Jan. 29, 1952 L. H. SMITH 2,583,899

ELECTROCHEMICAL PROCESS

Filed Nov. 29, 1950 2 SHEETS—SHEET 1

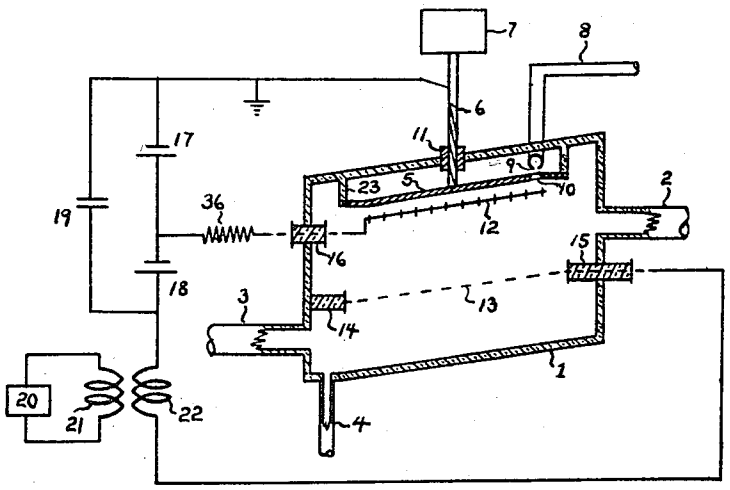

FIG. 1

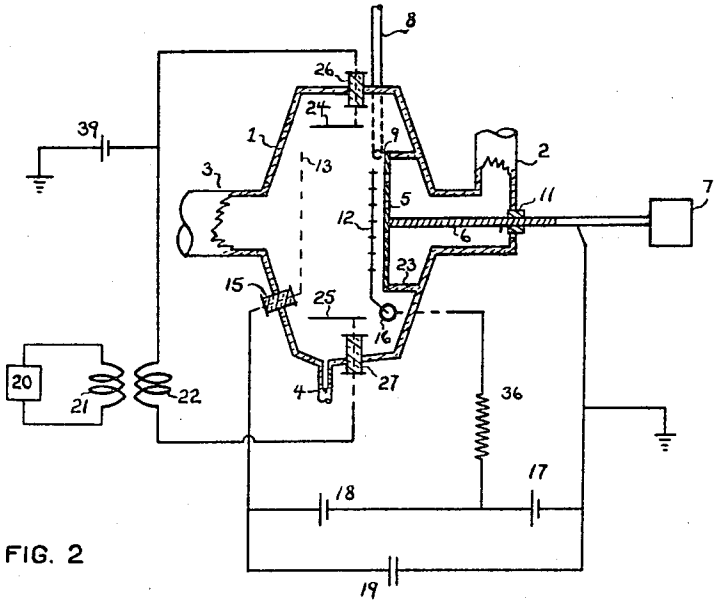

FIG. 2

INVENTOR.
Lester H. Smith.
By: Smith, Murchison & Gardner
attorneys.

