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DIRECT CONVERSION CHEMICAL PROCESSING ARC HEATER

Filed Feb. 16, 1966 2 Sheets-Sheet 1

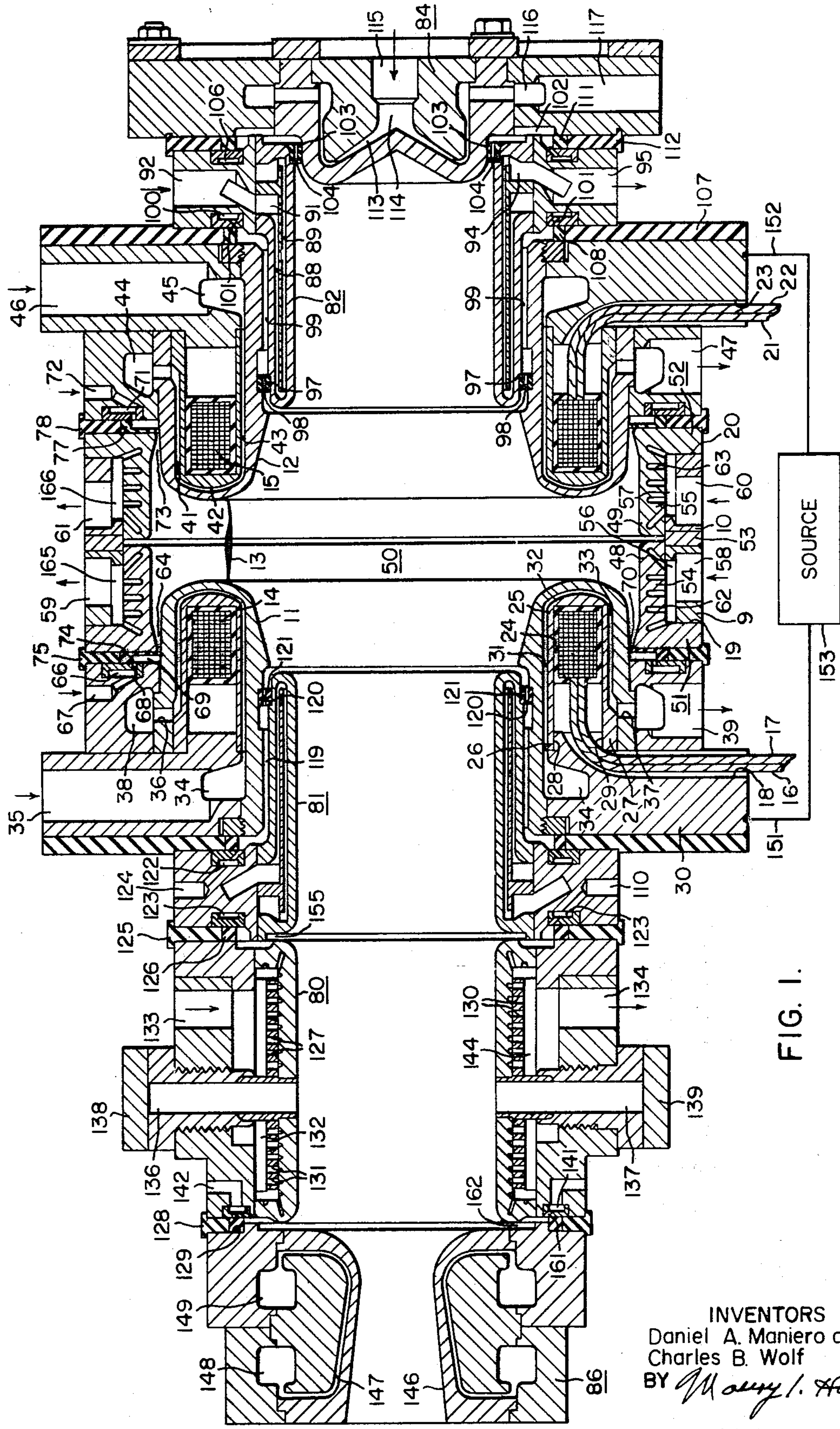

FIG. 1.

