United States Patent

Hammer

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[54] **ARC HEATER APPARATUS AND METHOD FOR PRODUCING A DIFFUSE ARC DISCHARGE**

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[52] **U.S. Cl.** **315/111**, 313/161, 313/162, 313/231

[51] **Int. Cl.** **H01j 17/26**

[58] **Field of Search** 313/161, 162, 231; 315/111

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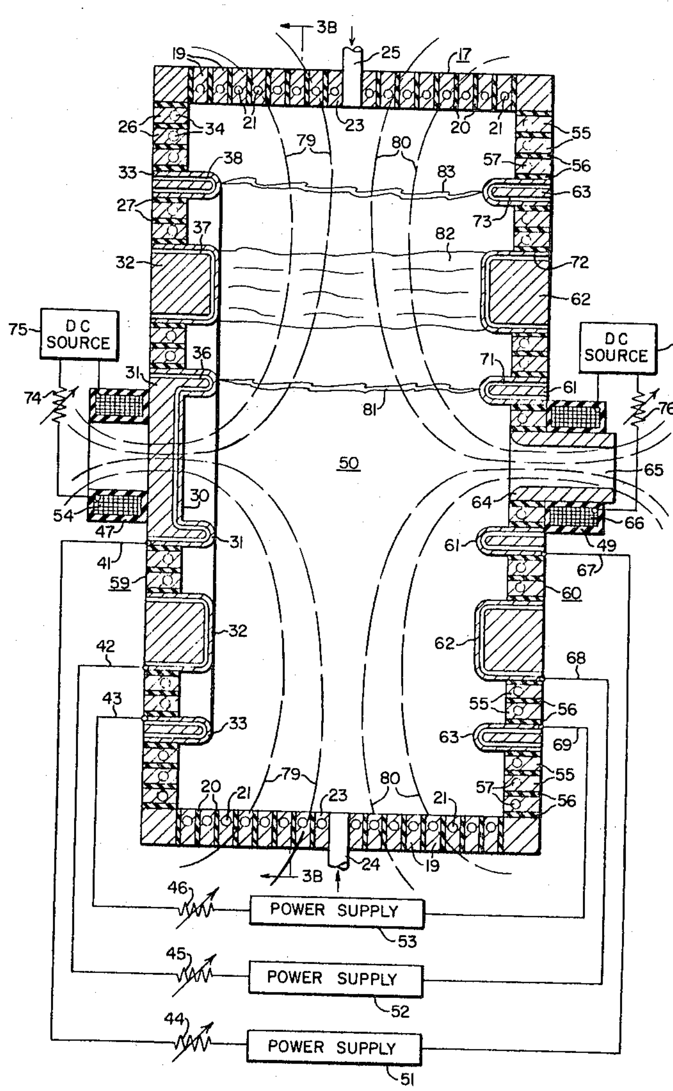
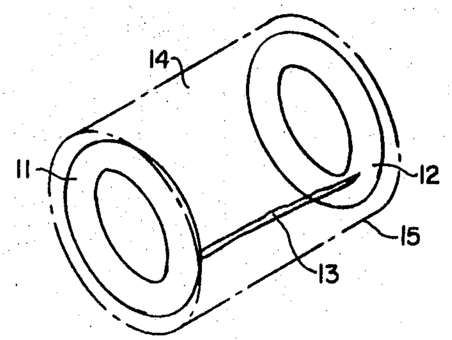
[57] **ABSTRACT**

An arc heater has three sets of substantially equally axially spaced annular electrodes of progressively increasing diameters coaxially mounted with respect to each other and electrically insulated from each other. Near the electrodes there are mounted magnetic field coils which set up magnetic fields which cause the arcs to move substantially continuously around the electrodes, the arcs being produced by connecting oppositely disposed electrodes of each set to terminals of opposite polarity of a source of potential. The arc between the pair of electrodes of smallest diameter and the arc between the pair of electrodes of largest diameter prevent loss of heat to the walls of the pressure vessel from the arc between the pair of electrodes of intermediate diameter; the last named arc may be of high current and have a diffused mode of operation, resulting in increased heating efficiency of gas admitted to the arc heater.

