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[33] **Japan**

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[54] **PLASMA JET GENERATING APPARATUS**
7 Claims, 7 Drawing Figs.

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219/121, 313/231, 315/111

[51] Int. Cl. **H01j 17/14,**
H01j 17/26

[50] Field of Search **313/161,**
231; 315/111; 219/121 P

ABSTRACT: A plasma jet generating apparatus comprising a cathode formed of an annular electrode and an anode formed of a cylindrical electrode inserted at the central portion of said annular cathode wherein an arc is generated between the electrodes to heat a gas to a high temperature.

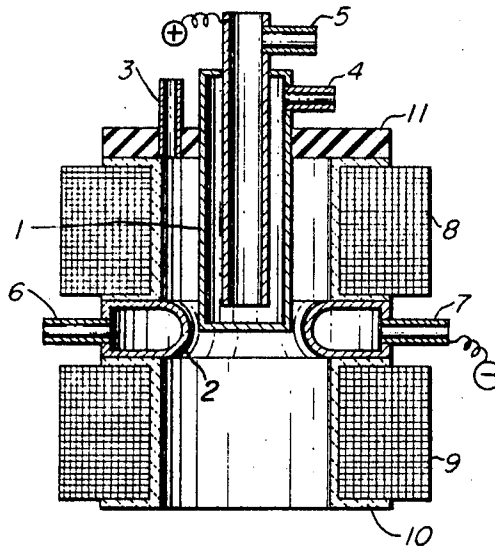


FIG. 1

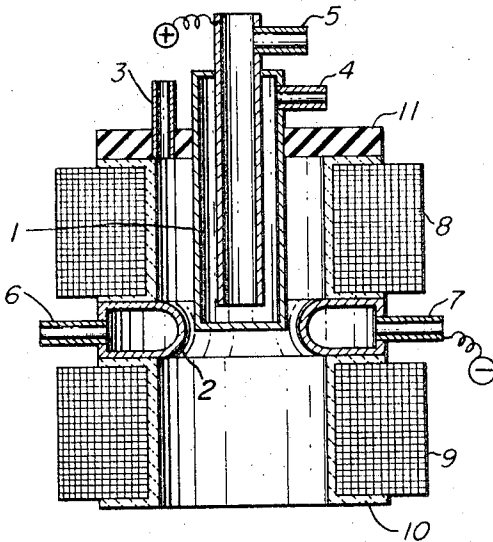


FIG. 2

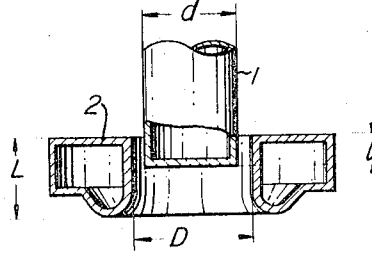


FIG. 3

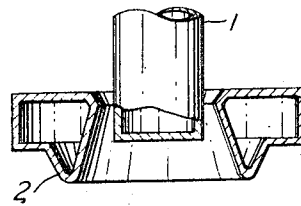


FIG. 4

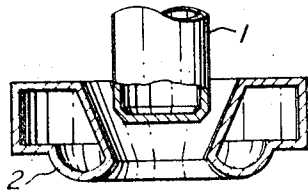


FIG. 5

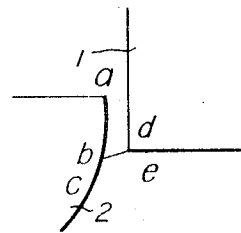
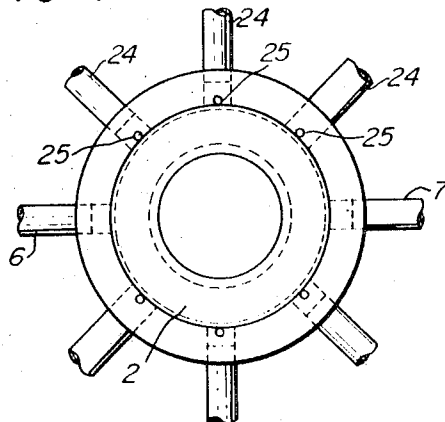


