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(54) **Non-clogging high efficiency plasma torch.**

(57) An arc-heated plasma lance which is not exposed to clogging by superheat hydrocarbon gases is characterized by a shorter downward electrode and a generally shorter length of the upward and downward electrodes combination, with a flaring out electrode end at the outlet port for receiving the arc roots of the downward electrode, thereby to provide increased efficiency and generate radiant energy, as well as insuring non-clogging operation.

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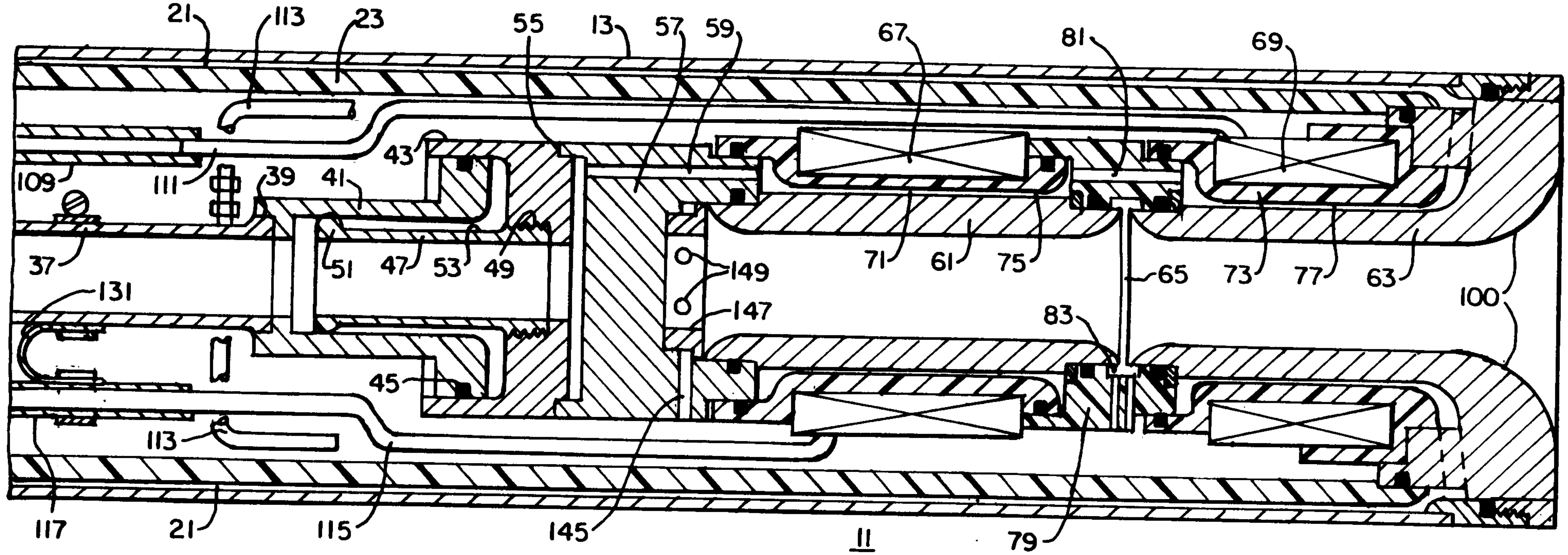
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FIG. 2.

This invention relates to a portable plasma torch.

The invention in its preferred embodiment is closely related to the plasma torch described in U.S. Patent No. 4,668,853; accordingly, this patent is hereby incorporated-by-reference.

Plasma torches are used to supply superheated process gas. Typically, the plasma torch has also been used as an igniter for coal-fired boilers. Typical of a plasma-torch with its upstream and downstream electrodes having a rotating arc stricken therebetween, is the arc heater apparatus described in U.S. Patent No. 3,705,975. For the purpose of describing a plasma torch, U.S. Patent No. 3,705,975 is hereby incorporated-by-reference. An illustration of a possible use of a plasma torch is described in U.S. Patent No. 4,571,259. The plasma torch described in U.S. Patent No. 4,571,259 is characterized by an elongated tubular housing having, between a closed end and an open end, a central elongated narrow chamber surrounded by two electromagnetic coils associated with respective upper and lower electrodes striking an arc rotating under the field of the coils from the closed end to the open end, while a gas is being blown through the arc length from the closed end toward the open end. With such arrangement, the gas is decomposed and heated by the arc, and the resulting gases are projected as a flame from the open end, thus providing a source of heat which can be applied, for instance to a metal bath to be melted or smelted, or to any other process requiring superheated gases. Other uses include any process that can benefit from a supply of superheated gas. See, for instance, U.S. Patent Nos. 4,107,445; 4,718,477 and 4,734,551.

