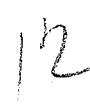


3,407,281

2 Sheets-Sheet 1



INVENTOR.

BY

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PLASMA PRODUCING APPARATUS

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2 Sheets-Sheet 2

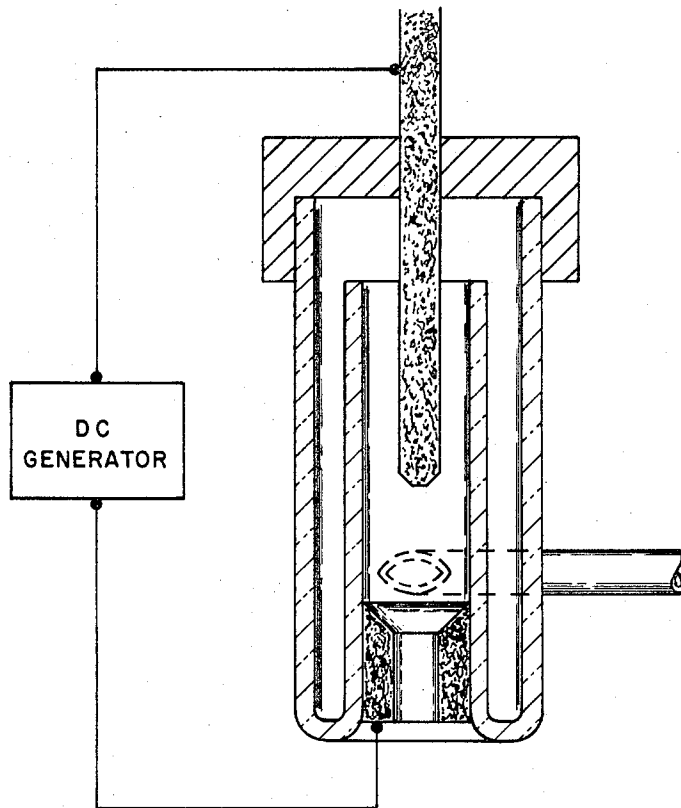


FIGURE 2

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PLASMA PRODUCING APPARATUS

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9 Claims. (Cl. 219—121)

ABSTRACT OF THE DISCLOSURE

A plasma apparatus and process for operating such apparatus in a manner which achieves unusually low levels of energy loss by way of heat dissipation into the apparatus. The apparatus includes a plasma zone enclosure substantially completely surrounded by an annulus. The annulus forms a closure with the outlet end of the plasma zone enclosure, and is in open communication with the inlet end thereof. Fuel introducing means are provided to supply gas into the annulus in such a manner as to cause spinning of the gas therewithin. The spinning fuel gas flowing into the inlet end of the plasma zone enclosure is maintained at a linear velocity of at least about 75 ft./second. Either a high frequency induction heating means or an electric arc producing means are associated with the apparatus for producing ionizing energy within the enclosure.

This application is a continuation of patent application Ser. No. 354,413, filed Mar. 24, 1964, and now abandoned.

Thermal plasmas, i.e. the phenomena which occur when sufficient energy is imparted to a gas under at least about 1 atmosphere of pressure to maintain at least about 10% of the atoms of said gas at above the ionization potential thereof, have found many useful applications in science and industry. For instance, welding, cutting and spraying of metallic or refractory materials, the growth of metallic or refractory crystals, and high temperature chemical reactions have been successfully accomplished with the aid of thermal plasmas.

Several methods exist by which thermal plasmas can be formed. One such method is that most commonly realized in an AC or DC plasma torch wherein an electrically induced arc is formed between two electrodes one of which is provided with an orifice. A flow of fuel gas is provided adjacent the arc and a plasma is formed within and about said arc and is discharged through said orifice. A modification of said type of thermal plasma forming apparatus is that commonly encountered in metal cutting plasma apparatus which comprises a gas jet and electrode. In operation, an arc is struck between said electrode and the metallic piece to be cut; the gas issues from the gas jet and is ionized by said arc, thereafter cutting said piece. Examples of thermal plasma forming devices of the above-described types can be found in U.S. 2,858,411, issued Oct. 28, 1958 to R. M. Gage and U.S. 2,874,265, issued Feb. 17, 1959 to T. B. Reed et al.

