United States Patent [19]

Mahaffey et al.

[11] **3,893,845**

[45] **July 8, 1975**

[54] **METHOD FOR REDUCING MATTER TO CONSTITUENT ELEMENTS AND SEPARATING ONE OF THE ELEMENTS FROM THE OTHER ELEMENTS**

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[73] Assignee: **The Boeing Company,** Seattle, Wash.

[22] Filed: **June 1, 1973**

[21] Appl. No.: **365,925**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 269,634, July 7, 1972, which is a continuation-in-part of Ser. No. 172,674, Aug. 18, 1971, abandoned.

[52] **U.S. Cl.** ..... **75/10 R;** 75/11; 55/100; 204/164; 250/298

[51] **Int. Cl.** **C22d 7/00**

[58] **Field of Search** ..... 75/10 R, 10 V, 10 P, 68 R, 75/11; 250/298; 55/100; 204/164

[56] **References Cited**

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1,954,900 4/1934 Varney ..... 75/10 V

Primary Examiner—L. Dewayne Rutledge
Assistant Examiner—M. J. Andrews
Attorney, Agent, or Firm—Seidel, Gonda & Goldhammer

[57] **ABSTRACT**

A method and apparatus for reducing matter, particularly chemical compounds, to constituent species in a high temperature environment (plasma) and separating one of the species from the other species. Reduction is effected by raising the input compound to a high temperature so that it is thermally dissociated. Reduction can also be effected by chemically reducing the compound to a gas consisting of a specie which can be more readily ionized and another product of the chemical reduction reaction. Separation is effected by partly ionizing one of the species to be separated and moving the resultant mixture of gas and plasma through a magnetic field (B). The magnetic field B is shaped so as to increase in intensity in the direction of flow of the gas and plasma. The plasma is squeezed by the magnetic field. Although the plasma tends to follow the magnetic field lines, there is some slippage across them. The net result is that the plasma is moving at a velocity ($\vec{v}$) through a magnetic field $\vec{B}$ having vector components $\vec{B}_{\perp}$ perpendicular and parallel $\vec{B}_{\parallel}$ to the plasma velocity vector. The interaction of the perpendicular ($\vec{B}_{\perp}$) and parallel ($\vec{B}_{\parallel}$) components of the magnetic field with the ions and electrons in the plasma produces a separating force perpendicular to the direction of plasma flow — the force tending to squeeze the plasma. The separating force acts upon the entire specie which is significantly ionized even though it is only partly ionized because of resonant charge exchange. The neutral or unionized specie is not directly affected by the magnetic field.