Like the plasma torch described by U.S. Patent No. 4,668,853, the torch according to the present invention includes opposite arc supporting surfaces defining a narrow cylindrical arc chamber within which an arc is lengthwise spontaneously generated while it rotates thereacross between the upward surface at the higher electrode potential and the downward surface at the lower electrode potential. The two electromagnetic coils, generating the magnetic field required, are surrounding the respective surfaces. From the inner and closed end at 149, and through a small gap 65 established between the two electrodes, means are provided for injecting and for channeling in the central and axial bore of the electrodes, gas to be heated by the arc. At a high velocity the gas flows, through the gap and through the bore, toward the outlet port defined by the open end of the tubular housing. All along the walls, between upstream and downstream, proper water cooling is provided. Also, between the serially-connected electrodes and coils, insulation is provided. The arc heated plasma gas ejected from the outlet port may be superheated air, or virtually any other gas, with a heat to a temperature range from 3,000°F to 12,000°F, forming a plasma jet to be projected into a comminuted material for combustion, as shown in U.S. Patent No. 4,571,259, or for any other process requiring superheated gas.

The torch electrodes have a long life, typically several hundred hours. It uses a high effective DC power supply for both the electrodes and the coils. The coils are water-cooled coils and internally connected by a hollow conductor. All the torch connections are placed at one end, namely upward of the closed end. When water vapor is the process gas, feed water of a boiler may be used as a coolant at high temperature preventing steam from condensing. A high frequency ignition HF/HV pulse is superimposed on the electrode in order to cause arc breakdown over the small gap 65, thereby to initiate the arc and start the torch.

Because of the inherent asymmetry in the functions of the upward and the downward sections of the airgap due to blowing gas at high speed thereacross, in the original design the tendency has been in the prior art to lengthen the downward section, namely the coil and arc surface, thereby to maintain the arc within the central and axial bore. Indeed, the arc originating on the upward surface and landing on the downward surface is distorted forward by the high velocity gas flow. Accordingly, in the original design, instead of having two equal adjoining upward and downward sections, while the upward section only requires a short section, the length of the downward section has been substantially increased between the gap 65 and the outlet port in order to prevent the arc from being blown out of the torch. Although this approach has been working quite satisfactorily for most plasma torch applications, it has been found recently that, when the gas generates certain heavy chemical elements, such as carbon, clogging may occur in the narrow chamber along the downward surface thereof. When clogging occurs, the flow of gas is hampered, the effectiveness of the arc is reduced and the generation of a heated process gas from the outlet port is lost. Such a situation has been experienced, particularly when the gas blown through the torch chamber is freon.

The invention resides in an arc-heated plasma lance that can superheat hydrocarbon gases without clogging. It includes: a longitudinal cylindrical chamber extending along an axis between a gas input and a plasma outlet port and defined by the surrounding surfaces of two adjoining electrodes, with one electrode having an upward surface and a second electrode having a downward surface, a DC voltage being applied thereacross for generating a recurrent arc between said surfaces, coil means being provided for rotating the arc about said axis, and a gas characterized by a chemical compound being blown through the arc from said gas input toward said outlet port for generating a plasma jet of substantially high temperature at said outlet port.

According to the present invention, for a given length of said chamber and a given velocity of said gas, the length of said second electrode has been made substantially smaller than in previous designs, and an externally rounded and flared end has been provided for the outlet port to receive the arc root, whereby the arcing effect is no longer totally contained within the confines of the electrodes and, rather, due to such rounded and flared end defining the outlet port, the downward electrode receives thereupon a substantial portion of the recurring arc. As a result of much of such interaction between the rotating arc and the gas substantially taking place on such outside surface of the downstream electrode near the outlet port, clogging of said chamber by an element of the hydrocarbon gas is eliminated. Moreover, the increased generation of radiant energy by the outlet port may be beneficial to some processes. The shorter downstream electrode leads to a torch operating with an increased efficiency.