Another suitable method for generating and maintaining a thermal plasma comprises an "electrodeless discharge technique." In accordance with said technique, a thermal plasma is formed by heating a fuel gas to ionization temperatures within an induction field created by a high frequency current. By enclosing the ionization zone and providing a continuous flow of fuel gas to said ionization zone, a torch effect is produced. Generally speaking, frequencies of from about 0.4 megacycle to about 100 megacycles are used at power outputs of greater than about 2 kilowatts. A more complete understanding of thermal plasma formation by high frequency induction heating can be had when reference is made to Reed,

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"Plasma Torches," International Science and Technology, June 1962, pp. 42-48.

One of the problems normally associated with the formation of a thermal plasma resides in the fact that the extremely high temperatures (i.e. above about 6000° K.) attained in the formation thereof are generally extremely deleterious to the apparatus in which said plasma is formed. Thus, said apparatus must normally be protected by auxiliary cooling means, such as by water jacketing, etc. The apparatus associated with said auxiliary cooling often represents a considerable and undesirable increase in the bulk, weight and complexity of the thermal plasma forming apparatus. Furthermore, a substantial portion of the energy required to produce and maintain the plasma and/or the heat released by recombination of the ions and electrons comprising the plasma are often wasted through radiation and conduction of heat to walls of the apparatus. Hence, the cooling of plasma forming apparatus by presently utilized methods, although often producing the desired effect of preserving the physical integrity of said apparatus during operations, nevertheless generally results in substantial and undesirable heat losses. In accordance with the present invention, however, these problems have been minimized.

Accordingly, it is a principal object of the present invention to provide an improved process for the formation of thermal plasmas.

It is a further object of the present invention to provide improved plasma forming apparatus.

Other objects and advantages of the present invention will in part be obvious and will in part appear hereinafter.

In accordance with the present invention it has been discovered that heat losses from a thermal plasma to the confining apparatus are vastly reduced when said plasma is produced by introducing a spinning fuel gas into an ionizing zone at a linear velocity of greater than about 75 ft./sec. If the linear velocity of the fuel gas is maintained substantially lower than about 75 ft./sec. the benefits accruable from the process of the present invention, i.e. greatly reduced transfer of heat to the confining apparatus, are usually not realized. Generally speaking, linear velocities of between about 100 ft./sec. and 350 ft./sec. or even higher will be utilized. Thus, when high temperature reactions such as the production of ammonia, acetylene, zirconia, carbon black, and the like are to be accomplished within the thermal plasma, it is preferred that the linear velocity of the fuel gases be maintained above about 100 ft./sec.

Due to the fact that in accordance with the present invention heat losses to the confining apparatus are vastly reduced, the apparatus utilized generally need neither be provided with water jackets or other cooling means nor be constructed of a highly refractory material such as quartz.

Suitable fuel gases for the practice of the present invention are subject to considerable variation. Generally speaking, monatomic gases such as helium, neon, xenon, radon, argon, cesium vapor, mercury vapor, etc., are entirely suitable. Diatomic gases, such as hydrogen, chlorine, oxygen and the like are however, also generally suitable. The monatomic species are generally preferred due to the fact that no energy is required to dissociate the molecules of said gases prior to ionization thereof. When plasma forming apparatus as previously described of the DC or AC arc type is to be utilized, it is normally preferred that oxygen-containing gases such as air, oxygen and carbon monoxide, not be introduced into the ionization zone due to the inherent dangers of thermo-chemical attack by said oxygen-containing gases upon the electrodes of the apparatus. In the process of thermal plasma formation via radio frequency induction heating, however,

oxygen-containing gases can generally be introduced into the ionization zone with relative immunity.

As is well known to the art, when a gas having a relatively high ionization potential is to be utilized as the fuel gas, it is preferred that a "pilot" plasma be first initiated using a gas having a relatively low ionization potential such as argon, and thereafter the desired fuel gas, possessing the higher potential, is introduced into the ionization zone.

In accordance with the present invention, the fuel gas is introduced while spinning into the ionization zone. The spinning motion can be imparted to said fuel gas in any suitable manner. For instance, we find it convenient to effect said motion by introducing said gas tangentially into the thermal plasma forming apparatus. A better understanding of the process of the present invention can be had when reference is made to FIGURE 1 forming part hereof wherein there is provided a schematic diagrammatic view of a preferred embodiment of a thermal plasma forming apparatus wherein a spinning gaseous fuel is supplied to the ionization zone via an annulus surrounding said zone.

