Sept. 22, 1970 M. L. THORPE ET AL 3,530,334

INDUCTION PLASMA GENERATOR HAVING IMPROVED CHAMBER STRUCTURE AND CONTROL

Filed Sept. 14, 1967 3 Sheets-Sheet 1

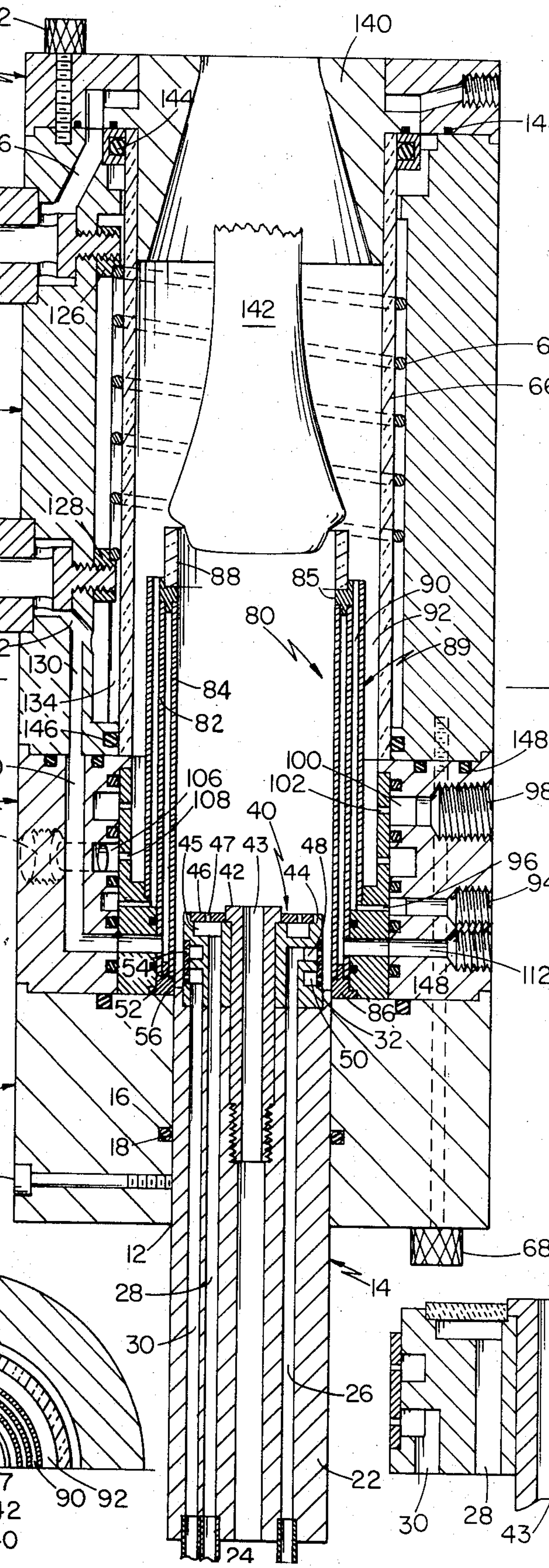


FIG I

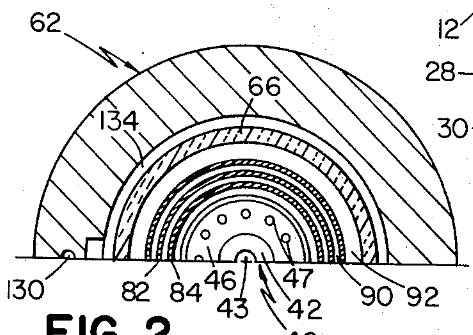


FIG 2

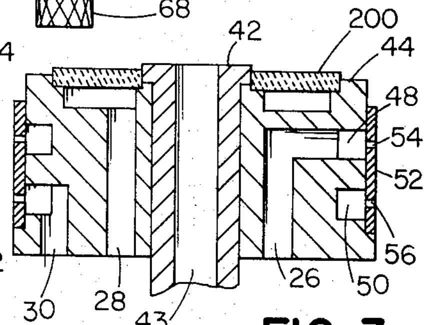
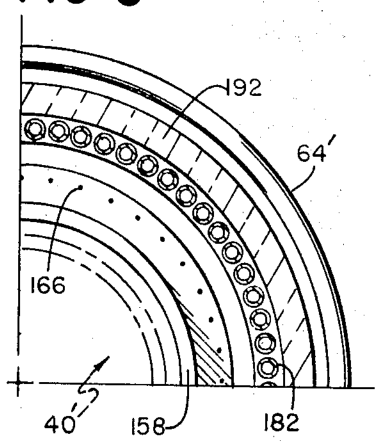


