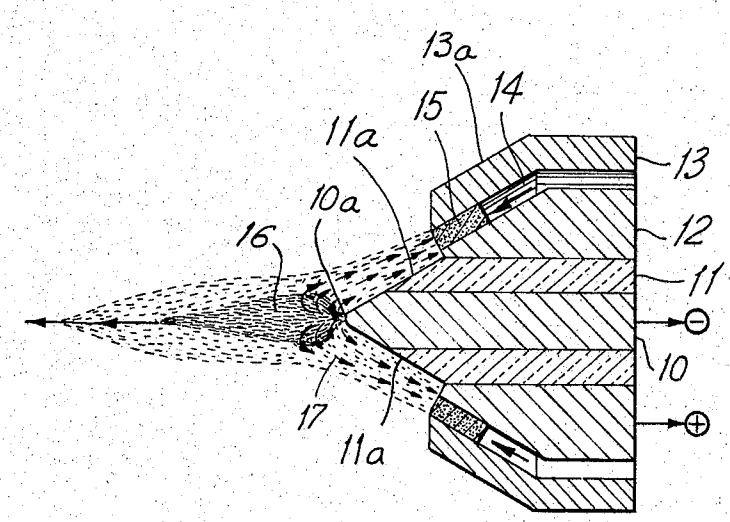
Oct. 26, 1965 C. SHEER 3,214,623

FLUID TRANSPIRATION PLASMA JET

Filed Feb. 12, 1962 2 Sheets-Sheet 1

Fig. 1.



INVENTOR
CHARLES SHEER

BY Willis B. Rice

ATTORNEY

Oct. 26, 1965 C. SHEER 3,214,623

FLUID TRANSPIRATION PLASMA JET

Filed Feb. 12, 1962 2 Sheets-Sheet 2

Fig. 2.

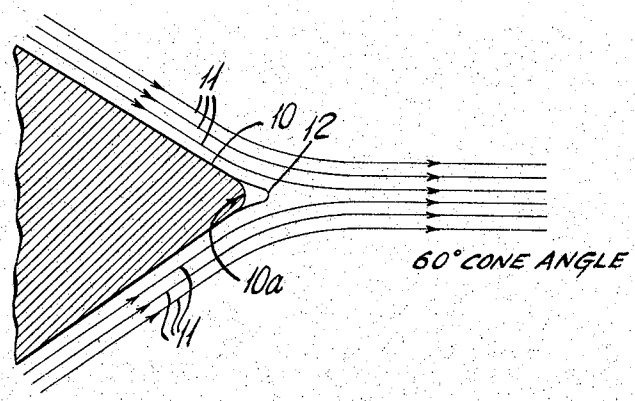


Fig. 3.

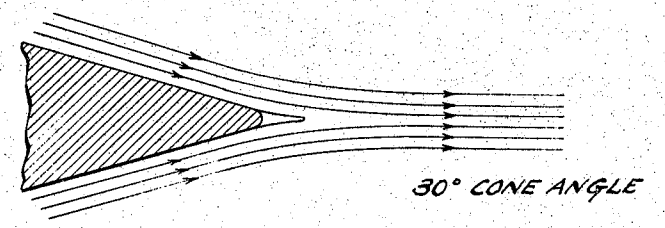
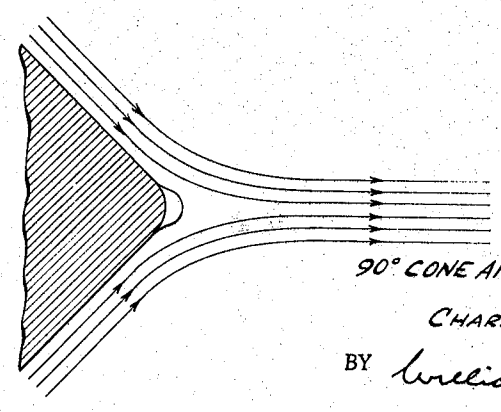


Fig. 4.



INVENTOR
CHARLES SHEER

BY Curtis B. Rice

ATTORNEY

United States Patent Office 3,214,623 Patented Oct. 26, 1965

3,214,623

FLUID TRANSPIRATION PLASMA JET

Charles Sheer, Teaneck, N.J., assignor to Sheer-Korman Associates, Inc., New York, N.Y., a corporation of Delaware

Filed Feb. 12, 1962, Ser. No. 172,618
2 Claims. (Cl. 313—231)

This invention relates to an improvement in the technique of transferring energy from an electric arc to a stream of fluid.