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FIG. 3

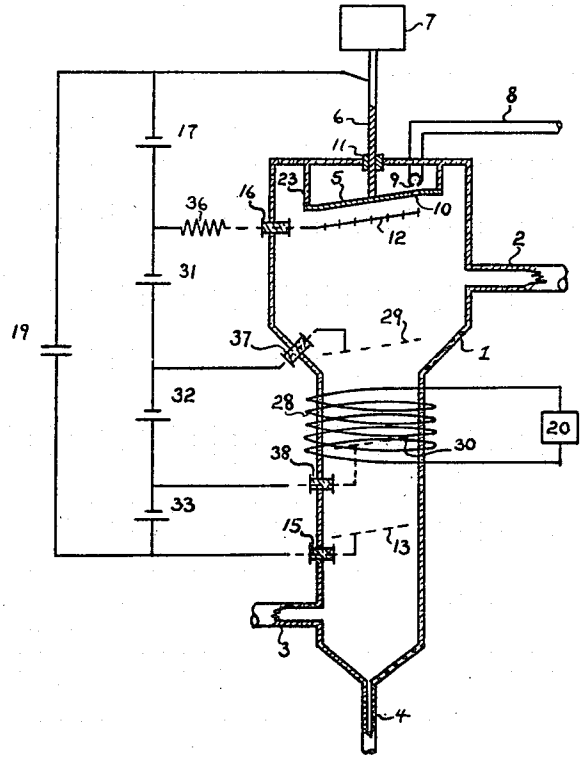


FIG. 4

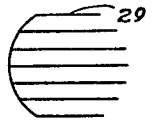


FIG. 6

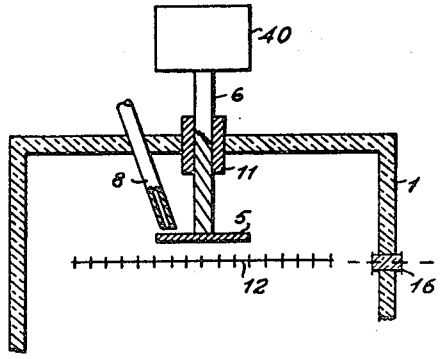
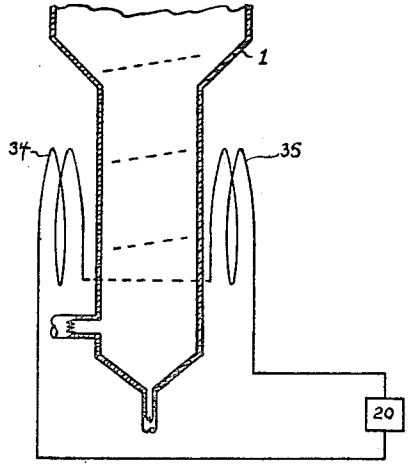


FIG. 5



INVENTOR.
Lester H. Smith.
By Smith, Michael & Friedman
attorneys

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UNITED STATES PATENT OFFICE

2,583,899

ELECTROCHEMICAL PROCESS

Lester H. Smith, Maplewood, N. J.

Application November 29, 1950, Serial No. 198,081

9 Claims. (Cl. 204—164)

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This invention is concerned with an improved method of producing electrochemical reactions in gases or suspensions in gases by means of passing electrically charged material particles through the gas or suspension, and at the same time subjecting the gas or suspension and electrically charged particles to a high frequency electrostatic or electromagnetic field.

This application is a continuation in part of my application No. 613,174 now abandoned.

Considerable experimental work has been done in the field of electro-chemistry of gaseous systems using high frequency electrostatic or electromagnetic fields. Direct current discharges through gases at low pressures have also been used to bring about electro-chemical reactions. Certain chemical processes have been proposed utilizing high voltage direct current surface emission type discharges through gases in combination with high frequency electric fields acting on the zone of direct current discharge.

My invention is concerned with a method of mechanically projecting material particles into a gas such as the spraying of liquid particles from a nozzle or projecting liquid or solid particles from vibrating or rotating surfaces into a gas, electrically charging these particles by electrostatic induction as they are projected and subjecting the drifting charged particles and surrounding gas to a high frequency electric field.

In this application as well as my divisional applications, I have used the expression electric space charges to describe an accumulation of electrically charged material particles, either liquid or solid, drifting in space between electrodes in the apparatus. At the same time, I also refer to electric charges which may become attached to gas molecules if electrically charged material particles are evaporated or gasified in space.

Substances which are in a gaseous state are in their molecular form, and the method of bringing about evaporation or gasification of electrically charged liquid particles in space by means of taking up heat from the surrounding gas or heat that may be generated in the liquid particles by means of a high frequency electric field or heat generated by chemical action, is a means of producing ionized gas and transient free electric charges. The chemical activity of various mixtures of gases partially ionized by electric high velocity discharges is well known. In this invention, however, gas ionization is not brought about by electron emission from cathode surfaces, but is by dispersion and attachment to gas molecules of electric charges originating in gasified electrically charged liquid particles. The influence of a high frequency electric field on gas ions and transient free electric charges is to

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produce motion of gas ions and circulating currents in a gas mixture. Obviously, this method is much more effective in producing gas phase chemical reactions than the use of high frequency electric fields only through gases at low pressures.

The principal object of this invention is to combine the effect of an electric space charge, as defined previously, and a high frequency electrostatic or electromagnetic field on various gases or suspensions in gases. The said gases in the zone of reaction may include ionized gas derived from the gasification in space of electrically charged particles such as liquid spray particles.