FIG 3

FIG 5


192
64'
166
40'
158
182

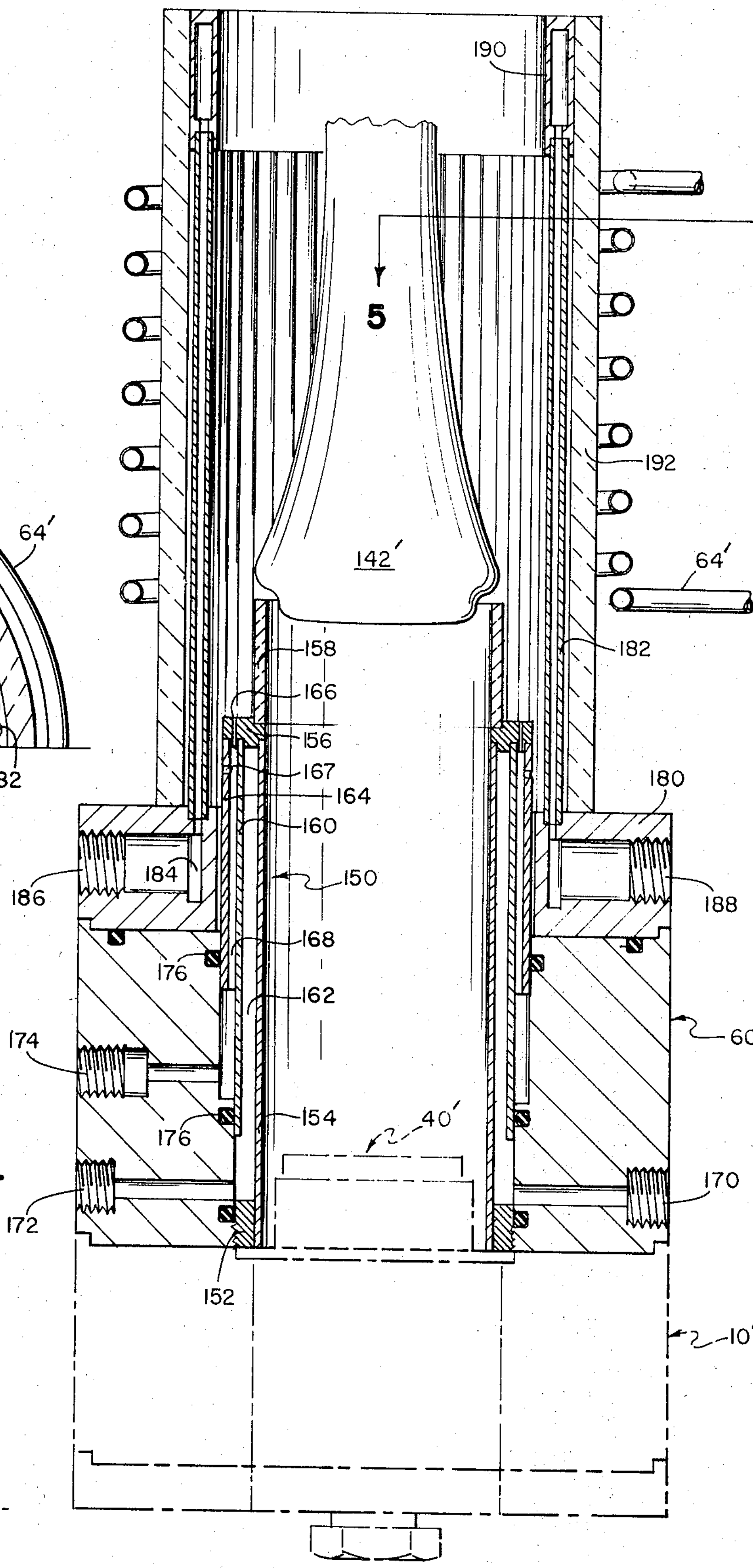

190
5
5
192
142'
64'
158
166
156
167
164
160
150
182
180
184
186
188
168
176
162
174
60'
154
40'
176
170
172
152
10'

FIG 4

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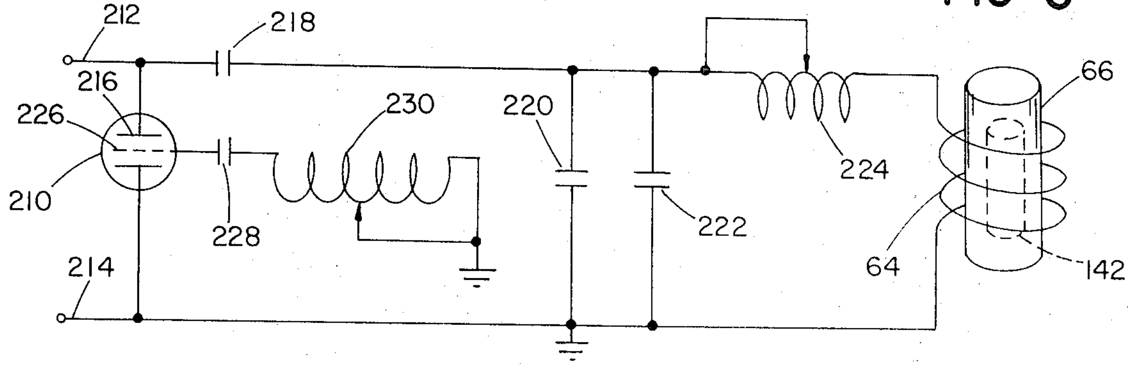
FIG 6



