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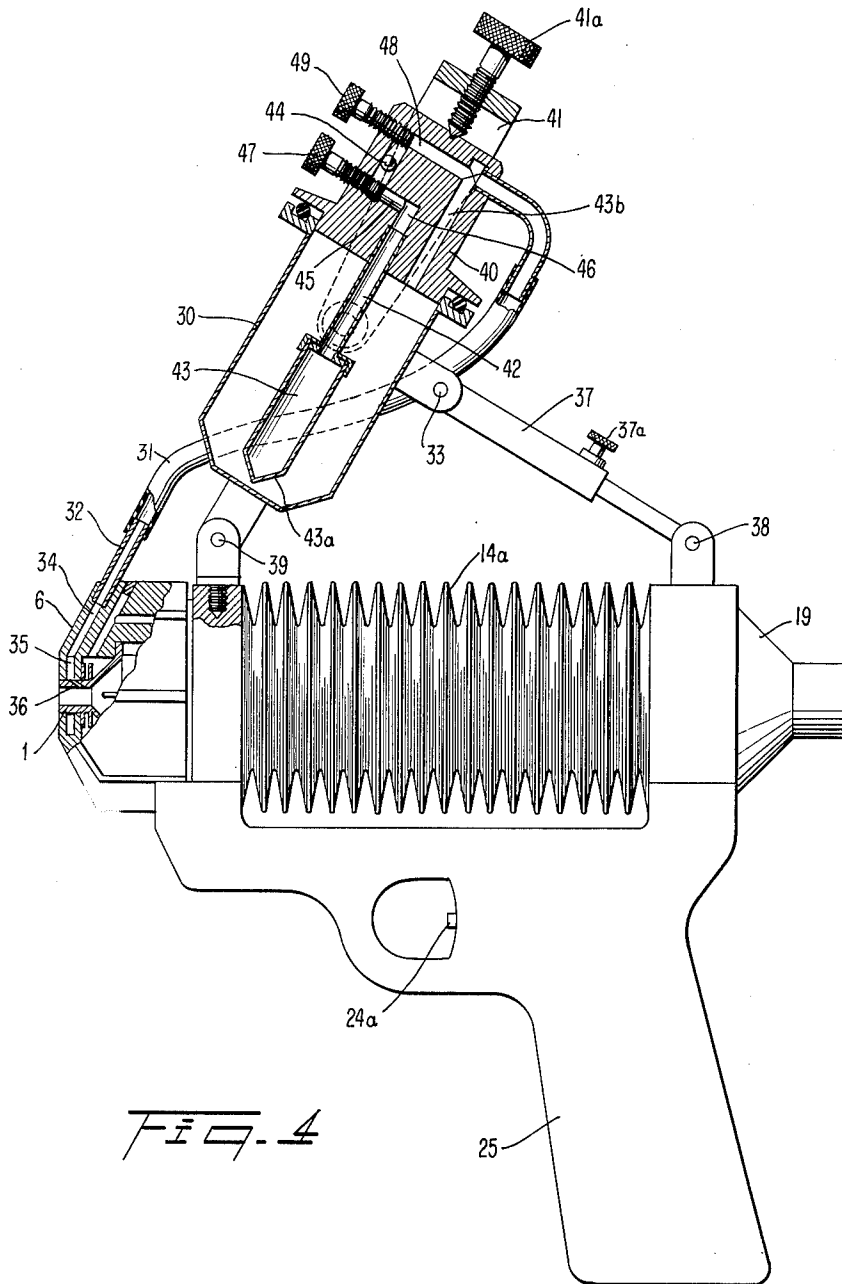
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3,217,133

