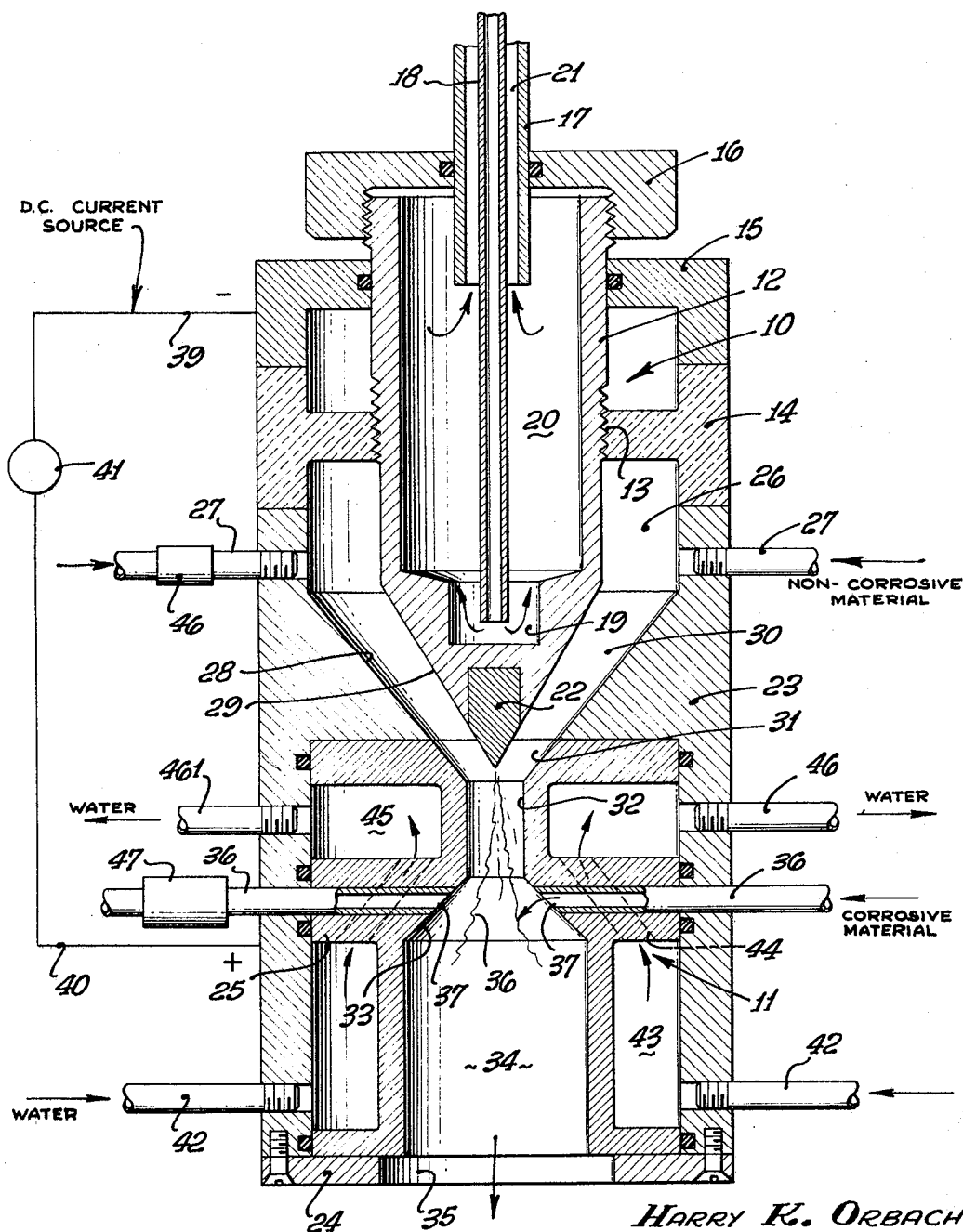


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BY MEANS OF AN ELECTRIC ARC
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1

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METHOD AND APPARATUS FOR EFFECTING CHEMICAL REACTIONS BY MEANS OF AN ELECTRIC ARC

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This invention relates to improved apparatus and methods for carrying out chemical reactions in direct current gas-stabilized electric arcs of the type known as plasma jets.

The general object of this invention is to provide a means for subjecting two or more materials to the action of an arc in order to effect reaction between them, in a manner such that the energy of the arc is used most effectively while corrosion of the electrode surfaces is minimized and the stability of the arc is maximized.