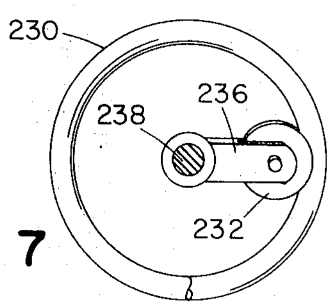


FIG 7

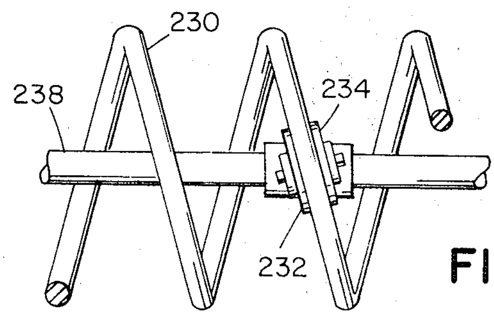


FIG 8

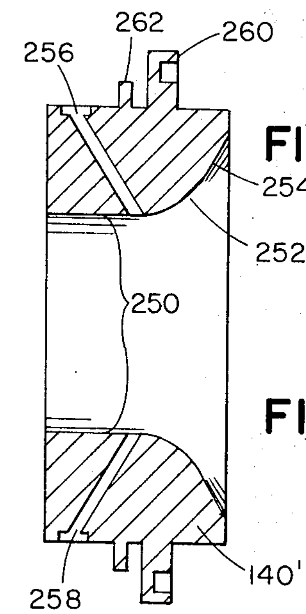


FIG 10

FIG 9a

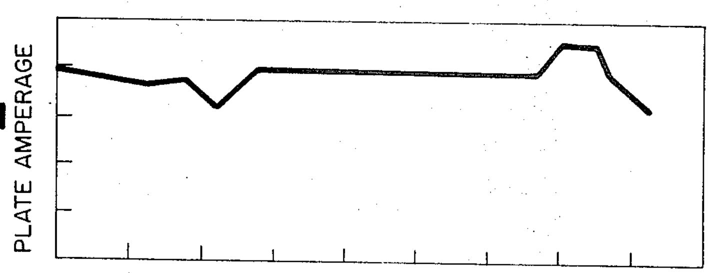


FIG 9b

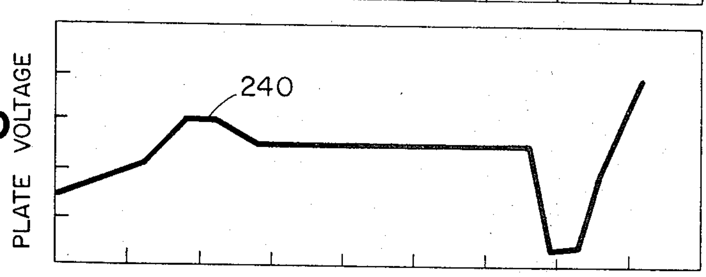
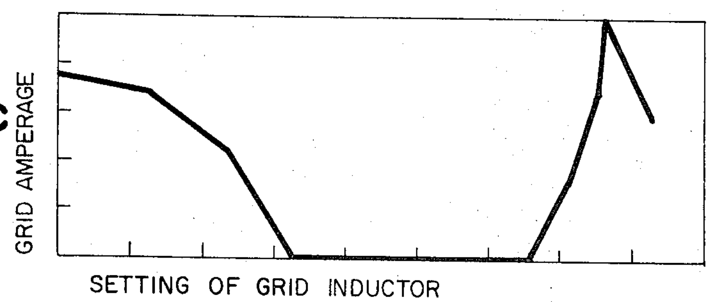


FIG 9c



United States Patent Office 3,530,334
Patented Sept. 22, 1970

3,530,334
INDUCTION PLASMA GENERATOR HAVING IMPROVED CHAMBER STRUCTURE AND CONTROL

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U.S. Cl. 315—111 16 Claims

ABSTRACT OF THE DISCLOSURE

An induction plasma generator has a plasma forming chamber defined by sixty-seven axially extending metal tubes surrounded by a 3½ inch diameter ceramic tube that is 7¼ inches long. A six turn induction coil of ¼ inch copper tubing surrounds the ceramic tube. Extending into one end of this chamber is an assembly that defines a main gas injector and an auxiliary gas injector with a tube (2⅛ inches I.D. and 6½ inches long) between the two injectors. The main injector has twelve axial discharge ports, twelve radial discharge ports and twelve swirl ports, while the auxiliary injector has forty-two axial ports, and six swirl ports.

This invention relates to induction plasma generators and more particularly to apparatus for inductively heating a gas with high frequency electrical energy. Such generators create high temperature thermal plasma gas by inductive coupling high frequency electrical energy to ionized gas and are useful for a variety of purposes, including producing chemical reactions, material testing and treatment, and general industrial heating.

An object of this invention is to provide novel and improved induction plasma generators.

