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Foex et al.

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[45] **Mar. 19, 1974**

[54] **METHODS AND DEVICES FOR PLASMA PRODUCTION**

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[73] Assignee: **Agence Nationale De Valorisation De La Recherche (Anvar)**, Neuilly-sur-Seine, France

[22] Filed: **Dec. 20, 1971**

[21] Appl. No.: **209,885**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 888,508, Dec. 29, 1969, Pat. No. 3,714,390.

[30] **Foreign Application Priority Data**

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Dec. 31, 1968 France 68.182839

[52] **U.S. Cl.** .... **219/121 P**
[51] **Int. Cl.** **B23k 9/00**
[58] **Field of Search** .... 219/121 P, 74, 75; 313/231; 315/111

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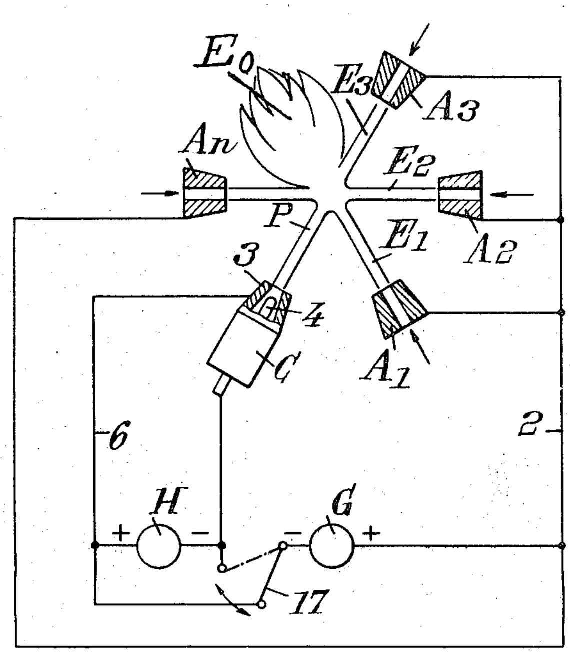
Assistant Examiner—Gale R. Peterson
Attorney, Agent, or Firm—Larson, Taylor & Hinds

[57] **ABSTRACT**

A plasma generating installation comprises a pilot generator and nozzles supplying respectively convergent gas flows. These nozzles are inserted in a circuit capable of being completed across these flows by reducing the electrical resistance therein. This circuit and the supply circuit for the pilot generator are connected in parallel to a single current source. The installation is suitable for generation of plasmas of large volume.

The invention relates to methods and devices for the production of plasma jets in the midst of convergent fluid flows giving rise to a main flow of plasma and of which at least certain of them are supplied through nozzles devoid of their own electrical supply.

25 Claims, 17 Drawing Figures



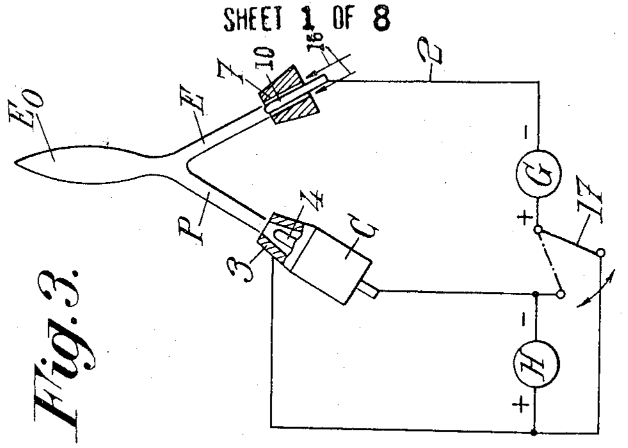


Fig.3.

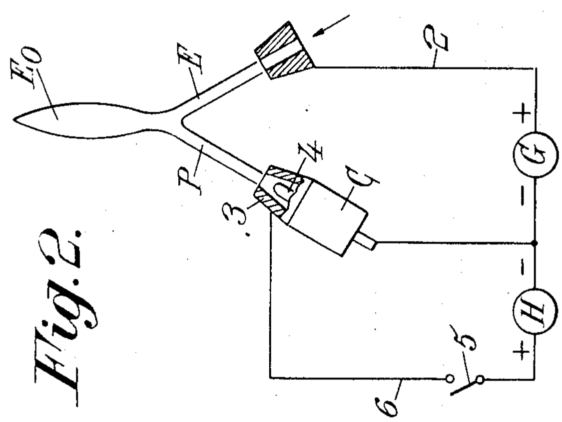


Fig.2.

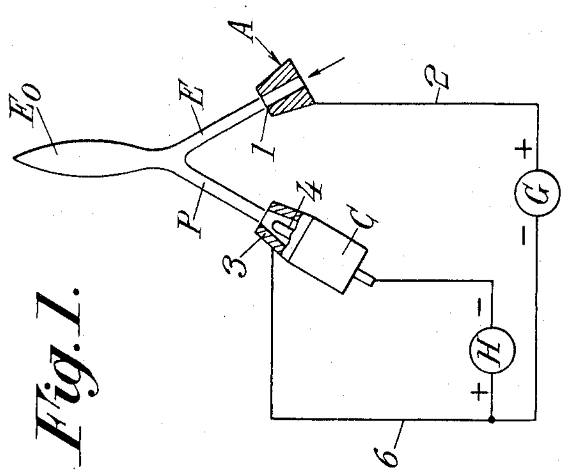
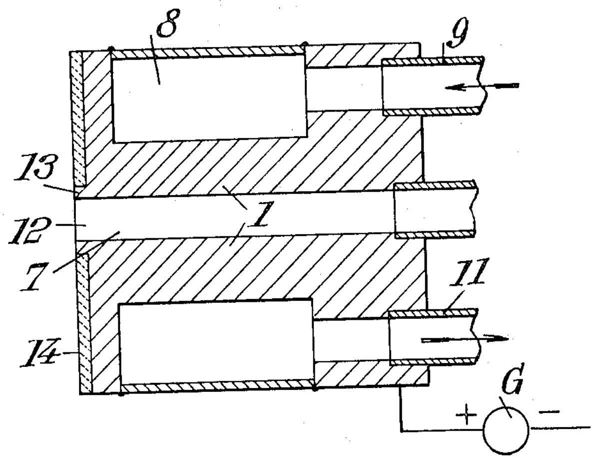


Fig.1.

Fig. 4.



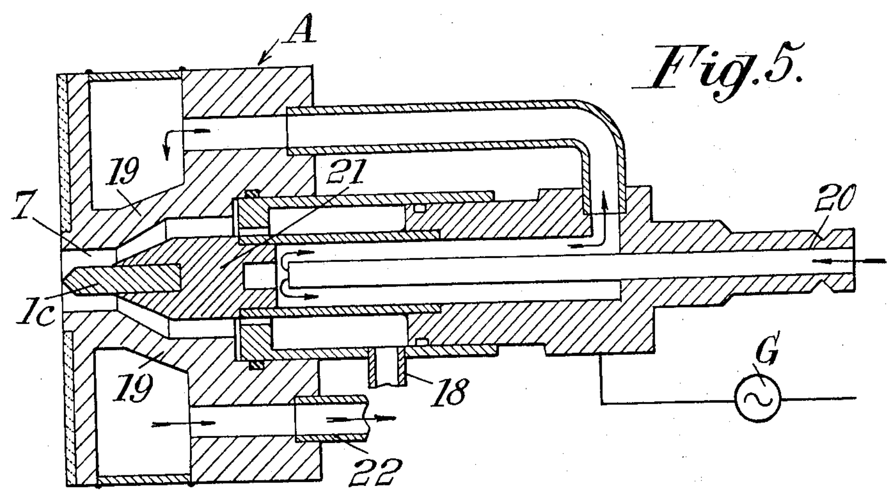


Fig. 5.

Fig. 6.