In particular it refers to a new modification of the fluid transpiration arc as disclosed in our co-pending application 749,132 which application was refiled as case No. 172,735. In that application a novel method of exposing the fluid to the energy of an arc is disclosed, which consists of passing the fluid continuously through a porous anode so that it enters the discharge via the active anode surface, i.e., where said surface is acting as the arc terminus. That application further discloses that unique and valuable results can be obtained if certain criteria are satisfied in operating such a device.

Specifically the performance criteria required to achieve the desired results are the following:

(1) The average diameter of the pores on the surface of the anode is less than the thickness of the anode fall space which is normally established in the *absence* of fluid flow adjacent to the active area; i.e., the fall space thickness of a conventional arc operating under no-flow conditions.

(2) The fluid is forced to transpire through the passageways in the porous electrode so that the fluid emerges directly from the electrode surface into the fall space over the area integrally congruent with the arc terminus on the porous electrode surface, and nowhere else.

(3) The surface distribution of orifices, through which the fluid emerges from the electrode into the fall space, is sufficiently uniform that the individual streams of fluid from each orifice will diffuse laterally, merging with each other stream adjacent to it to form a homogeneous stream, as though it were issuing as a vapor from a solid surface, and further, the averge interorifice distance on the active surface is sufficiently small that essentially complete flow homogeneity is established before the fluid penetrates an appreciable distance into the fall space.

(4) For a given arc current, gap distance, and ambient pressure, the rate of fluid transpiration through the porous anode is adjusted so that it is greater than the value required to effect a transition to the hierarc mode of arc operation.

It is an object of this invention to provide a new arc configuration by virtue of which the advantages of fluid transpiration into the arc through porous electrodes in accordance with the above criteria may be enhanced.

It is a further object of this invention to provide a configuration in which the fluid may be made to absorb a large fraction of the total energy dissipated between the arc electrodes over a wider range of operating parameters than possible with the configuration previously disclosed.

It is a still further object of this invention to provide a configuration in which the transpired fluid, subsequent to receiving energy in the fall space, in caused to flow in converging fashion so that the energy density achieved at the focus of convergence is much greater than could otherwise be achieved for the same electrode dimensions, fluid flow rate, and arc power input.

It is a still further object of this invention to provide a configuration in which the flow of fluid through the arc zone occurs in a much smoother and non-turbulent fashion than heretofore possible, without sacrifice of energy transfer efficiency, or energy handling capability.

It is a still further object of this invention to provide

a configuration in which the converging flow establishes a region of flow stagnation near the apex of the cone, said stagnant region being coincident with a region of higher current density and low potential gradient so that the gas in the stagnant zone is not only characterized by maximum enthalpy, but is also maintained at a very high level of atomic excitation, thus generating a region of exceptionally high intrinsic brilliance, without thermally overloading the electrode.

It is a similar object of this invention to provide a configuration in which the zone of maximum brilliance is minimally occluded by the arc electrodes and supporting structures so that the radiant energy generated by said zone is emitted through a much wider solid angle than most other types of high brilliancy sources provide, thus maximizing the achievable optical efficiency of a device using this configuration as the source of radiation.

It is alternatively an object of this invention to provide a configuration whereby the zone of maximum enthalpy may be shortened and widened to provide a useful arrangement for the rapid welding or brazing of refractory materials; or, conversely, whereby said high enthalpy zone may be lengthened and narrowed to provide a more effective ultra-high temperature flame for use as a cutting torch for refractory materials.

Other objectives and uses of this invention will be apparent from the unusual properties and effects which are peculiar characteristics of the configuration with which this invention is concerned.

The basic improvement which this invention embodies is the establishment of an arc discharge having an essentially conical geometry. The cathode, anode, and insulating supports are arranged in geometrical relation to each other so that the conduction column assumes the shape of an axially symmetrical conical shell.

This invention is illustrated in the accompanying drawings, in which:

FIG. 1 is a section through a device embodying this invention, and FIGS. 2, 3 and 4 are diagrammatic representations with different cone angles.

Referring now to FIG. 1, numeral **10** is a solid cylindrical cathode which may be made of thoriated tungsten or similar material having high thermionic emissivity (e.g., a sintered mixture of uranium carbide and tungsten). For most applications it will be desirable that the cathode be a refractory material, and also that it be provided with means of internal cooling. These factors, while not essential to its operation, will extend the energy handling capability of the device without significant lowering of the energy transfer efficiency.