INVENTORS
Daniel A. Maniero and
Charles B. Wolf
BY [signature]
ATTORNEY

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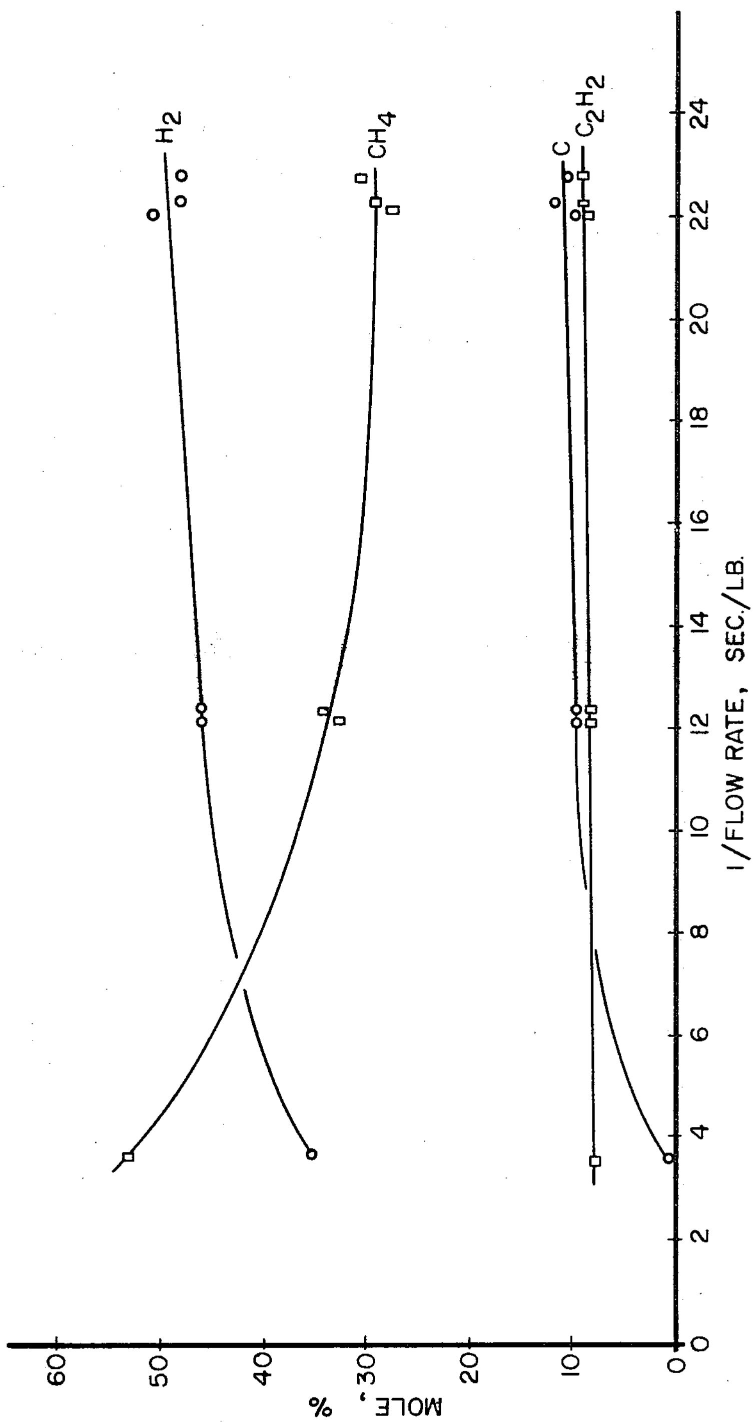

FIG. 2.

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DIRECT CONVERSION CHEMICAL PROCESSING ARC HEATER

Daniel A. Maniero, Monroeville, Pitcairn, and Charles B. Wolf, Irwin, Pa., assignors to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

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U.S. Cl. 23—277 5 Claims

ABSTRACT OF THE DISCLOSURE

An arc heater has a pair of axially spaced annular electrodes forming a gap with a generally axially extending arc therebetween, the electrodes having magnetic field coils therein for generating a magnetic field which exerts a force on the arc and cause it to move substantially continuously around and between the electrodes and to describe a generally annular or cylindrical path. Process gas to be pyrolized is substantially continuously admitted under pressure into the arc heater through a substantially circumferential admission path radially external to the electrodes from which it passes rapidly in a generally radial direction through the gap between electrodes and through the annular path described by arc movement and into an arc chamber. The arc describes its annular path at such a fast repetitive rate that pyrolysis with substantially uniform heating of the process gas are obtained. The arc chamber is elongated providing a long path for process gas between arc pyrolysis area and exhaust area; cooling of the pyrolized gas to a temperature at which a a desired recombination product is present in substantial proportion may occur within the arc chamber. Quenching gas may be introduced into the arc chamber at one or more axially spaced positions along the path of the process gas. The volumetric capacity of the arc chamber is increased by having the upstream end of the arc chamber closed in a substantial axial distance from the upstream electrode.