The invention will become more readily apparent from the following description of a preferred embodiment thereof shown, by way of example only, in the accompanying drawings, wherein:

Figure 1, taken from U.S. Patent No. 4,571,259, shows a refractory lined reactor with its reduction chamber entered by a plasma torch;

Figure 2 shows a plasma torch according to the preferred embodiment of the invention;

Figures 3A, 3B and 3C illustrate schematically the effect of the relative proportions of the upward and the downward sections of the electrode portions of a plasma torch upon the generated arc, with Figure 3C being related to the design according to the invention; and

Figure 4 is a schematic illustrating gas and water cooling flows, as well as electrical connections for the plasma torch.

Referring to Figure 1, which is taken from U.S. Patent No. 4,571,259, a reduction chamber 22 is shown including a plasma torch 30 connected to a gas supply 32, a source of electric power 34 and a supply of cooling water 36, forming a high temperature heated stream 44 thereacross. This reduction chamber is used for the reduction of material, fed at 62, including comminuted metal oxide, slag formers and a reductant. The metal oxide is heated by the hot plasma stream 44 from the plasma torch in the presence of the reductant, melted and reduced to molten metal collected in the metal bath 54, slag being separated therefrom. Gas is introduced in the plasma torch by one or more flow paths including the axial gap 40, and it is heated by an arc 38 struck across the axial gap 40 between two hollow cylindrical electrodes 42. Preferably, the flow rate of the gas through the plasma torch is held at a level such as to prevent the electric arc 38 from being carried over into the reduction chamber 22, although the plasma heated stream 44 extends beyond the end of the plasma torch.

Figure 2 is a sectional view of the plasma torch according to the present invention. As the preferred embodiment of the invention, it has many of the characteristics of the elongated arc heater plasma lance described in the incorporated-by-reference U.S. Patent No. 4,668,853. However, in contrast to Figure 1B of this incorporated-by-reference patent, Figure 2 clearly shows that the downstream electrode 63 has been specifically designed so as: 1) to be substantially shorter than the prior art downstream electrode; and 2) to exhibit at the outlet 100 a substantially outwardly flaring opening with an outside surface 100'. The upward electrode 61 has been kept relatively short, namely as it extends from an inner end 149 where gas is blown, axially along the central bore of the electrodes, onto the gap 65 separating the two electrodes. Across the two electrodes an arc is struck which is being blown downward due to the high flow rate of the injected gas. Accordingly, while under a DC voltage, the upward and downward electrodes are supporting an arc across the gap 65 which separates them. The two coils are serially connected, typically, under the same DC voltage so as to create a transversal magnetic field which causes the arc to rotate while being stricken across the cylindrical and relatively narrow channel defined by the aligned surfaces of the two electrodes. This has been fully described in the '853 patent. The gas is blown from two input orifices 149 along the axis of the channel as well at 83 and 85 through the electrode gap 65. As a result, this gas is exposed to the arc as it is forced at a high velocity, typically at 20 scfm (std. cu. ft. min.) from the rear inputs 149 to the outlet port at the end of the downward electrode 63. Under the electrical discharge, the atoms or molecules of the gas are at least partially ionized, and the gas becomes a plasma. With the arc current, the operating pressure, the gas and electron temperature becomes very high with equally high current and power densities. Electric power for the electrodes 61, 63 and for the coils 67, 69, is provided at a level up to 200 KW, with 400 amperes. Higher powers are possible with larger components, higher arc currents and higher gas flow. The resulting plasma jet is projected outside the outlet port toward the bath to be treated, or other process requiring high temperature gases. Power flows through hollow conductors 109, 111 to downstream coil 69 and returns through conductor 113 to the upstream coil 67, then, through conductors 115, 131. Cooling water for coil cooling is inputted from 109 through the tubular conductor 111 (along downstream coil 69), with exit therefrom via conductor 113 leading to upstream coil 67 and therefrom, through conductor 115, with return via tubular conductor 117. Clearance spaces are provided between coil spools and electrodes, at 75 for the upstream and at 77 for downstream, for electrode cooling water passage. All this has been explained in detail in relation to Figure 1B of '853 patent.