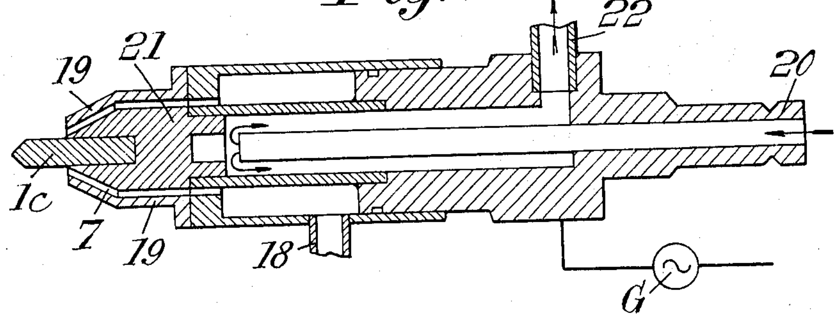


Fig. 7

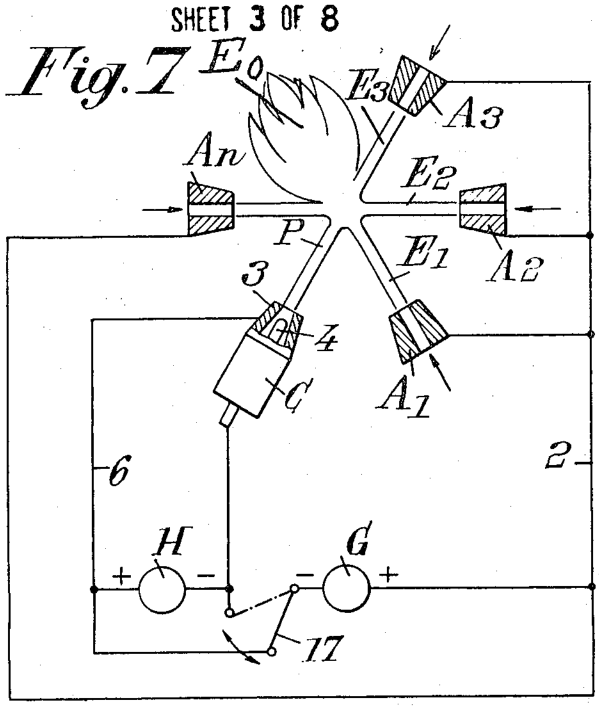

E0
E3
A3
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Fig. 9.

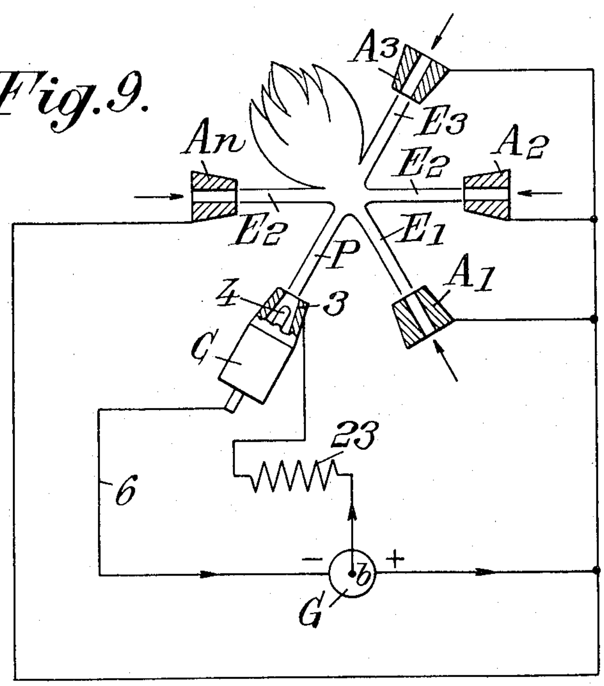
A3
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Fig. 8.

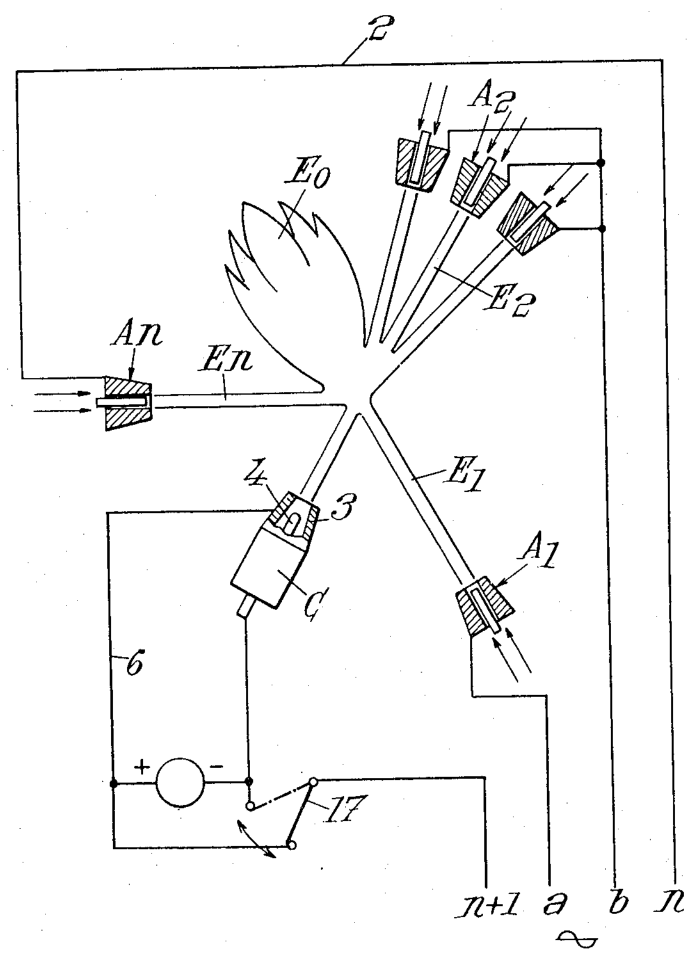


Fig. 10.

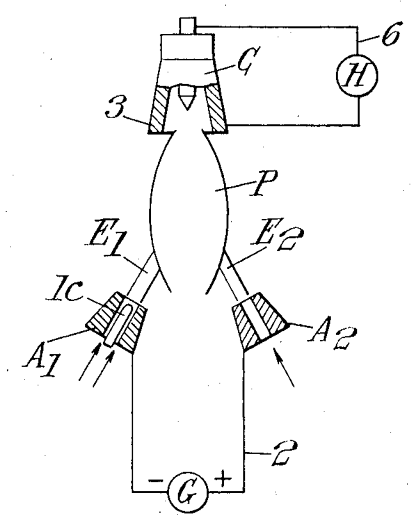


Fig. 11.

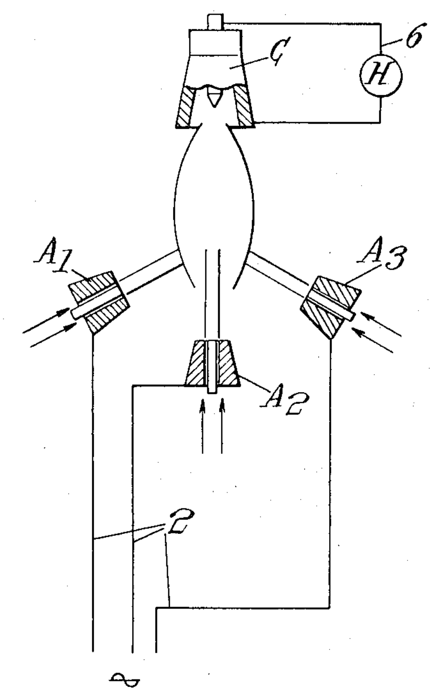


Fig. 12 a

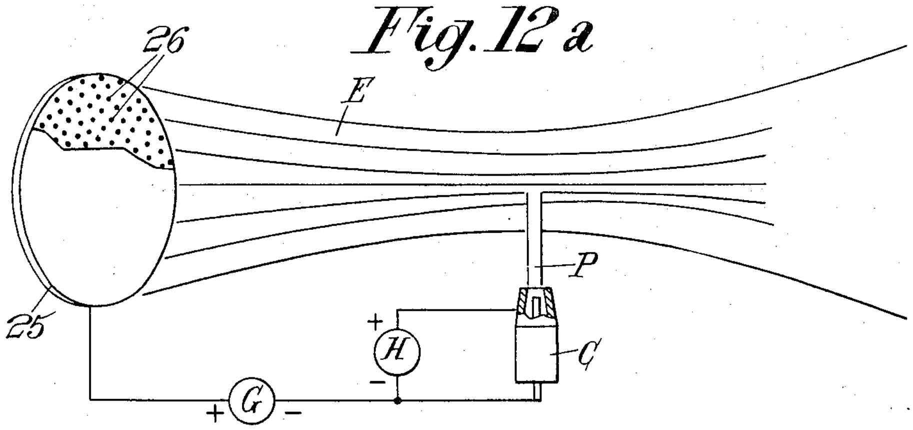


Fig. 12.