10 Claims, 3 Drawing Figures

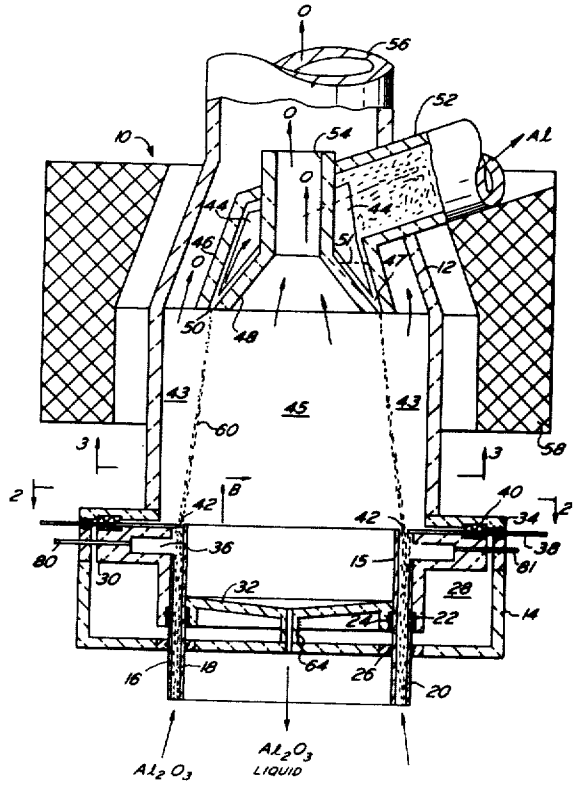


FIG. 1

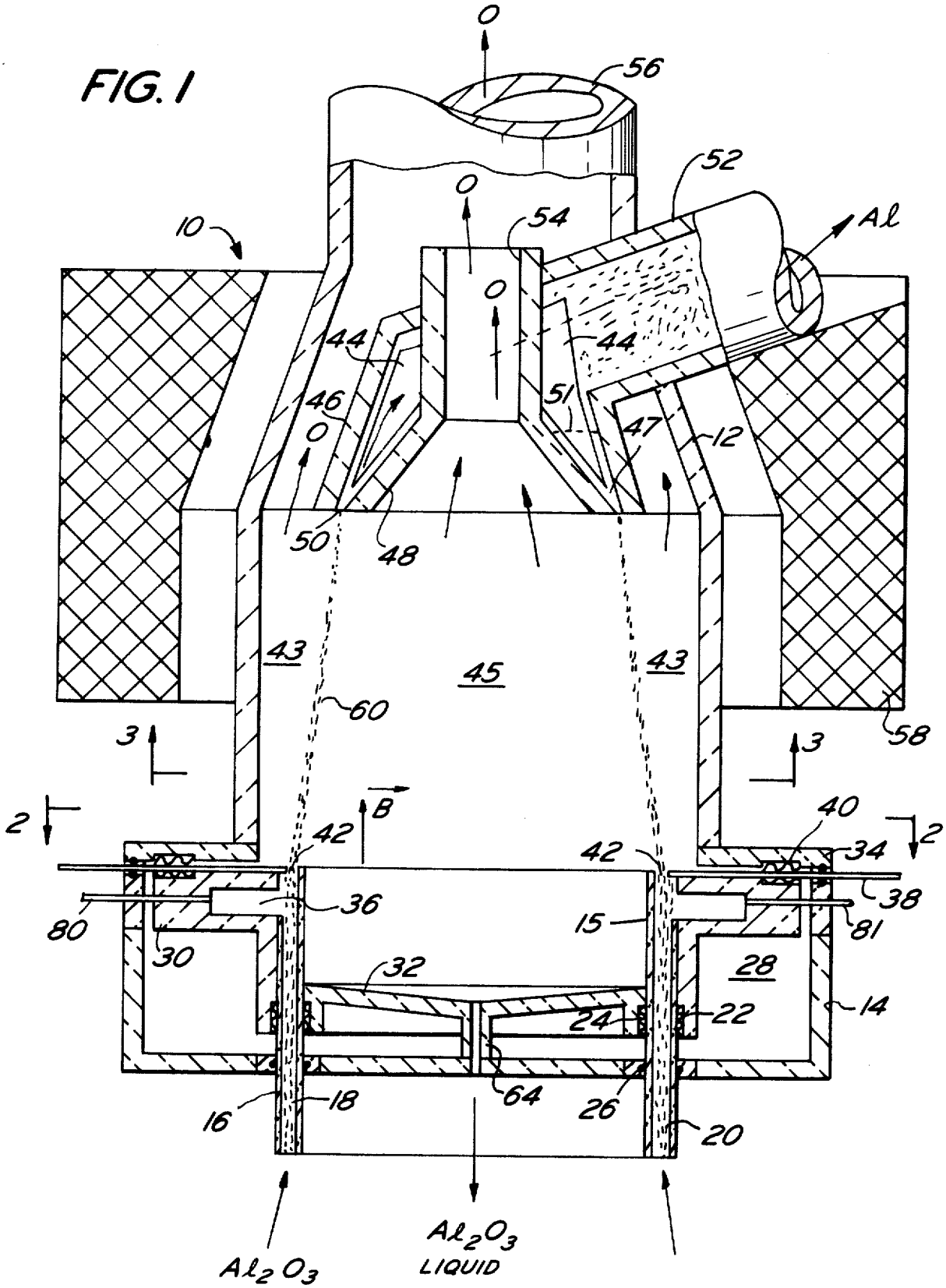