Other objects of this invention will be apparent from the drawings and the following description of the features of the invention and in the provision of apparatus and methods of operation for accomplishing the foregoing object.

As specifically stated in the claims, the interelectrode potentials are limited to values such that direct interelectrode breakdown type unidirectional discharging does not take place. In other words, whatever current passes between the electrodes in the apparatus is derived principally from electric charges on material particles projected into the gas in the reaction zone. This will be made clear in connection with the description of the drawings. Breakdown potentials between electrodes in air and in the common gases are of the order of 20,000 volts per centimeter. Such breakdown potentials vary to a minor degree between gases. For a given gas they increase slightly with increased gas density and decrease substantially for high frequency potentials. Breakdown potentials or ionization potentials of the common gases including many hydrocarbons are well known to those skilled in the art.

The unidirectional potential differences, electrode spacings and other operating conditions illustrated in connection with the several figures are intended to give potential gradients which are well below breakdown values.

In accordance with one modification of my invention, electrically charged material particles are projected from an emitting electrode which may be a nozzle, a vibratory plate, or a rotating surface. Necessary electrostatic fields to induce the flow of electric charges on the projected particles are set up by an intermediate electrode in close proximity to the emitting electrode and by a collecting electrode located at a proper distance from the emitting electrode. Interelectrode unidirectional potential differences are maintained at suitable values so as to promote a drift of the charged particles toward the collecting electrode which also may provide an external

electrical return circuit to the emitting electrode. At the same time, a flow of gas or of a gas containing a suspension is maintained through the apparatus housing these electrodes. This flow of gas may contribute to the drift of charged particles previously mentioned. In addition to the direct current potentials, a high frequency potential source is connected between the emitting electrode or intermediate electrode and the collecting electrode, using these same electrodes to produce a high frequency electrostatic field. The design of the electrodes, the path of the drifting space charge and the circulation of the gas or suspension in a gas are such as to obtain maximum processing effect.

In accordance with a second modification of my invention, electrodes for producing a high frequency electrostatic field which are separate from the electrodes used to produce the unidirectional potential gradient, are used.

In accordance with a third modification of my invention, a space charge is produced in the same manner as described in connection with the first modification, by the projecting of electrically charged material particles from an emitting electrode in combination with an intermediate electrode and a collecting electrode. This space charge is passed through or in close proximity to a high frequency winding which generates a high frequency magnetic field. At the same time a flow of gas or of a gas containing a suspension is maintained through the same path traveled by the drifting space charge.

In each of the above modifications when the circulation of gas through the apparatus is in the same direction as the drift of charged material particles, this flow of gas may contribute to the said drift. The flow of gas through the apparatus may be counter-current to the projection of charged particles with proper proportioning of the potential gradients and gas velocities.

Referring to the drawings:

Figure 1 is an illustration of a preferred form of space charge device in which the same electrodes are used for setting up both the unidirectional electrostatic fields and the high frequency electrostatic field.

Figure 2 shows a modification of Figure 1 in which the entering gas may pass through the emitting electrode which is perforated. Furthermore, separate electrodes are provided for setting up the high frequency electrostatic field.

In Figure 3 is shown a preferred form of space charge device in which the drifting space charge and the gas or suspension circulating through the device are subjected to a high frequency electromagnetic field.

Figure 4 shows a typical intermediate electrode used in the device of Fig. 3.

In Figure 5 is illustrated an alternative arrangement of the high frequency electromagnetic winding of Fig. 3.

Figure 6 shows a form of rotating emitting electrode which can be utilized in either Fig. 1 or Fig. 3 in place of the vibratory emitting electrodes shown.