As shown in Figure 2, the combined length of the two sections (sections S1 and S2 in Figure 3C) which correspond to the upward and the downward coil and electrode combinations, respectively, is, according to the present invention, much shorter than according to Figure 1B of the incorporated-by-reference patent '853. Indeed, as shown in the prior art, it is a straightforward approach to give S1 and S2 the same length, as, shown in Figure 3A. However, since a gas is being blown from the back of the upward section S1 with a high flow rate toward the outlet port of the downward section S2, in order to compensate for such forward shifting of the arc, and increase the time of interreaction between arc and gas so as to maximize the generation of a plasma flame, the length of S2 has been increased, while accessorily decreasing the length of S1. This is what has been described in the -853 patent with reference to Figure 1B. Such unequal length sections S1 and S2 of the prior art are now schematically represented in Figure 3B. However, in practice, this approach has revealed that when the torch is operating with a gas such as methane, freon, or other hydrocarbon composition, the chemical compound disassociates during heating and forms a solid material, basically carbon, which results in clogging the narrow downward end of the torch. The build-up of pyrolitic carbon on the torch surface blocks the gas flow through the torch, shutting it down. In order to overcome this problem, without having to redesign the whole plasma torch, an experiment was made with a solution different from what Figure 3B proposes. As shown by Figure 3C, the downward section S2 is now substantially shortened and, at the outlet, the downward electrode is given a wide surface flaring out of the central bore, thus, quite externally toward the process exposed to the plasma jet. This redesign is intended to eliminate the downstream water seal and cause the arc root to rotate at the flared end 100 of the downward electrode 63. At first sight, this would seem an improper approach since it would, under gas flow, tend to minimize the function of the downward electrode 63, by having the arc less exposed to the gas within the central bore. Experience has proved the contrary. The rotating arc will not lose its effectiveness by tending to land upon the external surface 100' of the outlet port 100. This will minimize the deposition of carbon within the narrow zone of the operative channel and eliminate clogging. Moreover, the aforestated external arc portion becomes a source of radiant energy, and such modified torch, as proven, offers an increased overall efficiency quite sizable, since the resulting efficiency reached a range of 80 to 90% range in contrast to 60 to 70% previously. The beneficial results are as follows: non-clogging operation, a higher efficiency and a longer electrode life. The experiment has been conducted with gas other than air. The most striking results have been obtained with FREON 23 and CHF3. However, the torch according to the present invention also offers with air flow a higher efficiency level than previously obtained, a reduced electrode erosion rate, and a higher percentage of radiant energy due to external arcing to benefit chemical processes, such as the destruction of chlorinated carbons.

All this has been obtained at low cost in the redesign, without having to sacrifice on the overall qualities of the original design. Thus, a plasma torch is provided still having tubular electrodes, small electrode gaps for simple arc starting and stabilization, field coils for moving the arc over the electrode surfaces, a simple and solid construction, an equipment easy to maintain, as explained in the afore-stated incorporated-by-reference patent. Also, the new plasma torch still embodies a tubular shape with an overall length manufactured to suit the particular application, where all the connections extends from the bore of the upper end. Tubular and axially spaced electrodes, having a small gap therebetween for starting and for gas admission, are surrounded by electromagnetic coils providing a field to cause rotation of the arc and statistically distributed arc roots on the surfaces of the electrodes. Everything is sized to suit the power requirements. Such a plasma torch is easily serviced by removal of a relatively short tip assembly.

Figure 4 is a schematic representation, by reference to reference numbers of Figure 2, of gas and cooling water flows through the torch assembly, and of the electrical power connections. Cooling water input into line 109 leads to a hollow tube 111 feeding into the ampere-turns of downward coil 69. Water flow returns therefrom by another tube, identified as line 113, becoming the input to the upward coil 67. Such serial water flow through the two coils is returned by line 115. Cooling water input is also provided at W1 into the space between coils and electrodes, with a return by W2. Gas is injected from input 149 into the bore of the electrodes, as well as from inputs 85 and 83 into the electrode gap 65. The gas erosed to the arc will exit as a plasma jet at the outlet port. The generated rotating arc is shown with its roots at the inner surface of electrode 61 and on the outer surface 100' of electrode 63. The arc is caused by the DC voltage applied by the DC power source to the two electrodes, on the one side on conductor A for the positive side, on the other side on conductor B for the negative side. Conductor B is applied directly to the downward electrode, typically to the outlet port, as shown. Conductor A is first applied to the hollow tube 111 which goes through coils 69 and 67 by lines 113 and 115, and an electrical connection is provided by line 131 going from line 115 to the upward electrode 67.