This invention relates to improvements in arc heaters, and more particularly to an improved arc heater for the processing of one gas and the conversion thereof to another desired product gas, or carbon.

It has been known for some years that an electric arc may be used to pyrolyze a gas, and after the gas has been decomposed into atoms and free radicals, the atoms and free radicals may recombine to produce a different and desired product gas, depending upon the temperature to which the decomposed gas is quenched or cooled and the speed with which it is cooled after pyrolysis takes place. Sometimes an auxiliary gas may be added to assist in rapid cooling.

The arc heater of our invention utilizes an arc to pyrolyze the process gas or feed stock, for example CH_4 or C_3H_6 which is thereafter quenched and cooled, so that a substantial yield of the product gas, for example C_2H_2, is obtained. The arc heater of our invention is especially suitable for handling high flow rates of the process gas, and for producing the product gas with a minimum of kilowatt hours of electricity to the arc per pound of the product gas. For example, in one experimental test run of our arc heater, methane (CH_4) was utilized as a process gas with a flow rate of 0.275 lbs. per second. The power to the arc electrodes was 840 kilowatts, and the acetylene, C_2H_2, yield was 5.03 kilowatt hours of electricity utilized by the arc, per pound of acetylene C_2H_2, a figure which compares very favorably with other processes now in general use, such as the Du Pont process and Huels process.

Accordingly a primary object of our invention is to

provide a new and improved direct conversion chemical processing arc heater.

Another object is to provide a new and improved chemical processing arc heater in which large flow rates of a process gas may be employed.

Still a further object is to provide a new and improved arc heater for chemical processing in which the kilowatt hours per pound of a product gas are maintained at a low value.

These and other objects will become more clearly apparent after a study of the specification, when read in connection with the accompanying drawings, in which:

FIG. 1 is a cross-section through the direct conversion chemical processing arc heater according to the preferred embodiment of our invention; and

FIG. 2 is a graph illustrating the operation of the apparatus of FIG. 1.

Referring now to the drawing of FIG. 1 for a more detailed understanding of the invention, a pair of fluid cooled electrodes **11** and **12** have an arc **13** therebetween. It is seen that the electrodes **11** and **12** are annular in shape, and that each of the electrodes has an annular magnetic field producing coil therein, these being designated **14** and **15** respectively. If desired, field coils **14** and **15** are energized by direct current, the leads to the coil **14** being shown at **16** and **17** passing through a passageway **18**, the leads to coil **15** being shown at **21** and **22** passing through passageway **23**. Coils **14** and **15** may be energized by direct current with their fields in opposition so that a magnetic field is produced between electrodes which is substantially transverse to the path of the arc **13** and which exerts a force on the arc **13** which causes it to rotate substantially continuously around the annular arcing surface of the electrodes in a conventional manner. The rotation of an arc by a magnetic field has been described elsewhere in the literature of the art and in prior art patents and need not be described in detail.

Coil **14** is seen to be mounted in an annular housing **24** composed of insulating material, the housing **24** being disposed within an annular cup-shaped member **25** which is generally U-shaped in cross section, which has ends **26** and **27** thereof abutting against annular shoulders **28** and **29** of an electrode supporting and fluid channeling member **30**. The cup-shaped member **25** is seen to be spaced from the inner wall of the generally U-shaped electrode **11** providing fluid passageways **31**, **32** and **33**. It is seen that the portion of the fluid passageway **31** at the left-hand end thereof communicates with a fluid header **34**, which may be a fluid inlet header, and which has fluid inlet **35**. Passageway **33** around the other side of the coil and coil housing communicates by way of a plurality of circumferentially spaced passageways **36** and **37** with a fluid header **38** which may be a fluid outlet header. In actual practice in the construction of the arc heater of the figure, two fluid inlets spaced 180° apart are provided for the fluid inlet header **34**, there being an inlet in addition to the inlet shown at **35**; and in addition there are two fluid outlets **39**, only one being shown for simplicity of illustration for the fluid outlet header **38**, the fluid outlets being preferably spaced 180° apart.