In Fig. 1 the vessel 1 is constructed of electrically non-conducting material such as glass sections or solvent resistant plastic material. Vessel 1 is provided with a gas inlet 2 and processed gas outlet 3 and drain outlet 4. A flexible circular metal plate electrode 5 in the upper portion of vessel 1 is supported from insulating collar 23 and is connected to the lower end of the shaft 6 which is in turn connected to a source 7 of intermittent vertical vibratory motion of approximately 120 cycles per second, operating on a cycle of on for 2 seconds and off for 2 seconds. The plate electrode 5 is the emitting electrode and is supplied with a fluid used to form charged particles through the tube 8. The tube 8 passes downward through the top of vessel 1 and makes a right angle bend and runs horizontally close to the upper surface of plate electrode 5. The tube 8 has a slot 9 in the lower surface. A slot 10 is also provided in the plate electrode 5 close to the slot 9 in tube 8. In between the periods of vibration of emitting electrode 5, additional fluid is supplied through tube 8 and slots 9 and 10 and runs downhill on the lower surface of plate electrode 5 covering this surface with a thin film of liquid. This film of liquid is projected downward as tiny droplets on vibration of the plate electrode 5. If required, electrode 5 may be provided with perforations at the lowest point to prevent liquid accumulation above the electrode. A gas-tight sleeve 11 in the top of vessel 1 permits vertical motion of the shaft 6. An intermediate electrode 12 of ¼ inch spacing $\frac{1}{8}$ inch diameter wire mesh is located close to the lower surface of emitting electrode 5, also a collecting electrode 13 in the form of a screen. Electrode 13 is supported by an insulator 14 and insulating bushing 15. Item 16 is also an insulating bushing. The emitting electrode 5 is connected to ground, as shown. Intermediate electrode 12 is maintained at a unidirectional potential of around 800 volts relative to ground by means of potential source 17. Collecting electrode 13 is maintained at a unidirectional potential of about 1500 volts relative to intermediate electrode 12 by means of potential source 18. The electrical condenser 19 of 0.10 microfarad capacity acts as an accumulator and facilitates the flow of electrical charges between emitting electrode 5 and collecting electrode 13. Resistor 36 of 2000 ohms is for current limiting purposes in case of temporary fluid bridges grounding electrode 12. A source 20 of high frequency current at about 50,000 cycles per second is connected to primary coupling coil 21. A secondary winding 22 coupled with coil 21 introduces a high frequency potential in series between collecting electrode 13 and direct current potential source 18.

The dimensions of the apparatus shown in Fig. 1 for the most part are not critical. Vessel 1 may be 6 inches in diameter measured horizontally and electrode 5 may be 4 inches in diameter. For the interelectrode potential differences specified, I prefer a minimum spacing between emitting electrode 5 at its nearest flexed position and intermediate electrode 12 of ¼ inch, and between intermediate electrode 12 and collecting electrode 13 of 1½ inch.

Operation of the device shown in Fig. 1 is as follows: A gas to be reacted such as propane, for example enters through gas inlet 2 at 165 lbs. p. s. i. g. pressure and about 35° C. temperature. The propane gas passes downward through collecting screen electrode 13 and leaves through outlet 3. The emitting electrode 5 projects a cloud of liquid butane spray particles at the reaction zone pressure of 165 lbs. p. s. i. g. The liquid butane would be at about 65° C. temperature and would be projected as spray from electrode 5 during periods of vertical vibration. The liquid butane particles projected downward carry an electric charge due to the electrostatic induction effect of grid electrode 12 and collecting electrode 13. After passing downward through the

intermediate grid electrode 12 the charged butane particles mix with the propane gas entering through connection 2. At the same time the electric charges carried on the particles are subjected to the high frequency electrostatic field set up between grid electrode 12 and collecting electrode 13. Gasification of the butane spray particles occurs at a reaction zone temperature of about 95° C. due partly to heat transfer from the propane gas, partly to heat generated by high frequency circulating currents and partly to reaction heat evolved in surrounding gas. Ionization and local electrolytic action also take place in the gas mixture which is in the reaction zone. Polymerization products resulting from this action may be collected as condensate in the bottom of vessel 1 or they may be separated from the gas leaving the apparatus by means that do not form a part of this invention. Between periods of vibration of the emitting electrode 5, the lower surface of electrode 5 is rewet with fluid entering through the tube 8. Residual electric charges are collected largely by electrode 13 and returning through the external circuit to emitting electrode 5. Flow rates may be 8 lbs. per hour of liquid butane to 600 std. cu. ft. per hour of propane gas.