Another object of the invention is to provide a novel and improved induction plasma generator configuration which provides stable operation with a variety of gases and of a variety of plasma chamber configurations.

Another object of the invention is to provide novel and improved configurations of induction plasma generators particularly useful in industrial processes which involve either the heating of fluids or the injection of particles into a heated gaseous stream.

Still another object of the invention is to provide a novel and improved plasma chamber configuration for use in induction plasma generators.

Other objects of the invention include the provision of novel and improved control and ignition techniques for use with induction plasma generators.

Plasma generators of the type to which the invention relates include a plasma chamber, an induction coil surrounding the chamber, and an injector for introducing gas into the chamber for conversion to thermal plasma condition under the influence of the electromagnetic field created by the induction coil. In accordance with one feature of the invention, a multiplicity of closely spaced, axially extending tubular elements are used to form the plasma chamber, together with means for passing a coolant material through the tubular elements. Such a plasma chamber defining structure has been found to have greater resistance to damage at high heat flux than ceramic materials such as quartz and thus permits greater energy transfer to the output gas without significant reduction in the efficiency of the generator. It has been found necessary from the standpoints of electrical and gas flow stability that each tubular element be a small fraction of the angular extent of plasma chamber and it is preferred that that angular extent

be less than twenty degrees. In a particular embodiment the tubular elements are metal cylinders.

Another feature of the plasma generators is the use of a porous disc element as the axial flow distributor component in the injector structure. Such disc elements provide axial gas flow over their entire surface areas and improve the distribution and volume of gas flow in stable plasma generator operations. In order to provide uniform gas distribution it is desired that the porous element have a pressure drop of at least five inches of water and a pore size of less than twenty-five microns is preferred.

Other features of the invention include discharge nozzle arrangements which enable improved injection of particles for treatment by the stream of hot gas emerging from the generator; and which provide increased protection for elastomeric sealing members employed in the plasma generator.

Still another feature relates to an improved mode of operation of plasma generators. The electrical system is provided with a continuously variable control (either an inductor or a capacitor) in the oscillator grid circuit which is adjusted to vary oscillator parameters and maximize the electric potential applied to the plasma chamber coil at no load (no plasma arc in the plasma chamber); gas in the plasma chamber is then ionized and the electric field couples to the ionized gas to establish the plasma condition; and then the variable control is further adjusted to increase current flow in the oscillator control circuit within the region of maximized electric potential on the plasma coil. Such operation has been found to increase the percentage of power transferred to the plasma gas and hence increased the useful output of the generator. As the region of optimum operation is relatively narrow, the provision of a continuously variable control to obtain this mode of operation is particularly useful.

Other objects, features, and advantages of the invention will be seen as the following description of particular embodiments progresses, in conjunction with the drawings, in which:

FIG. 1 is a sectional view of a first embodiment of an induction plasma generator constructed in accordance with the invention;

FIG. 2 is a sectional view, taken along the line **2—2** of FIG. 1 of the plasma chamber of the generator;

FIG. 3 is a sectional view of a modified form of injector useful in the apparatus shown in FIG. 1;

FIG. 4 is a sectional view of a second embodiment of a plasma generator constructed in accordance with the invention;

FIG. 5 is a sectional view along the line **5—5** of FIG. 4, details of the structure defining the wall of the plasma chamber;

FIG. 6 is a schematic diagram of induction coil energizing circuitry for use with the induction plasma generator arrangements shown in FIGS. 1–5;

FIG. 7 is an end view of the inductor tuning arrangement used in the circuit of FIG. 6;

FIG. 8 is an enlarged side view of a portion of the inductor tuning arrangement shown in FIG. 7;

FIG. *9a, b* and *c* are a series of three curves indicating variation in oscillator parameters of the circuit shown in FIG. 6 as a function of the position of the variable control inductor; and

FIG. 10 is a modified form of nozzle useful for processing particulate matter with the generators shown in FIGS. 1 and 4.

The plasma generator as shown in FIG. 1 includes a base **10** having a central bore **12** in which a main gas injector assembly **14** is mounted. A groove **16** in the bore houses an O-ring **18** which is employed as a seal against the injector assembly and set screws **20** secure the injector assembly **14** in axial position relative to base **10.**

The injector assembly includes a cylindrical body **22** (two inches in diameter) having a central material introducing passage **24** and three axially extending gas flow passages **26**, **28**, and **30**. A counterbore **32** at the upper end of cylinder **22** provides a seat for a mixer head **40** which is secured in place by stud **42** (that has a hollow passageway **43** which is aligned with and forms an extension of passageway **24**). Mixer head **40** includes a cylindrical block **44** (1.875 inches in diameter) having at its upper end an annular distributor channel **45** (0.062 inch deep and 0.312 inch wide) over which is secured a ring **46** having a series of twelve 0.026-inch axial discharge ports **47** disposed in it on 1.200-inch diameter center. Immediately below channel **45** are two peripheral distributor channels **48** (in communication with passage **26**) and **50** (in communication with passage **30**). On the wall of the seated mixer body is an annular ring **52** having a set of twelve radially extending ports **54** (each 0.026 inch in diameter) disposed immediately in front of distributor channel **48** and a set of twelve swirl ports **56** (each 0.026 inch in diameter) disposed in front of distributor channel **50**.