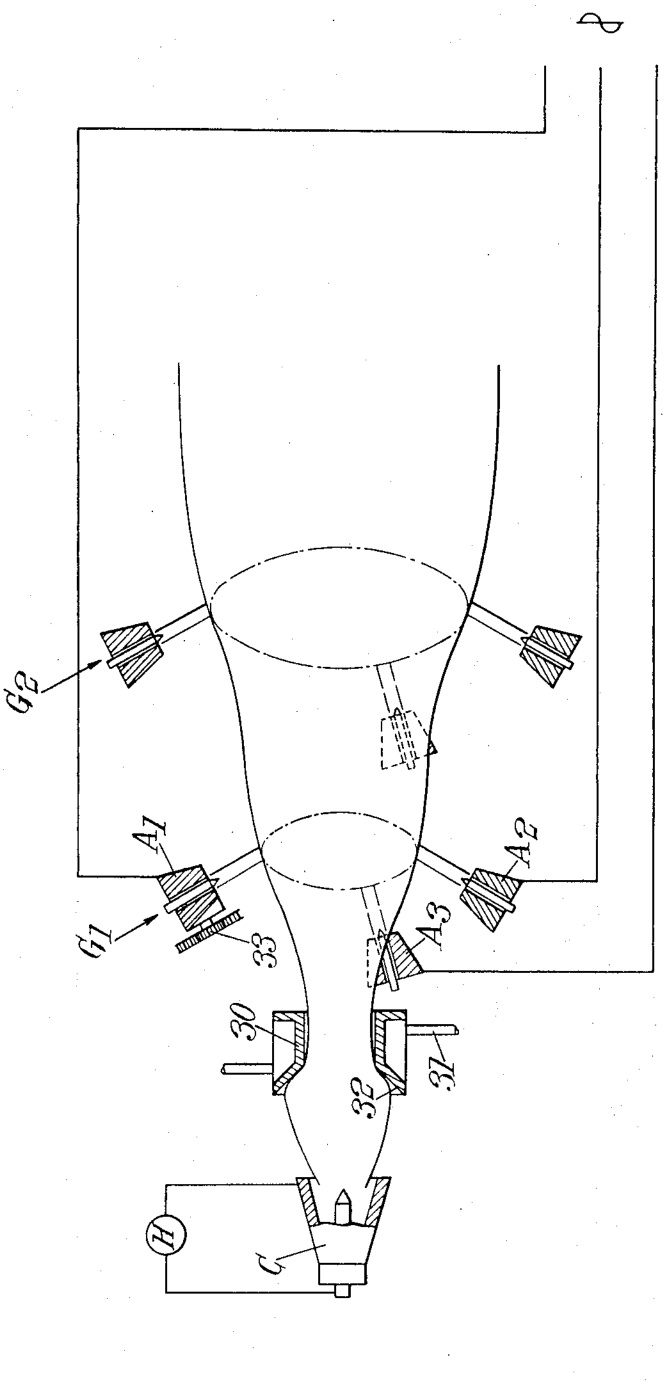
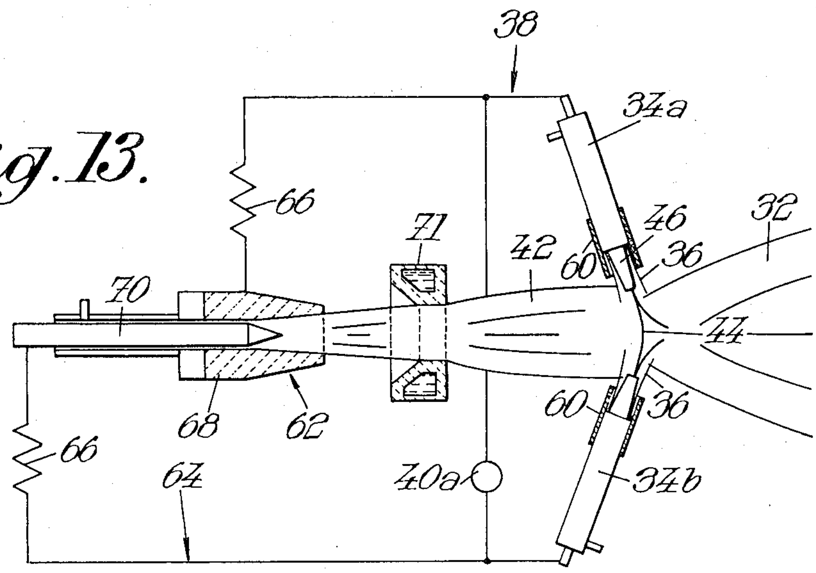


Fig. 13.


38
34a
66
46
32
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70
44
60
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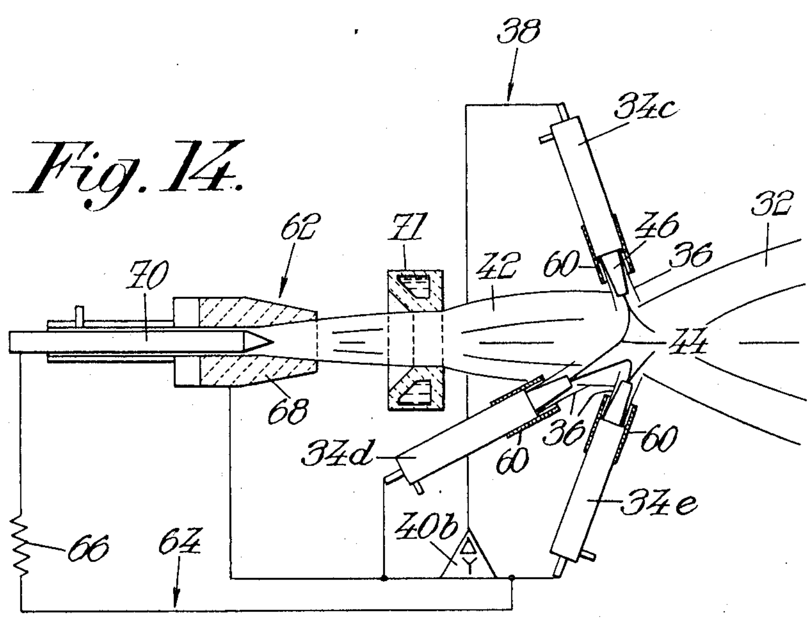
64
40a
34b

Fig. 14.


38
34c
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71
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68
36
60
34d
60
34e
40b
66
64

Fig. 16.

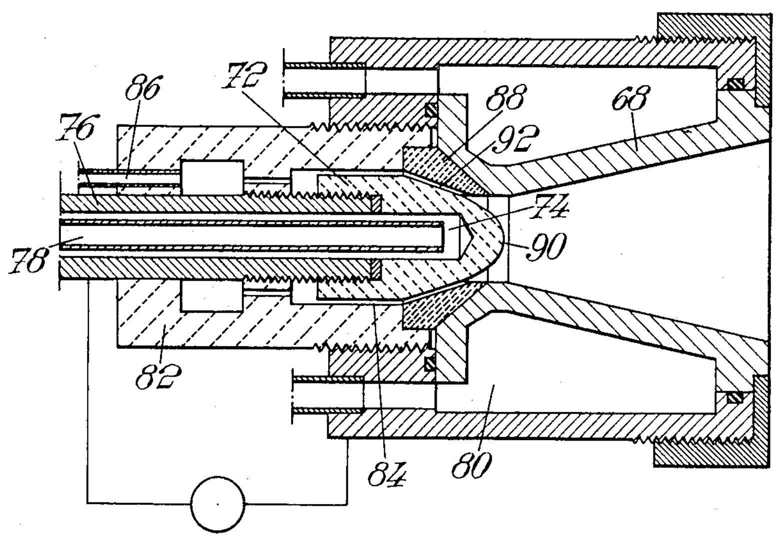
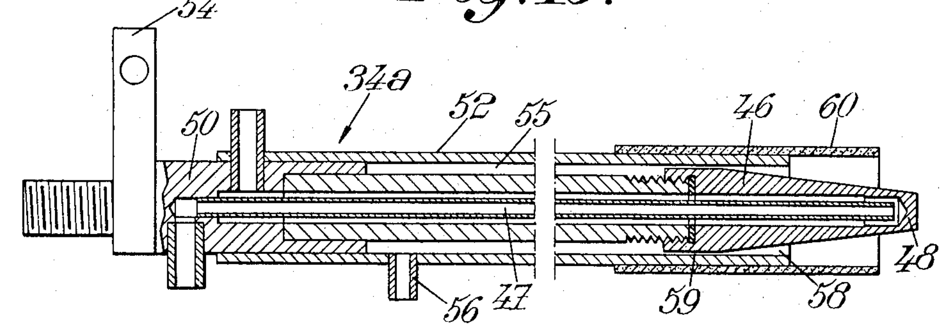


Fig. 15.



METHODS AND DEVICES FOR PLASMA PRODUCTION

The present invention is a continuation-in-part application of our copending application Ser. No. 888,508 filed Dec. 29, 1969 now U.S. Pat. No. 3,714,390 issued on Jan. 30, 1973.

Installations have already been disclosed wherein at least two generators of ionized gases are positioned such that the plasma elementary flows delivered by said generators converge substantially with one another and wherein these generators are connected to an external electric current supply source such that an electric heating current is caused to travel along a path passing through the converging zone of these flows, whereby the energy supplied by said external electric current source is recovered within said elementary flows and the permanent flow resulting from the convergence of the former.

Although the independent electrical supply of one or several of the generators may be reduced, and even eliminated under certain conditions, such as when the external electrical current supply source provides direct current, and when the heating electric current has been initiated within the elementary flows, the energy which may be recovered remains however dependent upon the flows of fluid likely to be delivered by said generators, which flows remain themselves practically dependent upon the characteristics of operation of the corresponding generators.