PLASMA TORCH

Filed Feb. 14, 1963

3 Sheets-Sheet 2



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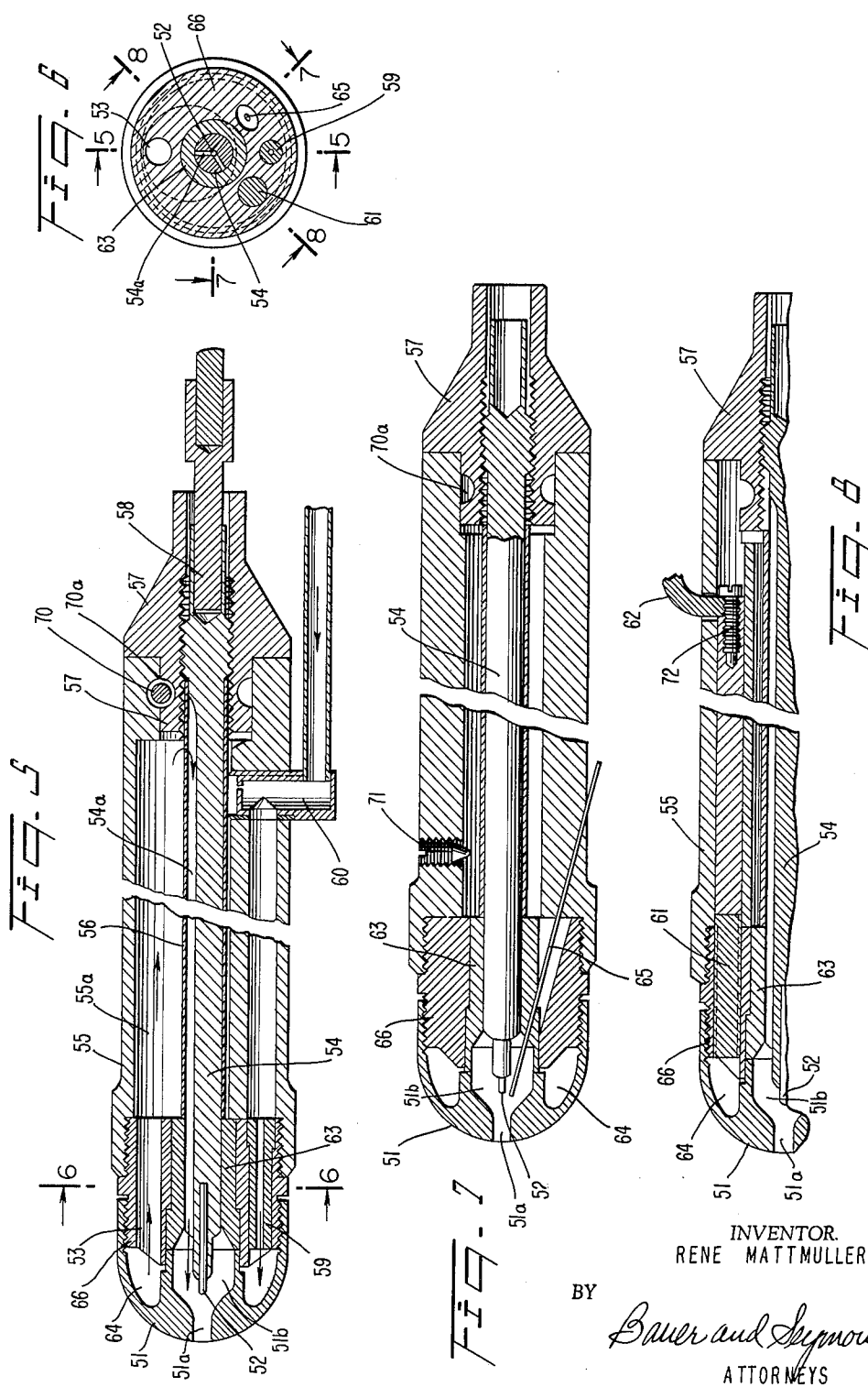
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PLASMA TORCH

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13 Claims. (Cl. 219-75)

This invention relates to apparatus in which a gas flows through an electric arc. It has particular relation to plasma torches and will be described in relation to their construction and operation. Plasma torches include a cathode of highly refractory metal and an anode near it, and a source of current to pass an arc between the electrodes. Means are provided to blow a gas into the arc, disassociation of the gas taking place in the arc and recombination taking place later, the product of this action being the plasma flame. The electrodes run hot and cooling means must be provided for them. Plasma torches differ from each other in shape and internal construction, but they have one characteristic in common that the electrodes are cooled by liquid refrigerant which circulates through chambers near the anode and cathode.

It is an object of this invention to improve plasma torches and to heat treat surfaces. Another object is to provide apparatus for the heat treatment of surfaces. A further object is to provide apparatus in which an electric arc combines with a flow of gas to generate molecular and thermal phenomena. Other objects are to reduce the size of such apparatus, to increase its thermal efficiency, to reduce losses, to give greater control, to eliminate liquid cooling of such apparatus, to make available the cooling effect of the expansions of fluids, and to make such apparatus available for coating and working the surface of objects.