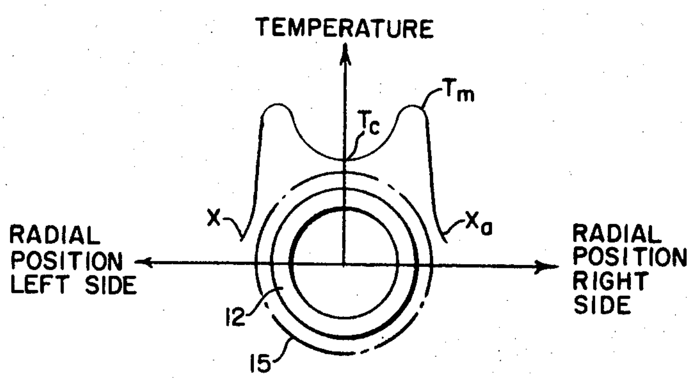
12 Claims, 4 Drawing Figures





PRIOR ART

FIG. 1.



PRIOR ART

FIG. 2.

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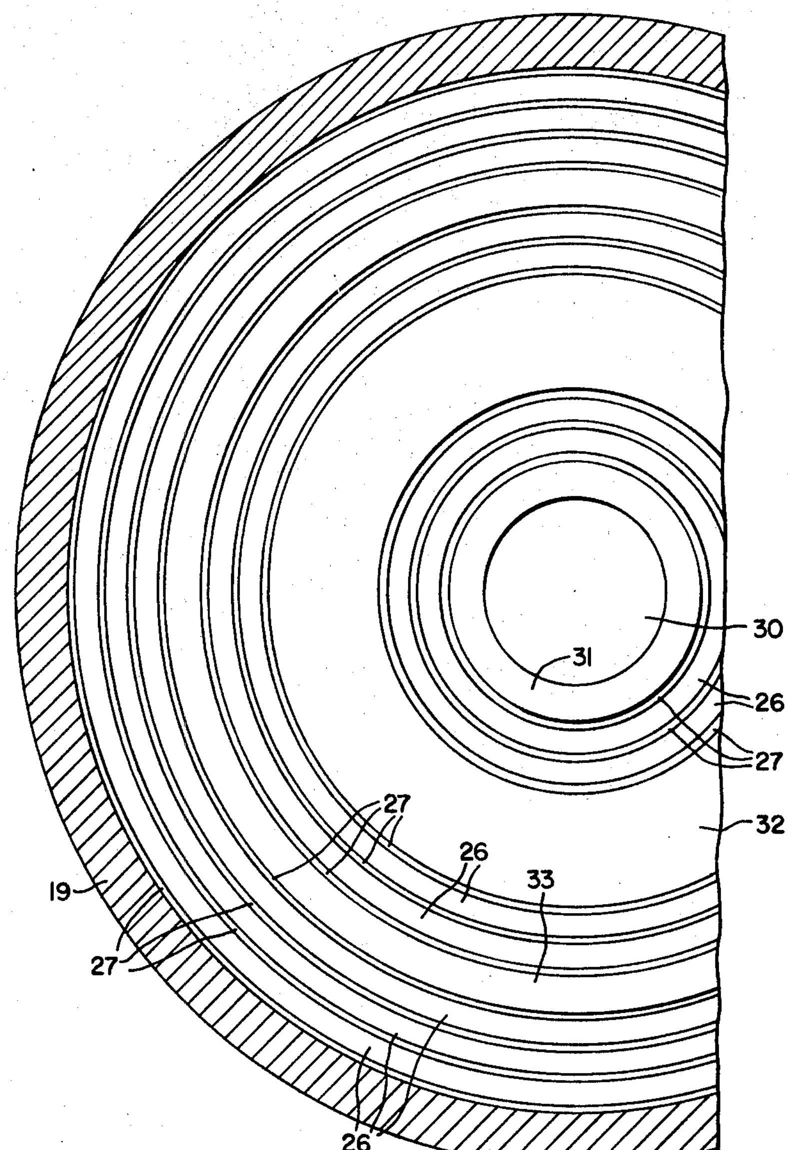
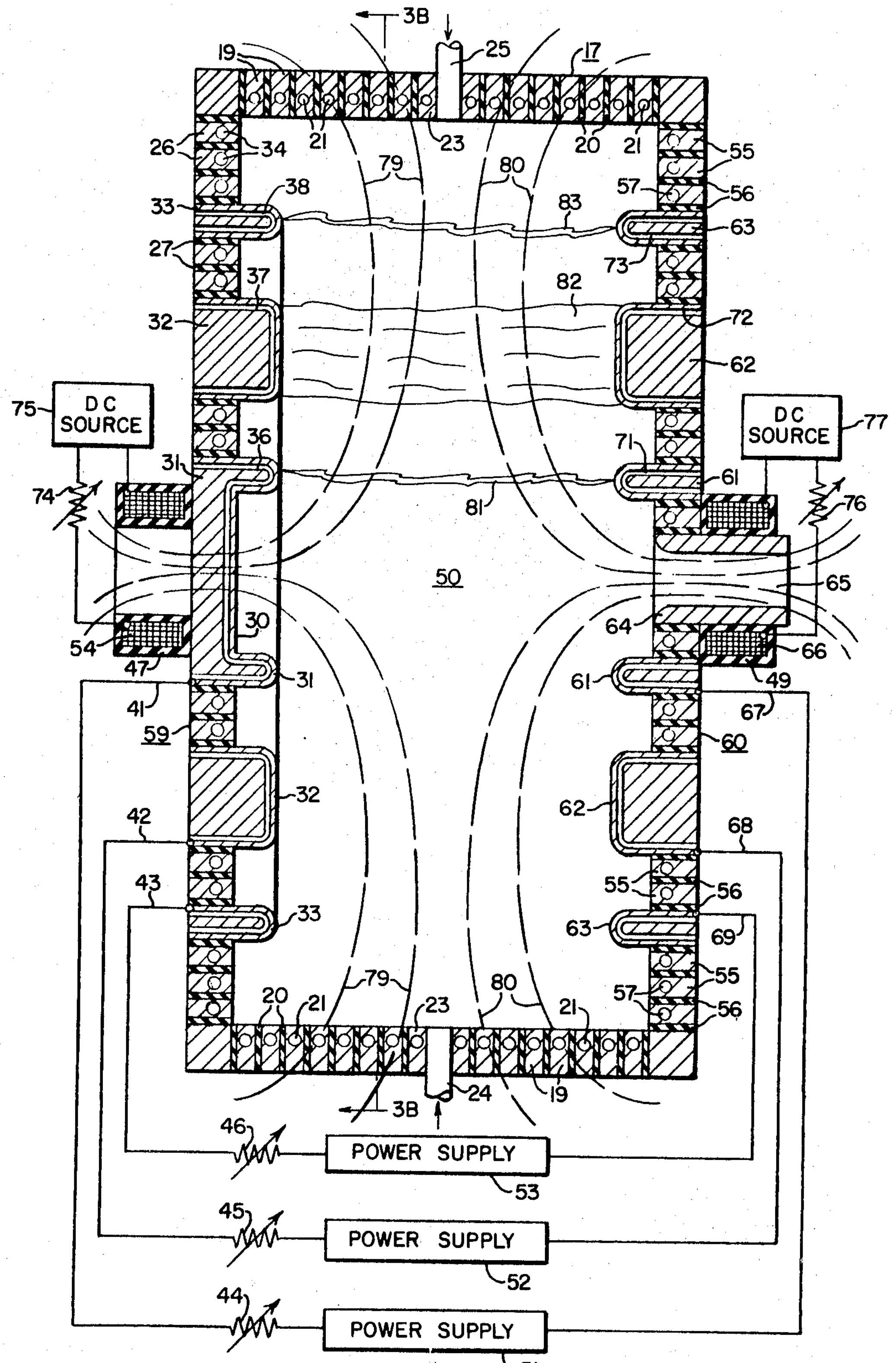


FIG.3B.


3B
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DC SOURCE
DC SOURCE
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80
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23
21
56
24
19
3B
46
POWER SUPPLY
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45
POWER SUPPLY
52
44
POWER SUPPLY
51

FIG.3A.

ARC HEATER APPARATUS AND METHOD FOR PRODUCING A DIFFUSE ARC DISCHARGE

the invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to improvements in arc heaters and more particularly to an improved arc heater including means for producing a diffuse arc discharge and providing the advantages resulting therefrom.

2. Description of the Prior Art

It has been shown that arc heater efficiencies could be improved if the arc could be operated in a diffuse rather than a constricted mode. A very large reduction in radiative heat loss occurs by going to a diffuse mode of arc operation. In conventional arc heaters it is difficult if not impossible to make the transition at the high pressure which is of interest in wind tunnel operation.