An object of the invention is to modify these installations such that they meet better than heretofore the different requirements of practice, especially to provide processes and installations of a considerably simpler nature than those known heretofore and which are able to produce plasma streams within flows of fluids of any nature (pure gases, gaseous mixtures, vapors, liquids or liquid solutions, aerosols, broths, foams, emulsions and suspensions) under any flow rate.

Other objects and advantages of the invention will emerge from the description which follows.

The invention is based on the discovery that advantage may be taken of the difference in electric conductibility which exists between the gases contained within a plasma flow and the surrounding atmosphere, even if the latter is less dielectric than the above gases in their cold state, for forming in said flow a preferential path for an electric current.

The installation according to the invention comprises a first nozzle for producing at least one elementary flow of fluid, said first nozzle including a channel with an outlet and an electrode disposed substantially along the longitudinal axis of said channel and having a front extremity which extends to a plane at least flush with respect to the end of said channel around said electrode, the annular space formed within said channel and around the electrode forming the ejection channel for the corresponding elementary flow; at least one second nozzle for producing another fluid flow, said first nozzle and second nozzle being positioned relative to each other so as to cause said elementary flow to converge with said another fluid flow for producing a principal flow resulting from the convergence of said elementary flow and said other fluid flow; said electrode and said second nozzle being connected in a normally open electrical circuit including an external voltage source which is capable of producing a voltage sufficient to

cause completion of said circuit through said elementary flow and said another fluid flow when the electrical resistance therein is reduced; and means for producing a plasma flow having a cross section greater than that of said elementary flow and said another fluid flow and so positioned as to permit ionization of the atmosphere in which said elementary flow and said another fluid flow are formed to thereby cause a reduction of the electrical resistance in, and an ionization of, said element flow and said another fluid flow.

These installations comprise generally a "pilot" generator provided with its own electrical supply, this generator being oriented so that the plasma jet that it produces converges with the flows supplied by the nozzles. The supply itself of this pilot generator can, in some assemblies, be interrupted as soon as the closing of the abovesaid circuit has been effected.

In the majority of these assemblies, the electrical supply of the circuit in which the nozzles are inserted and that of the pilot generator are separate. Thus the pilot generator —generally constituted by a plasma torch (or blowpipe) operating on direct current or by a plasma torch operating on high frequency current — is not only more complex but also relatively more expensive than the principal plasma production device itself, taking into account the source of electric current (direct or high frequency) necessary for the production of the pilot plasma.

It is possible to use an assembly in which these supplies are merged into a single supply. In this assembly, however, the pilot generator and the nozzles are connected in series, the intensity of the electric current furnished by the supply being divided, once the starting has been effected, between the maintenance intensity of the electric current in the plasma jets formed in the flows emerging from the nozzles and between the maintenance intensity of the plasma emerging from the pilot generator, whence the necessity of disposing to this end a fairly powerful electric current supply source. In addition, this assembly can only be used, when the pilot plasma generator is constituted by a plasma torch of conventional design, comprising for example a cooled copper anode and an emitter cathode constituted of a tube of tungsten, with a direct current supply. Such a torch could not in effect operate with alternating current, the tungsten rod being unable, without deterioration, to receive periodically and during a prolonged period of time, the thermal flux of high value to which it would normally be subjected each time that it acts as an anode.

It is accordingly a further object of the invention to enable the production of assemblies of the type concerned, comprising a single supply, of relatively reduced power, and, insofar as necessary, a pilot generator capable of being supplied with alternating current.

According therefore to another feature of the invention, the installation comprises a single supply, characterised by the insertion of the pilot generator, on one hand, and nozzles, on the other hand, in circuits respectively connected in parallel to a single source of supply, and by the presence, in the circuit of the pilot generator, of a resistance having a sufficiently high value for the current to pass preferentially in the supply circuit of the nozzles.

In a preferred embodiment of the invention, the source of current produces alternating current, the two electrodes of the pilot generator are constituted of energetically cooled parts, preferably constituted of a same material, such as copper, and the abovesaid resistance has a value such that, when the arcs are started in the flows emerging from the nozzles, the operation of the pilot generator is interrupted.

The invention will in any case be more fully understood with the air of the supplementary description which follows, as well as of the accompanying drawings, which supplement and drawings are, of course, given purely by way of example and are to be regarded as in no way limiting.

In the drawings:

FIGS. 1, 2 and 3 are diagrammatic representations of various embodiments of installations according to the invention, for producing plasma streams within gaseous flows;

FIGS. 4 to 6 are axial sections of nozzles suitable for use in preferred embodiments of installations, according to the invention;

FIGS. 7 to 12 and 12a are diagrammatic representations of additional embodiments of installations according to the invention;

FIGS. 13 and 14 show diagrammatically assemblies according to preferred embodiments of the invention;

FIG. 15 is a cross-section of a nozzle suitable for the assemblies shown in FIGS. 13 and 14; and

FIG. 16 is a diagrammatic cross-section of a preferred embodiment of a pilot plasma generator, according to the invention.

The invention will be disclosed below, as applied to the production of plasma streams in gaseous flows, it being however understood that the invention could also be applied to other fluids, in particular to those referred to above.

The process according to the invention comprises causing at least two gaseous flows P and E, of which at least one is supplied through a nozzle A associated with an electrode maintained in contact with the corresponding flow (E in FIG. 1), to converge with another, said electrode being provided within an electric circuit 2 including an external electric current supply source referred to hereafter as principal generator G, and producing in these flows, outside of said nozzle, a reduction of the electric resistance within said flows such that said electric circuit 2 may be completed through said flows. The electrodes associated with the above nozzles may be constituted by conducting parts of the nozzles themselves (FIGS. 1, 2, 4, 7 and 9) or, on the contrary, consist of distinct elements $1c$ as will become apparent in embodiments of the invention which will be described later.

In a first group of preferred embodiments of the invention, one of the flows, for instance flow P, is supplied by a plasma blowpipe C, referred to hereafter under "pilot blowpipe," of which at least one electrode (anode 3 or cathode 4) is itself provided within circuit 2.

The independent supply source H of the pilot blowpipe may be itself provided within or separate from circuit 2 (in particular when the switch 5 provided within the supply circuit 6 of the pilot blowpipe C in FIG. 2 is opened.

As indicated hereabove, a preferential path may be formed for an arc in flow E, even if its electric conductivity, before ignition of an electric arc therein, is lower than that of the surrounding atmosphere, subject however to this arc originating in a zone of the nozzle in contact with the gas of the flow. The ignition of the arc, which produces heating of the abovementioned zone of the nozzle, will also heat the gas in the flow, and hence reduce its resistivity, thereby forming a path of less resistance than the surrounding atmosphere for electric current. Obviously the intensity of this phenomenon will be even greater if the gas in the flow is itself, at rest, less of a dielectric than the surrounding atmosphere.

As a result, especially in the installations shown in FIGS. 1 and 2, it will be sufficient to initiate an arc along flow E between nozzle A and flow P, since the latter is already ionized itself, to complete close the above-mentioned circuit 2.

It has been found that the ignition may be performed in many ways, for instance by resorting to the conventional methods used for causing the ignition of a plasma blowpipe, these methods, when applied to the nozzles, consisting for instance, of producing electric discharges along the gaseous stream delivered by the nozzle or producing a temporary electric connection between nozzle A and flow P, for instance by means of a rod of graphite or the like. This ignition may also, especially when nozzle A and blowpipe C are movable, be produced by bringing them closer to one another that is to say to a distance of separation such that the voltage available at the terminals of the principal generator G will be able itself to produce the ionization of the gaseous flows delivered by the nozzle. In such a case, their ionization will be facilitated by the peak effect or corona effect produced when the electrodes exhibit the forms shown in FIG. 5 or 6. The ignition may also be performed by introducing in the flow delivered by the nozzle ionizable substances, for instance alkaline halides or metallic oxides, or by ionizing the whole ambiant medium as will be disclosed more particularly in connection with FIGS. 10 and 11 below.

When generator G delivers direct current and its positive terminal (FIGS. 1 and 2) is connected to nozzle A, the same may be constituted by a mere metallic nozzle, for instance such as shown in greater detail in FIG. 4, which nozzle comprises an ejection channel 7 for the gases, surrounded by a cooling chamber 8 connected to an inlet 9 for a refrigerating fluid and to an outlet 11 for the removal of this fluid, after the same has travelled through chamber 8. The conducting part 1 consists advantageously only of an annular narrow part 13 surrounding the gas outlet 12 of the nozzle, whereby a satisfactory centering of the arc formed in the gaseous flow is obtained.

In that respect, the exterior side of the nozzle, around that annular part 13, is advantageously covered with an electric insulator 14 which, in addition, prevents the formation of parasitic arcs during the operation of the installation.

Such a nozzle, even though it has no independent electric current supply system, is then able to operate like a true plasma blowpipe as soon as an arc has been ignited between nozzle A and the pilot ionized flow P, along flow E under the conditions set forth hereabove.