The internal construction of the other electrode **12** is similar to that of the electrode **11** and need not be described in detail. Fluid passageways **41**, **42**, and **43** around the three sides of the field coil **15** communicate, one with fluid outlet header **44** and another with fluid inlet header **45**. Fluid inlet header **45** is seen having the inlet passageway **46** communicating therewith, and outlet header **44** has outlet **47**.

Between the two electrodes **11** and **12** there is a heat shield enclosing the chamber in which the arc takes place, this heat shield including two generally annular ring members **51** and **52**, separated by a center ring **53**. The two annular L-shaped ring members generally designated **51** and **52** each has a plurality of annular fingers **54** and **55** respectively extending from ring inside wall portions **48** and **49** respectively forming in each ring member a plurality of spaced annular passageways **62** and **63** respectively. Within 360° annular grooves **19** and **20** of ring members **51** and **52** respectively are disposed ring members **9** and **10** respectively having short fluid inlet headers **56** and **57** respectively, fluid header **56** having inlet **58**, and fluid header **57** having inlet **60**. Disposed 180° from the aforementioned inlets **58** and **60**, are two outlets **59** and **61** communicating with fluid outlet headers **165** and **166** in rings **9** and **10** respectively, so that fluid flows in two semicircular paths in passageways **62** and **63**.

Between the aforementioned ring member **51** and the adjacent electrode **11** there is disposed means for introducing gas, either a process gas or a quenching gas or some auxiliary gas, at a plurality of circumferentially spaced points around the electrode **11**, the gas entering the chamber **50** through the annular passageway **64**. The annular passageway or opening **66** constitutes a gas header, and in actual practice the arc heater would employ two gas inlets to this gas header **66**, one of these gas inlets being shown at **67**, it being understood that another gas inlet spaced if desired at 180° therefrom would also be provided. From the gas header **66** gas passes through a plurality of circumferentially spaced passageways **68** and into annular space **69**, thence through gaps or spaced

Adjacent the aforementioned electrode **12** is a similar into the portion of the chamber **50** where the arc rotates. bores **70** into the aforementioned annular space **64** and gas header **71** having gas inlet **72**, gas from the gas header **71** entering the arc chamber through the annular space **73**.

It is noted that electrode **11** is separated from annular ring **51** by annular insulating means including annular insulating members **74** and **75**, and that electrode **12** is electrically insulated from ring member **52** by means including annular insulating members **77** and **78**.

It is noted that the remainder of the arc heater includes sectionalized arc chamber walls, these including a heat shield generally designated **80**, which section may be eliminated if desired, a heat shield generally designated **81**, and a heat shield generally designated **82**. It is further noted that the right-hand end of the arc chamber **50** is closed by an end plug generally designated **84** and that on the left-hand of the arc heater as seen in the figure there is a nozzle generally designated **86**.

It is seen that the aforementioned cylindrical heat shield **82** is fluid cooled by fluid flowing in passageways **88** and **89**, passageway **88** connecting with fluid header **91** and thence with fluid inlet **92**, passageway **89** communicating with fluid header **94** and thence with fluid outlet **95**.

It is further to be noted that gas is admitted into the chamber **50** at a plurality of circumferentially spaced positions around the heat shield **82**, there being an annular insulating member **97** with spaced bores **98** communicating with an annular passageway **99** which communicates by way of spaced bores **101** with an annular gas header **100** which has a gas inlet, not shown for convenience of illustration, disposed at a convenient position on the arc heater.

Gas is also admitted at a plurality of circumferentially spaced positions around the end plug generally designated **84** and near the inner chamber wall of the heat shield **82**. There is an annular space **102** which serves as an auxiliary gas header, and an annular gasket of insulating material **103** having a plurality of bores **104** at spaced intervals therearound to permit a quenching gas or an auxiliary gas or a process gas to be introduced into the chamber **50**. The annular space **102** communicates with annular gas header **106**. It is further seen that the heat shield generally designated **82** is electrically insulated from the electrode **12** by means **107**, **108**, and that the heat shield generally designated **82** is electrically insulated from the end plug **84** by means **111** and **112** composed of insulating material. End plugs **84** is seen to be fluid cooled, having a conical passageway **113** extending from fluid header **114** connected to fluid inlet **115**. The conical passageway **113** communicates with a fluid header **116** connected to fluid outlet **117**.