Mounted on base **10** is a spacer **60** which houses a transition channel—auxiliary gas injector structure. Housing **62**, in which induction coil **64** and plasma chamber defining quartz tube **66** are disposed, is in turn mounted on spacer **60**. Through bolts **68** pass through base **10** and spacer cylinder **60** into housing **62** and secure that assembly together. End cap **70** on the upper end of housing **62** secured in position by bolts **72**.

Spacer cylinder **60** has an inner diameter of 3¼ inches and receives in sealing relation a stabilizing structure in the form of transition channel **80** and auxiliary injector structure **89**. Transition channel structure **80**, of two inches inner diameter and 4⅞ inches long, includes a water cooled section made up of walls **82** and **84**, upper header **85**, lower header **86** and cylindrical quartz separator **88** one-half inch in length, the end of which is located substantially in alignment with the lower power lead of coil **64**. Surrounding transition channel **80** is an auxiliary gas injector structure **89** that includes an annular axially extending buffer passage **90**, $\frac{1}{16}$ inch in width, and a surrounding annular axially extending main passage **92**, $\frac{3}{16}$ inch in width. Auxiliary gas is supplied to buffer channel **90** through port **94** and passage **96**; while the main flow of auxiliary gas is supplied through port **98** to distributor channel **100** and through radial ports **102** (42 in number, each 0.026 inch in diameter), and through a second main inlet including port **104** to distributor channel **106** and through swirl ports **108** (12 in number, each 0.026 inch in diameter).

It will be noted that the auxiliary gas distributor and transition channel structure, formed as an integral unit, are mechanically positioned with respect to injector structure **14** so that a precise coaxial configuration results. Quartz tube **88** forms an extension of the inner wall of transition structure **80** so that a smooth flow of plasma gas (separate from the auxiliary gas supplied by injector structure **89**) is provided along the walls of the quartz extension **88**.

A coolant passage inlet **110** extends from the mating surface between cylinder **60** and housing **62**, to the channel between walls **82** and **84** and an outlet passage **112** extends radially outwardly from the channel between walls **82** and **84** at the side opposite inlet **110**.

Housing **62**, of a suitable material of uniform high dielectric integrity, which is unaffected by the coolant employed, a suitable material being polytetrafluoroethylene (Teflon), has attached tubular electrical terminals **120**, **122**, each of which has a water cooled passageway **124**. The upper terminal **120** is connected to terminal block **126**, which in turn is connected to one end of coil **64** ($\frac{3}{32}$-inch round copper wire wound to provide five turns over a length of about 4 inches, about 3¼ inch I.D.). The other end of coil **64** is connected to block **128** to which terminal **122** is threadedly connected. The coolant passage **124** of terminal **122** is connected to passage **130** in housing **62** which passage is in turn aligned with passage **110** in section **60**. A second passage **132**, connected to annular chamber **134** in which coil **64** is disposed, permits coolant flow upwardly past coil **64** and around the upper end of quartz tube **66** for return through exit passage **136** to the passage **124** in upper terminal **120**.

The nozzle **140** secured to end cap **70** provides a restricted orifice through which both the plasma gas and the auxiliary gas flows. In addition, the nozzle structure extends down into the plasma chamber defined by quartz tube **66** sufficiently to interpose a shield opaque to radiation from the arc region between that arc region (indicated at **142**) and the upper quartz tube support O-ring **144**. The transition channel structure **80** provides a similar radiation opaque protective shield for lower O-ring **146**. A number of other O-ring seals **148** are provided between the mating components of the generator, end cap **70** and housing **66**; housing **66** and cylinder **60**; and auxiliary injector **89** and cylinder **60** and base **10**.

In a typical operation of this plasma generator a plasma is initiated by introducing argon gas at 30 s.c.f.h. through axial inlet ports **46** (passage **28**) and 80 s.c.f.h. through inlet ports **56** (passage **30**). The plasma may be initiated by suitable means such as temporary insertion of a graphite rod into the plasma chamber where it is heated by the electromagnetic field established by coil **64**. After the plasma is created, the plasma sustaining argon flow is adjusted to the following values:

Passage:	S.c.f.h.
26	40
28	0
30	80

The resulting arc **142** is of configuration generally as indicated in FIG. 1. A gas for chemical reaction or for analysis purposes may be supplied through ports **94**, **98**, and **104**. Port **94** is primarily for buffering purposes while the main gas flow is through port **98** (with added gas through port **104** is desirable). With this apparatus hydrogen as the auxiliary gas has been heated to a temperature of 2800° F. at a flow rate of 3600 s.c.f.h. distributed among the auxiliary ports in the following quantities:

Port	S.c.f.h.
94	200–1000
98	2600–3600
104	0

in a continuous operation over one hour without creating unstability in the arc **142**. At lower flow rates hydrogen introduced through the auxiliary injector **89** has been heated up to 5000° F.