FIG. 7



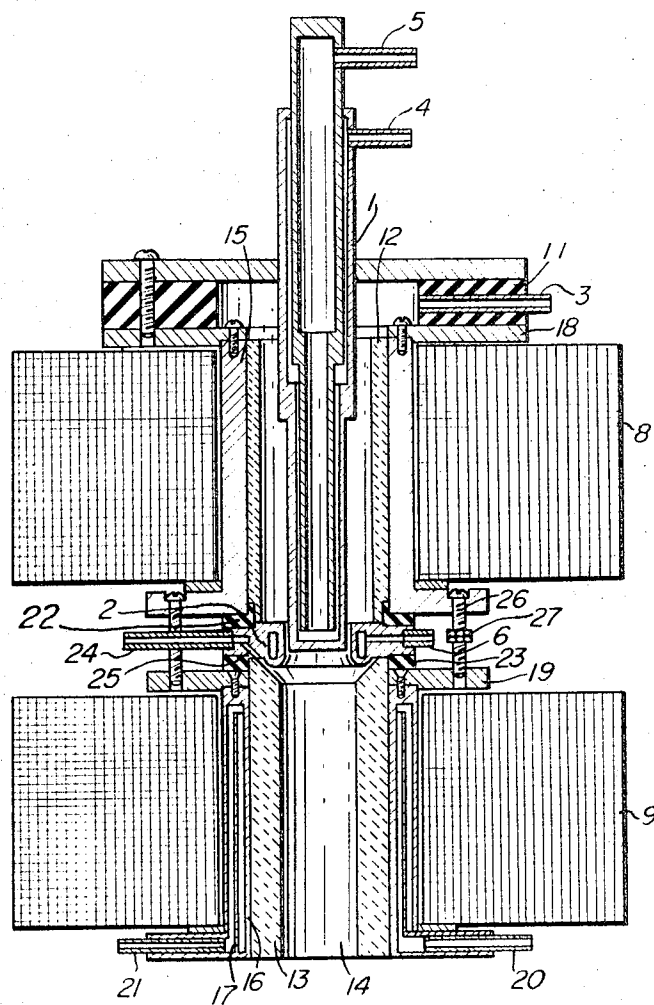
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FIG. 6



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PLASMA JET GENERATING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a plasma jet generating apparatus and more particularly to a plasma jet generating apparatus comprising an annular electrode and a cylindrical electrode disposed at the central portion of the annular electrode wherein an arc is generated between the electrodes to heat the working gas to a high temperature.

2. Description of the Prior Art

Conventionally, a plasma jet generating apparatus is composed of an annular anode and a cylindrical cathode disposed centrally. It is also common practice to use tungsten which is a thermal electron emitting material as cathode and to use copper which is nonmagnetic and has good thermal conductivity as anode. With such structure, the apparatus can operate without significant defects when the working gas is composed of an inert gas such as argon, helium or nitrogen, or of pure hydrogen. However, when nitrogen or hydrogen which contains some amount of carbon and/or oxygen, air, carbon dioxide, hydrocarbon or a mixture thereof is used as working gas, the rate of corrosion of the cathode is extremely large and the device is far from practical. In order to overcome this problem, it is proposed to use a carbon black cathode which is continuously supplied to compensate for the expended amount. But this type is also hard to be produced on an industrial basis because of manufacturing costs and the requirement of stopping the operation to exchange the cathode as well as the problems of the feeding mechanism.

Also, a water-cooled type metal electrode has been developed recently which uses copper, silver, iron, etc. as the cathode material and a system is proposed which uses an annular copper electrode as anode and a cylindrical electrode disposed coaxially and made of the aforementioned water-cooled type metal electrode as the cathode, and in which an arc generated between the electrodes is made to rotate by the Lorentz force due to the crossing of the arc with a magnetic field when a magnetic field is applied in the axial direction.