The arc terminus end of the cathode **10** is shaped into a cone as shown whose apex at **10***a* may be rounded into a small hemispherical surface, the radius of which will be determined by specific applications as will be explained below. The cathode **10** is surrounded by and fitted tightly into a tubular ceramic sleeve **11**, having its outer end terminating in the same conical surface as the cathode. This sleeve **11** may be made of any high temperature ceramic material having good thermal shock resistance, but preferably one combining high electrical resistivity with good thermal conductivity, such as boron nitride or beryllium oxide.

Surrounding the insulating sleeve **11**, and fitting close upon it, is a metallic supporting member **12**, and surrounding the member **12** is an outer sleeve **13**, also metallic, the members **12** and **13** being spaced from each other to form a cylindrical gas channel **14**.

A porous block anode **15**, which may be composed of porous graphite or a porous metal such as tungsten, fabricated by sintering the metal powder, and which is in the shape of a truncated conical shell, fits within the channel **14** and is held firmly between members **12** and

13 in such a way that good electrical and thermal contact is provided at both the outside and the inside lateral surfaces of the conical anode block.

It is essential that the porous anode satify the structural citeria relating to maximum average pore diameter and homogeneity of orifice distribution on the active anode surface, as set forth heretofore and as described in our co-pending application Serial No. 749,132. It is likewise desirable from the standpoint of operational facility that the porous material have high mechanical strength, so as to withstand the pressure of transpiring fluid, as well as sufficient bulk electrical conductivity to conduct the required arc current through its body without excessive internal ohmic heating, and good thermal shock resistance, to avoid spalling upon ignition of the arc. Similarly the porous material should posses a high bulk thermal conductivity to facilitate removal of the residual absorbed heat through its body to the supporting members **12** and **13**. Finally, the porous material must also possess adequate gas permeability (i.e., absence of blind passageways between front and rear annular surfaces) so that the criterion of minimum fluid flow rate may be satisfied within an impractically high pressure drop across the porous body.

Members **12** and **13** are electrically joined together and connected to the positive terminal of the power source, thus serving jointly to supply the arc current to the conical anode via its lateral surfaces. It will be desirable to fabricate these members of a high conductivity metal such as copper, and to provide each with interior water cooling channels in order to extend the range of energy handling capability of the device.

When fitted in place, the porous conical anode **15** has its smaller annular surface disposed perpendicularly to the conical surface formed jointly by cathode **10** and insulator **11**, and it is this annular surface which comprises the positive terminus of the arc discharge. In operation the cathode **10** is connected to the negative terminal of the power source.

The transpiration fluid is introduced into chamber **14** and forced under pressure to transpire through the porous anode **15**. Whether the injected fluid is normally a gas or a liquid, it always emerges from the anode in the gaseous state, when the injected fluid is initialy in the liquid state, sufficient heat transfer occurs during operation in its passage through the porous body to convert the flowing liquid into a gaseous stream before emerging from the active anode surface. After emerging from this surface the gas stream tends to flow parallel to the conical surface in such a way that the flow converges at a point slightly beyond the tip of the cathode. Following this the conical stream merges into an approximately cylindrical jet travelling away from the cathode along the axis.

The most convenient method of igniting the arc in this configuration is to cause a high frequency spark to jump momentarily between the anode face and the cathode while the arc power source is connected to the electrodes. This causes a sufficient momentary conductivity of the intervening atmosphere to ignite the arc. Alternatively, the arc may be ignited by means of a striker mechanism which may consist of any movable conducting member which can be caused momentarily to touch both anode and cathode while the power source is attached. After the striker is removed from contact with the electrodes the arc will remain ignited.

When a sufficient arc current is used the discharge will form completely around the annular surface while the converging gas flow will cause the cathode spot to remain seated on the small hemispherical cathode tip. Thus the arc conduction column takes the shape of a thin conical shell, except for the reentrant portion near the apex where the discharge current bends back to enter the cathode.

The flow paths of the electron drift current between the electrodes are indicated by the arrows **17** in FIG. 1. It is important that sufficient arc current be used to permit the anode fall space to become established completely around the annular anode surface. The amount of current required to do this depends on the physical dimensions of the arc as well as the nature of the transpiration fluid and the ambient operating pressure. This condition is essential to the achievement of maximum energy transfer, since gas will flow through the entire anode annulus regardless of whether the entire surface is receiving current or not. Therefore, unless the positive arc terminus extends around a complete 360° azimuth a certain fraction of the gas will not enter the discharge and will mix with and reduce the heat content of the fraction that actually enters the discharge.