The completion of circuit 2 through flows P and E then permits the reduction and even the interruption of the current delivered by generator H. In the installation shown in FIG. 1, the electric current within circuit 2 may travel either through the cathode or through the cathode and anode, and further through generator H when the same is positioned within the circuit, generator H then acting like a mere resistance. It has however been found that in the installation of FIG. 1, the electric current travels preferentially through cathode 4 of blowpipe C so that the negative terminal of generator G may also be directly connected to cathode 4 of blowpipe C (FIG. 2). Generator H may also be disconnected from circuit 2, such as by the opening of a switch 5 provided within the corresponding part of the independent electric current supply circuit of the pilot blowpipe (FIG. 2).

There is thus provided an installation in which plasmas may be produced in gaseous flows delivered by mere nozzles, whereby the flow rates of these flows may be controlled responsive to parameters different from those taken into account in former systems, more particularly the operational characteristics of each of the sources which delivered these flows.

It is possible in the installation according to the invention to produce plasma streams within the gaseous flows delivered by the nozzles at rates either much smaller or, in the contrary, much higher than the usual supply rates of the conventional blowpipes, depending on whether it is desired to obtain laminar plasma flows E_o or resulting flows exhibiting a high power and a high temperature.

Moreover, the installations according to the invention enable the easy production of plasma streams within flows of corrosive or oxiding gases, such as oxygen, which have no effect on the above mentioned nozzles, especially in the installations shown in FIGS. 1 and 2.

By way of example only, and for the mere purpose of illustrating the invention, the results obtained with an installation according to FIG. 1 will be set forth herebelow ; more particularly these results were obtained under the following experimental conditions :

rate of the nitrogen flow delivered by the pilot blowpipe C : 7 l./minute ;

rate of the argon flow delivered by nozzle A : 7 l./minute ;

angle formed between the axes of blowpipe C and of nozzle A : 90° ;

distance between the outlet of pilot blowpipe C and the point of convergence of flows E_1, E_2 : 13 cm ;

distance of the outlet of the nozzle A from the same point : 5 cm.

The energy supplied during the operation of the installation by generator G and generator H, especially when the latter is maintained in operation, are respectively set forth in the two first columns starting from the left in Table I herebelow. The measured amount of energy (yield) which has been dissipated in flows, P, E and in the flow E_o resulting from their convergence, has been set forth in the column on the right side of Table I.

TABLE I

Energy supplied by H (kW)	Energy supplied by G (kW)	Yield
15 (60 V – 250 A)	30 (130 V – 250 A)	78 %
15 (60 V – 250 A)	38 (160 V – 240 A)	81 %
0	45 (185 V – 240 A)	>90 %

The comparison of the yields set forth in the first and third horizontal lines of the table, which corresponds to results of experiments which involved the use of equal total energies, shows that the interruption of the independent electricl current supply of pilot blowpipe C causes a considerable increase of the energy yield of the installation. The results set forth in Table II herebelow were obtained when supplying the same nozzle A with oxygen and when the respective distances of the pilot blowpipe C and of the nozzle A from the point of convergence were equal to 7 and 5 cm, the other conditions of operation of the installation being the same as indicated above.

TABLE II

Energy supplied by H (kW)	Energy supplied by G (kW)	Yield
15 (60 V – 250 A)	60 (200 V – 300 A)	80 %
15 (60 V – 250 A)	44 (200 V – 220 A)	75 %
0	48 (230 V – 210 A)	90 %

In the installations described above, the conducting part 1 of nozzle A was connected to the positive terminal of generator G. It may also be connected to the negative terminal of generator G as shown in FIG. 3, or to one of the terminals of a source of mono- or polyphase alternating current, this conducting part behaving accordingly like a cathode, either continuously or periodically.

After ignition of the arc in the flows P and E and the possible disconnection of generator H, one of the electrodes, for instance the anode 3 (FIG. 2) of the pilot blowpipe may be disconnected also by means of a switch 5 provided in circuit 2, so that only the cathode 4 of the pilot blowpipe participates in the passage of the electric current used in the formation of the plasma in the flows P and E.

Obviously one could have resorted to the reverse provision, i.e., to the disconnection of the single cathode of the pilot blowpipe. The two electrodes 3 and 4 of blowpipe C could also be short-circuited.

The greater the ability of the material constituting the conducting part of nozzle A to emit electrons or ionized particles, the better also its ability to act as a cathode continuously (when generator G delivers direct current) or periodically (when generator G delivers an alternating or a polyphase current). It consists advantageously of tungsten. More particularly it is advantageous to resort to nozzles devised as shown in FIGS. 5 and 6, wherein the conducting part 1*c* which acts as the cathode is provided within the ejection channel 7, the gases supplied to nozzle A entering into the same through inlet 18 and flowing within the ejection channel around part 1*c*.

In preferred embodiments of this last type of nozzle, the cathodic part 1*c* is flush with the frontal surface of the nozzle (FIG. 5) or protudes with respect thereto (FIG. 6) thereby providing for both a good heating and a good contact of this cathodic part with the ionized portion of the gaseous flow delivered by the nozzle.

The parts of the nozzle surrounding the ejection channel 7 may then consist of a material which has conducting properties and which is brought to the same potential as the cathode 1*c* (FIG. 5) or of a refractory insulating material. In this last instance, the conducting part is alone connected to the principal generator G.

Such nozzles may then also be provided with cooling means, with an inlet 20 for a cooling fluid along a path shown by arrows in FIGS. 6 and 7 for cooling the cathode support 21 and, if need be (FIG. 5), the parts 19 of the nozzle which surround ejection channel **7** prior to leaving the nozzle through an inlet **22.** The cooling may also be performed with the plasma forming fluid, if the same is supplied to the nozzle under a rate sufficient to that effect.

The pilot blowpipe C may cooperate not only with one single nozzle, like in the installations which have been discussed, but with a plurality of such nozzles $A_1, A_2, A_3 \ldots A_n$; positioned such that the gaseous flows delivered by them intercept the plasma flow P produced by the pilot blowpipe, the creation of a voltage at generator G then being able to produce the simultaneous or successive ignition of electric arcs in the *n* flows delivered by the *n* nozzles.

In the installation shown in FIG. **7,** these *n* nozzles are connected to the positive terminal of the common supply generator G. Obviously the polarities of the nozzles could be reversed, in which instance however it would be advantageous to provide these nozzles with emissive cathodes **1***c* of the type described in connection with FIGS. **5** and **6.**

In another embodiment of this last type of installation, shown in FIG. **8,** nozzles $A_1, A_2, \ldots A_n$ are respectively connected to n distinct phases a, b . . . .n of a polyphase alternating supply source comprising a $n+1^{th}$ phase connected to one of the electrodes of the pilot blowpipe C, either to the anode or to the cathode, depending upon the position of the switch **17** provided between the generators G and H. When the alternating polyphase current has been ignited in flows P, $E_1, E_2 \ldots E_n$ in the presence of the plasma P delivered by the pilot blowpipe, after the creation of a voltage at generator G and, when needed, by the reduction of the resistance within each of these flows by the means referred to above, the electric supply of the blowpipe C may be disconnected, the electric arc then being maintained by the sole polyphase current supply.

Each of the phases of the polyphased current supply may be connected to more than one nozzle (as represented for the phase *b* of the polyphased supply in FIG. **8**), provided that the streams delivered by these nozzles converge with one another.

In an additional embodiment of the invention shown in FIG. **9,** generators G and H are merged into a single generator G which comprises a negative terminal connected for instance to the cathode **4** of the pilot blowpipe C, a positive terminal connected to the nozzles $A_1, A_2 \ldots A_n$, and finally a terminal *b* at an intermediate potential connected to anode **3** of the pilot blowpipe through a resistance **23.** Assuming I_0 is the current intensity delivered by generator G in the sole supply circuit **6** of the pilot blowpipe, before ignition of the arcs within the flows $E_1, E_2 \ldots E_n$, it will be appreciated that this intensity I_0 divides, after ignition, between an intensity I_1 for the maintenance of the pilot plasma P and an intensity I_2 for the maintenance of *n* plasma streams formed within the flows delivered by the nozzles.

The value of the resistance **23** is advantageously chosen such that the value of intensity I_1 be small compared to the value of intensity I_2. However if for some reason the electric circuit formed within the plasma stream P and the *n* flows delivered by the nozzles tends to be cut off, I_1 will tend to become equal to its original value I_0 and accordingly will permit the re-igniting of the electric current in the *n* flows, this re-ignition being then followed by the concomitant decrease of the intensity of the supply current of the pilot blowpipe to the value I_1.

