 through which the gas for treatment circulates, this duct being connected to a feed source of gas for treatment, which source has not been depicted.

10 As an alternative, the injector 30 has a base consisting of a cylindrical tubular portion extended by a nozzle of cylindrical or conical overall exterior shape (Figs. 4 to 12 and Fig. 19). The diameter of the circular orifice 26 formed in the large face of the guide is tailored to give the circular gap 26A a small
15 enough width for the microwave power to be conducted out of the guide toward the tip of the nozzle. The width is large enough to avoid the risk of arcs being generated between the injector 30 and the waveguide.

20 The width of the gap 26A is, for example, between 1 mm and 3 mm.

The device 10 comprises a treatment reactor 42 mounted on the structure 12 at its central region 20 in such a
25 way as to cap the free end of the injector 30 of the torch so that this end opens into the reactor 42.

It will be noted that the reactor 42 is mounted imperviously on the structure 12 and communicates with
30 the internal volume of said structure via the circular gap 26A delimited by the injector 30 and the orifice 26.

35 The ends 14, 16 of the structure are closed gastightly by the two plates 43 made of dielectric material, preferably of Teflon®, and which are transparent to microwave energy. These two plates 43 thus form "windows" for the microwaves, whereas corrosive or harmful gas that might be present in the structure 12

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coming from the reactor 42 cannot circulate toward the environment or toward the microwave generator 60.

5 The wall of the reactor 42 is cylindrical and equipped with cooling means, in the form of a coil 44 connected to a source of appropriate cooling fluid (the source is not depicted).

10 It also bears a plasma striking member designed in the form of a wirelike conducting rod 46, for example made of tungsten, extending toward the free end 34 of the injector of the torch and connected to a low-frequency or radio-frequency high AC voltage source (not depicted). This rod 46 is equipped with movement means
15 (not depicted) allowing it to be withdrawn from the vicinity of the free end 34 once the discharge has been ignited.

20 A pipe 48 is connected to the reactor 42 to collect the gases after they have passed through the plasma, which pipe is, in this example, provided with means 50 of pumping the atmosphere in the reactor.

25 As will be understood, the reactor 42 allows the gases leaving the torch 29 to be isolated from the external environment and collected in full for the remainder of the treatment process.

30 The dimensions of the chamber of the reactor 42 need to be large enough not to disrupt the conditions of sustaining a plasma which it is desired be stable and symmetric, either by parasitic coupling of the microwave energy with the walls of the chamber, or by degradation of the conditions of flow of the gas near
35 the torch 29. However, the dimensions of the chamber of the reactor 42 need to remain small enough to keep the device as a whole compact.

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For example, the reactor 42 consists of an aluminum cylinder about 200 mm in diameter and 480 mm tall.

5 In this case, the pumping means 50 have in general to be used to maintain gas flow conditions close to laminar conditions at the site of the plasma flame.

Of course, use may be made of greater dimensions if the compactness of the entity is not a prohibitive
10 disadvantage.

Thus, when use is made of a large sized reactor, the cooling means may be omitted.

15 With reference to Figures 4 to 13, the free end of the injector 30 of the plasma torch may have various configurations.

Specifically, whereas in the exemplary embodiment
20 described schematically with reference to Figures 1 to 3, the injector has a conical exterior shape, it may just as easily have a cylindrical exterior shape as depicted in Figure 5.

25 The free end of the nozzle has a diameter of between 4 and 4.8 mm, preferably equal to 4 mm.

For a higher diameter, the treatment yield is deteriorated in that the plasma column does not cover
30 the entire opening.

For smaller diameter values, the resulting increase in the speed for gas for treatment decreases the residence time of its species in the plasma and therefore the
35 level of destruction.

It can be seen that, for an injector 30 with a single opening, the plasma is struck in a region of

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circumference and is therefore placed eccentrically with respect to the stream of gas.

As is visible in the examples of Figures 6 to 11, the free end of the injector has a central tip 52 forcing the plasma to fix itself on the axis of the nozzle, at the centre of the gas stream.

In this case, the free end 34 of the injector has a set of gas passage orifices, such as 54, distributed uniformly about the central tip 52, there being for example 2, 4 or 6 (Figures 7, 9 and 11) of these to form an injector of the "shower head" type.

As an alternative, as depicted in Figures 12 and 13, the central tip 52 is replaced by a tip 56 forming the bridge mounted at the free end 34 of the injector.

A gas treatment installation employing the device which has just been described will now be described with reference to Figure 14.

As can be seen in this Figure 14, the device comprises two torches 29 capped by a single reactor 42, which opens into a gas collection pipe 48.

As an alternative, it is obviously possible to have one reactor for each individual torch.