In the drawings and specification has been set forth the preferred embodiment of the invention. It is understood, however, that variations from a general outline can be made which still are under the main points of the invention. For instance, the upward section, coil and electrode may be lengthened somewhat. It may also be made equal, without making the torch similar to the prior art example schematized by Figure 3A. Still the substantial shortness of the downward electrode, and the flared external surface 100′ provided toward the plasma jet exposed process, would be major distinctions over the prior art affecting the non-clogging quality and the increased efficiency and maximized radiant energy. It is also contemplated to so design the downward electrode that the central and axial bore thereof will be somewhat diverging toward the outlet port. This will be done to an extent that it does not affect the interaction of the arc with the high velocity gas. Nevertheless, this approach will increase the non-clogging effect and the radiant energy level to the outside.

IDENTIFICATION OF REFERENCE NUMERALS USED IN THE DRAWINGS

LEGEND	REF. NO.	FIGURE
REDUCING GAS	32	1
ELEC. POWER	34	1
COOLING WATER	36	1
FEED MATERIAL	62	1
EXHAUST SYSTEM	80	1

Claims

1. An arc-heated plasma lance including: a longitudinal cylindrical chamber extending between an inner end and an open end along an axis, with a gas input (149) at said inner end and a flame exit at said open end (100), said chamber being defined by an upward cylindrical electrode (61) of one polarity near said inner end and a downward cylindrical electrode (63) of the other polarity near said open end, said electrodes being disposed along said axis and having a gap therebetween, a DC voltage being applied across said electrodes for generating a recurrent arc therebetween, coil means being provided for rotating the arc about said axis, and a gas characterized by a chemical compound being blown through the arc and said chamber from said gas input toward said open end for outputting a plasma jet of substantially high temperature at said open end; said open end (100) being defined by said downward electrode (63); characterized by:
   an outer portion (63) provided at said open end (100) for said chamber and said downward electrode, said outer portion having a gradually increasing radial dimension defining an outer surface (100); and a length being selected for said downward electrode in relation to gas velocity and electrode polarity potential so as to root said rotating arc upon said outer surface; thereby to substantially eliminate clogging of the downward electrode and increase externally radiant energy therefrom.

2. The plasma lance of claim 1 characterized in that said selected length is combined with a selected radial dimension for said downward electrode for increased non-clogging effect and increased externally radiant energy therefrom.

3. The plasma lance of claim 2 characterized in that said selected radial dimension of said downward electrode is gradually increasing from said gap to said open end.

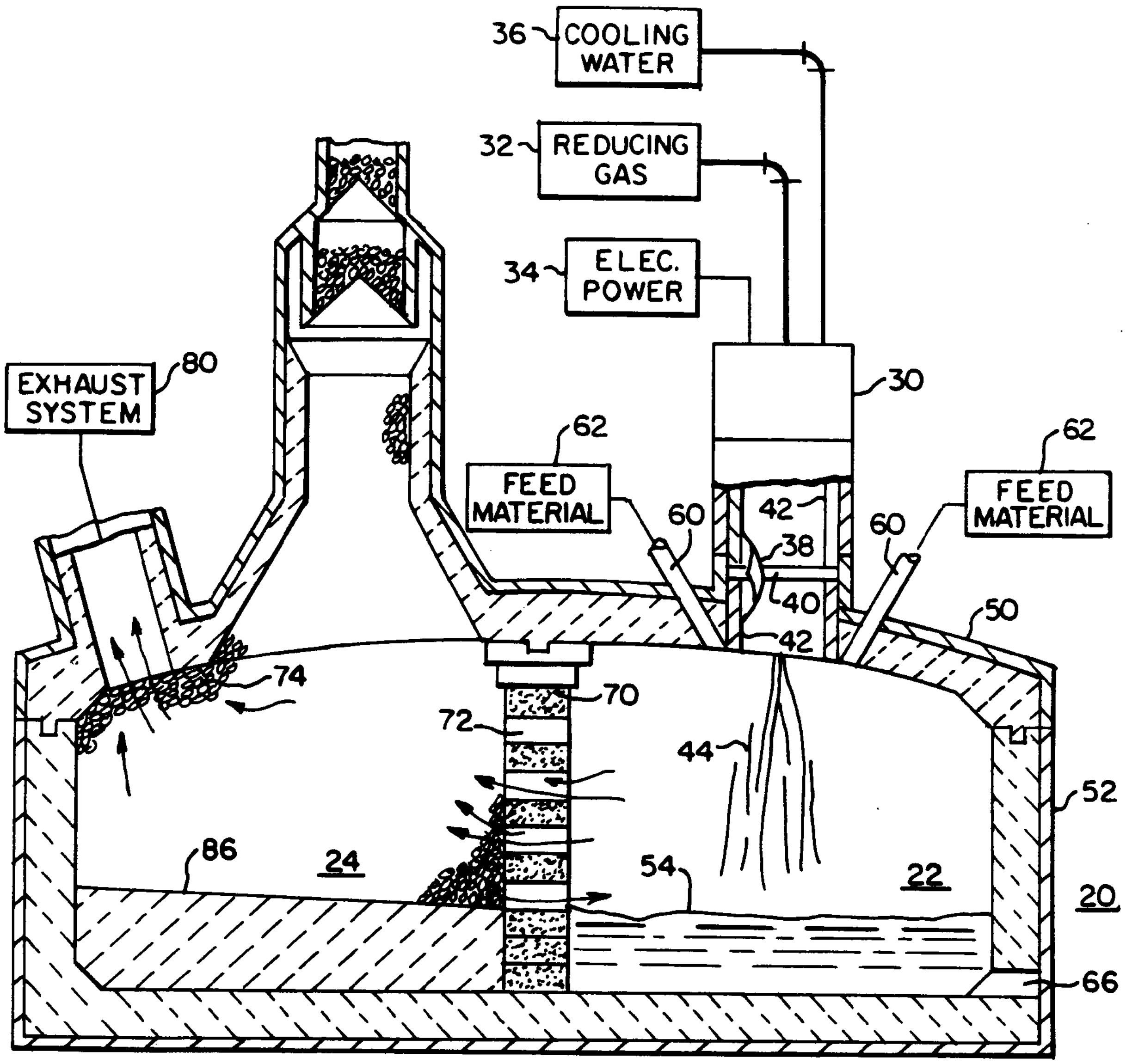

FIG. 1.

PRIOR ART

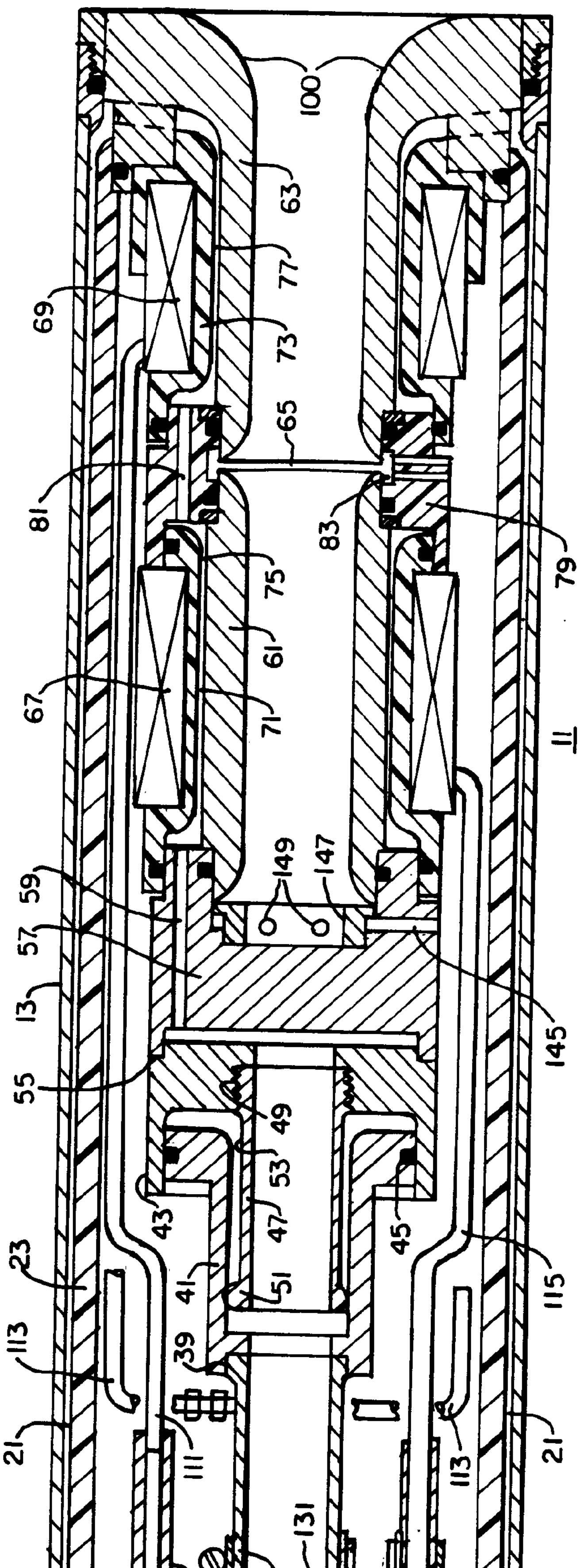
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FIG. 2.

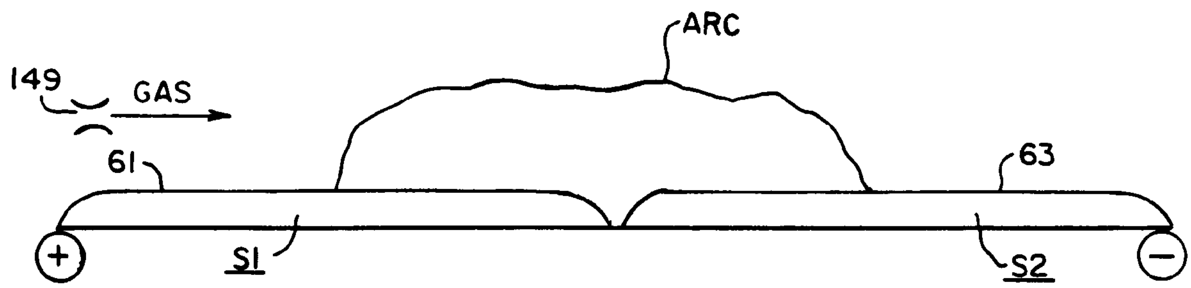


FIG. 3A.

PRIOR ART

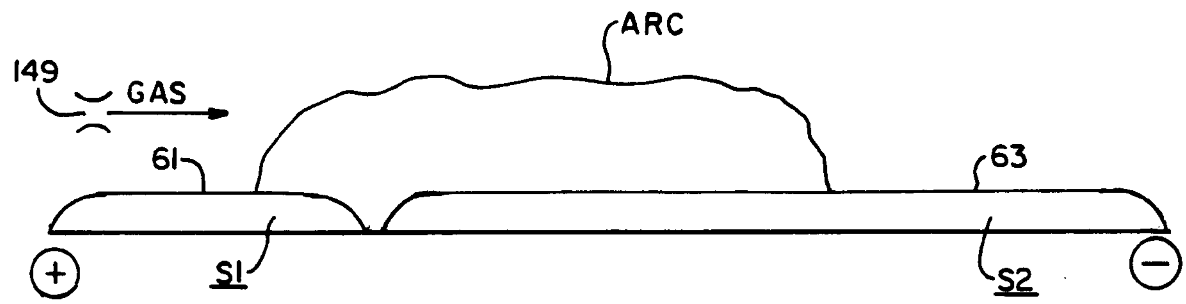


FIG. 3B.