In summary, this invention comprises an arc device having the general shape, structure, configuration and composition of its component parts as disclosed above, in which the porous conical anode satisfies the porosity criteria relating to pore size and surface distribution, and which additionally possesses the properties of good mechanical strength, electrical and thermal conductivity, thermal shock resistance, and transpiration permeability, all of which combine to optimize practical performance. This invention also includes two further requirements upon the operation of this device, namely, that the arc current be large enough so that the discharge covers the entire annular surface of the anode, and that the flow rate of anode transpiration fluid be great enough to effect the transition to the hierarc mode.

A device of the type described possesses a number of practical advantages over the cylindrical geometery disclosed in our previous application.

The first significant advantage of the conical configuration over the cylindrical configuration in our earlier application that we have observed is the fact that high energy transfer efficiency can be maintained over a much wider range of operating conditions.

Referring now to FIG. 1, the arc gap distance in the case of the conical geometry is determined by the slant height of the conical surface measured from the active annular surface of the anode to the apex of the cathode. It will be seen, therefore, that the transpiration fluid, after first absorbing some energy from the porous anode itself, and then becoming further energized in the annular anode fall space, proceeds to flow down the entire length of the conical conduction column, thus absorbing energy from the column over its entire length, regardless of the gap distance.

On the other hand, in our earlier configuration, the transpiration fluid, after successively traversing the porous anode and the anode fall space, flows through only a portion of the conduction column before it breaks away from the discharge to emerge as the plasma jet. Hence if the conduction column is lengthened the fluid is exposed to a smaller fraction of the energy dissipated in the column. Therefore, although the overall energy transfer efficiency is high for the cylindrical geometry provided a short arc gap is used, it decreases steadily with increasing arc gap length. As explained above, this does not happen in the conical configuration.

Another feature of this configuration is the fact that it has a higher power handling capability for the larger arc gap distances. Thus, for example, assume that for a given column length and flow rate the current is adjusted to the maximum value consistent with negligible anode erosion. If it is then desired to increase the total energy transferred to unit mass of fluid, the required scale-up in arc power may be accomplished by increasing the arc gap length and voltage, while maintaining the same arc current and fluid flow rate. The effluent jet enthalpy will then be increased in proportion.

Whereas in the cylindrical configuration an increase in power level due to enlargement of the arc gap at the same arc current results in the same current density at

both electrodes, this is not true for the conical geometry. When the conical "gap length" (i.e., slant height of the cone from apex to anode) is increased at constant current, the current density remains the same only at the cathode. On the other hand the current density at the anode actually decreases. This follows from the fact that the annular anode terminus must increase in area as the distance from the cathode tip increases. Thus with a given total current, the increased anode area results in a *decrease* in anode current density and therefore in the thermal loading of the anode.

We have therefore found it possible to increase the arc current, in addition to the gap distance and voltage, until the anode current density reached the same value as with the shorter gap, without causing significant consumption of the anode. Although the *cathode* current density does increase in this case over that pertaining to a shorter gap, this does not generally result in erosion of the cathode, since the increased thermionic emission occasioned by the higher arc current also increases the degree of cooling by electron evaporation, which serves to maintain a relatively constant cathode spot temperature over a wide range of operating conditions.

Another important feature of the conical configuration is that the energized fluid passes through the arc discharge in a converging flow, so that the zone of maximum energy density is not developed until the fluid reaches the focus of flow convergence beyond the cathode tip. Owing to the conical shape the energy which is transferred back to the electrodes by radiation and thermal conduction is less than that for the cylindrical case operating at the same power level. This arises from the fact that the solid angle subtended by both electrodes at the maximum energy zone beyond the cathode is reduced. Although these sources of electrode heating are minor at pressures less than about 10 atmospheres, they become important when it is desired to operate at higher pressures, in which case the advantages offered by the conical geometry in this respect become quite important.