A modification of the main gas injector, useful particularly with argon as the arc forming gas as it produced longer and hotter gas stream issuing from the torch with the same power and allows a substantial increase in power capability of the generator without failure of quartz tube **66**, is shown in FIG. 3. A porous bronze metal disc **200**, ⅛ inch in thickness and 1⅝ inch diameter when it is positioned coaxially with respect to the 1⅞ inch diameter mixer structure as substitution for the axial orifices **47** (in plate **46**). The center section defined by stud **42** was ½ inch in diameter. Porosities of 1.5 to 25 microns which produced pressure drops of 30–70 to 7–14 inches of water respectively were operated satisfactorily. Satisfactory operation was also obtained with a main injector that employed a porous bronze disc without stud **42** so that the main gas flow extended over the entire width of the disc. Also, a porous ring of this type may be utilized at the annular outlet of the auxiliary injector **89**.

A second embodiment is shown in FIGS. 4 and 5. That plasma generator has a base **10'** in which is supported a plasma gas (main) injector structure with a mixer head diagrammatically indicated at **40'** and an auxiliary gas injector transition channel structure **60'**. Disposed in structure **60'** is a transition channel insert **150**, 2⅛ inches in inner diameter, and 6½ inches in length. This transition channel **150** includes a base **152** which is threadedly secured to the section **60'**; an inner metal wall **154** to which is secured a header **156** on which is received quartz tubular extension **158**; and a surrounding tubular wall member **160** which depends from header **156** and forms with wall **154** an annular coolant channel **162**.

A third tubular member **164**, also secured to header **156**, has a series of 42 axial ports **166** (0.026 inch in diameter) and a series of 6 swirl ports **167** (0.026 inch in diameter) in communication with annular chamber **168** formed between members **160** and **164**. This insert structure **150** is secured in structure **60'** which includes coolant inlet **170**, coolant outlet **172**, and auxiliary gas inlet **174**. O rings **176** provide seals to isolate the coolant from the auxiliary gas.

Mounted on spacer **60'** is a plasma chamber defining structure which includes a base **180** (functioning as a header) to which are secured in a ring a series of ⅛ inch O.D., 0.085 I.D. copper tubes **182** spaced 0.022 inch apart. The lower ends of the tubes are soldered to base **180** for communication with distributor channel **184** which in turn is connected to inlet port **186** and outlet port **188**. The upper ends of tubes **182** are similarly connected to header **190**. The distance headers **180** and **190** is 5¾ inches and the inner diameter of each header is three inches.

Surrounding the set of tubes **182** is a ceramic (Rotasil) tube **192**, 3½ inches I.D. and 7¼ inches long. A six turn induction coil **64'** of ¼ inch O.D. copper tubing surrounds the tube **192** and is connected to the power supply.

The use of this metal wall structure to define the plasma chamber has been found to have particular advantage in operating the generator without auxiliary gas flow. For example, generators in which the plasma chamber is defined by the ring of metal tubes have been operated with percentages of hydrogen in the main gas flow in excess of those percentages which would cause cracking of the quartz tube in a generator of the type shown in FIGS. 1 and 2. Further, higher power densities were obtainable with the ring of tubular elements. In a generator having a one-inch diameter plasma chamber formed of tubes as above described, a power density of 60 kilowatts was obtainable while a power density of 25 kilowatts was the maximum obtainable using a one-inch diameter quartz tube.

Ignition of this plasma generator configuration may be obtained by contacting a graphite plate on stud **42** of mixer **40** with an energized electrode introduced axially through the discharge end of the plasma chamber. A DC arc is drawn, ionizing gas in the chamber to which the electric field produced by coil **64** couples.

Operation of the plasma generator shown in FIGS. 4 and 5 with the following values has been obtained:

Argon center core—115 s.c.f.h.
Hydrogen sheath—2730 s.c.f.h.
Coil turns—6.
Coil I.D.—4 inches.
Oscillator tank capacitor—900 microfarads.
Blocking capacitor—125 microfarads.
Frequency—2.5 mc.

In a modification of the plasma generator structure shown in FIG. 4, the plasma chamber structure shown in FIG. 1 may be substituted while locating the coil **64** at the end of the quartz extension **158** in the same relation as shown in FIG. 4. Operation with the following values

(which may be compared with those indicated above) was obtained:

Argon center core—120 s.c.f.h.
Hydrogen sheath—3610 s.c.f.h.
Coil turns—5.
Coil I.D.—3.3 inches.
Oscillator tank capacitor—900 microfarads.
Blocking capacitor—200 microfarads.
Frequency—3.1 mc.

The heat energy in the gas leaving the torch was measured to be in excess of 40% of the DC input energy to the generator.