Obviously the connections could be reversed; the conducting parts of the nozzles $A_1, A_2 \ldots A_n$ should then preferably be devised as described previously in connection with FIGS. **5** and **6.**

According to a further embodiment of these installations, the supply circuit **2** of nozzles $A_1, A_2 \ldots$ is distinct from the supply circuit **6** of the pilot blowpipe, the latter then merely producing an ionization of the atmosphere in which the converging gaseous stream $E_1, E_2 \ldots$ delivered by the nozzles are caused to flow, this ionization being sufficient to favor an easier completion of circuit **2** through said streams.

Such embodiments are shown in FIGS. **10** and **11.** In the installation of FIG. **10,** generator G delivers direct current. If it were to deliver alternating current the nozzles A_1, A_2 shown in FIG. **10** should preferably be both provided with emitting central parts **1***c*. In the installation of FIG. **11,** the nozzles are respectively connected to the phases of a polyphase current supply source.

When the arcs have been established in the converging flows (irrespective of whether the current is direct, mono- or polyphase) the independent electric supply of the pilot blowpipe may be disconnected, so that plasma streams are finally obtained within flows all delivered by mere nozzles, all of which are devoid of any particular current supply.

This can be achieved for instance with two or three nozzles positioned such that the point of convergence of their axes is 5 cm from their frontal surfaces respectively, when these nozzles are supplied with argon at flow rates varying from 1 to 100 l./minute and when they are respectively connected to a monophase electrical current supply or to a triphase electrical current supply at 380 V and 50 Hz.

The pilot blowpipe was supplied with nitrogen at a flow rate of 7 l./minute and with electric current under 60 V and 250 A, the frontal face of the pilot blowpipe being at a distance of 10 cm from the abovesaid point of convergence.

After the disconnectioon of the pilot blowpipe, the following values for the intensity and the voltage of the current travelling between the nozzles were measured :

voltage : 100 V r. m. s.

intensity : 280 A r. m. s.

Accordingly a triphase alternating useful energy of 48.5 kW was recovered in the gaseous flows, thus with an energy yield higher than 95 percent.

It will be appreciated that in all the installations which can be devised, electric arcs can be formed in the flows delivered by the different nozzles, including the pilot blowpipe, by merely bringing them sufficiently close to one another ; it should be noted that the flow need not be in all instances rigorously convergent ; for instance it is sufficient to cause them to be tangent with respect to one another to obtain the completion of the arc through these flows.

The characteristics of operation of the installations concerned will be further improved when resorting to another feature of the invention which consists in imparting to the anode **3** of the pilot blowpipe C, a form diverging in the direction of emission of the corresponding plasma flow P (FIGS. **10** and **11**).

A plasma flow having a greater section and a smaller resistivity, hence a flow having improved electrical conducting prperties is obtained with a pilot blowpipe using such a particular anode **3**. Moreover, it facilitates the production of the contact of the flows delivered by the pilot blowpipe and by the other nozzles with each other, hence the ingition of electric arcs in these flows.

This particular construction of the anode is of particular value when it is desired to ionize a relatively large volume of the atmosphere, in particular to facilitate the ignition of electric arcs in the flows delivered by nozzles arranged and cooperating as shown in FIGS. **10** and **11**.

This construction of the anode **3** also favors the maintenance of the electric current within the gaseous flows under the sole action of the principal generator G, particularly when generator H has been disconnected.

The results obtained in such an installation will further be improved if it further comprises, in addition to the diverging anode disclosed hereabove, an annular member **30** (FIG. **12**) refrigerated by a water current supplied to this member through a duct system, part of which has been shown diagrammatically at **31**, said annular member **30** further comprising a conical surface **32** widening out toward the pilot blowpipe and whose axis coincides with that of the pilot blowpipe.

The annular member **32** may then perform one or several of the following functions :

1- centering and shaping of the pilot plasma flow,

2- forming the principal anode of the pilot blowpipe (when the former is electrically connected to the latter) ; the internal anode of the pilot blowpipe which served for the ignition of the arc thereof may then be disconnected ; a pilot flow of increased power may thus be obtained due to possible increase in the operating voltage of the blowpipe ;

3- stabilizing the operation under pressure of the pilot blowpipe, when this member is used as the principal anode (for instance when the whole installation operates under an external atmosphere maintained under pressures varying for instance from 1 to 20 bars).

This combination of a pilot blowpipe with diverging anode and of said annular member **30** is used with advantage in installations for the production of plasmas of large volume and high energy, for instance of the type disclosed in FIG. **12.** Such installation comprises at least one group, referred to generally under G_1 in FIG. **12,** of nozzles A_1, A_2, A_3 cooperating with copper electrodes cooled by water and supplied for instance with nitrogen (or any other fluid). The electrodes are respectively connected to the phases of a triphased electric current source, each of these nozzle-electrode assemblies being slidable along its axis (as diagrammatically represented for one of them by a rack and pinion system **33**), the axes of the three nozzle-electrode assemblies being contained in three planes passing through the axis of the pilot blowpipe, on the one hand, and making respectively an angle of 60° with the axis of the pilot blowpipe, on the other hand.

This installation can then be operated as follows : the pilot blowpipe is first operated; the flow rate of the plasma forming gas and the electric supply of the pilot blowpipe are controlled to produce the necessary ionization of the space between the electrodes associated with the nozzles A_1, A_2, A_3, upstream from the annular centering member **30.** Arcs are thus ignited between the nozzle-electrode assemblies A_1, A_2, A_3 and the triphase alternating current flows through the electrodes along the gaseous flows delivered by the corresponding nozzles. The interelectrode distance may then be varied in large proportions, by moving the nozzle-electrode assemblies along their axes. It will be appreciated that the greater the interelectrode distance between the nozzle-electrode assemblies A_1, A_2, A_3, the higher the difference of potential that may be applied between them and accordingly the higher the energy recovered in the resulting flows. The supply of electric current to the pilot blowpipe may be disconnected , and the flow rates delivered by the different nozzles varied to a large extent.

The results obtained with such an installation (with only one group G_1 of three nozzle-electrode assemblies) are tabulated below.

TABLE III

Interelectrode distance (d_{mm})	30	40	60	100	120
V (volts Interelectrode voltage	90	100	140	200	220
I Intensity in each phase	160	160	180	200	200
P (kW)	24,5	27	43,6	69,7	76,1

The pilot blowpipe was operated at the time of ignition at 60 V, 400 A, and at a nitrogen flow rate of 20 l./minute.

The nitrogen flow rate delivered by each of the nozzle-electrode assemblies A_1,A_2,A_3, was 30 l./minute; the interelectrode distances in the first horizontal row of the Table III were taken between the tips of the corresponding electrodes ; it will of course be appreciated that the actual length of the path travelled by the electric current from one electrode to the other was longer since it passed through the point of convergence of the three plasma flows.

The total energy yield of the installation was 90 percent.

This installation may be completed with additional groups of nozzle-electrode assemblies, for instance with one or several triphase groups (only one additional group G_2 being shown in FIG. **12**), each of these groups comprising for instance three identical nozzle-electrode assemblies in the same angular positions as those of the group G_1. The flows delivered by each of those groups converged substantially with one another at a point located on the axis of the pilot blowpipe. Each group is associated with an independent electric current supply source.

This installation can thus be operated as follows : the pilot blowpipe ionizes the interelectrode space of the first group and causes the ignition of electric arcs in the flows delivered by the corresponding nozzles. The pilot blowpipe C may then be electrically disconnected.

The first group G_1 (whether the blowpipe C is electrically disconnected or not) is then able itself to act as a pilot blowpipe to favor the ignition of electric arcs in the flows delivered by the nozzles of group G_2. The electrodes of group G_1 may then be electrically disconnected. G_2 could in turn act as a pilot for an additional group G_3 (not shown) etc.

Since the energy recovered in each of the pilot plasma flows so obtained increases from one group to the other, the interelectrode distances, hence the energy supplied to the common resulting flow, can be increased at the level of each group, whereby a flow of plasma can be obtained with a large cross-section and at a considerable delivery rate. Actually the geometry of the latter flow may be controlled by the proper positioning and orientation of each of the nozzle-electrode assemblies and the flow rate delivered by the same. The power supplied to the plasma increases very rapidly with the number of groups, starting from a pilot blowpipe of low energy.

Many other installations can be devised according to the invention. They will all be characterised by a very simple electrical current supply circuitry, each of these installations requiring at most one pilot generator of ionized gases. The plasma pilot blowpipe in all the preceeding embodiments, whose electrical supply may be of any type (direct current, alternating current, under low or high frequencies) can be replaced by any other type of generator, such as a chemical combustion blowpipe whose flame may, if need be, be sown with particles of an ionizing product, or by any other type of generator of ionized vapors or gaseous mixtures, or even by any short circuiting device coacting with the nozzles able to generate the ignition of arcs within the gaseous flows.