The aforementioned heat shield **81** is similar to the heat shield **82** and need not be described in detail. Suffice it to say regarding the heat shield **81** that the surface thereof which faces the arc chamber **50** is fluid cooled by fluid passageways having fluid inlet and fluid outlet headers communicating with fluid inlets and fluid outlets. A gas is admitted at a plurality of circumferentially spaced positions between heat shield **81** and heat shield **80** and a gas is admitted at, or can be admitted at, a plurality of circumferentially spaced positions between heat shield **81** and electrode **11**, the last named gas passing through the passageway **119** and through spaced bores **120** in an annular ring of insulating material **121**. The gas header for the last named gas is designated **122** having inlet **124**, while the gas header for gas admitted by way of annular space **155** the heat shields **80** and **81** is designated **123**, having a gas inlet, not shown, for convenience of illustration.

Particular attention is directed now to the heat shield **80**, which is electrically insulated from heat shield **81** by insulating means **125** and **126** and electrically insulated from nozzle **86** by insulating means **128** and **129**. Heat shield **80** is cooled by fluid passing through annular passages **131** communicating by way of holes **127** with a fluid header **132** having fluid inlet **133**, and communicating by holes **130** with outlet header **144** having fluid outlet **134**, spaced 180° from inlet **133** so that fluid flows through two semicircular paths. Passageways **136** and **137** may be used for seeding or sampling or quenching or mixing purposes, but may be plugged up by plugs **138** and **139**, which may be secured thereto by bolts, not shown for convenience of illustration.

If desired, the heat shield **80** may be entirely eliminated from the arc heater, and the arc chamber wall may comprise an up-stream heat shield **82**, and a downstream heat shield **81**.

Gas may be injected between the aforementioned heat shield **80** and the aforementioned nozzle **86** by way of gas header **141** having inlet **142**, header **141** communicating by spaced passageways **161** with annular space **162**.

The aforementioned nozzle **86** is seen to include a fluid cooled inner surface **146** having fluid flow passageway **147** near the inner surface, the passageway **147** communicating with a fluid inlet header **148** and a fluid outlet header **149**, these communicating with inlets and outlets respectively, not shown for convenience of illustration.

It is seen, then, that there is provided an arc heater with means for supplying a large electrical current to the electrodes, symbolized by leads **151** and **152** connected to source of potential **153** to produce and sustain the arc **13**; magnetic field coils **14** and **15** are energized to set up a magnetic field which causes the arc to rotate at a predetermined speed which is neither too fast nor too slow, the arc moving from any particular position before the intensely hot arc spot has burned through the electrode, the arc not returning to the same position until that area or that point on the electrode has had a chance to cool down to a safe temperature. It is further seen that gas may be admitted into the arc chamber at a plurality of points depending upon the process gas used and the desired product. As will be readily understood, the process gas is pyrolized or decomposed by the heat of the arc and thereafter it is cooled to a temperature at which some desired recombination product is present in substantial proportion, the exact temperature of cooling determining in part the proportion of the desired recombination product.

It will be understood that the gap between electrodes **11** and **12** is adjustable, if desired by having a number of rings **51–52** of various widths available for use.

Particular reference is made now to Tables I, II, III, and IV which show the results of tests runs. In all of these test runs, the arc was powered by alternating current, and the electrode gap was ⅜ inch.

To insure purity of process gas and accurate measurements of the recombination products, the arc chamber was "flushed" before process gas was admitted by supplying chemically pure nitrogen to the chamber for several seconds. At the conclusion of the supplying of process gas to the arc heater, nitrogen was again supplied to the arc heater for several seconds.

The tables show results for various flow rates of the process gas and various powers to the electric arc.