By such a system, however, according to the experimental results of the inventors, the apparatus can operate normally with a monatomic rare gas such as helium, argon, etc. or with nitrogen which is diatomic and a stable plasma jet is obtained with the cathode region spread in the axial direction. (In this specification, the region where the cathode spot moves will be referred as the "cathode region.") But among diatomic molecules when hydrogen gas is used as the working gas, the behavior of the cathode spot varies and the cathode region is focused on the same circular periphery with little spread. Thus a part of the cathode surface is intensively corroded by the arc with the result that a groove is formed. Then, the cathode spot becomes stable in the groove thus formed to corrode the groove deeper and deeper. Accordingly, the life of the cathode is very soft and the apparatus of this type is also far from practical.

Further, if a hydrocarbon is contained in the working gas, local corrosion decreases but there arises another problem, namely the arc is extremely unstable and liable to break when the amount of the working gas varies even to a small extent. Thus, the apparatus of this type is also impracticable.

General properties of the arc found by the inventors' experiments are as follows:

1. The cathode and anode spots of an arc move by the application of outer force. Specifically, the anode spot moves easily, but the cathode spot is relatively hard to move.

2. Thus, the stability of an arc is determined by the cathode spot.

3. The behavior of the cathode spot is also dependent on the gas atmosphere. In the case of an inert gas such as argon, nitrogen, etc., the cathode spot is relatively easy to move but in the case of hydrogen, hydrocarbon or a mixture gas thereof, the cathode region is strongly focused and hard to move.

As is understandable from the above properties, the basic defect of the conventional plasma jet generating apparatus lies in the immovability of the cathode spot. Even if the arc is rotated in a circle by the Lorentz force due to the application of a magnetic field, especially when an active gas such as hydrogen, hydrocarbon, etc. is used as the working gas, the axial spread of the cathode region is very small and consequently the rate of corrosion of the cathode is very large. Thus, a long continuous operation of the apparatus is impossible.

Nonexistence of a reliable plasma jet generating apparatus, especially when an active gas is to be used as the working gas, has been the main reason forestalling the production on an industrial basis of such chemical reaction apparatus as a thermal cracking reactor for hydrocarbons or the like which is to be realized utilizing a plasma jet generating apparatus as described here above. Therefore, the realization of a reliable apparatus is requested also for the above reason.

SUMMARY OF THE INVENTION

The present inventors have found after long years of research that the above-mentioned defects can be eliminated by a plasma jet generating apparatus which has a polarity opposite to the conventional one.

The object of this invention is to provide a plasma jet generating apparatus comprising cathode means and centrally disposed cylindrical anode means whereby the apparatus operates normally and effectively even when the working gas is an active gas such as hydrogen, hydrocarbon, air, carbon monoxide, carbon dioxide, etc. as well as when the working gas is an inert gas.

In a plasma jet generating apparatus according to this invention, the cathode region of the arc has a far larger spread in the axial direction than that of the conventional one, thus the rate of corrosion of the cathode is very low and long continuous operation is possible.

Further, as an application of this invention, there can also be provided a thermal cracking reactor which effectively performs chemical reactions of hydrocarbon, etc., utilizing a plasma jet generating apparatus having a low rate of corrosion of the cathode and a stable arc atmosphere.

Now, embodiments of the invention will be described in detail hereinbelow with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal cross section of a plasma jet generating apparatus according to this invention;

FIGS. 2 to 4 show various arrangements of the cathode according to this invention;

FIG. 5 is an enlarged schematic view of the electrodes portion for explaining the behavior of an arc;

FIG. 6 is a longitudinal cross section of a thermal cracking reactor for hydrocarbons applying a plasma jet generating apparatus according to this invention; and

FIG. 7 is a plan view of the cathode portion of the reactor shown in FIG. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a plasma jet generating apparatus. Arc discharge is caused by high frequency spark or the like between a centrally disposed cylindrical anode 1 of nonmagnetic metal which is cooled by water and an annular cathode 2 which is also cooled by water. The working gas is introduced from a working gas inlet 3 into the arc to form plasma by the heat energy of the arc. The outer diameter of the cylindrical anode is smaller than the inner diameter of the annular cathode 2. The annular cathode 2 is formed to have a certain width in the direction of the gas flow and the anode is supported to place the end thereof at the middle portion of the cathode.

The cylindrical anode 1 is forcedly cooled by introducing and exhausting water through conduits 4 and 5, and the annular cathode 2 is likewise cooled through conduits 6 and 7.