In the embodiments of the installations according to the invention, shown in FIGS. **13** and **14**, which installations comprise groups of nozzles **34***a*, **34***b* (FIG. **13**) or **34***c*, **34***d*, **34***e* (FIG. **14**) supplied with gas under pressure and furnishing convergent elementary gas flows **36** to form the principal plasma **32**, these nozzles are inserted in a normally open circuit, generally denoted by **38**. This circuit comprises a source of electric current supply **40***a* (FIG. **1**) or **40***b* (FIG. **2**) and is capable of being completed through these elementary flows, when the resistance of the latter is sufficiently reduced, especially by means of a pilot flow of plasma **42** of section, preferably, large, which is adapted to sufficiently ionize the atmosphere between the outputs of these nozzles for electric arcs **44** to be startable in the convergent elementary flows, between the conductive portions **46** of these nozzles (FIG. **15**) in contact with these flows. Each of these nozzles then behaves as an arc electrode with respect to the circuit **38**.

There is shown in FIG. **15** a nozzle of the type concerned which is used in advantageous manner in assemblies according to the invention. The conductive portion of this nozzle is constituted by an elongated part provided with cooling means **47** with fluid circulation and of which the free end **48** is in the shape of a point, and of which the other end is engaged in a base **50**, itself engaged in a metallic sleeve **52**, which surrounds the conductive part **46** over a portion of its length. The base **50** comprises a connecting part **56** with one of the terminals of the supply source **40***a* or **40***b*. The space **55** with annular cross-section formed between the conductive part **46** and the sleeve **52** is supplied with plasmagenic fluid through a connector **56**. The plasmagenic fluid is ejected from the nozzle, through the annular slot **58** formed between the end of the sleeve **52** and the point **48** of the conductive part **46**, so that the latter bathes on every side in the plasmagenic gas. There is possibly provided, in the annular space **55**, a throttled zone **59** contributing to the acceleration of the plasmagenic fluid before its ejection at the level of the point **48**. Advantageously a transparent silica tube **60**, arranged around the point of the conductive part enables the shielding of the plasmagenic fluid up to the vicinity of the point **48**.

Under these conditions electric arcs **44** can be started between the conductive parts of the different nozzles of the installations of FIGS. **13** or **14**, if their points **48** are sufficiently close to one another, if the atmosphere in which these points are immersed is sufficiently ionised, especially by means of the pilot flow **42** of plasma, and lastly if the open circuit voltage in vacuum of the supply source **40***a* or **40***b* is sufficiently high. The peripheral gaseous flows emerging from each of these nozzles are then transformed into plasma jets traversed by electric current. There can then, due to sliding devices (not shown) enabling movements of the nozzles along their axes, to a retraction movement given to these nozzles relative to the converging zone of their elementary flows, and consequently the electrical energy dissipated in these flows and finally recovered in the form of heat energy in the principal flow **32** can be increased.

The pilot plasma flow is produced by a pilot generator **62** (shown in diagrammatic manner in FIGS. **13** and **14**), which, according to the invention, is inserted in a circuit **64** also connected to two terminals of the supply source **40***a* or **40***b*, hence in parallel with respect to the circuit **38** of the nozzles, this circuit **64** comprising at least one resistance **66** of which the value is sufficiently high for the current to pass preferentially in the supply circuit **38** of the nozzles.

In the case where the source **40***a* supplies direct current (FIG. **13**), the generator plasma **62** may be constituted by a conventional plasma torch, comprising a refrigerated anode **68** connected to the positive terminal of the source **40**a and an emitter cathode constituted, for example, by a rod of tungsten **70** connected to the negative terminal of the suppl source **40***a*.

Advantageously, the anode **58** has a divergent shape. The pilot torch then produces a pilot flow **42** of large cross-section, which is capable of ensuring better ionisation of the atmosphere in the inter-nozzle space. In order to ensure improved stability and centering of the pilot flow, recourse is advantageously had to a cooled centering ring **71**. arranged between the outlet of the pilot torch and the nozzles.

If consequently, the resistances **66** have a sufficient value, there is obtained complete extinction of the pilot torch **62**, as soon as the arcs **44** are started in the elementary flows energing from the nozzles **34***a*, **34***b*. The accidental interruption of these latter arcs can actuate the production of immediate restarting of the pilot torch, consequently the reionisation of the inter-nozzle space and the re-establishment of the arcs **44** in the elementary flows **36**, etc., if the pilot torch is provided with conventional means (not shown) for starting (high frequency of short-circuit spark).

This assembly hence permits the use of a supply source **40***a* of less power, limited to that necessary for sustaining the arcs formed in the midst of the elemental flows.

The assembly in parallel of the circuits of the nozzles and of the pilot generator become also particularly advantageous, when the source **40**a supplies alternating current, the pilot torch having then a structure of the type represented in FIG. **16**. This torch is essentially distinguished from a conventional torch in that the rod of tungsten is replaced by a conductor part **72**, advantageously of copper, as the other electrode, this conductor part **72** then being also provided with energetic refrigeration means. To the extent in fact that the pilot torch is normally placed out of operation and intended only to operate during very short intervals of time, especially those necessary for the starting or the restarting of the arcs in the elementary flows supplied by the nozzles, the electrodes **68** and **72** are not subject for long to strong periodic thermal flows, characteristic of their operation as an anode, for one alternation in two of the alternating supply current of the torch.

As indicated above, the two electrodes of this torch must be cooled efficiently. To this end, the part **72** comprises a hollow **74** and is mounted on a concentric part **76** provided with cooling passages **78** enabling access in the hollow **74** of a cooling fluid and the removal of the latter. In the same way, the electrode **68** is provided with a cooling chamber **80** by the circulation of fluid. Advantageously, the two electrodes **68** and **72** are both mounted on a same central insulating bloc **82.** The electrode **68** is screwed into the central bloc **82,** whilst the part **76** bearing the electrode **72** is screwed into the insulating bloc **82,** the electrode **72** being housed with play in a cavity **84** of the insulating bloc. The space formed between the walls of this cavity and the electrode **72,** which communicates with a supply passage **86** for plasmagenic gas, then defines the ejection slot **92** of the plasmagenic gas. If necessary, a groove insulating shielding part **88** surrounds the electrode **72** up to the neighborhood of its point **90** and contributes to the adjustment of the velocity of ejection of the plasmagenic gases from the pilot torch.

The same type of pilot plasma generator may be used in the assembly of FIG. **14.** in which the supply source 40b is a source of triphase current, of which the three phases are respectively connected to the conductive portions of the nozzles **34***c*, **34***d* and **34***e*, and of which two phases are also connected to the pilot generator. Of course, the triphase source **40***b* could be replaced by any other polyphase source, of which the different phases would be connected to a corresponding number of nozzles.

There is thus obtained a particularly advantageous pilot generator, it that it can be inserted without difficulties in the supply circuits for alternating or polyphase current, whence a certain advantage in the matter of cost of assembly.

In all cases, there is obtained an assembly enabling the restarting of the principal plasma, by using a very simple pilot torch not requiring, for its supply, a supplementary source of electric current and of which the auto-extinction is ensured as from the production of the principal plasma.

In order to illustrate the invention further, without however limiting it, the operational characteristics of the pilot torch and of the nozzles of an installation according to the embodiment shown in FIG. **14,** adapted to operate as has been described above, that is to say with auto-extinction of the pilot torch as soon as the principal arc if formed, will be specified.

Operational characteristics of the pilot torch:

Effective operating voltage:	100 V
Effective operating intensity:	300 A
Flow rate of nitrogen:	20 l/mn
Resistance **66** inserted in the supply circuit of the pilot torch:	1 Ohm

Production characteristics of the principal plasma :

Inter-nozzle distance on starting:	6 cm
Inter-nozzle distance after their relative spacing in operation:	21,5 cm
Operational voltage (neutral electrode)	180 V
Intensity of operation	200 A
Rate of nitrogen in each nozzle	2 g/s
Effective power dissipated in the principal flow	95 kW
Yield	93 %

It will be noted that as regards the source of polyphase alternating current, two types of electrical equipments will be advantageously used.

Equipment with a variable output voltage:

Such equipment enables, due to the flexibility of operation easier adaptation to the characteristics of the plasma jets formed. In this case, it is advantageous to provide equipment with high internal impedance, enabling an open circuit voltage to be available, approximately double of the operating voltage.

The adjustment of intensity is effected then in a continuous manner by means of the member ensuring the variation in open circuit voltage or in power.

The internal impedance of the assembly of the equipment will be preferably inductive taking into account, on one hand, the better yield recorded, on the other hand, the stabilizing role on the production of plasma jets.

Equipment with fixed output voltage:

The output voltage to be provided is by way of indication of the order of twice the operational voltage. The transformer used, for example, having a negligible internal impedance, there could be arranged on each phase an impedance between each electrode and the current source.

The impedance, ensuring the voltage drop on operation, will preferably be inductive, taking into account the better yield and the stabilization introduced by an assembly of inductances.

The variation in intensity is then effected by continuous variation of the value of these inductances.

In this case the value of the inductances can be adjusted to the optimum of yield and of stabilization.