For chemical processing the prior art arc heaters employing a constricted arc sometimes suffer from overcracking the feedstock in the high temperature core of the constricted arc.

Furthermore, in a conventional arc heater on start-up the gas in the heater is cold and consequently the arc is in a constricted mode of operation. Later the gas in the heater comes up to a condition of steady temperature profile. Power is lost from the arc path annulus by radiation and convective cooling to the cold walls of the pressure vessel or the cold walls which form the arc chamber. A balance of power is created between electrical input and loss caused by radiation plus convection which limits the temperature near the arc even where there is no through flow of gas. Above a certain pressure it has been found that this limit is too low for the arc to spread into a diffused mode. Further increase in arc current reaches a value such that no increase in the gas temperature results therefrom, due to increased radiation. It can be shown by calculations that at the pressures of the order of interest in arc heaters now employed, a diffused arc should sustain itself, but that the losses in the constricted mode prevent the local temperature from nearing a value permitting the transition from a constricted to a diffused mode. It has been found that it is this inability to make the constricted-diffuse transition which prevents diffuse arc operation in prior art heaters.

SUMMARY OF THE INVENTION

In summary, apparatus embodying my invention includes means for making the constricted-diffused transition. My apparatus is so constructed that on start-up two pairs of electrodes will operate in the constricted mode. Parallel arc operation is maintained by ballasts or resistors in the leads to a pair of the electrodes. The annulus of the arc, that is the annulus on the longtime basis between the first pair of electrodes, provides two mechanisms for elevating the temperature in and around the arc between the other pair of electrodes, thereby creating a high conductivity environment which causes the last-named arc to spread into a diffused mode.

BRIEF DESCRIPTION OF THE DRAWINGS

The method of my invention may be described with respect to the drawings in which:

FIG. 1 shows the arc in a conventional arc heater;

FIG. 2 shows the temperature in a conventional arc heater after the arc has been in existence for a period of time; and

FIGS. 3A and 3B show an arc heater constructed according to my invention in which a transition occurs from a constricted mode to a diffused mode, the diffused arc thereafter sustaining itself.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1, to which particular attention is directed, a pair of prior art annular electrodes designated **11** and **12** have an arc **13** therebetween, but the arc chamber **14** is formed by a cold wall pressure vessel **15**, or alternatively the cold walls of heat shield means enclosing the arc chamber. It is seen that the arc **13** between electrodes operates in the constricted mode of operation.

Particular reference is made now to FIG. **2** which illustrates the profile of the steady temperature condition reached by the gas in the conventional prior art arc heater after the arc has been running for a sufficient period of time to have reached steady operating conditions. One electrode is shown at **12**, the pressure vessel wall is indicated by dashed line at **15**, the curve "X" represents temperature distribution in the gas flowing through the arc chamber. In the curve of FIG. **2** the vertical coordinate represents temperature with positions along the vertical coordinate further from the lines labeled "radial position" representing greater temperatures. It is seen that a point on the curve designated X_a represents the temperature at the wall, that the gas temperature is relatively low, that a position on the curve indicated T_c represents the temperature at the center, and that other positions on the curve designated T_m represent a maximum temperature reached which is considerably greater than the temperature at the center. Conditions are not produced which would cause the arc to go into a diffused mode of operation.

Particular reference is made now to FIG. 3A in which is shown an arc heater according to the preferred embodiment of my invention and suitable for practicing the method of my invention. The pressure vessel generally designated **17** is generally cylindrical in shape, the cylindrical wall portion of which consists of a plurality of stacked rings of similar dimensions, each ring being electrically insulated from the adjacent rings on both sides thereof, the rings being designated **19** and the insulating spacers **20**. Each of the rings preferably has a passageway therearound and therein for the flow of cooling fluid, such passageways being shown at **21**. The passageways in all of the rings may have fluid inlets and fluid outlets disposed 180° with respect to each other and lying in planes other than that selected for illustration, the fluid inlets and outlets being connected with fluid headers, not shown for convenience of illustration, so that cooling fluid follows two semicircular paths through each ring in the cylindrical wall portion of the pressure vessel.