In Fig. 2 the vessel 1 also is of electrically non-conducting material as in Fig. 1. Likewise, a gas inlet 2 and gas outlet 3 and drain connection 4 are provided. An emitting electrode 5 is vibrated in a horizontal direction by shaft 6 which passes through the gas-tight sleeve 11 and is connected to the source 7 of intermittent vibratory motion. The emitting electrode 5 is a 4 inch diameter flexible plate of metal provided with $\frac{3}{32}$ inch perforations to the extent of 40% of the plate area. Electrode 5 is supported at the edges by the insulating collar 23. Emitting electrode 5 is supplied with fluid used to form charged particles through the tube 8 which makes a right angle bend and extends horizontally across the top of emitting electrode 5. A slot 9 is provided in the horizontal portion of tube 8 close to the surface of emitting electrode 5. In between periods of vibration of electrode 5 the fluid supplied through tube 8 and slot 9 runs down over the front surface of emitting electrode 5. The intermediate grid electrode 12 and collecting screen electrode 13 are similar to those in Fig. 1 and function in the same manner except that they do not set up any high frequency electrostatic field. Vessel 1 may be 6 inches in diameter measured vertically. The spacings between electrodes 5, 12 and 13 may be the same as in Fig. 1. The parallel plate electrodes 24 and 25 which are spaced approximately 5 inches apart are connected through insulating bushings 26 and 27 to the high frequency secondary winding 22. The source 20 of high frequency current and primary winding 21 are the same as in Fig. 1. The emitting electrode 5 is connected to ground. Direct current potentials 17 and 18 and electrical condenser 19 and resistor 36 are the same as in Fig. 1. The high frequency electrodes 24 and 25 are maintained at a negative direct current potential of about 150 volts relative to ground by potential source 39.

Operation of the device shown in Fig. 2 is very similar to that of Fig. 1. The gas or suspension of material in a gas to be reacted enters through inlet 2, passes through the perforations in emitting electrode 5 toward the grid electrode 12 and collecting screen electrode 13 and out through the connection 3. At the same time, charged particles of the fluid supplied through the tube 8 are projected from emitting electrode 5 through the

intermediate grid electrode 12 and toward the collecting screen electrode 13. Circulating currents and electrolytic action in the mixture of charged particles and gas or suspension is promoted by the high frequency electrostatic field set up between electrodes 24 and 25. If, as in Fig. 1, propane gas were introduced through inlet 2 and liquid butane through tube 8, the same pressures and temperatures would be used as in Fig. 1, also the same flow rates and vibration cycle.

It may be desirable to make use of a perforated emitting electrode such as has been described in connection with Fig. 2 and to circulate the gaseous substances to be reacted counter-current to the projection of electrically charged spray particles, at the same time connecting the high frequency potential between the intermediate grid electrode and collecting electrode as in Fig. 1. In this case, referring to Fig. 2, the gaseous substances to be reacted would enter the apparatus through connection 3 and exit gas including some reaction products would leave the apparatus through connection 2. The high frequency potential winding 22 would be connected into the lead to electrode 13, as it is shown in Fig. 1. Potential 39 and its ground connection would be omitted. Liquid reactant would enter at 8 and would be projected as spray particles from the surface of emitting electrode 5 toward electrodes 12 and 13 as previously described. Such an arrangement appears to be advantageous since the gaseous reactant substances would be intimately mixed with the projected electrically charged spray particles of liquid reactant immediately upon these spray particles leaving the surface of the emitting electrode, minimizing the distance that these charged spray particles must be projected. This effect could be carried even further by connecting the high frequency potential between the emitting electrode 5 and the intermediate grid electrode 12. With counter-current flow of the gaseous reactant and electrically charged spray particles, gas ions and electrically charged products may not travel all the way to the collecting electrode. A reversal of the direction of travel may take place with the electric charges ultimately reaching the intermediate grid electrode and the discharged products passing out of the reaction zone through the perforations in the emitting electrode. Variation of the potential of the collecting electrode 13 enables this to be controlled together with the velocity of the gaseous reactant through the apparatus to obtain the best operating conditions.

With such an arrangement for applying the high frequency electrostatic field between electrodes 12 and 13 in Fig. 2 which has just been described for countercurrent flow, if liquid butane and propane gas were reacted the temperatures and pressures and reactant flow rates may be the same as in Fig. 1.