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FIG. 2

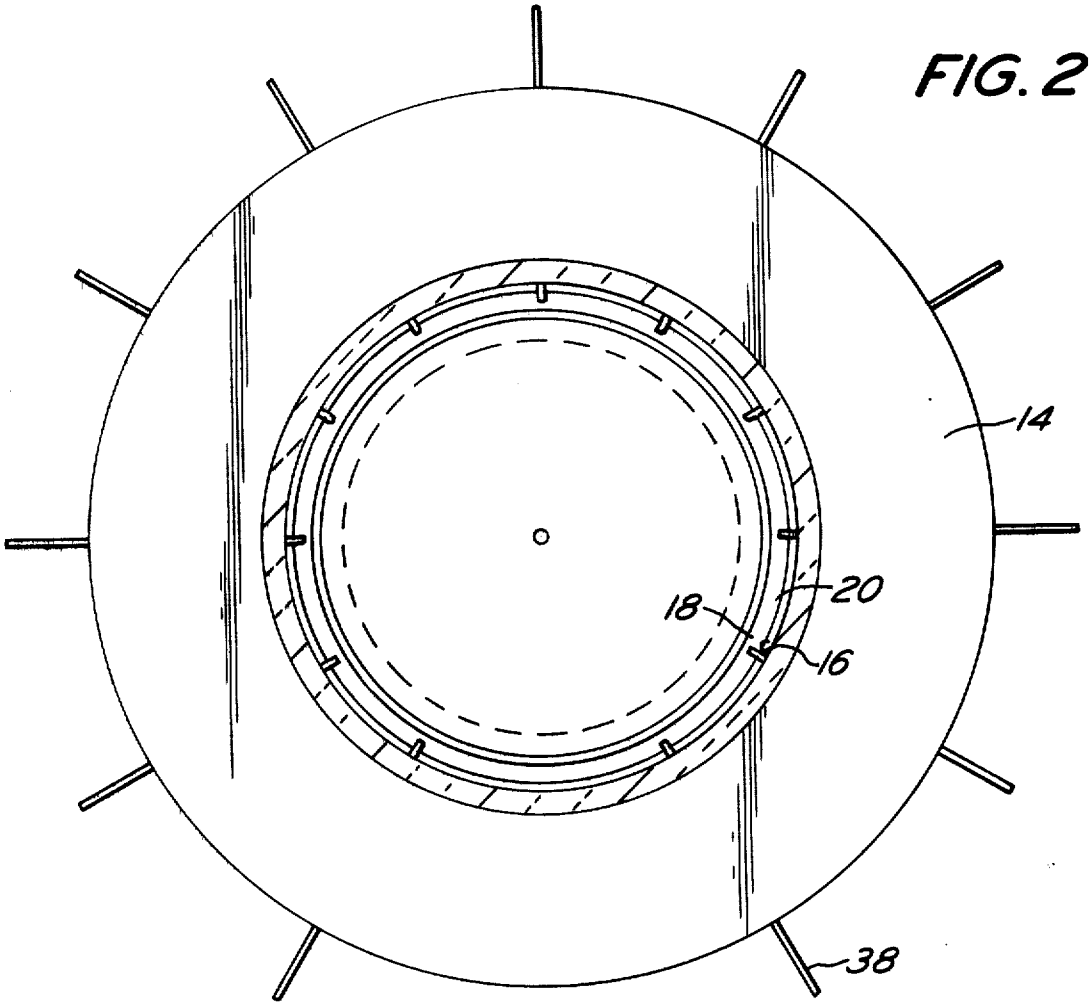
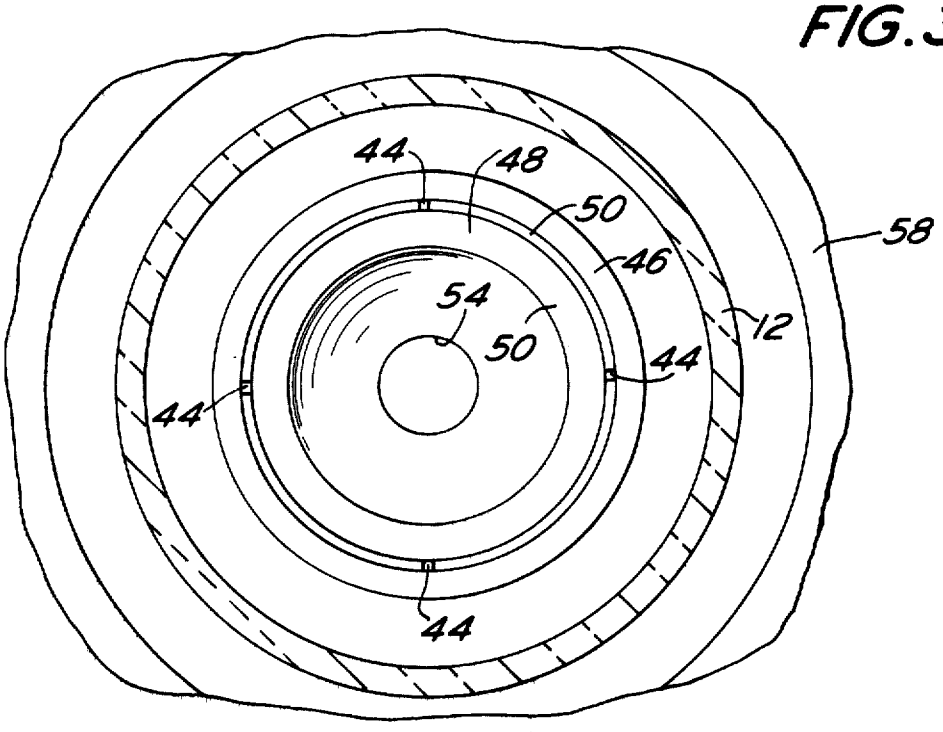


