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METHOD AND APPARATUS FOR PRODUCING A PLASMA

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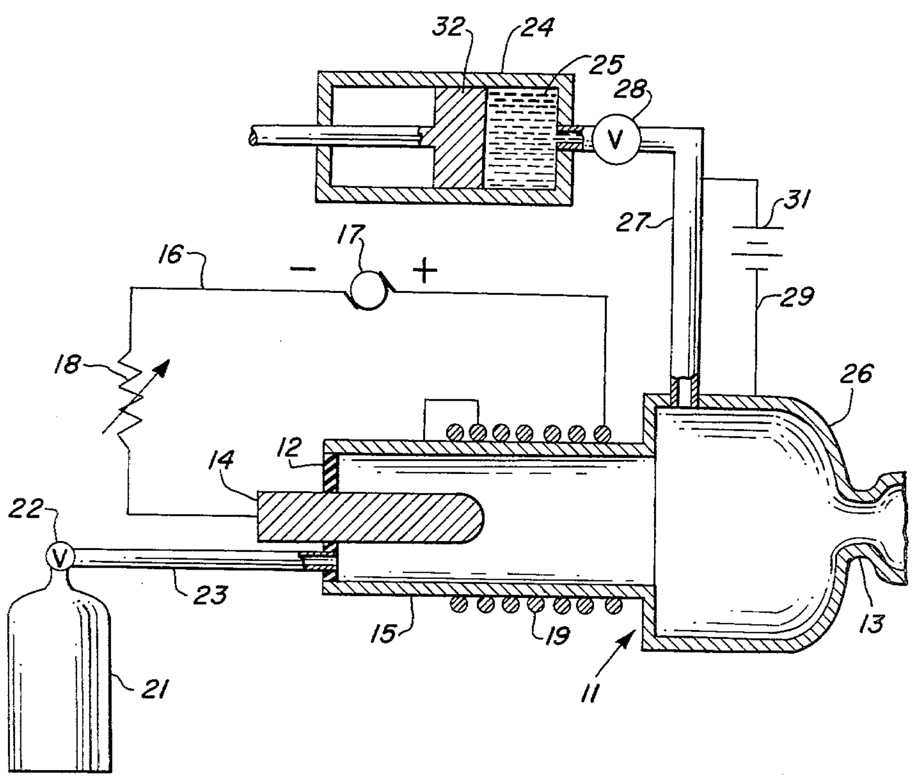

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METHOD AND APPARATUS FOR PRODUCING A PLASMA

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The invention described herein may be manufactured and used by and for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates generally to the production of a plasma, and more particularly to an apparatus and method for producing a highly conductive plasma, having an electron concentration on the order of 10^{16} electrons per cubic centimeter, and having a homogenous temperature and pressure distribution.

A highly conductive plasma having a homogenous temperature and pressure distribution has many, varied, experimental and practical applications. One important application for such a plasma is its use as the working medium in hypersonic electromagnetic plasma accelerators. Plasma accelerators of this type have a wide range of utility, such as providing a source of high-speed flow for aerodynamic testing, and providing a propulsive system for space vehicles. Another application of such a plasma is in the laboratory simulation of the plasma sheath which is formed around a hypersonic reentry vehicle. Plasma-attenuation experiments are performed on the laboratory produced plasma in which telemetry and microwave signals are transmitted through the plasma to determine the effect of the plasma on the transmitted signal; thereby aiding in the solution of the problem of transmitting radio-frequency signals to and from a high altitude hypersonic vehicle.

It is well known that a plasma, or body of ionized gas, may be produced by heating a gaseous material to a temperature whereat the molecules of the gas dissociate into positive ions and negative electrons. However, the high degree of ionization required by present day applications has heretofore not been attainable through chemical processes; and the production of a suitable plasma, i.e., a plasma having a concentration of electrons on the order of 10^{16} per cubic centimeter, through use of known electrical arc jet apparatus requires an exorbitant amount of electrical power, in the 10^3 kilowatt range. Further, operation of such a high powered arc has been found to result in excessive electrode erosion, and subsequent contamination of the plasma by the eroded electrode particles.

One object of the present invention is to provide a new and improved apparatus for producing a highly conductive plasma having a homogenous temperature and pressure distribution.

Another object of this invention is to provide a novel method of producing a plasma having an electron concentration on the order of 10^{16} electrons per cubic centimeter.

A further object of this invention is to provide an efficient and effective method and apparatus for increasing the conductivity of an electrical arc jet.

A still further object of this invention is to provide a method and apparatus for increasing the electron concentration of an arc jet without increasing the electrical power required in operating the arc.