The objects of the invention are accomplished, generally speaking, by the method of cooling the electrodes of an electric arc which comprises expanding a gas in contact with one electrode of the arc, and flowing the expanded gas over the cooperating electrode, and by an arc heating apparatus having electrodes, in which a fluid flows through the arc between the electrodes and away, means to expand the said fluid from a prior condensed state in contact with at least one of said electrodes before it reaches the arc, and means to deliver the expanded gas to the arc.

According to the invention the fluid which is projected into the flame of the arc to generate the plasma flame is utilized to cool the electrode of the plasma torch. In view of the low specific heat of gases compared to liquid refrigerants such as water, it may be regarded as astonishing, particularly in view of the intense heats obtained, that this process should be possible. In order to achieve the invention advantage has been taken of the cooling effect of an expanding gas and a vaporizing liquid. Furthermore, in constructing the torch the anode means is made of metal having a high reflective power such as silver or silver alloy, and its interior surface is given as perfect a polish as possible. The outer surface of the anode means is provided with fins which may be machined into the body of the piece itself, and which serve to improve the heat exchange with the gas.

When the refrigerating fluid is brought into the torch in the gaseous state it is brought in under high pressure and is expanded into the cool chamber in contact with the anode, the expansion of gas in the expansion chamber producing an increasing efficiency of refrigeration.

When the fluid used for cooling is brought into the torch as a liquid it is put under pressure and injected into the expansion chamber through a vaporizing means such as

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an atomizer so that the heat of vaporization is extracted from the electrode.

The gas after having been expanded in the expansion chamber adjacent to the electrode is conducted into cooling relation to the cathode and the cathode carrier, these parts being localized in another cooling chamber, so that the cooling gas extracts heat from the cathode and cathode carrier before it is injected into the electric arc. The cathode chamber may be supplied with cooling fins to effect heat exchange with the atmosphere. In that particular construction the cooling gas may pass from the chamber containing one electrode to the other through channels drilled in one of the electrode carriers, usually the cathode carrier. Other characteristics of the invention will be set forth in connection with the accompanying drawings.

FIG. 1 is a vertical section through a plasma torch;

FIG. 2 is a front end view in elevation of the torch of FIG. 1;

FIG. 3 is a detail partly in section on the line 3-3 of FIG. 2;

FIG. 4 is a vertical elevation partly in section of an invention pertaining to specialized uses for a plasma torch;

FIG. 5 is a vertical section on the line 5-5 of FIG. 6 through a modification of the device of FIG. 1;

FIG. 6 is a vertical section on the line 6-6 of FIG. 5;

FIG. 7 is a section on the line 7-7 of FIG. 6;

FIG. 8 is a section on the line 8-8 of FIG. 6;

Referring to the torch of FIGS. 1 to 3, the apparatus is shaped like a pistol having a grip 25 which constitutes a frame, a barrel 14, a removable muzzle 6, and a removable breech block 19. Power lines 22, 26 pass through the handle, one of which is operated by an on-off switch 24 with operating plunger or trigger 24a, the details of which are known and need not be described.

A fluid supply conduit 23 also extends through the frame. The barrel, the muzzle, and the breech are mounted on the frame by means not shown. The muzzle includes a centrally apertured crown 4 which includes a cylindrical extension and the circular flange 27a. Muzzle 6 includes a cap piece which fits over the crown 4 and the entire assemblage is attached to the barrel 14 by bolts 4a, FIG. 3. The rim of a diaphragm electrode 1 is clamped between the cap and the rim of the cylindrical extension of the crown.

The electrode 1 in the invention of FIGS. 1 to 3 is a metallic diaphragm which is partially conical and partially cylindrical, the cylindrical portion 1b extending from the conical portion 1 and supporting cooling fins 1a. The cylindrical tubular forward extension 1b has a tight fit in an aperture provided in the frontal wall 6a of muzzle 6. This provides a chamber 2 between the electrode and the muzzle which is employed as an expansion chamber to cool electrode 1. The power line 26 is connected to the muzzle or cap piece 6 and thus transmits current to the electrode 1. For purposes of this description the electrode 1 may be deemed to be the anode.