A ring centrally disposed along the axis, designated **23**, may be somewhat thicker than the other rings of the wall portion and having a plurality of peripherally spaced gas inlets extending therethrough, two of these gas inlets being shown at **24** and **25**.

It will be understood that suitable clamping means, not shown for convenience of illustration, is provided at peripherally spaced intervals around the outside of the cylindrical wall portion of the pressure vessel for clamping all the rings **19** and the ring **23** securely with respect to each other.

The ends of the pressure vessel, the downstream end being designated **60**, are each composed of a plurality of stacked coaxially aligned ring members having graduated mean diameters, each ring member having a carefully graduated inside diameter and a carefully graduated outside diameter whereby the ring members will fit adjacent each other with insulating spacers therebetween, the ring members of the upstream end generally designated **59** being shown at **26** and the spacers at **27**. Annular gaps or spacers are provided at radially spaced intervals in the stack of ring members of each end, for example, the left-hand end or upstream end as seen in FIG. 3A, to accommodate three annular electrodes, the annular electrodes being of progressively increasing diameters and being electrically insulated from the adjacent ring members on both sides thereof, the electrodes being coaxially mounted with respect to each other, the electrode of smallest diameter being shown at **31**, the electrode of intermediate diameter being shown at

32, and the electrode of largest diameter being shown at 33. Each ring member 26 preferably has a fluid passageway therein extending around the entire ring member, two of these passageways being shown at 34, the passageways having inlets and outlets which may be disposed at 180° with respect to each other and located in planes other than the one selected for illustration, the inlets and outlets communicating with fluid inlet and fluid outlet headers, not shown for convenience of illustration.

Electrode 31 is seen to have a fluid passageway 36 therein near the arcing surface for the flow of a cooling fluid to remove heat flux; electrode 32 has a fluid passageway 37 therein extending around the entire electrode, and electrode 33 has a fluid passageway 38 therein extending around the entire electrode near the arcing surface thereof for conducting heat flux from the arcing surface. It will be noted that the electrode 32 has an arcing surface of substantially greater area than the arcing surfaces of the other electrodes; the high current diffused arc discharge illustrated at 82 takes place from electrode 32 to a corresponding electrode in the other downstream end of the pressure vessel hereinafter to be described.

Leads 41, 42 and 43 connect the electrodes 31, 32 and 33 respectively by way of variable ballast resistors 44, 45 and 46 respectively to power supplies 51, 52 and 53 respectively. Three separate power supplies are shown for the three electrodes respectively; it will be understood that under certain conditions one power supply may supply all three electrodes where suitable values of ballast resistance are provided in the individual circuits of the electrodes to ensure that after an arc has started between one pair of oppositely disposed electrodes, there is sufficient voltage available to thereafter start the arcs between the other pairs of electrodes.

The aforementioned fluid cooling passageways 36, 37 and 38 in electrodes 31, 32 and 33 respectively may connect with fluid inlet and fluid outlet headers, not shown for convenience of illustration. Furthermore, it will be understood that means, not shown is provided for closing these passageways so that the fluid therein does not escape from the passageways to the outside of the pressure vessel.

Disposed just outside of the aforementioned electrode 31 and electrically insulated therefrom is a magnetic field coil 54 in housing 47 composed of insulating material, the purpose of which will be described hereinafter.

The other end of the cylindrical pressure vessel generally designated 60, which will be referred to herein as the downstream end since it contains the exhaust nozzle, includes a plurality of stacked coaxially aligned rings of carefully graduated mean diameters and inside and outside diameters which may be mounted with respect to each other to form the end wall portion, the rings being designated 55 and spaced from each other by electrically insulating members 56. Preferably each of the rings 55 has a fluid passageway extending therein and therearound for cooling the ring, the passageways being shown as 57. Spaces or gaps are provided at certain radially spaced positions within the downstream end generally designated 60 to receive three annular coaxially mounted electrodes of graduated diameters, the electrode of smallest diameter being designated 61, the electrode of intermediate diameter being designated 62, and the electrode of largest diameter being designated 63. Electrodes 61, 62 and 63 correspond in dimensions to those of the electrodes 31, 32, and 33 respectively in the other end 59 of the pressure vessel.

Coaxially mounted in the downstream end 60 is an exhaust nozzle 64 having an exhaust vent 65 therein. Mounted around the outside of the exhaust nozzle adjacent the surface of the end 60 of the pressure vessel is a magnetic field coil 66 in housing 49, provided for purposes to be hereinafter explained.