According to the present invention, the foregoing and other objects are attained by providing an electrical arc jet apparatus for producing a high temperature gaseous jet and combining therewith a means for seeding the produced jet with an easily ionizable material in order to increase the conductivity of the jet. The apparatus comprises a chamber wherein an electrical arc is struck and maintained between a pair of electrodes. A fluid, such as compressed gas, is fed through the arc and heated so as to form a high temperature, gaseous jet. The gaseous jet then passes into a settling chamber located adjacent said electrodes wherein the jet is seeded and mixed with the ionizing agent. The ionizing agent is stored in liquid state, and is passed through a vaporizer prior to injection into the settling chamber, wherein it mixes with and is thermally ionized by the high temperature gaseous jet, thereby producing a highly conductive plasma jet. The alkali metals, because of their low ionization potential, are preferred materials for use as ionizing agents.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the solitary figure of the accompanying drawing wherein is shown a diagrammatic view, partially in section, of the apparatus of the present invention.

Referring now to the drawing, a metallic, thin walled, substantially cylindrical chamber 11, in which the plasma is produced, is closed at its forward end by a transverse wall 12 and terminates in an expansion nozzle 13 at its after end. A negative electrode or cathode 14 is positioned in transverse wall 12 and extends into chamber 11 along the longitudinal axis thereof. The forward cylindrical wall 15 of chamber 11 serves as the positive electrode or anode and concentrically surrounds cathode 14 as shown. Transverse wall 12 may be formed of suitable insulating material so as to insulate the concentric electrodes 14, 15 from each other. A circuit 16, containing a direct current generator 17, is connected across cathode 14 and anode 15. The circuit 16 includes a variable resistance 18 by which the current flow through circuit 16 may be selectively varied. Circuit 16 also includes therein a solenoidal coil 19 wrapped about cylindrical anode 15 so as to produce an axial magnetic field in chamber 11. This magnetic field spins the electrical discharge or arc struck between electrodes 14, 15 at a high speed; thus preventing burnout of the anode 15, raising the energy input into the arc, and more uniformly heating a fluid, such as a compressed gas, passing through the arc.

A high-pressure fluid source 21 is connected via conduit 23 and control valve 22 to chamber 11 so as to introduce a fluid flow into chamber 11 adjacent electrodes 14, 15 and through an electrical arc struck and maintained between electrodes 14, 15. A preferred fluid for utilization in this plasma generating apparatus is gaseous nitrogen, of which the physical properties are to some extent similar to those of air. The gaseous nitrogen having relatively large molecular size may be readily raised to high temperatures by an electrical arc. Also, the stability of nitrogen at high temperatures limits the likelihood of the high temperature, gaseous, nitrogen combining with the seeded alkali metals, as is discussed subsequently, thus enabling full use to be made of the ionizing capabilities of the alkali metals.

A reservoir **24** for an ionizing agent **25**, preferably an alkali metal, is connected to the after portion **26** of chamber **11** by a vaporizing tube **27** and a flow control valve **28**. The reservoir **24** is preheated by means such as a hot oil bath, not shown, to melt the ionizing agent **25** and maintain it in a liquid state. The vaporizing tube **27** is a stainless steel tube which is heated electrically by its own resistance to current passing through circuit **29** connected between chamber portion **26** and tube **27**. A potential source **31** in circuit **29** provides the energy for the heating current flow through circuit **29** and tube **27**. A piston member **32** is reciprocable in reservoir **24** to force the liquid ionizing agent **25** from reservoir **24** into vaporizing tube **27** upon opening of valve **28**. Other means, such as gas pressure, may be used to force the liquid material **25** from reservoir **24**; however it has been found that the use of a piston, as shown, best eliminates any pulsations in the flow of the liquid material **25** from the reservoir.

The method of the invention may best be described with reference to the apparatus shown in the drawing, although it is to be understood that the method may be performed with other apparatus as well.

The circuit **16** is first energized to provide an electrical discharge or arc between electrodes **14**, **15** in chamber **11**; the coil **19** producing an axial magnetic field in chamber **11**. The gas source **21** is then employed to introduce a gas flow through conduit **23** into chamber **11** adjacent electrodes **14**, **15**. The gas flow passes through the arc struck and maintained between electrodes **14**, **15**, producing a high temperature, gaseous jet. This high temperature jet proceeds into after portion **26** of cylindrical chamber **11** wherein it is seeded with the alkali metal ionizing agent **25** and mixed therewith. The liquid alkali metal **25** in reservoir **24** is forced therefrom at a predetermined rate by piston **32** and enters the electrically heated vaporizing tube **27** through flow control valve **28**. The liquid metal **25** is vaporized during its transit through tube **27** and is then injected into the after portion **26** of chamber **11** to seed and mix with the high temperature gaseous jet. The chamber after portion **26** serves as a settling chamber wherein the injected alkali metal is evenly mixed with and ionized by the gaseous jet, and the plasma jet produced thereby is accorded a homogenous temperature and pressure distribution. The resulting plasma jet then issues from the expansion nozzle **13** into an accelerator, not shown, or a laboratory testing apparatus, not shown.