Coaxially mounted with respect to the anode 1 is the cathode 5, which is of heat resistant metal such as tungsten, which is mounted in the cathode carrier 11, 15, and which has its active arcing surface at what amounts to the focus of the conical part of the anode. The muzzle is insulated by crown 4, from the barrel so that the current supplied by power line 26 is confined to the anode. The needle valve 3 is connected to chamber 2 and to a conduit 9 which extends through the cap, the flange of the crown, the insulation, and connects with the fluid supply conduit 23. The valve 3 is in effect an expansion valve of adjustable orifice, the size of which can be altered by set screw 3a which controls the position of the needle. A conduit 10, 10a extends from the chamber 2 to the hollow interior of the barrel 14.

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Behind the electrode 1 is a spark chamber 27, the rear wall of which is partly formed by the crown 4 and partly by the electrode carrier 15 which has an adjustable fit in a central aperture in the base of the crown. The electrode carrier is provided with peripherally-spaced, longitudinally-extending channels 12 which extend from a position adjacent to the breech block 19 into the chamber 27. Channels are thus provided for the flow of fluid through conduit 23, the needle valve 3, the expansion chamber 2, the conduits 10a, 10, the space 13 inside the barrel, the channels 12 into chamber 27 from whence it may issue through the cylindrical extension 1b of the anode. The flow of gas is to some extent indicated by arrows.

The gas which is used for the generation of plasma is usually some inert gas such as argon, nitrogen, and hydrogen, and this is introduced into the apparatus by conduit 23 from which it passes into conduit 9 to the expansion valve 3. The gas is introduced at relatively high pressure, for instance at 150 to 200 kg. per cm.², which is maintained behind the needle valve, while the gas which passes through the valve expands rapidly in the expansion chamber 2 and cools the anode 1. By adjusting the needle valve one can adjust the flow of gas to that which is desired, for instance 5, 10, 15 or 20 cubic meters per hour. The cooling of the chamber and the anode is thus obtained not only by the circulation of gas, but by expansion which the gas undergoes in the expansion chamber.

The anode cooling chamber is formed conjointly by the forward wall 6a of the muzzle and the external surface of electrode 1. The muzzle is preferably made of a light alloy such as aluminum bronze.

The gas which has expanded in the cooling chamber 2 flows through conduit 10 to cathode cooling chamber 13 formed between the inside wall of barrel 14 and the exterior wall of carrier 15. The wall of barrel 14 is provided with fins to assist in the cooling of the internal chamber. The barrel is preferably of a light alloy the same as the muzzle, and it is electrically insulated from the muzzle by crown 4. In cooling chamber 13 the gas loses some of its heat and enters the channels 12 which extend longitudinally through the cathode carrier 11. Thus, the gas passes twice throughout the entire whole length of the barrel and is finally discharged into the spark chamber 2 where it is acted on by the arc and blows the arc, the arc and the flowing gas forming together the plasma flame. The gas which flows through cathode carrier 15 takes with it a large part of the heat which is transmitted to the cathode carrier by the hot cathode 5. The cathode carrier is coaxial with the axis of the annular chamber 13 and annular cooling chamber 27.

The rear end of the barrel is closed and sealed by a flanged tube 18 in which the extension 21 of the cathode carrier is mounted. The piece is metallic and the current from the power line 22 passes through it to the cathode. The part 21 of the cathode carrier is screw threaded and is screwed into the screw thread on the inside of tube 18. Thus, by rotating the button 19 which is attached to the cathode carrier one can at will change the spacing of the two electrodes. A spring 20 keeps the cathode carrier under tension.

The cathode carrier is provided throughout the larger part of its length inside the cooling chamber 13 with an insulating tube 15 which closes the conduit 12. Thus, in this particular construction channels are provided in the material of the cathode carrier and the tube 15 transforms them into conduits.

It is to be observed in FIG. 1 that the introduction of the cathode current through line 22 and of anode current through line 26 is controlled by the spring pressed trigger 24a which is connected to the switch 24 through which the line 26 passes. When this trigger is pressed the switch permits current to flow between the anodes. It is usually set to allow the gas to flow continuously as this tends to operate the torch at a generally lower temperature.

As shown in FIG. 3 means is provided to connect the

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spark chamber 27 with ambient atmosphere through a conduit 7a by means of an adjustable relief valve 8-7. Thus, as the gas is being supplied to the spark chamber at a rate higher than is necessary for the formation of plasma flame, the excess can be relieved through the valve 7-8, which is indicated in this instance to be simply a screw threaded plug adjustable by a screwdriver.