TABLE I.—COMPOSITION IN VOLUME PERCENT OF PRODUCT GAS IN CH_4 FLAME

Run No.	CH_4, lbs./sec.	Power to gas, kw.	Composition, percent							Kw. hr./lb. C_2H_2
			H_2	CO	CH_4	C_2H_2	C_2H_2	C_4H_2	Other	
1	0.045	360	54.93	--------	33.39	10.16	1.05	0.23	0.24	9.9
2	0.081	440	50.98	--------	38.17	9.52	0.88	0.21	0.25	6.8
3	0.275	840	35.80	1.47	53.59	7.82	0.83	0.29	0.20	5.03

TABLE II.—CONVERSION OF CH_4 TO PRODUCTS

Run No.	Percent reference to total carbon					
	Soot	C_2H_2	C_2H_4	C_4H_2	CO	Other
1	37.58	52.03	5.36	2.34	--------	2.69
2	32.29	56.97	5.24	2.49	--------	3.01
3	2.92	73.99	7.70	5.30	6.02	4.07

Tables I and II show a chemical analysis of the gas in the arc heater where methane is used as the process gas, and the desired recombination product is acetylene C_2H_2. In obtaining test samples of gas for chemical analysis, a probe consisting of a water cooled concentric copper tube with a ⅛ inch bore was employed, the bore opening of the probe being at the nozzle, preferably of the axis thereof. Runs 1, 2 and 3 are the same runs in Tables I and II with their results analyzed in different manners and show the results for different flow rates of the matane, and different input powers to the arc heater, together with the quantity of the desired output (Table I), measured in kilowatt hours per pound of the desired recombination product gas. Test run number 3 shows that for a certain flow rate and arc input power, the yield of acetylene, measured in kilowatt hours per pound of acetylene, compares very favorably with presently used processes. In test run No. 3 which produced such efficiency in the conversion of Methane to acetylene, Methane was introduced at the following points in the arc heater:

40% by gas inlet **67**.
40% by gas inlet **72**.
4% by gas inlet **124** and gas header **122**.
4% by the corresponding gas inlet (not shown). for gas header **100**.
4% by the gas inlet (not shown) for gas header **106**.
4% by gas header **123** and gas inlet **110**.
4% by gas inlet **142** and gas header **141**.

Particular references made now to Table II, where test runs 1, 2 and 3 are analyzed with respect to, or with reference to, the total carbon, and it is seen that the electrical and flow rate conditions which produce the most efficient conversion to acetylene are also accompanied by the production of the least carbon in the arc heater.

Particular reference is made now to Graph No. 1, where variations in some of the products are charted for various flow rates.

In the curves of FIG. 2, the quantities of H_2, CH_4, C, and C_2H_2 expressed in mole percentage are shown varying with variations in the reciprocal of the flow rate of CH_4 supplied to the arc chamber, and the curves correspond generally to the values of Tables I and II.

Particular reference is made now to Table No. III, where the process gas employed was C_3H_6 and the composition of the product is analyzed with respect to the three different flow rates and three different input powers to the arc heater.

Particular reference is made now to Table No. IV, where product values obtained during the same test runs, that is runs 4, 5 and 6, are shown with percent reference to the production of total carbon, where the process gas is as before C_3H_6.

In summary, we have provided an arc heater in which a process gas may be introduced at one or more of a number of points up-stream and down-stream of an arc to assist in providing maximum production of the desired product for a given kilowatt hours of power to the arc.

Further, although an auxiliary quenching gas was not employed in the test runs described, out apparatus provides that a quenching gas or an auxiliary gas may be introduced at a number of points up-stream and down-stream of an arc or substantially in the area of the arc path.

TABLE III.—COMPOSITION IN VOLUME PERCENT OF PRODUCT GAS IN C_3H_6 FLAME

Run No.	C_3H_6, lbs./sec.	Power to gas, kw.	Composition, percent								
			H_2	CO	CH_4	C_2H_2	C_2H_4	C_3H_6	C_4H_2	C_6H_6	Other
4	0.106	630	96.71	1.52	0.25	1.16	0.15	--------	0.12	--------	0.08
5	0.035	330	76.34	--------	16.69	3.22	3.30	--------	--------	0.31	0.13
6	0.061	170	39.36	--------	6.97	12.07	3.80	36.11	0.29	0.16	0.67

These auxiliary/or quenching fluids, including gases and liquids, may be desirable or needed in other chemical conversion processes for which our apparatus is adapted.

We have provided a direct conversion chemical processing arc heater which, in terms of kilowatt hours per pound of the product gas desired yields far greater efficiency than any known method of gas conversion.