A schematic diagram of an electrical system used with these plasma generators is shown in FIG. 6. That system includes an oscillator tube **210** to which D.C. power is applied over lines **212**, **214**. The plate (output electrode) **216** of tube **210** is coupled by blocking capacitor **218** to the main tank circuit that includes capacitors **220**, **222**, an adjustable inductor coil **224** and generator coil **64**. Connected to the grid (control electrode) **226** of tube **210** is capacitor **228** and continuously variable inductor **230**. Diagrammatic end and side views of continuously variable grid inductor **230** are shown in FIGS. 7 and 8. The inductor coil **230** has thirty-six turns, one of which is contacted by a tap in the form of two juxtaposed discs **232**, **234** which are mounted on an arm **236** which arm, in turn, is mounted for rotation on shaft **238** at the center of coil **230**. This tap structure, as shaft is rotated, transverses the helical coil **230** and thus permits variation of the tap position over a large and continuous range.

Variation of system plate voltage, plate amperage, and grid amperage as a function of the position of the tap on coil **230** under no load operation is indicated in FIGS. 9A–C. In operation, region **240** is first located (the region of maximum plate voltage [FIG. 9B] and minimum plate amperage [FIG. 9A]). The plasma arc **142** is then ignited to establish a load. The setting of the grid inductor is then varied to maximize the grid amperage within region **240** and the power ratings of the system.

A modified nozzle structure **140'** which has particular utility for introducing particulate material into the flow of heated gas from the plasma chamber is indicated in FIG. 10. The nozzle has a discharge passage section **250**, 1½ inches in diameter, and a tapered transition section that includes a first segment **252** disposed at a 45° angle to the axis of the generator and a second segment **254** disposed at a 60° angle to the axes of the generator. Extending from the outer wall of the nozzle to the discharge passage section **250** are two opposed passages **256**, **258**, each of which is 0.082 inch in diameter and which is drilled at an angle of 120° to the direction of gas flow through the discharge passage **250**. Flanges **260** and **262** provide clamping and sealing surfaces for securing the nozzle **140'** to the plasma generator structure.

In operation, particulate matter is introduced through passages **256**, **258** into the stream of hot gas issuing from the plasma chamber. The particulate material is introduced in a direction countercurrent to the gas flow and at a point within the cylindrical discharge passage section **250** so that it is acted on by the hot gas flow for a substantial period of time while none of the heated particulate matter impinges on any surface of the nozzle structure disposed at an angle to the direction of gas flow through the nozzle structure. In this manner all the heated particulate matter is carried out of the nozzle structure by the gas flow in the heat treatment process and does not accumulate on nozzle surfaces.

While particular embodiments of the invention have been shown and described, various modifications thereof will be obvious to those skilled in the art. The specific dimensions and configurations of the described embodiments are for purposes of illustration and not intended as limitations other than as recited in the claims. It is therefore not intended that the ivention be limited to the disclosed embodiments or to details thereof and departures may be made therefrom within the spirit and scope of the invention as defined in the claims.

What is claimed is:

1. An induction plasma generator comprising means defining a plasma chamber including a multiplicity of closely spaced, axially extending tubular elements, means for passing coolant fluid through said tubular elements,

a high frequency electrical coil surrounding said chamber for creating an electric field within said chamber,

a main gas injector spaced from one end of said chamber for introducing a first gas for flow into said plasma chamber and conversion to plasma arc condition under the influence of said electric field, and

a stabilizing structure of smaller cross-sectional dimension than said plasma chamber for introducing said first gas from said main injector to said plasma chamber in the vicinity of said electrical coil in a main stream coaxial with and spaced from the wall of said plasma chamber.

2. The plasma generator as claimed in claim 1 wherein each said tubular element is a metal cylinder and the spacing between each pair of adjacent cylinders is less than 0.1 inch.

3. The induction plasma generator as claimed in claim 1 wherein said gas injector includes a gas distributor body having a recess therein, and a porous disc element disposed over said recess between said recess and said plasma chamber for passing gas from said recess in the axial direction for flow through said plasma chamber, said disc element having porosity producing a gas flow pressure drop across said disc element of at least five inches of water.

4. The plasma generator as claimed in claim 3 wherein said disc element is a metal element having a pore size of less than twenty-five microns.

5. The induction plasma generator as claimed in claim 1 and further including a high frequency osciallator for energizing said electrical coil, said oscillator including a control device having an output circuit and a control electrode, a tank circuit connected aross the output circuit of said control device, said tank circuit including said electrical coil, and a continuously variable inductor connected to said control electrode.

6. An indution plasma generator comprising means defining a plasma chamber, an electrical coil surrounding said chamber, a high frequency oscillator for energizing said electrical coil, said oscillator including a control device having an output circuit and a control electrode, a tank circuit connected across the output circuit of said control device, said tank circuit including said electrical coil and a continuously variable inductor connected to said control electrode, said continuously variable inductor including a helical coil, a rotatable shaft coaxially disposed inside said helical coil, and a tap structure mounted on said rotatable shaft, said tap structure having an end portion in wiping engagement with a portion of one turn of said coil and adapted to be moved along said coil in a helical path to traverse the length of said coil in response to rotation of said shaft and a main gas injector spaced from one end of said chamber for introducing a first gas for flow into said plasma chamber and conversion into plasma arc condition under the influence of said electric field.