The above described seeding of a high temperature gaseous jet with an alkali metal produces a highly conductive plasma jet, having an electron concentration on the order of 10^{16} electrons per cubic centimeter. An alkali metal is preferred as the seeding material or ionizing agent because of its low ionization potential; the vaporized alkali metal readily dissociating into positive ions and negative electrons when injected or fed into the high temperature, gaseous jet. The metal is vaporized prior to being mixed with the gaseous jet so that the heat available in the jet may be used wholly to ionize the metal, and need not be expended in vaporizing the liquid metal. The preferred alkali metal for use in the system is cesium, dissociation energy 0.49 electron volt; however, potassium and sodium have also been favorably employed. An interesting study on the dissociation properties of cesium may be found in National Aeronautics and Space Administration Technical Note D-380, published in May 1960, titled "Temperature and Composition of a Plasma Obtained by Seeding a Cyanogen-Oxygen Flame with Cesium."

To afford a clearer understanding of the present invention, the physical characteristics of one experimental apparatus constructed and operated in accordance with this invention will now be described. A ½ inch diameter water-cooled tungsten rod was used for the cathode **14** and surrounded by a 1⅛ inch diameter water-cooled copper cylinder for the anode **15**. The circuit **16** for striking an arc between electrodes **14**, **15** was operated at a voltage of 110 volts and 1,400 amps, or approximately 150 kilowatts. The efficiency of the arc as determined by calorimetric tests was 32 percent, which gives an enthalpy of 8,860 B.t.u./lb. and a stagnation temperature of 6,900° K. The nitrogen from source **21** was regulated to flow at 2.6 grams/second. The coil **19** wrapped about anode **15** produced an axial magnetic field of 0.5 weber/meter^2. The settling chamber **26** was made 2 inches in length, it being found that a greater length resulted in a relatively larger heat loss to the chamber wall.

The reservoir **24** contained liquid cesium and was formed of Plexiglas. Piston **32** was motor-driven to force the cesium from the reservoir at a flow rate set to give a 2 percent mole-fraction ratio between the cesium and molecular nitrogen. The cesium was vaporized in a ⅛ inch stainless-steel tube 30 inches long, electrically heated to 800° C. With the reservoir **24** containing 10 grams of cesium, the duration of cesium flow was 40 seconds. The resulting plasma emerged from nozzle **13** at a Mach number of approximately 2, a calculated static temperature of 5,500° K., and with a cross-sectional area of 1 square centimeter.

It is to be understood that the dimensions given and materials used in the above described exemplary apparatus are merely illustrative of the present invention and that the reduction or enlargement of the physical dimensions of the apparatus, or the substitution of other materials for those described, is well within the scope of the present invention and is contemplated by the inventor thereof.

Obviously numerous modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as described herein.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. An apparatus for producing a highly conductive plasma jet comprising: means for striking and maintaining an electrical arc; means for conveying a fluid to said electrical arc, thereby producing a high temperature, gaseous jet; a reservoir containing a material having a low ionization potential; a settling chamber positioned adjacent said first named means and having an inlet for the ingress of the high temperature, gaseous jet and an outlet for the discharge thereof; conduit means communicating said reservoir with said settling chamber; and means to force said ionizing material from said reservoir through said conduit means into said settling chamber to mix with and seed said jet, thereby increasing the conductivity of the jet.

2. An apparatus for producing a highly conductive plasma jet comprising: means defining a substantially cylindrical chamber having a forward and an after end; means operatively connected thereto for striking and maintaining an electrical arc across the forward end of said chamber; means for conveying a fluid to said electrical arc, thereby producing a high temperature, gaseous jet; a reservoir containing a material having a low ionization potential; and means to convey the ionizing material from said reservoir to the after portion of said chamber to intermingle with and seed the high temperature, gaseous jet passing therethrough, thereby increasing the conductivity of the jet.

3. An apparatus according to claim 2, wherein said means to convey comprises a vaporizing tube connected between said reservoir and the after portion of said chamber, and means for forcing the ionizing material from said reservoir through said tube and into the after portion of said chamber.

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