In FIG. 4 is shown an invention in which the plasma pistol is used for the projection of materials such as metal powder or for the projection and spot application of enamel. The construction and operation is the same as that of the invention of FIGS. 1 to 3 except for the structure which will now be described. In a form of the invention not shown powder can be projected into the arc chamber, but a preferred form of apparatus is illustrated in FIG. 4 in which the metal powder is added to the plasma flame through orifices 36 which are provided in the walls of tube 1b, these orifices being connected by a conduit 35 in the muzzle cap 6 with a tube 32-31 which is connected to an apparatus for suspending powder in a gas. It will be observed in FIG. 2 that the cap has portions 6a of greater thickness through which appropriate conduits of supply can be drilled.

The apparatus is pivotally mounted on the pistol at 39 and 38, its position being adjustable by means of the extensible connection 37 which involves a sleeve and slider which can be fixed in position by a set screw 37a. There is a receptacle 30 which contains the powder which is to be projected into the plasma torch. This receptacle is covered by a head 40 which is surmounted by a strap 41 through which a set screw 41a projects. The strap 41 is shown in dotted lines to be pivotally attached to the sides of the receptacle 30. By tightening set screw 41a the closure between the head and the receptacle can be made pressure tight. Into the axis of the head extends a tube 42 which carries a plunger 43 which is perforated at its lower end 43a. The gas under pressure which is to carry the suspended powder into the plasma flame is injected into the receptacle 30 through a conduit 44, past manually adjustable valve 47, through conduit 46 and tube 42 into plunger 43. The amount of gas admitted is regulated through screw valve 47. The gas which issues from the plunger into the receptacle 30 flows through the powder with which the receptacle is filled, puts it in suspension, that is to say, fluidizes it, and drives it out through a conduit 43b. At the same time, a similar adjustable valve 49 admits the same gas to a conduit 48 through which it flows over the upper end of conduit 43b, thus assisting in drawing the gaseous suspension out of conduit 43b and impelling it through tubes 31, 32, 34, 35, and orifices 36 into the plasma flame which is passing through tube 1b. The adjustable valves 47 and 49 permit very efficient operation of this novel fluidizing and impelling device.

It is sometimes useful to incline canals 36 to the axis of the apparatus so as to direct the powder countercurrent to the plasma flame, as this aids in the injection of the powder into the flame.

In FIGS. 5 to 8 modifications are shown and the plasma torch is shown on an enlarged scale. In these figures the torch is tubular, and 51 is the anode which is formed in the cap of the muzzle. This apparatus includes, coaxially with the anode a cathode 52, which is supported by a cathode carrier 54. The anode cooling or expansion chamber 64 is formed directly in the head or anode 51 in which is centrally formed nozzle aperture 51a. This cap is advantageously formed of a material which has good thermal conductivity. It is equally recommended that the material utilized possess a good coefficient of reflection. Silver is useful for this piece as it is useful for the anode of the apparatus of the other figures. It can receive a high polish and a high polish is advantageous, at least for that surface upon which the arc plays. The body 55 of the torch is hollow so as to provide throughout the greater part of its length a chamber 55a which is for cooling the cathode carrier. Anode 51 and body 55

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are connected by a coupling member 66 whose ends are threaded into the correspondingly threaded ends of the anode and body. This coupling member is formed with longitudinally-extending, axially-offset conduit 53, and apertures within which are fixed a vaporizing nozzle 59 and an electrically conductive element 61. This chamber communicates by means of a conduit 53 with the expansion chamber 64 which receives the liquefied gas through conduit 60 and vaporizing nozzle 59. The vaporizing nozzle may be, for instance, polytetrafluoroethylene, a material which may also serve in the apparatus of FIGS. 1 to 4, as the cooling efficiency of the gas flow is ordinarily sufficient to protect it from disintegration by the arc. The cathode carrier comprises conduits through which the gas passes to the spark chamber and about which an electrically insulating body 56 is passed. The cathode carrier is fixed in an adjustable sleeve in the breech 57 substantially as described for FIGS. 1 to 3.