FIG. 3



METHOD FOR REDUCING MATTER TO CONSTITUENT ELEMENTS AND SEPARATING ONE OF THE ELEMENTS FROM THE OTHER ELEMENTS

PRIOR PATENT APPLICATIONS

This application is a continuation-in-part of patent application Ser. No. **269,634** filed July **7, 1972** in the names James E. Drummond, David B. Chang and Derek W. Mahaffey; said application Ser. No. **269,634** being a continuation-in-part of patent application Ser. No. **172,674** filed Aug. **18, 1971** in the name of James E. Drummond, David B. Chang and Derek W. Mahaffey (now abandoned).

This invention relates to a method and apparatus for reducing matter to dissociated species and separating the species each from the other. More particularly, the invention relates to a method and apparatus for reducing compounds, such as metal oxides, to constituent elements or an element and chemical reduction reaction product and separating the selected element or product (e.g., aluminum from oxygen) using high temperature plasmas.

At sufficiently high temperatures, compounds will dissociate into their constituent elements, and if that temperature be high enough, one or more of the elements will ionize. The degree of ionization at a particular temperature varies from element to element. For example, the ionization potential of aluminum is about **5.98** eV and that of oxygen about **13.6** eV. The practical effect of differing ionization potentials and other factors (e.g., degeneracy of the lowest ionized state) is that certain elements of high ionization potential do not ionize appreciably at the temperature where significant ionization of other elements takes place. Examination of equilibrium composition of a gaseous mixture at elevated temperatures demonstrates that, for certain compounds, after dissociation, one element is partly ionized but the other element or elements are not significantly ionized.

The present separation process and apparatus operates upon a gas containing only one significantly ionized specie. Moreover, that specie is only partly ionized. Separation using only partial ionization means that lower temperatures can be used and lower temperatures mean less energy input. Analysis shows that throughput rates of production for the selected specie, whether it be the partly ionized specie or not, are little affected by ionization fractions as little as several percent. This means that the process can be operated at very small percentages of ionization (**0.2–20%**) and therefore significantly lower enthalpy relative to those processes which require full ionization (Varney U.S. Pat. No. **1,954,900**), while still producing greater output quantities of the selected specie. This is made practical by the very rapid (resonant) exchange of charge between atoms and ions of the partly ionized specie.

The invented process separates the partly ionized specie from the essentially un-ionized specie or species using a magnetic field. It has been found that the separating force can be generated by creating relative motion between the magnetic field and a partly ionized gaseous specie where said relative motion is at an angle β to the magnetic field. Preferably, the plasma flows relative to a fixed magnetic field, although other forms of relative motion may be created. The large flow velocities permitted by the process produce large

throughput rates. In patent application Ser. No. **269,634** filed July **7, 1972,** the separator uses an externally generated magnetic field through which the entire plasma including the ions, the electrons and the neutral elements are allowed to flow. The magnetic field is oriented at an angle such that it has both perpendicular and parallel components relative to the plasma flow velocity. The interaction of the perpendicular component with the plasma flow velocity produces a current density having both magnitude and direction. The interaction of the current density and the parallel magnetic field component produces a separating force upon the ions and the neutral elements of the partly ionized specie. So that a destructive space charge is not built up, the current is allowed to close upon itself. For this reason, a structure having axial symmetry is provided. The net result is a separating force acting on the entirety of the partly ionized specie.

Having created a separating force that is active only upon the partly ionized constituent specie, it is possible to isolate that specie from the remaining neutral elements which are not affected by the magnetic field. The specie upon which the separating force acts undergoes forced diffusion through the other species and so can be concentrated in one region of space. A scoop or cold wall for condensation located in this region completes the separation process. In the latter instance, for example, the ions and the neutral elements of the partly ionized species are permitted to strike a relatively cool surface and hence pass from the gaseous to the molten state.

The present invention uses the same basic principles to create the requisite separating force. Thus, a single constituent specie is partly ionized and relative angular displacement of that specie with respect to a magnetic field is created. The process used in the present invention is to move the plasma through a magnetic field having an intensity that varies in the general direction of plasma flow. In particular, the field intensity increases in that direction. The gaseous flow is relatively undirected, at least in comparison to the directed flow velocity of the invention described in patent application Ser. No. **269,634.** The plasma, however, tends to follow the magnetic field lines and is relatively squeezed together as the field intensity increases. This tendency, however, is by no means perfect and the plasma thus drifts across the magnetic field lines. Accordingly, the plasma is in effect moving at an angle relative to the magnetic field and this effect is enchanced by reason of the increasing field intensity. Such angular movement relative to the magnetic field necessarily generates the requisite force described above which causes the plasma to move in a defined region of space. Having confined the plasma to a particular region of space, it is now possible to separate it from the remaining un-ionized or neutral constituent species of the gas.