One of the free ends 16 of the waveguide structure 12 is equipped with an end plate forming a mobile short circuit 58 for adjusting the impedance and connected to a device 59 for adjusting its position within the structure 12.

35

The opposite end 14 is connected to a power generator 60 generating the incident microwaves via a circulator 62, of conventional type and optional, protecting the generator against the power reflected by the torches 29

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when the plasma is extinguished, or when the impedance matching is poor or in the process of being adjusted. The role of the circulator 62 is to transfer the reflected power to a device (not depicted) designed to
5 absorb this power, for example a device equipped with a charge of water.

Directional couplers 64 are also inserted between the circulator 62 and the device 10 so as to tap off a
10 determined fraction of the power passing through the waveguide, so as to determine its value.

The installation is supplemented by means of feeding the device 10 with gas for treatment (these means not
15 being depicted), connected to the torches 29.

An exemplary application of the treatment device which has just been described will now be described with reference to Figures 15 to 17 for the destruction of
20 C_2F_6 .

The incident microwaves have a frequency of 2.4 GHz. The mobile short circuit 58 mounted on the free end 16 of the structure 2 is set to optimize the impedance
25 matching and minimize the reflected power.

It has been found that, with the waveguide torch device according to the invention, a very low value for the power reflected to the generator can be obtained after
30 the mobile short circuit 58 has been adjusted. Optionally, a three-screw impedance matching (not depicted) may be installed on the waveguide on the microwave power arrival side, between the directional couplers 64 and the device 14 so as to improve the
35 adjustment.

Furthermore, as can be seen in Figure 15, adjusting the heightwise position of the injector 30 with respect to the upper surface of the face 33B constitutes a means

- 15 -

of very fine adjustment and makes it possible to minimize the reflected power. In this particular example, the height may be between 2.8 cm and 4.1 cm and is preferably 3.4 cm.

5

The pressure inside the reactor 42 is adjusted using the pumping means 50 (Figure 1) so as to avoid the development of an electric arc between the nozzle of the torch 29 and the wall of the reactor 42 and so as to obtain a plasma that is stable, for a given microwave power range.

It will be noted that, if the pressure inside the reactor 42 is lowered, the power of the incident microwaves has to be reduced accordingly in order to keep the plasma acceptably stable.

With reference to Figure 16, it can be seen that the pressure in the reactor 42 also has an influence on the level of destruction of C_2F_6 .

Thus, in order to keep the plasma acceptably stable, to avoid the risk of arcs appearing, and be able to maintain a sufficient level of power to reach the desired level of destruction, work is preferably carried out at pressures between 800 hPa (600 Torr) and 866 hPa (650 Torr).

Figure 17 depicts a curve illustrating the variation in the level of destruction of C_2F_6 as a function of the incident microwave power, for C_2F_6 diluted to 1% in nitrogen, this being given for various nitrogen flow rates. It can be seen that, at a low flow rate (5.0 liters per minute) the level of destruction easily reaches 100% for a modest power (1200 watts). By contrast, when the nitrogen flow rate is increased to 40.0 liters per minute, even using two torches, the level of destruction for a comparable power is then merely of the order of 40%. To return to a level of

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destruction of 70%, it is necessary to raise the power to as much as 2800 watts.

It can now be understood from the foregoing that the
5 operating conditions of the device described with
reference to Figures 1 to 13 can be adapted to obtain a
level of destruction of C_2F_6 close to 100% by altering
the flow rate and the absorbed microwave power. These
results are not affected by the generation of solids
10 originating from the breakdown of the treated gases, in
that the plasma is produced in the reactor 42
downstream of the torch 29 rather than in the pipe
feeding the device with gas for treatment.

15 The solid residues are therefore unable to block this
pipe or alter its internal geometry. They may also be
easily recovered in that these products of
decomposition accumulate in the bottom of the reactor
42.

20 Furthermore, this performance is obtained by means of a
gas treatment device according to the invention which
is of a simple and therefore inexpensive structure in
that the means provided for applying the electric field
25 associated with the incident electromagnetic wave are
greatly simplified by comparison with those with which
plasma torches are generally equipped, while at the
same time remaining highly effective.

30 Figures 18 and 19 depict a second embodiment of a
device according to the invention. In that which
follows, only the differences by comparison with the
first embodiment will be described. The elements
similar to those of the first embodiment bear identical
35 references.

This device 10 comprises a hollow structure 12 borne by
a support plate 79. The hollow structure has a region

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80 the cross section of which is identical across its entire length between the two ends 14, 16.

5 The support plate 79 has a tapping 82 coaxial with the two orifices 26, 28 of the hollow structure 12.

A double ring coupling device 84 is screwed into this tapping 82 and extends from the opposite side of the plate 79 to the hollow structure 12. This coupling
10 device 84 is known per se and marketed for example under the name of "Swagelock®".