In this form of the invention the liquefied gas is introduced by conduit 60 and nozzle 59 into the expansion chamber 64 in which the vaporized gas cools the head of the torch and the anode surface at the outside of the expansion chamber 64. The gas then enters chamber 55a where it cools the cathode carrier, passing thence through apertures indicated by an arrow in FIG. 5 into longitudinally-disposed, circumferentially-spaced channels 54a in cathode carrier 54. Three of these channels are shown in the model selected for illustration. It then flows into a spark chamber 51b where it externally projects the spark through aperture 51a with the formation of the plasma flame. The cathode 52 is advantageously constructed of tungsten and the cathode carrier may be copper. The electrical current is delivered by the plug 58 to the end of the cathode carrier. The return current is carried through element 61 of, FIGS. 6 and 8, and which is connected to outgoing cable 62. The spacing of the electrodes is obtained by rotating the end piece or breech 57 into which the cathode carrier is screwed. A stud 70 enters the annular groove 70a holding the cap piece 57 in position but allowing it free rotation. As it rotates it moves the cathode carrier longitudinally. The cathode carrier itself is prevented from rotating by the finned insulating ring 63 in which it has a tight fit and which allows it only to move longitudinally as the end piece 57 is turned.

In FIG. 7 a supporting electrode 65 has been provided which is attached to an appropriate generator which enables one to start the spark in the spark chamber more readily than can be done under ordinary circumstances using the working anode and cathode.

The introduction of liquefied gas into the expansion chamber produces a very energetic cooling and permits the device of FIGURES 5 to 8 to be made of very small dimensions, for example 18 mm. in diameter, 170 mm. in length and 8 g. by weight, using 2 kw. power.

This apparatus is light, of small size, and extremely useful. It can easily be mounted on a machining tool and can be put into cavities of very small volume, which is particularly advantageous in certain instances.

As visible in FIG. 7 one may provide a screw 71 which can be turned to constrict or to open the conduit into which it projects, thus making it possible to supply to the arcing chamber either the amount of gas adequate to the flame, or a surplus as desired.

The anode is preferably reflective and highly polished. The fluid which is injected into the expansion chamber may be either a compressed gas or a vaporizable liquid. Examples of gases have been given hereinabove. The liquids may be those gases in a liquid state or they may be other liquids such as pentane, hexane, etc. Vaporization of the liquid is assisted by the use of an atomizing nozzle at the port of entry to the expansion chamber.

An advantage of the invention is that the actual cooling by a liquid is no longer required. This results in simplification of operation, equal or superior efficiency of

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performance, and better cooling. Previously, an inlet and outlet conduit was required, but the outlet conduit has been made unnecessary as the gases are injected into the spark chamber and discharged in the flame. The energy output of the apparatus is increased, compared to similar apparatus cooled by water. The prior art types used 2.4 to 2.6 kw. of every ten put into the torch for cooling, and they were lost, a fact which produced a yield of 74% to 76%. On the other hand, using the new apparatus as described herein only 1 to 1.5 kw. are injected into the plasma flame, which provides a yield of 85 to 90%.

In this invention the gaseous fluid is introduced at high pressure and it is expanded in the chamber contiguous to the anode, the heat of expansion being drawn from the anode and contributing to its cooling.

The gas can also be brought to the expansion chamber as a liquid which enables one to use the heat of vaporization in addition to the temperature of the fluid for cooling. The new apparatus is of form and dimensions such that its size and weight are reduced to a minimum. It can be used for application to minute work, for example for making neat and precise separations of solid materials, as by cutting refractory metal along relatively fine lines, and it can also be used inside spaces of very small dimensions. The liquid employed can be drawn from a reservoir of gas such as liquified nitrogen, being kept under pressure so that it does not vaporize until injected into the expansion chamber. The cooling of the apparatus is thus assured, in a large part, by the extraction of heat from the apparatus as the liquid vaporizes.

As many apparently widely different embodiments of the present invention may be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments.

What is claimed is:

1. A plasma torch including a conical electrode provided with a nozzle, a cooperating electrode in operative association therewith, means to pass an electric arc therebetween, a first cooling chamber about the conical electrode, a second cooling chamber extending about the cooperating electrode to the nozzle, conduit means connecting the cooling chambers, an expansion valve opening into the first cooling chamber, and means to flow an expansible fluid through the expansion valve into contact with the first electrode, into the second cooling chamber and into contact with the second electrode, between the electrodes, and out through the nozzle.