In Fig. 3 the vessel 1 is constructed of electrically non-conducting material as in Figures 1 and 2. Likewise, a gas inlet 2, processed gas outlet 3 and drain outlet 4 are provided. The arrangement of the emitting electrode 5, its dimensions and the method of supplying fluid to electrode 5 from which charged particles are formed and means for vibrating the electrode are identical with those used in Fig. 1. The first intermediate grid electrode 12 is identical with that of Fig. 1 and serves the same purpose. Capacitance 19 and resistor 36 are the same as in Fig. 1. In order to have the high frequency

winding 28 at a proper distance from the emitting electrode and to avoid excessive circulating currents in the emitting electrode, it is necessary to make use of several intermediate grid electrodes 29 and 30. These second and third intermediate grid electrodes 29 and 30 as well as the collecting screen electrode 13 are shaped as shown in Fig. 4 so as to discourage circulating currents. If desired, electrode 12 can also be shaped as shown in Fig. 4. The unidirectional potentials 31, 32 and 33 are each 1500 volts. Unidirectional potential 17 is 800 volts. The high frequency winding 28, consisting of 40 turns approximately 4½ inches in diameter, passes completely around the vessel 1 as shown and is supplied with high frequency current from the source 20 at a frequency of about 50,000 cycles per second. Items 15, 16, 37 and 38 are insulating bushings. Vessel 1 may be 4 inches in diameter where the winding 28 passes around it. Electrode 12 may be ¼ inch from emitting electrode 5 in its nearest flexed position. The spacings between electrodes 12, 29, 30 and 13 are each 1½ inches.

Operation of the device shown in Fig. 3 is as follows: The gas to be reacted, such as propane for example, enters through the gas inlet 2 and mixes with the electrically charged particles of liquid butane, for example, which are projected downward from the lower surface of electrode 5, as in Fig. 1. Pressures and temperatures of the two reactants may be the same as in Fig. 1. The mixture of charged butane particles and propane gas travels downward through the intermediate grid electrodes 29 and 30. As this mixture passes through the high frequency electromagnetic field set up by the winding 28, circulating currents are produced throughout the mixture, resulting in increased ionization of the gas or suspension and local electrolytic action. Residual electric charges equal to those leaving the emitting electrode 5 are collected principally on the screen electrode 13 and partially on the intermediate electrode 12 and are returned through the external circuit shown and various leakage paths to the emitting electrode 5. Polymerization products resulting may be collected in the bottom of vessel 1 or may be separated from the processed gas leaving through outlet 3 by separate condensing means not shown. Flow rates are the same as in Fig. 1.

In Fig. 5 the alternative arrangemnet of the high frequency winding such as is used in Fig. 3 consists merely of directing the electromagnetic field across the path of the charged particles and gas by splitting the winding into two halves 34 and 35. Other parts of the construction would remain the same as in Fig. 3.

In Figures 1 and 3 there are shown electrical connections for creating space charges of negative polarity. Opposite polarities of the potential sources used will create positive space charges as readily as negative ones. The size of the potentials applied between the various electrodes and the rate of vibration or rotation of certain emitting electrodes are not critical but can be varied as desired.

In Fig. 6 is shown an alternative arrangement with a rotating emitting electrode which can be used in place of the vibratory emitting electrodes shown in Figures 1 and 3. A partial sectional view only is shown in which item 1 is the wall of the vessel, 11 is a gas-tight insulating bushing which allows rotation of the shaft 6 and a disc emitting electrode 5 attached thereto. Item 40 is a motor which turns shaft 6 at approximately 200 R. P. M. Tube 8 feeds fluid material to the top surface of disc 5 and the material is then projected in the form of fine particles from the edge of the disc 5 and falls through the openings in the intermediate grid electrode 12. Item 16 is an insulating bushing.

With regard to the electrical processing of suspensions in gases, it is contemplated that certain materials in a finely divided state may be suspended in a gas in order to be able to process them in electric space charge apparatus. The gas present may or may not enter into the reaction or change of state which it is desired to accomplish.

As mentioned in my copending applications, it may be desirable to use insulating bushings and electrode supports which are provided with internal heating coils so as to prevent wetting of the insulating surfaces exposed inside the processing chamber.

In my copending application No. 34,300 there is disclosed an emitting electrode arrangement for electric space charge devices which is particularly adapted to electrically charging and spraying high dielectric strength liquids. This arrangement is described as a liquid film charging arrangment, and consists of a close clearance passage with opposite electrode walls which produce a displacement type charging current in a liquid film which is passed through the close clearance passage and issues from it as a spray directed toward intermediate electrodes and a collecting electrode similar in principle to those used in this application. The use of emitting electrode arrangements of the type disclosed in my copending application No. 34,300 in combination with high frequency electric fields, as herein disclosed, is contemplated.