FIGURE 2 is a diagrammatic schematic side view of still another embodiment of the plasma producing apparatus of the invention wherein ionizing energy is supplied by means of electric arc producing means.

Referring now to said FIGURE 1, a gaseous fuel is introduced into annulus 5 through conduit 7 and tangentially oriented orifice 6. The gas courses upwardly in spiral fashion through said annulus and enters plasma chamber 9. Still spiraling, the gas then flows downwardly through chamber 9 and is heated in ionization zone 11, for example, by means of an induction field generated by the passage of high frequency radio waves through coils 13. Starting rod 15, comprising a conductive material such as tungsten, tantalum or carbon, is then positioned such that bottom end 10 is within the inductive field. End 10 is heated by the induction field and in turn heats the gas adjacent thereto, increasing the conductivity thereof, thereby serving to aid initiation of plasma formation. After said initiation, rod 15 is withdrawn and is thereafter maintained out of contact with the thermal plasma. The flow of fuel gas is adjusted to provide a linear velocity within chamber 9 of greater than about 75 ft./sec. The gas coursing upwards through annulus 5 serves to cool wall 17 (and outer wall 19) during the entire run, but more especially during startup when the linear velocity of said fuel gas into chamber 9 can be less than about 75 ft./sec.

Although there is no intent to be bound by this explanation, it is thought that introducing a spinning fuel gas to chamber 9 at a linear velocity of greater than about 75 ft./sec. creates a distinct boundary layer along walls 17. Said boundary layer tends to prevent heat losses therethrough and hence tends to maintain walls 17 and the entire apparatus at relatively low temperatures. Furthermore, as is well known to the art, a spinning gas creates turbulent mixing and recirculation, thus retaining the gases within the plasma producing environment for a relatively longer period of time.

The design specifics of the apparatus of the present invention are subject to considerable variation. Generally speaking, wall 17 and outer wall 19 can be suitably fabricated from a heat resistant metal or refractory such as aluminum, titanium, copper, silver, borosilicate or quartz glass. When it is contemplated that the generation of the thermal plasma be effected by high frequency induction heating, it should be noted that refractory materials are generally preferred, because said materials do not substantially interfere with formation of an inductive field within ionization zone 11.

The specific geometry and dimensions of the plasma chamber are generally dictated to a large extent, by the intended end use of the apparatus, the fuel gases to be utilized, the desired length of tailflame, etc. Where said

apparatus is to be utilized for high temperature reactions, crystal growth or spraying, it is generally desirable that the gases exiting from the plasma chamber have a relatively low velocity and that the heat therefrom be distributed over a relatively large area. In this case, said plasma chamber can be frusto-conical, the large end of said cone representing the downstream end. In those cases wherein a torch effect is desired, a more cylindrical configuration of the plasma chamber is generally desirable. Suitable dimensions and geometry for the chamber in any particular case can be readily determined when the operational parameters contemplated are taken into account.

It should be noted that formation of thermal plasmas can be accomplished without the aid of starting rod 15; however, the use of starting rods is currently conventional practice in the plasma art where the plasma is generated by high frequency induction heating. Moreover, where said rod is provided as illustrated in FIGURE 1, it is immediately obvious that the axial position thereof relative to the plasma chamber provides a suitable pathway for introduction of materials to the plasma zone during operations. Thus, said rod can be hollow, or in the absence thereof, materials can be introduced through a port 23. Initiation of the thermal plasma can also be accomplished by introducing a conductive rod in the induction field through outlet 21, the rod being withdrawn after said initiation. When it is desired that the ionization of the fuel gases be effected by an electric arc, it is obvious that port 23 also provides a convenient point of entry for an electrode.

There follows an illustrative non-limiting example:

Example 1

To a plasma producing apparatus of the type described in FIGURE 1, having a cylindrical quartz glass plasma chamber 9, ½ inch in diameter and about 4 inches in length, which is equipped with induction coil 13 comprising 5 turns of ¼ inch O.D. copper tubing, and a thermocouple (not shown) imbedded in wall 17 at point 18, there is charged through conduit 7 argon gas at a rate of about 200 s.c.f.h. which corresponds to a linear velocity through chamber 9 and into zone 11 of about 40 ft./sec. Power is supplied to induction coil 13 at a frequency of about 50 megacycles and an output of about 10 kilowatts. Next, end 10 of tantalum starting rod 15 is inserted into zone 11 and is withdrawn therefrom after initiation of the plasma. The temperature of wall 17 rises rapidly so that after about 4 minutes of operation at the above conditions, the temperature of wall 17 is greater than the upper limit sensitivity of the thermocouples, i.e. above about 900° C.