2. A plasma torch including an apertured anode, a cathode aligned with the aperture of the anode, means to pass an electric arc therebetween, a chamber enclosing the anode and cathode having an opening constituted by the aperture in the anode, an expansion valve opening into said chamber adjacent said anode, and means operable to conduct an expansible fluid into said chamber contiguous to the anode, over the cathode, and out the aperture.

3. The plasma torch of claim 2, means feeding expansible fluid under pressure to said expansion valve, said chamber effecting expansion of the fluid in heat exchange relation with at least one of said electrodes, before the expanded fluid passes to the arc between said anode and cathode.

4. Apparatus according to claim 3 including a concave electrode having a tubular, perforated extension through which the gasses flow to the work, a chamber adapted to contain powder, insufflating means in the chamber adapted to form a suspension of powder in gas, and conduit means connecting the chamber to the perforations in the tubular extension.

5. A plasma torch comprising, a frame, electric power lines carried thereby, a central cylindrical barrel supported by the frame, having an end wall; an elongated electrode carrier extending axially through the end wall of the barrel, said carrier having conduits opening into the

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cylinder and passing through the end wall; a breech closing the end of the cylinder opposite said end wall, means in the breech to move the electrode carrier axially; a muzzle, contiguous to the end wall of the cylinder, provided with a central cavity having front and rear openings, a conical electrode dividing said cavity into front and rear chambers and provided with a cylindrical extension projecting into the front opening in the muzzle, an electrode carried by said electrode carrier and projecting into said rear chamber, an expansion valve opening into the front chamber, fluid conduit means connected to the expansion valve, fluid conduit means extending from the front chamber to said barrel, and from the end thereof adjacent said breech, into and forwardly along said carrier, and means to connect the power lines to the electrodes.

6. A plasma torch having in alignment an expansion chamber, a spark chamber, and an electrode chamber, means to inject the gas to be used in the generation of the plasma flame into the expansion chamber, means to conduct the gas from the expansion chamber to the electrode chamber, means to conduct the gas from the electrode chamber to the spark chamber, and means to conduct the plasma through the spark chamber out of the torch.

7. A plasma torch having a spark chamber, one wall of which is constituted by a diaphragm electrode, another electrode in said chamber adjacent said electrode, means to flow gas into and out of the spark chamber, means to form a spark between the electrodes, means to cool the chamber and the electrodes comprising an expansion chamber contiguous to the diaphragm electrode, means to expand a fluid in the expansion chamber, and conduit means extending from the expansion to the spark chamber.

8. A plasma torch having a cylindrical body, an electrode extending therethrough, a muzzle attached to the cylindrical body having an apertured spark chamber into which the electrode extends, said muzzle and electrode being insulated one from the other and the inner surface of the spark chamber being formed as a complementary electrode, electric current supply means connected to the said electrodes, a gas chamber contiguous to the electrodes and connected to the spark chamber, and means to expand a fluid into the said gas chamber whereby the gas serves to cool the electrodes before being admitted to the spark chamber.

9. A plasma torch comprising, a frame, an apertured first electrode carried by said frame and forming the wall of adjacent expansion and spark chambers, expansion valve means in communication with said expansion

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chamber, a second electrode in said spark chamber, a cooling chamber about said second electrode, conduit means connecting said expansion chamber with said cooling chamber and said cooling chamber with said spark chamber, in sequence, and electric current supply means connected to said electrodes.

10. The apparatus of claim 9, and means to inject finely divided solids into the gases issuing from said spark chamber.

11. The apparatus of claim 9, a cylindrical body attached to said frame and through which one said electrode extends axially, a muzzle, including said expansion and spark chambers, attached to said cylindrical body, a breech including electrode adjusting means attached to said cylindrical body, and ducts extending along said one electrode into said spark chamber.

12. A plasma torch comprising, a hollow barrel, a muzzle secured to and over the forward end of said barrel and comprising a first electrode forming discrete expansion and spark chambers, said spark chamber opening forwardly through the muzzle, a second electrode extending in and along said barrel in fixed relation therewith and terminating in said spark chamber adjacent said first electrode, conduit means surrounding said second electrode and forming therewith a fluid passageway extending from adjacent the rearward end of said barrel into said spark chamber, said expansion chamber being connected with said spark chamber by a continuous passageway rearwardly through said barrel and return through said conduit means.

13. The torch of claim 12, a breech secured over and closing the rearward end of said barrel, and means mounting said second electrode in said breech for longitudinal adjustment with respect to said first electrode.

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