Particularly contemplated is an improved plasma jet system capable of use under specific conditions wherein selected compounds such as acetylene and ethylene are produced in a novel manner which is superior to other processes for producing these compounds.

In direct current plasma jet the cathode is usually a high melting metal which may contain small amounts of a low work-function material. An example would be tungsten containing a few percent of thorium which is present to aid in allowing electrons to be emitted from the cathode surface. However, despite this help, it is commonly recognized that most electron emission is thermionic, that is, that electrons "boil off" the surface due to the temperature at the surface. The higher the temperature, the better electron emission. This is the reason for the use of a high melting material like tungsten, since the point at which the arc attaches is usually molten even though water-cooling may be used to carry off the heat. Since the cathode material is at high temperature and the materials of construction are limited to the few very high melting materials, it is often found that the substances passing through the arc are not compatible chemically with the electrodes and that the electrodes are attacked. Examples of materials which attack hot tungsten are oxygen, the halogens, and carbon. This severely limits the utility of the arc because many processes involve these elements.

In addition to the economic limitation imposed on the use of the arc in commercial processes by such corrosion, the surfaces of the cathode are altered, thus changing the geometry and aerodynamics of the arc. Since the stable operation of the plasma jet type of arc is strongly dependent upon the aerodynamics, the operation is affected by changing the gap spacing between the cathode and anode and the stability is affected by the restriction of axial symmetry.

One means of overcoming these difficulties is to heat an inert material such as hydrogen in the arc and mix the heated material with the reactive materials at a point outside of the arc region. This has the disadvantage of low overall electrical efficiency since the arc chamber region is at a high enthalpy and a considerable amount of the energy is lost to the cold anode walls and is thus unavailable for reaction. In addition any benefits derived from reacting materials in the arc itself, such as bombardment by electrically accelerated ions and electrons, and the presence of dissociated species in or near the arc filament are lost. We have found these effects to be appreciable in determining rate of reaction and the amounts and kinds of side reactions.

Another means which has been tried to overcome the corrosion problem, while keeping the benefits of direct

2

contact of the mixture with the arc, has been to inject the corrosive substances into the arc at a point downstream of the cathode, but upstream of the point or points of arc attachment on the anode. In the commonly used type of system, however, wherein the anode is a straight tube, there is considerable circulation of the downstream gas, with corrosive components, back to the cathode.

The present invention provides a means for achieving low corrosion and high efficiency by inserting a restriction between the cathode and point of injection of material into the anode which acts to yield a very high velocity barrier to the back circulation of gas mixture, thus making possible the feeding of corrosive materials directly into the arc. This restriction also acts to increase stability by confining the arc axially and thus helping to maintain the position of the arc on the tip of the cathode. An additional benefit of using such a restriction has been the ability to control the voltage of the arc to some extent by varying the length of this restricted passage.

The invention will be more fully understood from the following detailed description of the illustrative plasma jet apparatus shown by the accompanying drawings, together with typical reaction processes for which the apparatus is highly suitable.

Referring to the drawing, wherein the apparatus appears in longitudinal axial cross section, the body structure of the equipment comprises a cathode assembly generally indicated at 10, and a tubular anode assembly generally indicated at 11. Referring first to the cathode components, the latter include a hollow cathode 12 suitably mounted for axial adjustment as by being threaded at 13 through a central opening in the annular insulator 14. The cathode extends through a top wall component 15 and carries a threaded cap 16 through which extends centrally an outer tube 17 and an inner pipe 18 through which cooling fluid such as water, may be delivered into cavity 19 in the closed nose of the cathode for recirculation out of the cathode chamber 20 by way of annular passage 21. As previously indicated, the top 22 of the cathode is formed by a high melting metal such as tungsten, which may contain a low percentage of low work-function metal such as thorium.

The anode assembly 11 comprises a tubular metallic anode body 23 which may be flanged at its lower end by plate 24 which supports the internal anode structure 25. The upper extent of the body 23 below the insulator 14 is annularly spaced at 26 about the cathode to provide an annular chamber through which a first fluid material to be delivered to the reaction zone is fed through one or more inlets 27. Below chamber 26 the anode wall 28 tapers at somewhat less angularity than the tapered cathode surface 29 to form a passage 30 converging at 31 through the top of the internal structure 25 to a restricted throat 32 which, as illustrated, is considerably smaller in diameter than the cathode 12. We have previously mentioned that the voltage of the arc emanating from the cathode tip 22 may be controlled to some extent by varying the length of the passage or throat 32. It has been determined that the length of the throat 32 may be extended up to about four times its diameter without causing excessive energy loss.