The aforementioned annular electrodes 61, 62 and 63 have fluid flow passageways 71, 72 and 73 therein respectively for the flow of cooling fluid near the arcing surface to conduct heat flux from the arcing surface. It will be understood that the passageways for the flow of cooling fluid extend around the entire electrodes and communicate with fluid inlet headers and fluid outlet headers, not shown for convenience of illustration, and that means, not shown for convenience of illustration, is provided for preventing fluid in the passageways from escaping to the outside of the end 60.

The aforementioned electrodes 61, 62 and 63 are connected by way of leads 67, 68 and 69 to the other terminals of power supplies 51, 52 and 53 respectively, power supply 51 providing arc current for an arc 81 between electrode 31 and electrode 61, power supply 52 providing arc current for an arc 82 between electrode 32 and electrode 62, and power supply 53 providing arc current for an arc 83 between electrode 33 and electrode 63.

Any convenient means may be employed for starting the arcs; for example, fuse wires may be placed in the arc chamber 50 between oppositely disposed pairs of electrodes, or the arc chamber 50 may be seeded with ionized gas to assist in starting the arcs.

The electrical circuit supplying each pair of electrodes has a switch therein, not shown for convenience of illustration, so that the arcs may be started in any desired order.

The aforementioned magnetic field producing coil 54 is connected by way of variable resistor 74 to a direct current source of potential shown in block form at 75, and the aforementioned magnetic field producing coil 66 is connected by way of variable resistor 76 to a source of direct current potential shown in block form at 77. Field coils 54 and 66 are so energized that their magnetic fields oppose each other with resulting magnetic field lines from field coil 54 being shown at 79, and resulting magnetic field lines from field coil 66 being shown at 80. I will be noted that the magnetic field lines from field coil 54 extend adjacent the arcing surfaces of electrodes 31, 32, and 33 and extend substantially transverse to the current paths of arcs 81, 82 and 83 between respectively electrode 31 and electrode 61, electrode 32 and electrode 62, and electrode 33 and electrode 63. In like manner, the magnetic field lines from coil 66 extend adjacent the arcing surfaces of electrodes 61, 62 and 63. Thereby in accordance with the well-known left-hand rule or Fleming's rule, forces are exerted on the arcs, the forces being in a direction substantially perpendicular to the magnetic field and perpendicular to the path of the arc current, the forces being in a direction to cause the arcs to rotate substantially continuously in annular paths around and between the respective pairs of electrodes.

It will be understood that the magnetic fields produced by coils 54 and 66 extend radially at substantially uniform strength around the entire periphery of the arc chamber 50 so that a force is exerted on each arc no matter at what point or peripheral position on the arcing surface the arc takes place from.

The magnetic fields of coils 54 and 66 should have strengths of at least 1,000 Gauss at the field coils, and such values are readily obtainable; indeed, values from 1,000 to 10,000 Gauss are obtainable by selecting the proper coil size and energizing the coil with the desired current. It will be readily understood that the force exerted on the arc is a function of both the magnetic field strength and the arc current; resistors 74 and 76 provide for adjusting the field strengths in accordance with the values of the arc currents to provide the desired speeds of rotation; a rotational speed of 7,000 R.P.M. would be a good design choice.

A sufficient number of gas inlets including inlets 24 and 25 are provided at peripherally spaced intervals so that gas admitted to the arc chamber 50 to be heated does not result in any substantial blowing of arc 83 in the direction of arc 82 in a manner which would interfere with the proper operation of the arc heater.

In operation, arcs 81 and 83 may be started first and caused to rotate, and thereafter the arc 82, which is a heavy current arc, is started and assumes a diffused mode of operation as illustrated; heat within the arc 82 is largely confined to the space between electrodes 32 and 62 by the arc 83 rotating around the outside or arc 82 and the arc 81 rotating around the inside or arc 82.

Particular reference is made now to FIG. 3B, a section through the line A—A of FIG. 3A. In FIG. 3B, the ring **19** adjacent the sectional line is seen forming the cylindrical wall of the pressure vessel, and adjacent thereto three rings **26** with spacers **27**, with cylindrical electrode **33** positioned radially adjacent the innermost of the aforementioned three rings **26**, and an additional two rings **26** with insulators spacing electrode **33** from annular electrode **32**, with an additional two rings **26** and electrical insulators spacing the electrode **32** from the electrode **31** of smallest diameter. The flat disc-shaped center portion of electrode **31** is seen in **30**.