These installations offer many advantages. They permit the production of plasma streams within gaseous flows of any nature, including gases which are corrosive for metals at high temperatures, such as oxygen, especially in the case where the nozzles are connected to the positive terminal of a common supply generator G of direct current.

The operation of such an installation is practically independent of the respective flow rates delivered by each of the nozzles, so that laminar plasma streams may be obtained under rates as low as desired, the possible minimum rate being in all instances lower than the minimum rate under which a conventional plasma blowpipe may be supplied.

As already disclosed hereabove, these installations also permit the production of plasma flows having a very large volume. Such plasma flows having a large volume may also be obtained by an installation such as shown in FIG. **12**a, whose principle of operation is substantially similar to that of the installation of FIG. **1,** wherein the nozzle has been replaced by a member **25** either porous or comprising a great number of apertures **26** enabling the delivery of a flow having an important volume, each of the said apertures then behaving like an individual nozzle.

In all installations, the nozzles or blowpipe may be moved with respect to one another in particular for stretching out the corresponding flows and for increasing in at least equal proportions the energy dissipated in these flows.

The form of the flow E_0 resulting from the convergence of the flows E_1, E_2 . . . may be acted upon by controlling the positioning of the pilot blowpipe and the nozzles cooperating therewith or also by resorting to auxiliary gaseous flows not travelled by an electric current, yet able to act on its orientation in a predetermined direction.

It is also possible to substitute the gas in one at least of the flows after ignition therein of an electric arc, for another gas, for instance a gas which would not permit as easily as the first one a direct ignition of the arc therein, without interrupting the current flow.

More generally these installations exhbit in addition to the advantages set forth hereabove, the low cost of the operation, the low wear, if any, of the nozzles, the elimination of the required insulation in the conventional blowpipes of its different parts, since in the nozzles according to the invention all the parts thereof may be maintained at a same potential, their ability to operate under reduced or increased pressure, etc.

The installations according to the invention are particularly suitable for many uses, such as for instance :

the nozzles of the installation may be mounted in a furnace, for instance in its cover portion, and oriented respectively towards the interior space of the furnace, their operation being then initiated from a pilot generator of ionized gases mounted either fixedly or removably in a part of the furnace, for instance also in its cover;

the installations according to the invention are of particular interest for all the known applications of plasma flows such as : the welding, cutting, or melting of materials;

the treatment of powders (either of a refractory nature or not) by injecting the same within one or several plasma flows depending upon the desired duration of the presence of these powders therein, which duration can be in any case much greater than in the conventional systems;

the heating of gases, vapors or mixtures of any nature and under any pressure ;

the performance of chemical reactions at high temperatures;

the plasmic propulsion authorized by the production of a very hot gaseous stream, under a high flow rate, and under high pressures which can reach several tens of bars or even more.

As is self-evident, and as emerges already from the foregoing, the invention is in no way limited to those of its types of application, nor to those of its embodiment of its various parts, which have been more especially indicated; it encompasses, on the contrary, all variations.

We claim:

1. An installation for producing a principal flow of hot gases which comprises a first nozzle for producing at least one elementary flow of fluid, said first nozzle including a channel with an outlet and an electrode disposed substantially along the longitudinal axis of said channel and having a front extremity which extends to a plane at least flush with respect to the end of said channel, the annular space formed within said channel and around the electrode forming the ejection channel for said elementary flow; at least one second nozzle for producing another fluid flow said first nozzle and second nozzle being positioned relative to each other so as to cause said elementary flow to converge with said another fluid flow for producing a principal flow resulting from the convergence of said elementary flow and said another fluid flow; said electrode and said second nozzle being connected in a normally open electrical circuit including an external voltage source which is capable of producing a voltage sufficient to cause completion of said circuit through said elementary flow and said another fluid flow when the electrical resistance therein is reduced; and means for producing a plasma flow having a cross section greater than that of said elementary flow and said another fluid and so positioned as to permit ionization of the atmosphere in which said elementary flow and said another fluid flow are formed to thereby cause a reduction of the electrical resistance in, and an ionisation of, said elementary flow and said another fluid flow.

2. A process according to claim 1 wherein said means for producing a plasma flow having a section greater than that of said elementary flow and said another fluid flow essentially comprises a pilot plasma torch having a diverging anode.

3. An installation according to claim 2 wherein the electrical supply of said plasma torch is independent from the said electrical circuit.

4. An installation according to claim 2, wherein said voltage external source is a DC generator and comprises a positive terminal connected to at least one of the electrodes of the plasma torch and a negative terminal connected to the electrode of said first nozzle.

5. An installation according to claim 2, wherein said voltage external source is an AC generator and comprises one terminal connected to at least one of the electrodes of the plasma torch and another terminal connected to the electrode of said first nozzle.

6. An installation according to claim 2 which further comprises an annular member whose axis coincides substantially with that of said plasma torch, and which exhibits a conical surface flaring out towards the pilot torch for insuring the proper centering of said plasma flow of greater cross section.

7. An installation according to claim 1 wherein said second nozzle is a plasma torch, said voltage source being connected to one of the electrodes of said plasma torch.

8. An installation for producing a principal flow of hot gases which comprises at least two nozzles for producing a corresponding number of elementary flows of fluid, each of said nozzles including a channel with an outlet and an electrode disposed substantially along the longitudinal axis of said channel and having a front extremity which extends at least to a plane flush with respect to the end of said channel, the annular space formed within the channel and around the electrode forming the ejection channel for the corresponding elementary flow; said nozzles being positioned relative to one another so as to cause their respective elementary flows to converge with one another for producing a principal flow resulting from the convergence of said elementary flows; the electrodes of said nozzles being connected in a normally open electrical circuit including an external voltage source which is capable of producing a voltage sufficient to cause completion of said circuit through said elementary flows when the electrical resistance therein is reduced; and means for producing a plasma flow having a section greater than that

of said elementary flows and so positioned as to ionize the atmosphere in which said elementary flows are formed to thereby cause a reduction of the electrical resistance in, and an ionization of, said elementary flows.

9. An installation according to claim **8** wherein said means for producing a plasma having a section greater than that of said elementary flows essentially comprises a pilot plasma torch having a diverging anode.

10. An installation according to claim **9** wherein the supply of said plasma torch is independent from said electrical circuit.

11. An installation according to claim **9,** which comprises n of said nozzles and wherein said voltage external source is a polyphase current generator having n + 1 phases, one of the phases of said polyphase generator being connected to at least one of the electrodes of the plasma torch, the n other phases of said polyphase generator being respectively connected to the electrodes associated with the n nozzles.

12. An installation according to claim **9,** wherein the electrodes of said nozzles are formed from an electron emitter metal.

13. Installation according to claim **12,** wherein said electron emitter metal is tungsten.

14. An installation according to claim **8** which comprises two of said nozzles, said voltage source being a DC generator whose positive and negative terminals are respectively connected to the electrodes of the two nozzles.

15. An installation according to claim **8** which comprises two of said nozzles and wherein said voltage source is an AC generator and the terminals thereof are respectively connected to the electrodes of the two nozzles.

16. An installation according to claim **8** wherein said voltage source comprises a polyphase source having a number of phases equal to the number of said nozzles, each of said nozzles having the electrode associated therewith connected to a corresponding phase of said polyphase source.

17. An installation according to claim **9** wherein said nozzles form several groups, the nozzles of a same group being positioned such that the flows which they deliver converge substantially at a point on the axis of the plasma flow produced by said pilot plasma torch, the points of convergence of the elementary flows produced by the nozzles of said different groups being located at different distances of said torch, and the electrodes of the nozzles in each of said groups being provided within an electrical circuit exclusively associated with that group and having a separate, individual external voltage source.

18. An installation according to claim **8** wherein the front extremity of each said electrode protrudes beyond the end of the ejection channel.

19. An installation according to claim **9** wherein the supply circuit of the pilot plasma torch is connected in parallel to the terminals of said external voltage source and said supply circuit comprises a resistance having a sufficiently high value for the current generated by said external voltage source to pass preferentially in the circuit in which the electrodes associated with the nozzles are connected.

20. An installation according to claim **19,** wherein said resistance has a value such that the completion of said normally open circuit through said elementary flows involves the self-extinction of the pilot plasma torch.

21. An installation according to claim **19** which comprises two of said nozzles and wherein said external voltage source is a DC generator whose terminals are respectively connected to the electrodes associated with the two nozzles.

22. An installation according to claim **19** which comprises two of said nozzles and wherein said external voltage source is an AC generator and the electrodes of the pilot plasma torch are both constituted by efficiently cooled parts.

23. Installation according to claim **22,** wherein the two parts of the pilot generator are constituted of a same material.

24. Installation according to claim **23,** wherein said same material is copper.

25. An installation according to claim **19,** wherein said voltage source is a polyphase current generator having a number of phases equal to the number of said nozzles, each of the electrodes associated with said nozzles being connected to a corresponding phase of said polyphase generator, and wherein said supply circuit is connected to two of the phases of said polyphase current generator.

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