Below throat 32, the anode wall has a flared enlargement 33 from which the reactants enter the chamber 34 below. The reaction products may be taken through the bottom 35 of the chamber and appropriate connections, not shown, for disposition for further treatment in accordance with the nature and any processing requirements of the reaction products. As illustrated at 36, the arc emanating from the cathode tip 22, tends to extend through the throat 32 to the reaction chamber wall, particularly when the rate of reactant delivery through inlets 27 and

flow velocity through the throat 32, are kept sufficiently high to tend to blow the arc to the reaction chamber walls, while maintaining a throat velocity so high as to prevent any reverse fluid flow through the throat.

Whereas the reactant fed through inlets 27 and contacting the tip 22 will be a fluid or gas such as hydrogen, nitrogen or ammonia, which are noncorrosive to the tungsten or equivalent tip, the second reactant, or mixture thereof, or the reaction products of the two reactants, would tend to corrode or react with the tip if permitted contact therewith. Accordingly, the second reactant material is introduced through one or more refractory and insulative lines 36 discharging at 37 through the outwardly flaring anode surface 37 directly beyond the restricted throat 32. The fluid barrier presented by adequately high velocity flow through the restriction 32, prevents access of any materials beyond the discharge end of the throat, to the cathode tip 22, thus assuring operation of the system with exposure of the tip to only noncorrosive material. The flared expansion of the stream leaving the throat provides for highly effective entrainment and mixing of the secondary material from line 36, all in the direct atmosphere of the arc passing through the throat, thus creating conditions ideally suited to efficient initiating and carrying forward of the reactions within the turbulent atmosphere of chamber 34.

Direct current at necessarily high voltage may be supplied respectively through the cathode 10 and anode 11, as illustrated diagrammatically by leads 39 and 40 from a suitable power source 41. As in the case of the cathode, the anode may be water cooled as by circulation from inlets 42 into space 43 surrounding the reaction chamber, thence through passages 44 into chamber 45 surrounding the throat 32, to be discharged through outlets 46. Where desirable for either or both reactant material streams to be preheated, appropriate heaters 46 and 47 may be provided in the feed lines or connections therewith.

When applying this system to processes involving endothermic reactions there is a definite efficiency advantage because the energy delivered to the system by resistive heating is absorbed immediately and at the place that it is generated. The longer the time between development of the high temperature and the more that the heated medium is transported, the more energy is lost from the system and is therefore unavailable for useful work. Another benefit is derived when it is desired to bring preheated reactants into the arc. The reactants may be preheated just prior to injection and carried directly into the anode through a short insulated channel. This eliminates the necessity for making the parts comprising the cathode, cathode adjusting mechanism and insulating spacers, of heat resistant materials.

The described apparatus is adaptable for effecting reactions between various materials, generally in the category of fluids to be introduced through lines 27 which are noncorrosive to the cathode tip 22, and reactants to be in-

TABLE I

Material to Cathode	Material to Anode	Products
N ₂	Hydrocarbon.....	HCN, (CN) ₂
NH ₃	do.....	HCN
N ₂	O ₂	NO
H ₂	Carbon+H ₂	C ₂ H ₂
H ₂	F ₂ (or other halogen).....	NF ₃ , N ₂ F ₄
H ₂	C+N ₂	HCN
N ₂	Al ₂ O ₃ +C+Cl ₂	AlCl ₃

The apparatus may also be used where a hot gas mixture containing a corrosive component is desired, as in the production of hot air for wind-tunnel use by feeding nitrogen past the cathode with oxygen added at 37.

As specific example of reaction particularly benefited by the invention is the production of acetylene from hydrocarbons. In this case hydrogen is brought into the cathode region 30 and passed through the restriction 32 into the anode chamber. The arc is struck and hydrocarbons are then brought into the anode chamber through the secondary injection ports 37. We have used hydrocarbons from methane through octane with and without additional hydrogen. In this manner good yields of acetylene are achieved, the efficiency of the arc was from 70 to 90 percent, versus a normal 40 to 50 percent, the arc was stable for periods up to 24 hours, and there was no detectable electrode wear (less than 0.1 gram) in 24 hours versus a 0.1 to 0.4 gm./minute weight loss in similar systems without a restriction.