Next, the power supplied to induction coil 13 is increased to about 80 kilowatts and the flow of argon gas is increased to about 660 s.c.f.h. which corresponds to a linear velocity into zone 11 of about 135 ft./sec. After about 30 minutes of operation at the above conditions, the temperature of wall 17 is determined to be about 100° C.

Obviously, many changes can be made in the above-described example and procedure without departing from the scope of the invention. For example, although in the above example thermal plasma generation is accomplished by means of an inductive field formed by the flow of high frequency current through a coil, other methods of plasma generation such as by means of a DC electric arc, as shown in FIGURE 2 are also suitable.

Furthermore, although only argon gas was utilized in the above example as the gaseous feedstock, clearly other gases such as neon, nitrogen and the like can be utilized either alone or in combination with other gases.

The thermal plasmas produced in accordance with the process of the present invention can be utilized in many ways. For instance, crystals of high melting point crystalline materials such as niobium or zirconia can be grown;

refractory and metallic materials such as chromium carbide, tungsten carbide, porcelain, beryllium oxide, and the like can be spray coated; and high temperature reactions, such as disclosed in copending U.S. application Ser. No. 289,350, filed June 20, 1963, by M. E. Jordan et al. wherein carbon blacks are produced by introducing a fluid hydrocarbon into a thermal plasma can be accomplished.

Accordingly, it is intended that the above disclosure be regarded as illustrative in nature and as in no way limiting the scope of the invention.

What we claim is:

1. In the process of forming a thermal plasma which process comprises flowing a fuel gas through an enclosed zone having an inlet end and an exit end at above about 1 atmosphere pressure and energizing a portion of said gas in said zone sufficiently to form a thermal plasma, the improvement which comprises:

- (a) providing an annular space adjacent the exterior of substantially the entire enclosed plasma zone, said annular space being in open communication with said plasma zone only at the inlet end thereof and, seriatim,
- (b) flowing said fuel gas into said annular space at a point substantially adjacent the exit end of said enclosed plasma zone and in a manner such as to provide a helical spin to the fuel gas thus caused to flow through said annular space, thereby cooling the plasma zone enclosure, and
- (c) flowing said spinning fuel gas from said annular space into the inlet end of said enclosed plasma zone at a linear velocity of greater than about 75 ft./second.

2. The process of claim 1 wherein said spinning fuel gas is flowed into said enclosed zone at a linear velocity of between about 100 ft./second and about 350 ft./second.

3. The process of claim 1 wherein said fuel gas is monatomic.

4. The process of claim 3 wherein said fuel is chosen from the group consisting of helium, neon and argon.

5. An improved thermal plasma forming apparatus which comprises a chamber having an inlet at one end and an outlet at the other, an annulus disposed about said chamber, the end of said annulus adjacent the outlet end of said chamber being closed, the other end of said annulus also being closed but extending beyond and spaced from the inlet end of said chamber thereby allowing gas to flow out of said annulus and into said chamber, inlet means into said end of said annulus adjacent the outlet end of said chamber adapted to impart a spinning motion to gases introduced therethrough into said annulus, and means associated with said chamber for producing ionizing energy therein.

6. The apparatus of claim 5 wherein said means for producing ionizing energy is a high frequency induction heating means.

7. The apparatus of claim 6 wherein said high frequency induction heating means operates at frequencies of between about 0.4 and about 100 megacycles per second.

8. The apparatus of claim 5 wherein said means for producing ionizing energy is an electric arc producing means.

9. The apparatus of claim 5 wherein there is provided port means positioned axially to said inlet end of said chamber means.

References Cited

UNITED STATES PATENTS

2,769,079	10/1956	Briggs	219—75
2,819,423	1/1958	Clark	313—231
2,922,869	1/1960	Giannini et al.	219—75
3,042,830	7/1962	Orbach	313—231
3,194,941	7/1965	Baird	219—121
3,200,233	8/1965	Anderson	219—74
3,264,508	8/1966	Lai et al.	313—231.5
3,327,040	6/1967	Molstedt et al.	219—75

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