Another advantage of this invention is that it mitigates to a major extent the difficulties caused by the so-called "cathode stream effect." This phenomenon, which is present to a greater or lesser extent in all arc discharges, arises from the fact that, under usual operating conditions, the area of the arc terminus on the active cathode surface is much smaller than the average cross-sectional area of the conduction column. For the conventional cylindrical configuration a marked constriction of the column may be observed in the vicinity of the cathode. In this region of constriction the current density in the column increases rapidly along the axis, reaching a maximum value at the cathode terminus. The self-magnetic field associated with this type of current distribution is highly non-uniform, having maximum intensity at the cathode surface and rapidly becoming weaker as one progresses away from the surface along the column axis, until a constant value is reached in the region of constant column cross-section. Now it is a well-known fact that an inhomogeneous magnetic field will exert a steady force on any conductive fluid, such as the ionized gas in the column, causing it to move in the direction of weaker field intensity. Consequently a steady pressure gradient is established in the zone of constriction directed away from the cathode along the axis of the column. In response to this axial pressure gradient, gas from the surrounding atmosphere is continuously aspirated radially inwards at the base of the constriction near the cathode and accelerated toward the anode inside the column. This cathode stream is of course heated to the high temperature of the column, and, in the conventional opposing geometry, ultimatly impinges upon the anode, thereby increasing by hot gas convection the thermal loading of the anode.

On the other hand it will be observed by reference to FIG. 1 that in the case of the conical geometry the cathode stream generated by the axial pressure gradient near the cathode spot projects the hot gas away from instead of toward the anode. Thus the cathode stream merges codirectionally with the converging flow of anode transpiration fluid and contributes to the total energy content of the effluent plasma jet, while at the same time it no longer acts as a source of heat convection to the anode.

Another advantage of the conical geometry is the fact that the flow regime of the plasma medium is smoother, i.e., less turbulent, than in the case of the cylindrical configuration over a very wide range of fluid flow rates. It will be observed that the flow of transpiration gas is compatible with (i.e., codirectional with) the flow of positive ions in the conical conduction column over practically its entire length. Therefore for most of the flow path there is no component of the fluid velocity perpendicular to the direction of the ion drift.

We have observed that when an external fluid is injected laterally through an arc column, the effluent heated gas bcomes turbulent. We have further observed that the degree of turbulence is related to the component of the injected fluid flow which is perpendicular to the direction of the ion drift current in the column. Accordingly this source of turbulence will be reduced to a minimum if the injected gas flow is codirectional with the motion of the ions for the entire passage of the fluid through the arc.

It will be observed that the flow of the transpired gas is indeed compatible with the flow of positive ions in the conical conduction column for practically its entire length. In other words, for the entire period of flow passage through the arc zone from the time it is introduced at the annular surface until it reaches the focus of gas convergence beyond the cathode, and there is no component perpendicular to the direction of the ion drift.

In addition, we have observed that this configuration eliminates another source of turbulence encountered in the cylindrical configuration of our previous case, even though the fluid is in that device compatibly injected, i.e., through the anode, and codirectional with the ion drift current. This refers to the fact that the cathode stream described above flows in opposition to the stream of transpiration gas emerging from the anode so that the two gas streams meet "head-on." Moreover it is impossible to obtain, for the cylindrical case, a stable operating configuration by varying the off-set angle of the cathode for which there does not exist some degree of turbulent mixing of the two streams. Conversely, in the conical configuration of the present case, the two streams merge smoothly and turbulent mixing is reduced to a minimum.

Still another advantage of the conical arc configuration is derived from its inherent property of forming a separation zone of flow stagnation when a stream of fluid is caused to flow parallel with and symmetrically about the conical surface. The dimensions of the stagnant zone (for a given flow velocity) are determined principally by the angle of the cone and the radius of curvature of the hemispherical tip. A sketch of the flow patterns for several conical shapes is given in FIGS. 2, 3 and 4.

Referring to FIG. 2, which depicts the flow pattern of a 60° cone, the numeral **10** represents a portion of the cone near its apex; e.g., the foremost part of the cathode **10**, of FIG. 1. The rounded tip of the cone is shown at **10***a*, where the cathodic terminus of the discharge is situated during operation of the arc. The lines **11** illustrate graphically the conical flow field as it converges toward the apex. After leaving the vicinity of the surface, the stream lines ultimately merge into a cylindrical jet. The stagnant zone occurs just beyond the blunt portion of the cathode tip and assumes a shape depicted by the darkened area **12**.