DC exciting coils 8 and 9 are wound around walls 10 above and below the annular cathode 2 to produce an axial magnetic field to give rotational force to the arc current. A strong flux density is obtained by this Mirro field. Electrical insulation between the two electrodes is achieved by an insulating flange 11 which also serves as a gas seal.

Various shapes are possible for the two electrodes 1 and 2. For example, in the construction of FIG. 1, the cross section of the inner portion of the cathode 2 is formed to have an arcuate shape. Alternatively, it may be formed parallelly linear as shown in FIG. 2, in divergent nozzle shape as shown in FIG. 3 or in convergent nozzle shape as shown in FIG. 4. Also as relative disposition of the two electrodes, various arrangements are possible. The end portion of the cylindrical anode need not be inserted in the inner periphery of the annular cathode. If it is inserted, there are also several possibilities such as that where it is positioned at the middle portion of the cathode 2 in the axial direction, that where it is aligned with the lower end of the cathode 2, or that where it projects a certain length below the lower end of the cathode 2. However, the construction in which the end of the anode is positioned approximately at the middle portion of the cathode is most preferable according to our experimental results. In this construction, it is found that the arc is very stable even when an active gas such as hydrogen, hydrocarbon, etc. is used as working gas and that the rate of corrosion is very low. Thus this construction is considered as the best to spread the cathode region of the arc in the axial direction, appropriately utilizing the properties of an arc as clarified by the inventors. That is, by this disposition the velocity of the working gas flow suddenly decreases at the middle portion of the cathode 2 due to a sudden increase of the flow path. When voltage is applied between the electrodes 1 and 2 and an axial magnetic field of suitable strength is produced by the DC exciting coils 8 and 9, the arc first generated at a point *a* (FIG. 5) is blown by the fast gas flow in the region where two electrodes are opposed and is moved to a point *b* at once. Here, the velocity of the gas flow becomes suddenly low. Thus, the arc becomes temporarily stable along a line *b-d*. However, since the arc is still blown by the gas flow to some extent, the arc gradually moves to a line *c-e*. The longer the arc becomes, the higher voltage is required between the two electrodes to maintain the arc. When the voltage across the arc becomes larger than the breakdown voltage between the electrodes at a minimum distance the arc breaks and reappears at the line *b-d*. This process is repeated during the operation. The waveform of the arc voltage becomes a sawtooth shape and the period of the cycle is about 10 to 100 μ s. The time during which the arc will remain in the region between *a* and *b* is very limited and in almost the whole period the arc stays in the region between the lines *b-d* and *c-e*. Apparently, the arc rotates around the axis of the apparatus throughout the period by the Lorentz force due to the magnetic field.

Thus, the cathode spot of the arc moves longitudinally and along the periphery of the cathode and the whole surface in which the cathode spot moves (that is, the cathode region) forms the working surface for the arc current. Therefore, the virtual current density on the electrodes surface is reduced and the rate of corrosion of the electrodes is extremely low even with the use of an active gas such as hydrogen, hydrocarbon, etc. as working gas, whereby long continuous operation is possible.

Now, a thermal cracking reactor for hydrocarbons employing the plasma jet generating device according to this invention will be explained with reference to FIGS. 6 and 7, in which like reference numerals denote parts similar to those shown in FIGS. 1 to 5. The basic structure of the reactor shown in FIG. 6 is almost the same as that shown in FIG. 1. Further, heat-resistible layers 12 and 13 are provided on the inner wall of a reaction chamber 14 of the thermal cracking