We have also discovered that the invention affords uniquely different optimum conditions for producing acetylene. Specifically, we have found that good yields of acetylene, or combinations of acetylene and ethylene, may be produced with a lower hydrogen to carbon ratio without forming solid carbon. In conventional systems, the formation of carbon in the arc is extensive and is detrimental to the economics as well as being an operational hazard in systems used to purify the raw acetylene gas. We have found that by feeding a part of the hydrogen about the cathode into the arc, and another part into the anode with the hydrocarbons, acetylene or combinations of acetylene and ethylene can be produced with no carbon formation.

This is accomplished in two ways. First, the partial pressure of carbon is reduced by hydrogen dilution so that at a given temperature more of the carbon is in the vapor phase where C₂ gas and C₂H gas, the precursors of acetylene and ethylene, may be formed. Second, the hydrogen that is brought in with the hydrocarbon feed is used to further dilute the hydrocarbon in the relatively cool boundary layer next to the anode walls, and thus prevent solid carbon from being formed there since at the lower temperature a greater dilution is necessary. As an example a run was made with the conditions and results presented in the following Table II.

TABLE II
[Production of acetylene]

Hydrocarbon	Feed, lb./hr.			Power, kw.	Products, lb./hr.			Percent of energy lost to electrodes
	Hydrogen to cathode	Hydrogen to anode	Hydrocarbon to anode		Acetylene	Ethylene	Carbon	
Octane.....	3.57	2.55	56.8	72.3	21.45	13.80	None	31.5
Propane.....	2.60	1.68	31.9	50.6	12.8	8.06	None	30.2

roduced through lines 36, which would tend to corrode the tip. The following table typifies feeds suitable for introduction through lines 27 and termed "Material to Cathode," other reactants which may be fed through line 36 are listed under "Material to Anode" with the reaction products listed in the "Products" column.

The hydrogen to carbon mole ratio was 1.89 in the octane case and 2.32 in the propane case, and both represent a much lower figure than has been attainable previously without appreciable amounts of carbon being formed. As the molecular weight of the hydrocarbon decreases, the ratio of hydrogen to carbon necessary to prevent carbon

formation increases. With methane the ratio is near 4.0.

An added advantage of being able to mix hydrogen with the hydrocarbons prior to injection into the anode is that the mixture may be preheated to a higher temperature in a gas-fired furnace without cracking, thus allowing substitution of more low cost fuel gas energy for high cost electrical energy at the lower temperature levels than is possible without hydrogen present.

As will be apparent from the foregoing, the invention contemplates, but without limitation, feeding to the cathode passage noncorrosive materials within the category of nitrogen, hydrogen and ammonia, for reaction with materials such as hydrocarbon, oxygen, hydrogen, halogen, and where desirable, with gas-entrained carbon, halogen-reactive metal and oxide of such metal.

We claim:

1. Gas ionizing apparatus for effecting chemical reactions, comprising

(a) walls including a tubular anode forming a conductive wall passage converging to a restricted throat and enlarging beyond said throat into a conductive wall reaction chamber,

(b) a cathode axially aligned with said throat and having a tip at arc gap spacing from the throat wall while being sufficiently close to said reaction chamber that an arc emanating from the cathode tip projects unattached through said throat and flares outwardly and attaches to the reaction chamber wall,

(c) means for admitting a first fluid to said passage at high velocity for flow about and past the cathode tip into said throat and chamber to prevent the arc attachment in said throat and thus provide for the arc attachment to the reaction chamber wall,

(d) means for introducing into said passage at a location beyond said throat in the direction of flow there-through and into the flaring arc within the reaction

chamber a second fluid stream containing a reactant for reaction with said first fluid, and

(e) electrical current connections for said cathode and anode for supplying current at potential sufficient to maintain said projection of the arc into the reaction chamber and to its wall.

2. Apparatus according to claim 1, in which said cathode is substantially larger in diameter than said throat.

3. Apparatus according to claim 1, in which said cathode has an essentially tungsten tip.

4. Apparatus according to claim 1, in which said throat is of substantially cylindrical form having a length to diameter ratio between about 1 to 1 and 4 to 1.

5. Apparatus according to claim 1, in which the conductive reaction chamber wall has an outwardly flared portion beyond the discharge end of said throat and means for passing said fluid stream into said flaring arc.

6. Apparatus according to claim 5, in which said throat is of substantially cylindrical form having a length to diameter ratio between about 1 to 1 and 4 to 1, and the reaction chamber has beyond said flared portion a cylindrical extent having a diameter greater than twice the throat diameter.

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