In the claims the expression "emitting electrode" is intended to cover broadly any type of electrode for projecting mechanically or hydraulically material particles which are electrically charged due to the functioning of the emitting electrode in combination with other separated electrodes in the apparatus.

Obviously, the electro-chemical reaction method which has been illustrated is applicable to many vapor phase reaction processes normally requiring material catalytic agents. Either unsaturated or saturated hydrocarbons can be polymerized and many other types of reactions accomplished between gasifiable liquids or solids and gases.

This invention has been illustrated only in a general preferred form throughout and it should be understood that it is capable of many and varied modifications without departing from its purpose and scope, and I therefore believe myself to be entitled to make and use any and all of these modifications such as suggest themselves to those skilled in the art to which the invention is directed, provided that such modifications fall fairly within the purpose and scope of the hereinafter appended claims.

What is claimed is:

1. A method of reacting a liquid and gaseous substances comprising providing a reaction zone with an emitting electrode, an intermediate electrode and a collecting electrode; passing said gaseous substances to be reacted through said zone while projecting electrically charged spray particles of said liquid substance from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collect-

ing electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; subjecting said gaseous substances and electrically charged spray particles of said liquid substance to a high frequency electric field having a frequency above about 50,000 cycles per second; gasifying said electrically charged spray particles of said liquid substance to produce ionized gas and concurrently causing a drift through said reaction zone of said electrically charged liquid spray particles, gas ions and electrically charged reaction products towards said collecting electrode and withdrawing the reaction products from said zone.

2. A method of reacting a liquid and gaseous substances comprising providing a reaction zone with an emitting electrode, an intermediate electrode and a collecting electrode; passing said gaseous substances to be reacted through said zone while projecting electrically charged spray particles of said liquid substance from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collecting electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences promote electrostatic inductive charging of said spray particles and progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; subjecting said gaseous substances and electrically charged spray particles of said liquid substance to a high frequency electric field having a frequency above about 50,000 cycles per second; gasifying said electrically charged spray particles of said liquid substance to produce ionized gas, said emitting, intermediate and collecting electrodes being so spaced that the reaction is initiated principally in the region between sad intermediate electrode and said collecting electrode; concurrently causing a drift through said reaction zone of said electrically charged liquid spray particles, gas ions and electrically charged reaction products toward said collecting electrode and withdrawing the reaction products from said zone.

3. A method of reacting a liquid and gaseous substances comprising providing a reaction zone with an emitting electrode, an intermediate electrode and a collecting electrode; passing said gaseous substances to be reacted through said zone while projecting electrically charged spray particles of said liquid substance from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collecting electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; subjecting said gaseous substances and electrically charged spray particles of said liquid substance to a high frequency electrostatic field having a frequency above about 50,000 cycles per second; gasifying said electrically charged spray particles of said liquid substance to produce ionized gas and concurrently causing a drift through said reaction zone of said electrically charged liquid spray particles gas ions and electrically charged reaction products towards said collecting electrode and withdrawing the reaction products from said zone.

4. A method of reacting a liquid and gaseous substances comprising providing a reaction zone with an emitting electrode, an intermediate electrode and a collecting electrode; passing said gaseous substances to be reacted through said zone while projecting electrically charged spray particles of said liquid substance from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collecting electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; subjecting said gaseous substances and electrically charged spray particles of said liquid substance to a high frequency electromagnetic field having a frequency above about 50,000 cycles per second; gasifying said electrically charged spray particles of said liquid substance to produce ionized gas and concurrently causing a drift through said reaction zone of said electrically charged liquid spray particles, gas ions and electrically charged reaction products towards said collecting electrode and withdrawing the reaction products from said zone.

5. A method of reacting a liquid and gaseous substances comprising providing a reaction zone with an emitting electrode, an intermediate electrode and a collecting electrode; passing said gaseous substances to be reacted through said zone while projecting electrically charged spray particles of said liquid substance from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collecting electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; subjecting said gaseous substances and electrically charged spray particles of said liquid substance to a high frequency electric field having a frequency above about 50,000 cycles per second; gasifying said electrically charged spray particles of said liquid substance thereby dispersing into surrounding gas the electric charges carried on said spray particles and concurrently causing a drift through said reaction zone of said electrically charged liquid spray particles, gas ions and electrically charged reaction products towards said collecting electrode and withdrawing the reaction products from said zone.