This coupling device 84 comprises a base body 86 roughly in the shape of a hollow cylinder.
15

The base body 86 has an external screwthread 88 via which it is fixed into the tapping 82. The base body 86 has, on the opposite side to the support plate 79, an external screwthread 90 and an interior conical surface
20 92 which narrows toward the support.

The device 84 further comprises two rings 94, 96 of frustoconical shape arranged coaxially with respect to each other and with respect to the base body 86. The
25 frustoconical surface of the first ring 94 is pressed against the frustoconical surface 92 of the base body 86.

A clamping nut 98 is screwed onto the external
30 screwthread 90 and clamps the first ring 94 between the second ring 96 and the base body 86.

The injector 30 comprises a cylindrical part and extends through the nut 98, the two rings 94, 96 and
35 the base body 86. The injector 30 is fixed axially by radial clamping of the first ring 94 against a cylindrical part of the injector 30.

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Continuous adjustment of the height of the injector 30 with respect to the face 33B of the hollow structure 12 is thus possible.

- 5 The device 10 further comprises an impedance converter 100 fixed on the interior surface of the opposite face 33B of the hollow structure 12.

10 The impedance converter 100 is essentially a hollow cylinder 102 arranged coaxially around the torch 29.

The end of this hollow cylinder 102 adjacent to the opposite face 33B comprises a fixing base 104 in the form of an annular disk in which a central orifice 105
15 is made for the passage of the injector 30. Three fixing holes 106 (one of which is visible) are formed in the base 104 and distributed uniformly about the axis of the cylinder. The impedance converter 100 is fixed to the hollow structure 12 by three screws 108.
20

It is to be noted that the central orifice 105 of the base 104 has a diameter slightly smaller than the diameter of the orifice 26 of the structure.

- 25 Thus, the two orifices 26, 105 are decoupled from an electromagnetic standpoint and the conveying of the microwave power to the end 34 of the injector 30 is, at the site of the orifices 26, 105, more or less determined by the gap 105A present between the orifice
30 105 and the injector 30. The edge of the central orifice 105 is of rounded, particularly semi-toric, shape, so as to reduce the risk of arcs being generated between the edge and the injector 30.

- 35 The fixing base 104 further comprises a circular axial rim 112 on its surface facing toward the opposite face 33B of the hollow structure 12. The rim 112 has roughly the same diameter as the fixing base 104. This rim 112 forms a spacer spacing the fixing base 104 away from

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the opposite face 33B and thus decoupling the impedance converter 100 from the hollow structure 12 as far as microwave energy is concerned.

- 5 In this way, the passage of the microwave power to the site of the discharge is determined mainly by the impedance converter 100.

10 The dimensions of the impedance converter are chosen so that the electromagnetic impedance of the injector 30 is roughly the same as the characteristic electromagnetic impedance of the hollow structure 12.

15 The impedance converter is made, for example, of copper or brass but may be made of any material that is a good conductor of electricity. For a microwave frequency of 2.45 GHz, the preferred dimensions of the converter are as follows: the length is between 30 and 40 mm and is preferably 33 mm, and the outside diameter is between
20 20 mm and 30 mm and is preferably 25 mm.

The way in which the device according to the second embodiment works is similar to the working of the device according to the first embodiment.

25

The second embodiment of the device according to the invention is of a particularly simple structure and has a low cost of manufacture.

CLAIMS

1. A device for treating gas with plasma, particularly sustained by microwaves, of the type
5 comprising a hollow structure (12) forming a waveguide intended to be connected to a microwave generator (60) and means (29) for causing the gas for treatment to circulate through said structure in a region in which the amplitude of the electrical field associated with
10 the incident wave is high and preferably at a maximum, characterized in that the means for causing the gas to circulate comprise at least one plasma torch (29) for producing, at its outlet, a plasma in the gas for treatment, the torch comprising an injector (30) made
15 of electrically conducting material mounted on a first large face (33A) of the waveguide-forming structure (12) and projecting through an orifice (26) made in a second large face (33B) opposite said first large face, a gap (26A; 105A) for the passage of the incident waves
20 extending around the injector (30).

2. The device as claimed in claim 1, characterized in that it comprises means (36, 38; 84) of adjusting the axial position of the injector (30) with respect to the
25 waveguide-forming structure (12).

3. The device as claimed in claim 2, characterized in that the adjusting means are designed in the form of a screwthread (36) formed on the external surface of the
30 injector (30) and collaborating with a tapping (38) borne by the waveguide-forming structure (12).

4. The device as claimed in claim 2, characterized in that the injector (30) has a roughly cylindrical outer
35 part, in that the adjusting means are designed in the form of a double ring coupling device (84) fixed to said first large face (33A) of the structure (12), the double ring coupling device having the injector (30)

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passing through it, and in that said cylindrical part is tightened radially onto said coupling device (84).