reactor for the thermal insulation and the protection of the inner wall. The upper portion of the layer 13 is tapered to bring the feed gas from inlet apertures 25 to the central portion. A cylindrical wall constituting the body of the reactor is divided into two parts 15 and 16 to support the DC exciting coils 8 and 9, respectively, each part being individually detachable. Upper flanges 18 and 19 are detachably mounted on the walls 15 and 16, respectively. The interior of the lower cylindrical wall 16 is made in a double structure to allow the cooling water to flow to protect the coil 9 and the heat-resistible layer 13. Specifically, the cooling water is introduced from a conduit 20 provided at a low portion of the wall 16 to the inner cylindrical chamber which is surrounded by a cylindrical separator 17. Then, the cooling water passes across the upper edge of the separator 17 to flow into the outer cylindrical chamber outside the separator 17, and is exhausted from an outlet conduit 21 also provided at a low portion of the wall 16. The annular cathode 2 is sandwiched and fixed between the upper structure including the coil 8 and the lower structure including the coil 9 through insulators 22 and 23, respectively. The upper and lower structures are fixed with bolts 26 and nuts 27. In the unique structure shown in FIG. 6, feed gas is introduced from a plurality of inlet pipes 24 provided on the annular cathode 2 and blown obliquely downward through small apertures 25 provided at the lower periphery of the cathode 2. By this construction, separate means for supplying the feed gas is unnecessary and the feed gas can be supplied to the highest temperature portion without affecting the cathode spot.

In one embodiment of this invention, both electrodes were made of copper, the diameter of the cylindrical anode was 40 mm., the minimum inner diameter of the annular cathode was 50 mm., the effective length of the cathode in the axial direction was 30 mm., and the distance of insertion of the anode into the cathode was 15 mm. When this embodiment was operated with hydrogen gas containing methane gas as working gas, an arc current of 400 A., a field intensity of about 2000 gauss at the center, a gas flow of 300 to 700 liters/min., and the mixing ratio of methane being varied from 0 to 50 percent by volume, the arc was very stable with the arc voltage being 200 to 300 v. and the corrosion of the electrodes was very small. When methane is used as working gas in a conventional apparatus, the cylindrical cathode having a thickness of 5 mm. is cut in about 10 minutes. Whereas, when the same gas was used in the inventive apparatus having a similar structure, the amount of corrosion of the annular cathode was very small and almost invisible after a continuous operation of about 90 minutes.

It is confirmed that in the apparatus according to the present invention, voltage and current characteristics of the arc are excellent and hardly affected by the variation in gas flow. This means that this invention is especially advantageous when used to obtain a high gas enthalpy.

We claim:

1. A plasma jet generating apparatus comprising:

A first cylindrical chamber wall;

A second cylindrical chamber wall having the same inner diameter as said first cylindrical chamber wall and being concentric therewith;

An annular cathode disposed between said first and said second cylindrical chamber walls so as to form a chamber therewith, the minimum inner diameter and the width along the axial direction of said annular cathode being smaller than the inner diameters and the widths of said first and said second cylindrical chamber walls, respectively, so that said annular cathode projects inwardly from the surfaces of said cylindrical chamber walls;

Sealing means attached to one end of said first cylindrical chamber wall for sealing the end of said chamber;

A cylindrically shaped anode coaxially disposed in said chamber and positioned to form an annular discharge gap between said annular cathode and said cylindrically shaped anode, the end of said cylindrically shaped anode

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being placed axially at the intermediate portion of said annular cathode, said cylindrically shaped anode being supported by said sealing means; and

A working gas inlet being arranged in said sealing means for introducing gas to said discharge gap.

2. A plasma jet generating apparatus as defined in claim 1, further comprising field generating means for generating a magnetic field in said chamber to rotate an arc formed in said annular discharge gap including first and second coil members arranged outside of said first and second cylindrical chamber walls, respectively.

3. A plasma jet generating apparatus as defined in claim 2, wherein said first cylindrical chamber wall and said first coil member form a first unit, and said second cylindrical chamber wall and said second coil member form a second unit, and further including means for detachably mounting said first and second units to each other.

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4. A plasma jet generating apparatus as defined in claim 3, further including at least one feed gas inlet provided in said annular cathode on the side of said second cylindrical chamber wall to supply feed gas to said chamber in a direction transverse to the axis of said chamber.

5. A plasma jet generating apparatus as defined in claim 4, wherein said annular cathode is nozzle-shaped.

6. A plasma jet generating apparatus as defined in claim 4, wherein the end of said cylindrically shaped anode positioned within said annular cathode has an end surface which is transverse to the axis of said anode, and the surface of said cathode facing said anode is arcuately curved.

7. A plasma jet generating apparatus as defined in claim 4, wherein the surface of said cathode facing said anode is conically shaped and inclined toward said second cylindrical chamber wall.

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