6. A method of reacting a liquid and gaseous substances comprising providing a reaction zone with an emitting electrode, an intermediate elec-

trode and a collecting electrode; passing said gaseous substances to be reacted through said zone while projecting electrically charged spray particles of said liquid substance from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collecting electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; subjecting said gaseous substances and electrically charged spray particles of said liquid substance to a high frequency electric field having a frequency above about 50,000 cycles per second for the purpose of gasifying and ionizing said liquid substance and producing circulating currents in the gas mixture, said emitting, intermediate and collecting electrodes being so spaced that the reaction is initiated principally in the region between said intermediate electrode and said collecting electrode; and concurrently causing a drift through said reaction zone of said electrically charged liquid spray particles, gas ions and electrically charged reaction products towards said collecting electrode and withdrawing the reaction products from said zone.

7. A method of reacting a liquid hydrocarbon and a gaseous hydrocarbon comprising providing a reaction zone with an emitting electrode, an intermediate electrode and a collecting electrode; passing said gaseous hydrocarbon through said zone while projecting electrically charged spray particles of said liquid hydrocarbon from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collecting electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; subjecting said gaseous hydrocarbon and electrically charged spray particles of said liquid hydrocarbon to a high frequency electric field having a frequency above about 50,000 cycles per second for the purpose of gasifying and ionizing said liquid hydrocarbon and producing circulating currents in the gas mixture, said emitting, intermediate and collecting electrodes being so spaced that the reaction is initiated principally in the region between said intermediate electrode and said collecting electrode; and concurrently causing a drift through said reaction zone of said electrically charged liquid hydrocarbon spray particles, gas ions and electrically charged reaction products towards said collecting electrode and withdrawing the reaction products from said zone.

8. A method of reacting liquid butane and propane gas comprising providing a reaction zone with an emitting electrode, an intermediate electrode and a collecting electrode; passing said propane gas through said zone while projecting electrically charged spray particles of said liquid butane from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collecting electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; subjecting said propane gas and electrically charged spray particles of said liquid butane to a high frequency electric field having a frequency above about 50,000 cycles per second for the purpose of gasifying and ionizing said liquid butane and producing circulating currents in the gas mixture, said emitting, intermediate and collecting electrodes being so spaced that the reaction is initiated principally in the region between said intermediate electrode and said collecting electrode; and concurrently causing a drift through said reaction zone of said electrically charged liquid butane spray particles, gas ions and electrically charged reaction products towards said collecting electrode and withdrawing the reaction products from said zone.

9. A method of reacting a liquid and gaseous substances comprising providing a reaction zone with a perforated emitting electrode, an intermediate electrode and a collecting electrode; projecting electrically charged spray particles of said liquid substance from said emitting electrode toward said intermediate electrode and said collecting electrode respectively; maintaining said intermediate electrode and collecting electrode at unidirectional electric potential differences relative to emitting electrode potential which potential differences progressively increase along the path of said electrically charged spray particles, said unidirectional potential differences between said electrodes being limited to values such that direct interelectrode unidirectional current discharging does not take place; passing said gaseous substances to be reacted through said zone and through the perforations in said emitting electrode countercurrent to the projection of said electrically charged spray particles from said emitting electrode; subjecting said gaseous substances and electrically charged spray particles of said liquid substance to a high frequency electric field having a frequency above about 50,000 cycles per second; gasifying said electrically charged spray particles of said liquid substance to produce ionized gas and concurrently causing an initial drift of said electrically charged liquid spray particles, gas ions and electrically charged reaction products towards said collecting electrode due to said interelectrode unidirectional potential differences and withdrawing the reaction products from said zone.

LESTER H. SMITH.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,930,964	Bethenod	Oct. 17, 1933
2,301,315	Opp	Nov. 10, 1942
2,334,377	Bennett	Nov. 16, 1943

FOREIGN PATENTS

Number	Country	Date
294,099	Great Brtiain	June 20, 1929
421,811	Great Britain	Dec. 20, 1934
502,063	Great Britain	Mar. 10, 1939