5 5. The device as claimed in any one of claims 1 to 4,
characterized in that the waveguide-forming hollow
structure (12) has a first end (14) intended to be
connected to the microwave generator (60), an opposite
second end (16) intended to be equipped with impedance
adjusting means (58) forming a short circuit, and a
10 region (18; 80) in which the means for causing the gas
to circulate and for conveying the microwave power to
the end of the injector (30) are provided.

15 6. The device as claimed in claim 5, characterized in
that said region is a region (18) of narrowed cross
section.

20 7. The device as claimed in claim 6, characterized in
that said region (18) of narrowed cross section
comprises a part (20) of constant cross section in
which the means (29) for causing the gas to circulate
are provided, and in that said region of narrowed cross
section extends between two parts (22, 24) the cross
section of which increases linearly toward the first
25 and second ends (14, 16).

30 8. The device as claimed in claim 5, characterized in
that said region is a region (80) of constant cross
section which extends between said two ends (14, 16),
and in that the device further comprises an impedance
matcher (100) which converts the electromagnetic
impedance of the plasma injector system into the
characteristic electromagnetic impedance of the
waveguide-forming structure (12).

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9. The device as claimed in claim 8, characterized in
that the impedance matcher (100) is a hollow cylinder
(102) made of a material that is a good conductor of
electricity, particularly of copper or brass, arranged

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coaxially around the injector (30), and extending from the second large face (33B) of the structure (12) toward said first large face (33A).

5 10. The device as claimed in claim 9, characterized in that the microwaves have a frequency of roughly 2.45 GHz, and in that the hollow cylinder (102) has a length of between 25 mm and 40 mm, preferably roughly equal to 33 mm and an outside diameter of between 20
10 and 30 mm, preferably roughly equal to 25 mm.

11. The device as claimed in any one of the preceding claims, characterized in that the gap (26A) is delimited by the orifice (26) formed in said large face
15 (33B) and the outline of the injector.

12. The device as claimed in any one of claims 1 to 10, characterized in that it comprises an annular disk (104) mounted on said second large face (33B) and
20 having a central orifice (105) which has a diameter smaller than the diameter of the orifice (26) of said second large face (33B), in that the gap (105A) is delimited by the central orifice (105), and in that a spacer piece (112) is placed between the annular disk
25 (104) and said second large face (33B) spaced away from the edge of the central orifice (105).

13. The device as claimed in claim 11 or 12, characterized in that the edge of the orifice (26; 105) delimiting the gap (26A; 105A) is of rounded,
30 particularly semi-toric, shape.

14. The device as claimed in any one of claims 1 to 13, characterized in that the gap (26A; 105A) is
35 between 1 mm and 3 mm wide.

15. The device as claimed in claim 5 or one of the claims dependent on claim 5, characterized in that the hollow structure (12) has, at least at one of its ends

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(14, 16), and preferably at each of these ends, a window (43) made of dielectric material, particularly of Teflon®, transparent to microwave energy and isolating the internal volume of the hollow structure (12) in a roughly gastight way from the waveguide sections extending respectively toward the microwave generator (60) and toward the impedance adjusting means (58).

10 16. The device as claimed in any one of claims 1 to 15, characterized in that it further comprises a treatment reactor (42) mounted on the waveguide-forming hollow structure (12) and capping the free end of the injector (30).

15 17. The device as claimed in claim 16, characterized in that the wall of the treatment reactor (42) is cylindrical and equipped with a cooling coil (44) in communication with a source of cooling fluid.

20 18. The device as claimed in either one of claims 16 and 17, characterized in that it further comprises means (50) of pumping the atmosphere in the treatment reactor (42).

25 19. The device as claimed in claim 18, characterized in that the pumping means constitute means of adjusting the roughly laminar flow of the gases at the site of the plasma.

30 20. The device as claimed in any one of claims 17 to 19, characterized in that the reactor (42) is equipped with plasma-striking means (46).

35 21. The device as claimed in claim 20, characterized in that the striking means comprise a wirelike rod (46) made of electrically conducting material, particularly tungsten, extending toward the free end (34) of the injector (30) and connected to a source of low-

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frequency or radio-frequency high AC voltage, and movement means allowing it to be brought closer to or moved away from the vicinity of the free end (34).

- 5 22. The device as claimed in any one of claims 1 to 21, characterized in that the free end (34) of the injector (30) has a cylindrical or conical overall exterior shape.
- 10 23. The device as claimed in claim 22, characterized in that the free end (34) of the injector (30) is equipped with a projecting central element (52; 56) for centering the plasma with respect to the outlet of the injector (30), gas passage orifices (54) extending on
- 15 each side of this element.