As previously stated, the arc between electrodes **31** and **61** starts in a constricted mode of operation, and the arc between electrodes **33** and **63** starts in a constricted mode; the arc **82** between electrodes **32** and **62** absorbs energy from the other two arcs and goes to a diffused mode, and then the current of arc **82** is substantially increased to make a high current diffused arc at **82** which efficiently heats the gas admitted to the arc chamber **50**, the heated gas being exhausted through the exhaust nozzle **64**.

The segmented nature of the cylindrical wall **17** with rings electrically insulated from adjacent rings on both sides thereof, and the segmented nature of the upstream end and the downstream ends enclosing the pressure vessel, prevent the arcs from striking to the cylindrical wall of the pressure vessel or to the upstream or downstream ends of the pressure vessel.

Whereas gas to be heated is shown entering the arc chamber **50** through a plurality of peripherally spaced gas inlets in the cylindrical wall **17**, additional gas inlets may be provided if desired, peripherally spaced between electrode **32** and electrode **33**.

The use of three separate power supplies reduces the possibility that an arc, for example, between electrodes **31** and **61** would strike to electrode **32** or electrode **62**. If desired, the number of ring segments separating the various annular electrodes may be increased to increase the spacing between electrodes, and a single source of power used to supply all three arcs, the values of ballast resistors **44**, **45** and **46** being adjusted to provide for stable arc operation and the desired arc currents in the various arcs.

Where the power supplies **51**, **52** and **53** are alternating current supplies the resistors **44**, **45** and **46** may be replaced with variable inductive reactors.

Under certain operating conditions and especially certain pressure conditions the arc rotating between electrodes **33** and **63** upstream of the main arc may be effective in preventing sufficient loss of heat from the main arc to the pressure vessel so that the main arc assumes a diffused mode of operation, and the arc between the pair of electrodes of smallest diameter **31** and **71**, may be dispensed with.

In summary the method of my invention includes producing a first arc operating in a constricted mode in an enclosure and producing at least a second arc in the enclosure, the first arc radiating energy which is partially absorbed by gas through which the second arc passes thereby increasing the temperature and conductivity of the gas; the first arc may also provide a high temperature region outside the inner or second arc which greatly reduces both conduction and convection of the energy away from the inner or second arc thereby reducing losses of power from the inner arc, thereby further increasing the temperature and conductivity of gas in the region of the inner arc and allowing the inner arc to undergo a transition from a constricted mode to a diffused mode of operation. The above described functions of the first arc may be divided between first and third arcs.

The foregoing written description and drawings it should be understood are illustrative only and should not be interpreted in a limited sense.

I claim:

1. Arc heater apparatus comprising, in combination, means forming a pressure vessel, means for admitting gas to be heated into the pressure vessel, means for exhausting heated gas from the pressure vessel, a first pair of axially spaced electrodes electrically insulated from each other disposed in the pressure vessel, a second pair of axially spaced electrodes electrically insulated from each other disposed in the pressure vessel, lead means for connecting the first pair of electrodes across a source of potential, other lead means for connecting the second pair of electrodes across a source of potential, the arc heater upon start-up having a first arc produced between the first pair of spaced electrodes which operates in a constricted mode and a second arc produced between the second pair of spaced electrodes which operates in a constricted mode, magnetic field means for causing both arcs to move in substantially repetitive generally closed paths between oppositely poled electrodes of a pair, the path of the second arc in general describing a cylinder and being interior to the path of the first arc, the outer exterior first arc radiating energy which is partially absorbed by gas adjacent the interior second arc thereby raising the temperature and conductivity of said last-named gas and allowing the interior second arc to undergo a transition from a constricted to a diffused mode of operation.

2. Apparatus according to claim **1** in which the arc heater is additionally characterized as having a third pair of electrodes therein spaced from each other and electrically insulated from each other, the third pair of electrodes being so located as to produce a third arc moving in a path confined within the path of the second arc, the third arc adding heat by radiation to the gas in the path of the second arc.