7. An induction plasma generator comprising means defining a plasma chamber, a high frequency electrical coil surrounding said chamber for creating an electric field within said chamber, a main gas injector spaced from one end of said chamber for introducing a first gas for flow into said plasma chamber and conversion to plasma arc condition under the influence of said electric field, and a nozzle structure at the output end of said plasma chamber remote from said main injector, said nozzle structure defining an axially extending discharge passage section of substantially smaller cross-sectional area than the cross-sectional area of said plasma chamber and a tapered transition section between said plasma chamber and said discharge passage section, said nozzle structure defining an axially extending distion passage having an outlet in said discharge passage section for injecting material into the gas flow in said tapered transition section at an angle greater than 90° to the direction of gas flow through said discharge passage section so that the injected material is carried through said discharge passage section without impingement on a surface of said nozzle structure.

8. An induction plasma generator comprising means defining a plasma chamber,

a high frequency electrical coil surrounding said chamber for creating an electric field within said chamber,

a main gas injector spaced from one end of said chamber for introducing a first gas for flow into said plasma chamber, characterized in that said plasma chamber defining means includes a multiplicity of closely spaced, axially extending tubular elements, and further including means for passing coolant fluid through said tubular elements.

9. The plasma generator as claimed in claim 8 wherein each said tubular element is a metal cylinder and the spacing between each pair of adjacent cylinders is less than 0.1 inch.

10. An induction plasma generator comprising means defining a plasma chamber,

a high frequency electrical coil surrounding said chamber for creating an electric field within said chamber,

a main gas injector spaced from one end of said chamber for introducing a first gas for flow into said plasma chamber, characterized in that said main gas injector includes a gas distributor body having a recess therein, and a porous disc element disposed over said recess between said recess and said recess and said plasma chamber for passing gas from said recess in the axial direction for flow through said plasma chamber, said disc element having porosity producing a gas flow pressure drop across said disc element of at least five inches of water.

11. The plasma generator as claimed in claim 10 wherein said disc element is a metal element having a pore size of less than twenty-five microns.

12. An induction plasma generator comprising means defining a plasma chamber,

a high frequency electrical coil surrounding said chamber for creating an electric field within said chamber,

a main gas injector spaced from one end of said chamber for introducing a first gas for flow into said plasma chamber and conversion to plasma arc condition under the influence of said electric field, and a high frequency oscillator for energizing said electrical coil, said oscillator including a control device having an output circuit and a control electrode, a tank circuit connected across the output circuit of said control device, said tank circuit including said electrical coil, and a circuit including a continuously variable inductor element and a capacitor element connected to said control electrode, said continuously variable inductor element includes a helical coil, a rotatable shaft coaxially disposed inside said helical coil, and a tap structure mounted on said rotatable shaft, said tap structure having an end portion in wiping engagement with a portion of one turn of said coil and adapted to be moved along said coil in a helical path to traverse the length of said coil in response to rotation of said shaft.

13. The induction plasma generator as claimed in claim **12** wherein said main gas injector includes a gas distributor body having a recess therein, and a porous disc element disposed over said recess between said recess and said plasma chamber for passing gas from said recess in the axial direction for flow through said plasma chamber, said disc element having a pore size of less than twenty-five microns and producing a gas flow pressure drop across said disc element of at least five inches of water.

14. The induction plasma generator as claimed in claim **13** wherein said means defining a plasma chamber includes a multiplicity of axially extending metal cylinders spaced less than 0.1 inch apart, and further including means for passing coolant fluid through said cylinders.

15. The plasma generator as claimed in claim **14** and further including a nozzle structure at the output end of said plasma chamber remote from said main injector, said nozzle structure defining an axially extending discharge passage section of substantially smaller cross-sectional area than the cross-sectional area of said plasma chamber and a tapered transition section between said plasma chamber and said discharge passage section, said nozzle structure further including a material injection passage having an outlet in said discharge passage section for injecting material into the gas flow through said nozzle at an angle greater than 90° to the direction of gas flow through said discharge passage section.

16. The method of operating an induction plasma generator having a plasma chamber, a coil surrounding said plasma chamber, and an oscillator for energizing said coil to establish an electric field in said plasma chamber, said oscillator including a tank circuit comprising an inductance and a capacitance, a control device having an output circuit connected to said tank circuit and a control electrode, and a circuit including an inductor element and a capacitor element connected to said control electrode, at least one of said elements being continuously variable,

comprising the steps of adjusting an element in said control electrode circuit to maximize the voltage in said output circuit,

ionizing gas in said plasma chamber to provide a conductive medium to which the electric field established by said coil will couple, and further adjusting said continuously variable element to maximize the current flow in said control electrode circuit within the region of maximized voltage in said output circuit.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,530,334 Dated September 22, 1970

Inventor(s) M. L. Thorpe et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 8, lines 7-8 "defining an axially extending distion" should be --further including a material injection--;
line 42, delete "said recess and".

SIGNED AND
SEALED
DEC 8 - 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents