Jan. 2, 1968 R. D. BUHLER 3,361,927

PLASMA GENERATING APPARATUS HAVING AN ARC RESTRICTING REGION

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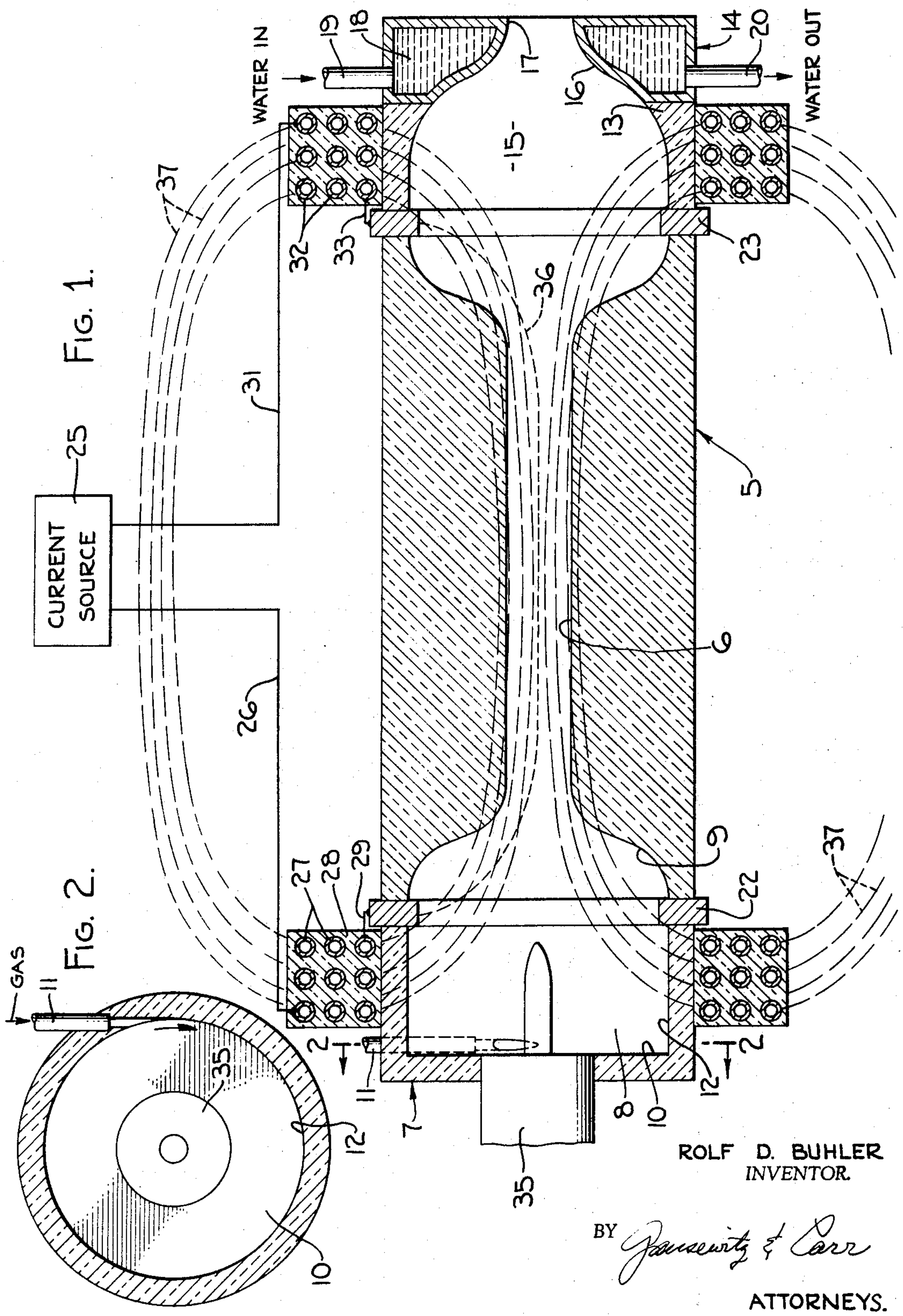
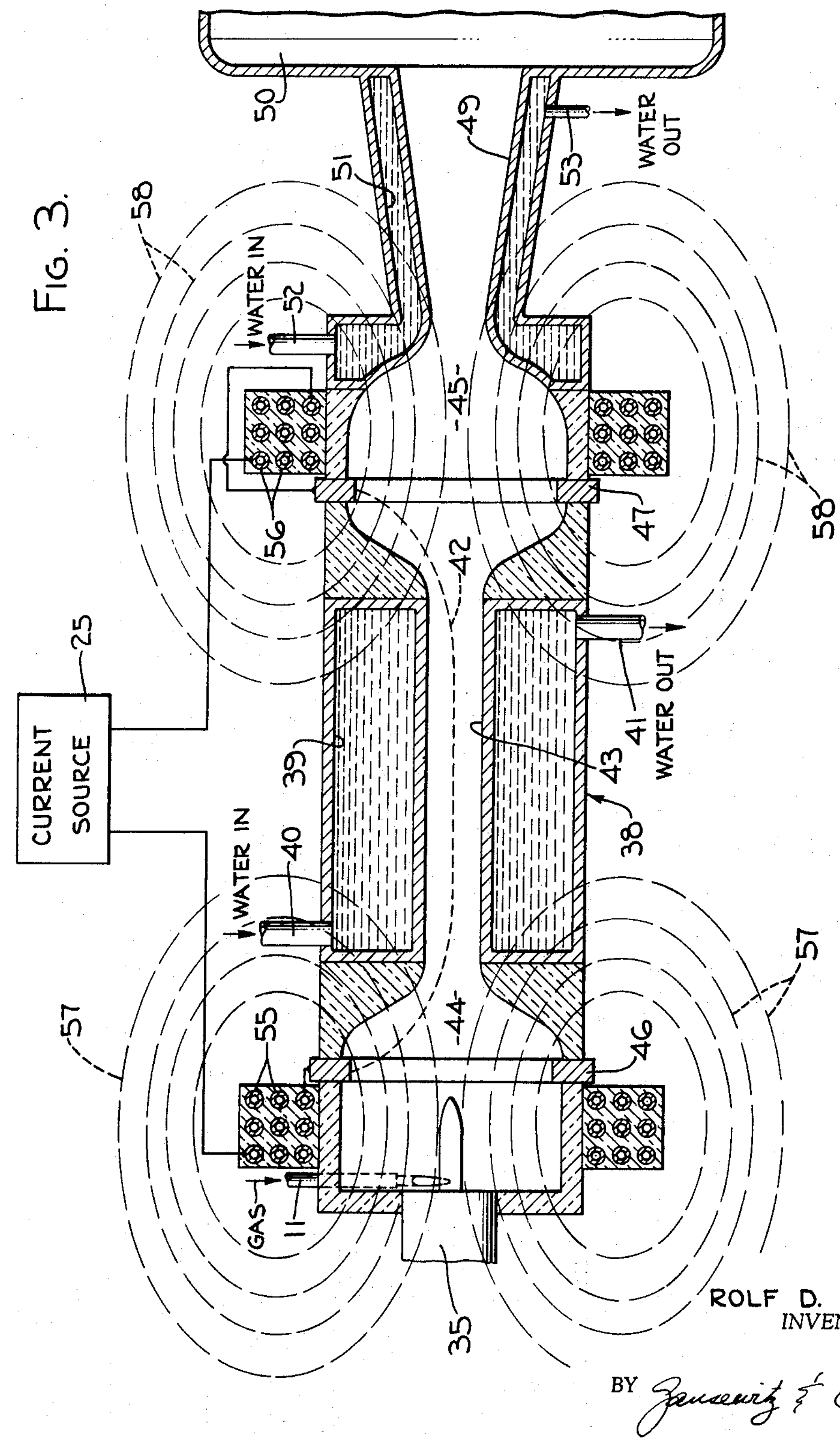


ROLF D. BUHLER
INVENTOR.

BY Jancewitz & Carr
ATTORNEYS.



ROLF D. BUHLER
INVENTOR.

BY Jancewicz & Carr

ATTORNEYS.

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PLASMA GENERATING APPARATUS HAVING AN ARC RESTRICTING REGION

Rolf D. Buhler, Newport Beach, Calif., assignor, by mesne assignments, to Giannini Scientific Corporation, Amityville, N.Y., a corporation of Delaware

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This invention pertains to the generation of plasma, and in particular to generating plasma of high enthalpy under high pressure conditions.

While the arrangement of this invention possesses utility where ever the generation of plasma is desired, it has been found especially useful in producing plasma of high heat content where the pressures are large. There are a variety of uses for such plasma generation, such as in research for simulating the re-entry of a nose cone into the earth's atmosphere. The great velocity of a nose cone at such conditions means that it encounters considerable pressures from the resisting atmosphere. Also the air friction generates extremely high temperatures. Consequently, in certain testing programs the need arises for plasma reproducing pressures and heats of such magnitude.

Several problems have been encountered in efforts to create high enthalpy plasma at comparable pressures. The current density of the arc increases to an extent that it becomes difficult to mix the gas with the arc. This reduces the efficiency of the heat transfer between the arc and the gas. Moreover, the high current densities cause the terminal portions of the arc to tend to burn into the electrodes and melt them. The result is electrode damage and contamination of the plasma by electrode material. Additionally, the arc becomes less stable under higher pressure conditions. Starting the arc becomes quite difficult. Heat losses by convection and radiation to the walls of the chamber, and hence the cooling water, become much larger under such conditions.

The present invention provides a plasma generator that is capable of producing high enthalpy plasma at elevated pressures It includes two annular electrodes spaced apart in a chamber having a relatively narrow interconnecting passageway. The arc is constricted to this passageway through which flows the gas which is introduced into the chamber in a rotational pattern. Consequently, the gas and arc are confined to the same locality and there is a more efficient transfer of heat from the arc to the gas. The footpoints of the arc are rotated which avoids burning of the electrodes and extends electrode life.

Accordingly, it is an object of this invention to provide a plasma generator capable of producing high enthalpy plasma at high pressures.

Another object of this invention is to provide a reliable and stable arrangement for the generation of plasma, adapted for various purposes including those where high heat content and elevated pressures are needed.

A further object of this invention is to provide a plasma generating arrangement in which the arc is restricted to a relatively narrow path through which the gas also passes to become efficiently heated by the arc.

A still further object of this invention is to provide a plasma generating arrangement in which both terminals of the arc are moved.

Yet another object of this invention is to provide a plasma generating arrangement in which the arc is relatively short to minimize loss of power due to convection and radiation.

These and other objects will become apparent from the following detailed description taken in connection with the accompanying drawing in which:

FIGURE 1 is a longitudinal sectional view of a plasma generating device embodying the invention,

FIGURE 2 is a transverse sectional view taken along line 2—2 of FIGURE 1, and

FIGURE 3 is a longitudinal sectional view similar to FIGURE 1 of a modified form of the invention.

With particular reference to FIGURES 1 and 2 of the drawing, the plasma generating arrangement of this invention includes an elongated housing **5**. This is constructed of a refractory material resistant to extreme temperatures, such as tantalum carbide or hafnium carbide. The member **5** includes an elongated relatively narrow opening **6** at its axis. The housing **5** and the aperture **6** may be cylindrical.

At the left-hand end of the housing, as illustrated, a generally cup-shaped member **7** fits on to the housing cooperating with the housing to define a chamber **8**. The end section **7** also is of heat resistant material such as one of the high temperature ceramics named above. A smoothly convergent wall **9** connects the enlarged chamber **8** with the smaller axial opening **6**.

The gas is introduced into the unit adjacent the outer wall **10** of the end member **7**. It is conducted to the chamber **8** through a conduit **11** and discharges inside the chamber tangentially along the cylindrical wall **12** of the chamber. In this manner the gas, which may be at a relatively high pressure, is caused to rotate rapidly and smoothly as it enters the chamber **8**.

At the opposite, or right-hand end, of the housing **5** are located annular members **13** and **14** which together with the housing define a plenum or mixing chamber **15**. The member **13**, like the housing **5** and the end member **7**, is made of a heat resistant ceramic. The member **14** includes an outwardly convergent inner wall **16** leading to the discharge opening **17** for the unit. Normally member **14** will be cooled in view of the rush of hot gases along the wall **16** toward the opening **17** when the unit is in operation. Consequently, the end member **14** may be constructed of a suitable metal and made hollow to define an annular passageway **18** around the wall **16**. Cooling water enters the chamber **18** through an inlet line **19** being exhausted through return line **20** that connects to the passageway **18** at a location opposite from the line **19**.

The front and rear electrodes **22** and **23** are disposed within the chambers **8** and **15**, respectively. These are annular members coaxial with the housing and end chambers, and may include internal passageways whereby the electrodes are suitably water cooled. It can be seen that the electrodes **22** and **23** have inside diameters that are considerably larger than the diameter of the elongated opening **6** that defines the gap between the electrodes.

Electrical energy for the plasma generating arrangement of this invention is supplied by an appropriate current source **25**. This may be a source of direct current, or it may be alternating current of single or multiphase. Lead **26** from the current source **25** connects to a coil **27** wound around the exterior of the chamber **8**. This coil may be made up of a length of copper tubing embedded in a block **28** of ceramic or other heat resistant material. The hollow tubing allows water to be circulated through the coil to keep it cooled during operation of the unit of this invention. A relatively short lead **29** connects the coil **27** to the electrode **22** which thereby is in series with the coil.

Conductor **31** interconnects the other terminal of the current source **25** and a similar coil **32** circumscribing the mixing chamber **15**. This coil through lead **33** connects in turn to the front electrode **23**.

In operation of the device of this invention gas under a relatively low pressure is admitted into the chamber **8** through the inlet line **11**. A torch **35**, which may comprise a small plasma generator, is ignited at this time thereby ionizing the gas that passes through the housing **5** and into the plenum chamber **15**. Then current is passed through the conductors 26 and 31 and the arc 36 is struck between the electrodes 22 and 23. As the term "arc" is used herein it refers to the central thin filament represented by the line 36, and to the high temperature gas or plasma that immediately surrounds the filament. After the arc is initiated the gas pressure is increased to its full value.

The coils 27 and 32 generate a magnetic field traveling generally as indicated by the dotted lines 37 in FIGURE 1 of the drawing. It may be observed that the arc 36 in extending downwardly to enter the central passageway 6 through the housing 5 cuts the lines of flux in the opposite direction from the other portion of the arc at the opposite end that moves upwardly from the passageway 6 to the terminal 23. As the arc passes through the flux field at either end it is caused to rotate in accordance with the Lorentz forces encountered. Thus, the arc travels along the inner wall of each electrode and does not remain stationary at its footpoints. In this embodiment of the invention the opposite ends of the arc rotate in different directions by virtue of the fact that the footpoints of the arc cut the flux field in opposite directions at the two terminals.

The rotational flow of the gas at the chamber 8 adjacent the terminal 22 assists in the rotation of the arc at that location. This gas normally is admitted at high pressures, such as 600 p.s.i.a. The entry velocity may be sonic as the gas leaves the tube 11. Thus, the footpoint of the arc at the terminal 22 is caused to rotate both magnetically and from the force of the gas impinging on it. Various gases may be used including nitrogen, hydrogen, argon and helium, as well as oxygen-containing gases such as carbon monoxide.

As a result of this construction, the plasma generator of this invention is an efficient unit producing plasma of high enthalpy. The power source typically will deliver around one million watts from one thousand amperes at one thousand volts. This is true under conditions where the gas may be introduced into the chamber 8 under very high pressures. The rotational path of the gas within the housing as it flows from the chamber 8 toward the outlet 17 causes a thorough mixing and the transmission of a large amount of heat from the arc to the gas. The rotation of the footpoints of the arc avoids erosion and melting of the electrodes, increasing the life of the electrodes and reducing contamination of the output plasma. The fact that the arc is forced to follow the relatively narrow passageway 6 at the axis of the unit aids considerably in the transmission of heat to the gas. The gas also flows through this narrow opening so that the arc and the gas are confined to the same locality. The vortical flow of the gas as it passes through the passageway 6 assures that the gas is heated efficiently and uniformly, and helps avoid damage to housing 5 from the intense heat generated. The more dense and cooler portions of the gas are forced to the periphery of the opening by centrifugal force. Hence, while the gas at the axis of the unit may be of extremely high temperatures, at the wall of passageway 6 it is somewhat cooler.

After passing through the opening 6 the gas enters the mixing chamber 15 and from thence leaves the unit through the outlet opening 17. Of course, from the opening 17 the plasma may be used for any desired purpose. Generally there will be a suitable nozzle, test chamber or other arrangement attached to the outlet 17. Also, in the mixing chamber 15 it is possible to inject various materials so that the exhaust plasma may have different compositions. Chemical synthesis effects may be achieved in this manner.

The modification of FIGURE 3 possesses the same general characteristic as the unit of FIGURES 1 and 2. A central portion of the plasma generator, however, is made up of a tubular metallic section 38 which is of hollow nature to define, a cooling water passageway 39. The coolant may enter the passageway through the inlet opening 40 at one end and exhaust through outlet 41 at the opposite end. Again the arc 42 is forced to follow the relatively narrow passageway 43 intermediate the end chambers 44 and 45. The electrodes 46 and 47 again are of annular construction having inside diameters considerably greater than the diameter of the aperture 43. As illustrated in this version of the invention a nozzle 49 is disposed at the outlet of mixing chamber 45 providing a means to accelerate the plasma to supersonic velocities. This nozzle empties into a suitable chamber 50, which may comprise a hyphershermal tunnel or any other test chamber. A water passageway 51 is provided around the length of the nozzle, with inlet and outlets 52 and 53 respectfully being provided for the coolant.

As illustrated in the arrangement of FIGURE 3 the current flows in opposite directions through the coils 55 and 56. Hence, the coils buck each other and there is an independent flux field 57 around the coil 56, and a second separate flux field 58 at the coil 56. Consequently, because the terminal portions of the arc travel in opposite directions as they cut their flux fields, the rotational effect at the footpoints of the arc 42 is the same, causing the arc footpoints to rotate in the same direction rather than in opposite directions as in the previously described embodiment. Hence, it is quite simple to cause the ends of the arc to rotate either in the same manner or oppositely. Of course, the coils 27 and 32 could be made in bucking relationship in so far as the version of FIGURE 1 is concerned, and similarly the coils 55 and 56 could act together so as to rotate the ends of the arc 42 in opposite directions.

From the foregoing it can be seen that I have provided a relatively simple plasma generator capable of producing plasma of a high heat content despite the presence of high pressure gas at the inlet to the unit. Consequently, the device is versatile and can be used for a variety of purposes. The unit is efficient as a result of the physical confinement of the arc to the relative narrow passage through the center of the unit which also transmits the gas that is circulated through the plasma generator. This, with the combination of the rotating footpoints of the arc, gives the unit a long life, a stable arc and predictable performance.

The foregoing detailed description is to be clearly understood as given by way of illustration and example only. The spirit and scope of this invention being limited solely by the appended claims.

I claim:

1. A plasma generating device comprising
a housing,
said housing having a first chamber at one end, and a second chamber at the other end,
said second chamber having an outlet openopening,
said housing having a relatively small aperture interconnecting said chambers,
a first electrode in said first chamber,
a second electrode in said second chamber,
said electrodes being of annular configuration, and having inside diameters greater than the diameter of said relatively small aperture,
a first coil circumscribing said first chamber adjacent said first electrode,
a second coil circumscribing said second chamber adjacent said second electrode,
means for introducing gas into said first chamber in a rotational pattern,
and means for supplying current to said coils and said electrodes.

2. A device as recited in claim 1 in which
said means for introducing gas into said first chamber adjacent said first electrode includes means for rotating said gas in the same direction as the rotation imparted by said first coil to the footpoint of said arc at said first electrode,
whereby said gas and said first coil cooperate in rotating said footpoint at said first electrode.

3. A plasma generating device comprising
a first chamber,
a second chamber,
an elongated passageway interconnecting said chambers,
said passageway and said chambers being substantially circular in cross section,
said second chamber having an outlet opening opposite from said passageway,
a first annular electrode in said first chamber adjacent said passageway,
a second annular electrode in said second chamber adjacent said passageway,
said electrodes being of greater diameter than the diameter of said passageway,
means for introducing gas into said first chamber in a rotational flow pattern,
a first coil circumscribing said first chamber adjacent said first electrode,
a second coil circumscribing said second chamber adjacent said second electrode,
means for supplying current to said electrodes and to said coils,
for producing an arc between said electrodes confined by said passageway,
and for imposing a magnetic rotational force on said arc by the flux fields of said coils, thereby to rotate the terminal portions of said arcs,
the flux field of said first coil producing a force having the same direction of rotation as that of said gas,
whereby said first coil and said gas cooperate in the rotation of the terminal portion of said arc adjacent said first electrode.

References Cited

UNITED STATES PATENTS

2,945,119	7/1960	Blackman	313—231 X
3,027,446	3/1962	Browning	219—75
3,075,115	1/1963	Flowers	315—111 X
3,097,292	7/1963	Kugler	219—121
3,140,421	7/1964	Spongberg	313—231 X

FOREIGN PATENTS

852,054	10/1960	Great Britain.

DAVID J. GALVIN, *Primary Examiner.*

GEORGE N. WESTBY, JAMES W. LAWRENCE, *Examiners.*

S. D. SCHLOSSER, *Assistant Examiner.*