TABLE IV.—CONVERSION OF C_3H_6 TO PRODUCTS

Run No.	Percent reference to total carbon						
	Soot	C_2H_2	CH_4	C_2H_4	C_6H_6	C_3H_4	C_4H_2
4	96.05	2.35	0.27	0.31	--------	0.27	0.41
5	73.46	5.34	13.83	5.48	1.56	0.33	--------
6	42.87	32.19	9.29	10.13	1.28	2.68	1.15

This invention constitutes a further development and advance in the chemical processing art, as described in the copending application of Messrs. Bruning, Kienast, Kemeny and Hirayama for "Cross-Flow Arc Heater Apparatus and Process for the Synthetic of Carbon, Acetylene and Other Gases," filed Nov. 12, 1965, Ser. No. 507,-345; to that of C. Hirayama et al. for "Method and Equipment for the Pyrolysis and Synthesis of Hydrocarbons and Other Gases and Arc Heater Apparatus for Use Therein," Ser. No. No. 446,012, filed Apr. 6, 1965, now issued Pat. 3,389,189; that of P. F. Kienast et al. for "Arc Heater Apparatus for Chemical Processing," Ser. No. 471,914, filed July 14, 1965, now Pat. No. 3,345,191; and that of D. A. Maniero et al. for "Process for Hydrogen Cyanide and Acetylene Production in an Arc Heater Having a Rotating Arc," Ser. No. 657,867, filed Aug. 2, 1967, now Pat. No. 3,460,902, all of the above-identified patents and the above-identified application being assigned to the assignee of the instant invention.

Whereas we have shown and described our invention with respect to an embodiment thereof which gives satisfactory results, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense; changes may be made and equivalents substituted without departing from the spirit and scope of the invention.

We claim as our invention:

1. Arc heater apparatus for chemical processing comprising generally cylindrical means forming an arc chamber, first and second axially spaced annular electrodes disposed in the arc chamber with an annular gap therebetween, the second electrode being the downstream electrode, means for producing and sustaining an arc between the first and second electrodes, the arc extending generlly in an axial direction, means for causing the arc to move substantially continuously around and between the first and second electrodes and to describe a generally annular path, means for introducing a process gas into the arc chamber through a substantially circumferential path radially external to the electrodes from which the process gas passes in a generally radial direction through the gap between electrodes and through the annular path described by arc movement, said arc pyrolizing the process gas, and means located downstream of the second electrode a distance substantially equal to the distance between the arcing surfaces of the first and second electrodes for introducing a quenching gas into the chamber, the quenching gas acting to cool the pyrolized gas, and nozzle exhaust means for the arc chamber.

2. An arc heater for chemical processing comprising generally cylindrical means forming an arc chamber, first and second axially spaced annular electrodes disposed in the arc chamber with an annular gap therebetween and assisting in defining the arc chamber, the second electrode being the downstream electrode, means for producing and sustaining an arc between the first and second electrodes, the arc extending generally in an axial direction, means for causing the arc to move substantially continuously around and between the first and second electrodes and to describe a generally annular path, means for introducing a process gas into the arc chamber peripherally spaced positions between the first and second through a

substantially circumferential path radially external to the electrodes from which the process gas passes in a generally radial direction through the gap between electrodes and through the annular path described by arc movement and is pyrolized by the arc, nozzle exhaust means for the arc chamber, and heat shield means extending between the second electrode and the nozzle exhaust means, the heat shield means being at least several times greater in length than the distance between the first and second electrodes whereby sufficient time is provided for the process gas after being pyrolized to be substantially cooled as it moves away from the arc zone before being exhausted from the nozzle means.

3. Arc heater apparatus according to claim **2** additionally characterized as including means for injecting a quenching fluid into the pyrolized process gas at some position along the length of the heat shield means and before the process gas is exhausted through the nozzle exhaust means.

4. Arc heater apparatus according to claim **3** in which the heat shield means is composed of two elongated sections and the quenching fluid may be injected at a plurality of peripherally spaced points between the two sections of the heat shield means.

5. Arc heater apparatus according to claim **1** in which the means forming an arc chamber includes a closing plug for the upstream end of the arc heater and an elongated heat shield interposed between the first electrode and the closing plug, the space enclosed by the last-named elongated heat shield increasing the volumetric capacity of the arc chamber thereby increasing the conversion effiency of the arc heater where methane is the process gas and the desired recombination product is acetylene.

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J. H. TAYMAN JR., Primary Examiner

U.S. Cl. X.R.

23—1, 209.3, 259.5; 204—311, 323; 219—75, 121, 123; 260—679; 313—32, 231