PRIOR ART

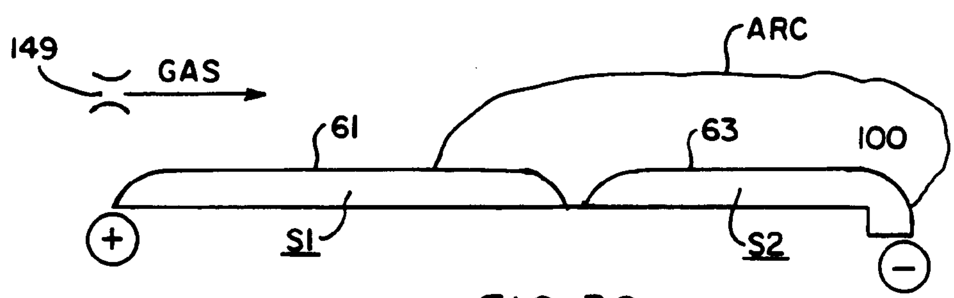
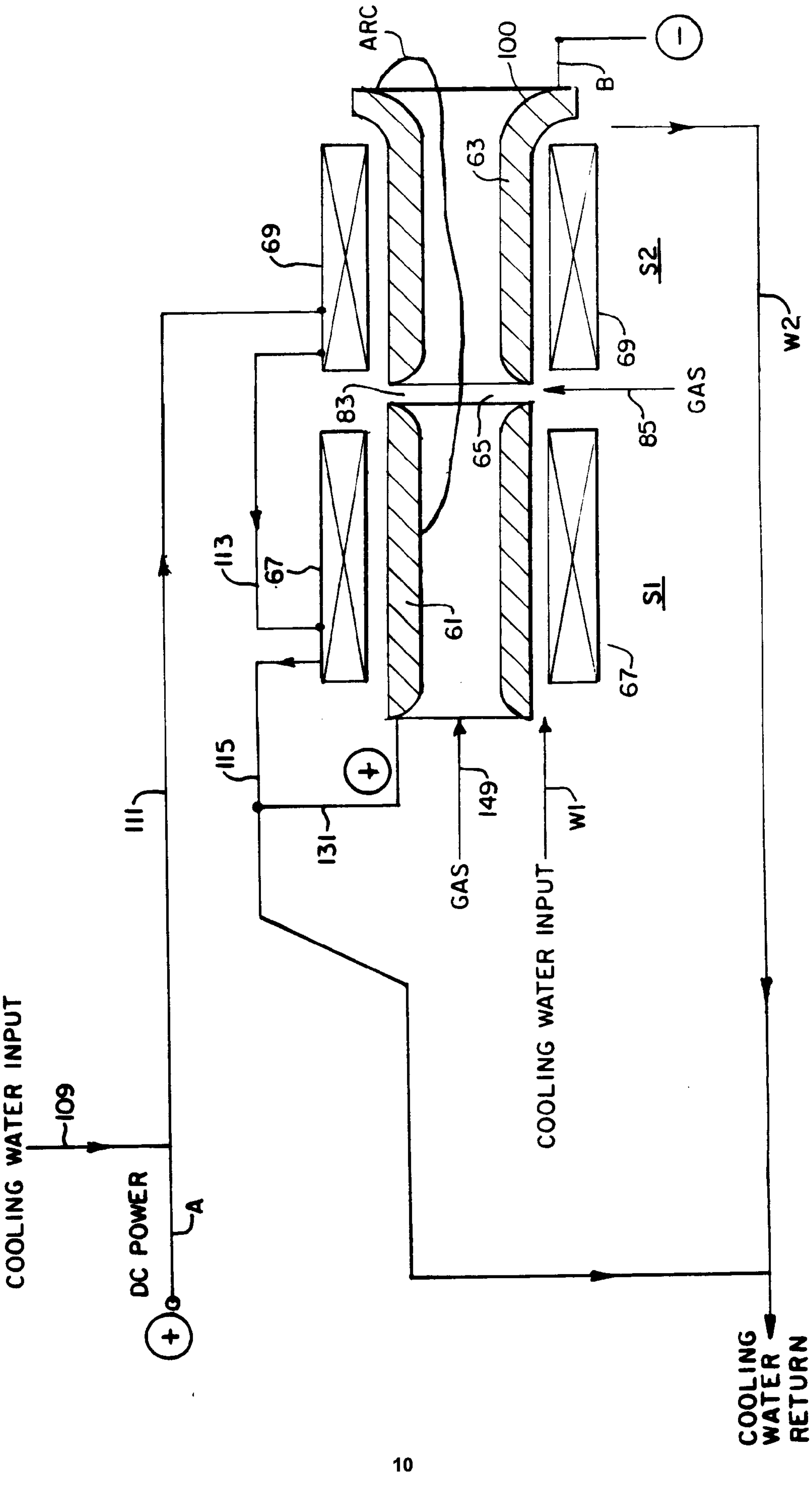


FIG. 3C.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63
S2
W2
GAS
85
83
65
113
67
61
S1
115
131
149
W1
GAS
COOLING WATER INPUT
111
109
COOLING WATER INPUT
DC POWER
A
COOLING WATER RETURN

FIG. 4.