FIG. 3 shows a similar flow pattern for a 30° cone,

having a tip with smaller radius of curvature. It is noted that the stagnant zone in this case is longer and thinner than that for the 60° cone of FIG. 2. Conversely the diagram of FIG. 4 shows the situation for a 90° cone with a much blunter tip, for which the stagnant zone is shorter and thicker than that shown in FIG. 3. It will be clear, therefore, that the axial and radial dimensions of the stagnant separation zone can be adjusted to provide the most useful shape for a given application by the proper combination of cone angle and bluntness of the tip.

The usefulness of the stagnant zone in several applications is derived from the fortuitous combination of two circumstances. First, the gas in this zone remains in the vicinity for a relatively long period of time, and exchanges slowly with the fast-moving layers of gas outside this region. Secondly, as may be visualized by comparing FIG. 3 with FIG. 1, this region coincides during arc operation with the region of high current density near the cathode tip. Furthermore, the voltage gradient in this region is relatively low, so that excitation rather than ionization of the gas molecules will be favored. Consequently this situation is ideal for establishing a very high brilliance source of radiation. Thus, the high current density and low voltage gradient are responsible for a high probability of atomic excitations, which in turn causes a large fraction of the energy absorbed in this region to be transformed into radiant energy; and, at the same time, the stagnant character of the gas in this zone is responsible for a slow rate of diffusion for the excited molecules out of this region, or, in other words, a high concentration of emitting centers within it, and therefore a high intrinsic brilliance. Indeed, an arc of this type, having a 60° cone angle and using argon gas at 30 atmospheres pressure as the flow medium, demonstrated in sustained operation a source brilliance for the stagnant zone of 5000 candles per square millimeter in the visible region alone. This achievement makes the conical fluid transpiration arc the most brilliant source of light yet known, which is capable of sustained operation.

Another useful feature of this device when used as a radiation source is the fact that the basic geometry provides a very wide acceptance angle for the emitted radiation, e.g., 300° for the shape of FIG. 3. This facilitates the design of an efficient optical system for collecting and forming the emitted light into long range parallel beams.

Simultaneously with high intrinsic brilliance, the stagnant zone, because of the long residence time of the gas within it, is characterized by a very high local specific enthalpy, that is, heat content per unit mass of gas. Furthermore, this condition exists "out in space" as it were, sufficiently far from material surfaces and under flow conditions such that it can be maintained for very long periods of time without interruption. This characteristic makes this device useful in applications where it is desired to concentrate an intense amount of heat locally to some material substance, as in the cutting or welding of refractory materials. For the cutting application a shape similar to that depicted in FIG. 4 would be most useful since a long, thin, high enthalpy zone would result in a deep and narrow cutting channel, which is desirable for such work. On the other hand a shape similar to FIG. 4 would be most useful in welding or brazing applications, where the short, wide high enthalpy zone would permit the maximum linear rate of joining.

For both cutting and welding applications, the peripheral layers of high speed, lower temperature plasma serve the double function of establishing a thermal "guard ring" around the point of application, thus setting up an intermediate temperature zone in the work and reducing the rate of heat withdrawal by thermal conduction, and also provides by proper choice of the fluid medium a protective atmosphere against oxidation and other undesirable chemical reactions at the heated surface.

Finally, because arc discharge is self-contained in this device, the arc circuit as a whole can be rendered electrically floating with respect to the work. This avoids the difficulty encountered when the work is a metallic substance and therefore tends to become part of the arc circuit. It also provides the opportunity to work on non-conducting ceramic materials with equal facility.

What is claimed:

1. A device of the character described for creating a plasma jet comprising a solid cylindrical cathode, a tubular insulator fitting over said cathode, said parts terminating in a common conical surface thus providing a protruding conical cathode point, a cylindrical anode fitting over said insulator, said anode having a circumferentially disposed conical channel having its inner surface in substantial alignment with the conical surface of said cathode and insulation whereby when gaseous material is discharged through said conical channel while said parts are energized it will be directed to pass over said conical surface of said insulator and cathode, to pass over the point thereof.

2. A device according to claim **1** in which a porous conducting block is fitted into the conical channel of said anode whereby the gases passing through said channel are more thoroughly energized.

References Cited by the Examiner

UNITED STATES PATENTS

2,806,161	9/57	Foster	313—63
3,009,783	11/61	Sheer et al.	313—231
3,136,915	6/64	Jaatinen et al.	313—231

FOREIGN PATENTS

189,023	2/57	Austria.
1,233,796	10/60	France.
881,242	6/53	Germany.

GEORGE N. WESTBY, *Primary Examiner.*

ARTHUR GAUSS, *Examiner.*