3. Arc heater apparatus according to claim **2** including in addition adjustable ballast means connected in series with at least one pair of the first and third pair of electrodes.

4. Arc heater apparatus according to claim **1** in which all of the electrodes are additionally characterized as being fluid cooled.

5. Arc heater apparatus according to claim **1** in which all of the wall portions of the pressure vessel are additionally characterized as being fluid cooled.

16. An arc heater comprising, in combination, a first pair of axially spaced annular electrodes of a first diameter, a second pair of substantially equally axially spaced annular electrodes of a second diameter greater than said first diameter, the second pair of annular electrodes being coaxially mounted and substantially coplanar with respect to the first pair of electrodes, a third pair of substantially equally axially spaced electrodes of a third diameter greater than said second diameter coaxially mounted with respect to the first and second pairs of electrodes, means enclosing the space between all said electrodes to form a closed arc chamber, said last-named means including means for admitting gas to be heated into the chamber and means for exhausting heated gas from the chamber, the first pair of electrodes being adapted to be connected to terminals of opposite polarity of a source of potential to produce an arc therebetween in a constricted mode of operation, the third pair of electrodes being adapted to be connected to terminals of opposite polarity of a source of potential to produce a constricted arc therebetween, the second pair of electrodes being adapted to be connected to a high current source of potential to produce an arc therebetween, magnetic field producing means so positioned with respect to all the electrodes that when energized a magnetic field is set up extending substantially radially in all directions from the axes of all the electrodes and having a strong magnetic field component transverse to all the arc paths between the first, second and third pairs of electrodes whereby the arcs between the respective pairs of electrodes are caused to move substantially continuously in annular paths around and between the electrodes, the third arc forming a rotary path around the second arc which substantially encloses the second arc and prevents loss of heat from the second arc to the walls of the means forming the arc chamber, the second arc absorbing additional heat by radiation from the first and third arcs whereby the second arc is permitted to go into a diffused mode of operation thereby increasing the enthalpy imparted to gas heated in the arc chamber.

7. An arc heater according to claim 6 wherein the means for exhausting heated gas from the arc chamber is nozzle means mounted coaxially in the arc chamber and extending through one electrode of the first pair of electrodes, and the means for generating a magnetic field includes two magnetic field coils, one of said coils being mounted around the outside of the nozzle means exterior to the means forming the enclosed arc chamber, and the other coil is mounted outside the arc chamber forming means adjacent the other electrode of the first pair of electrodes, said field coils being so energized that their magnetic fields oppose each other.

8. An arc heater according to claim 6 including an adjustable ballast means connected in circuit with each pair of electrodes to provide for stable operation of the arcs between the pairs of electrodes.

9. An arc heater according to claim 6 wherein the means forming the arc chamber includes a plurality of segmented wall portions electrically insulated from each other, each of said wall portions having a passageway there through for the flow of cooling fluid.

10. The method of producing a diffused first arc discharge between a pair of electrodes in an arc heater which comprises the steps of producing a second arc in the arc heater interposed between the path of the first-named arc and the wall of the arc heater to prevent loss of heat from the first-named arc to the wall of the arc heater, and producing a third arc having a path substantially parallel to the path of the first arc for adding heat in the form of radiation to gas in the path of the first arc, the confinement of the heat of the first arc and the addition of heat by radiation into gas in the path of the first arc causing said first arc to assume a diffused mode of operation.

11. The method according to claim 10 additionally characterized as including the step of cooling the electrodes forming the arc by conducting thermal energy therefrom.

12. In an arc heater including means forming an enclosed arc chamber with means for admitting gas to be heated and exhausting heated gas, and having a pair of spaced annular electrodes adapted to be connected to terminals of opposite polarity of a source of potential to produce an arc therebetween and magnetic field means for causing the arc to move substantially continuously around and between the electrodes, means for producing an additional second arc in the arc chamber under the influence of the magnetic field, the path of the second arc extending generally parallel to the path of the first-named arc and rotating around an axis substantially coaxial with that of the first-named arc, the second arc assisting in maintaining the temperature of gas in the path of the first-named are at a value which permits the first-named arc to go into a diffused mode of operation, and means for producing a third arc having a generally cylindrical arc path within but spaced from the path of the first-named arc, the third arc supplying heat by radiation to the gas in the path of the first-named arc.

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