The foregoing separation concept has certain advantages. In particular, the high temperature plasma is maintained at a position remote from the confining walls. Accordingly, there is no need to provide large areas of walls which must withstand contact with plasmas of about **3000°K** or higher. Another advantage of the system is that it can be designed to more readily recycle material which has not been separated into its constituent species.

These and other advantages will become apparent from what is disclosed hereinafter.

The present invention is directed toward separating ne constituent species from another constituent spe- ies of a chemical compound in a dissociated gaseous tate. In the embodiments and examples given herein, ietals are separated from their compounds; e.g., alu- ninum from alumina (Al_2O_3). In such examples, it is he partly ionized specie that is the desired product. lowever, it should be understood that the invention is iot limited to instances in which only the partly ionized pecie is to be recovered. The invention is the separa- ion process. This means that the un-ionized specie or pecies may be recovered as a primary output of the)rocess. It should also be understood that the invention s applicable to separating an element and molecule 'rom each other if that is the manner in which the input :ompound dissociates and there is partial ionization of he element but not the molecule. Indeed, in one exam-)le given herein, aluminum is separated from carbon nonoxide after first reducing the alumina to gaseous aluminum and carbon monoxide.

The principal advantage of the invented process and apparatus is in separating certain metals from the more electronegative elements; oxygen in particular, but also sulfur and silicon. These elements do not ionize appre- ciably at the temperatures where significant ionization of the metals with which they are chemically combined takes place.

The most common and economic process in current use for a wide variety of metals is to separate the metal element from its ore by chemical treatment yielding usually an oxide and then reducing the oxide with car- bon. However, certain other elements such as the met- als found in the III and IV columns of the Periodic Table tend to form stable carbides so that reduction to pure metal by carbon is not possible. The examples are aluminum (III), titanium (IV) and zirconium (IV). The present invention makes possible the retrieval of pure metal without forming carbides.

Separation of aluminum from its oxides is treated in detail herein. Aluminum silicate is a more widely avail- able source of aluminum than Al_2O_3. It is normally found in the form of clay. In aluminum silicate at 5000°K and 1 atmosphere of pressure aluminum ions are more than 1000 times as abundant as silicon ions. Accordingly, the present invention provides an appara- tus and process whereby abundant aluminum silicate clay is made to become a source of fairly pure alumi- num metal whereas it had not been so in the past.

Titanium is commonly prepared by converting it to titanium tetrachloride and then purifying the tetrachlo- ride by fractional distillation. The purified tetrachlo- ride is reduced with magnesium or sodium. It is the re- duction which is expensive and which makes titanium a relatively costly metal even though it is one of the most abundant in the earth's crust. The present inven- tion has the advantage of being able to reduce titanium tetrachloride without the use of magnesium or sodium residues.

Zirconium is manufactured by essentially the same process as titanium. Pure zirconium tetrachloride is prepared and then reduced. The present invention can be used to reduce zirconium tetrachloride to retrieve pure zirconium.

As previously stated, the invention takes advantage of the concept that certain constituent species of a dis- sociated gas may be partly ionized at temperatures where there is no significant ionization of the remaining species. In the case of metal ores, certain metal ele- ments are partly ionized at temperatures where there is no significant ionization of the more electro-negative elements such as oxygen, sulfur and silicon which com- bine to make up the ores. This provides a means whereby ionized metals can be separated from their compounds; aluminum from alumina (Al_2O_3); alumi- num from aluminum silicate (Al_2SiO_5); iron from ferric oxide (Fe_2O_3); tin from cassiterite (SnO_2); copper from various copper ores; nickel from nickelous oxide (NiO); or chromium from chromite (CR_2O_3).

At temperatures high enough for alumina, by way of example, to be completely dissociated and the alumi- num partly ionized in a gas, the negative charge carriers are electrons rather than ions. In a plasma, any current $\vec{I}$ flowing in a region having a magnetic field $\vec{B}$ experi- ences a force $\vec{I} \times \vec{B}$ at right angles to $\vec{I}$. The electrons are therefore forced in a new direction by their current. The electrons tend to pull the ions with them. They both move in the $\vec{I} \times \vec{B}$ direction with a speed propor- tional to the large electron current and proportional to the mobility of the ions and the hot gas. The current $\vec{I}$ is created by flowing the plasma gas through the mag- netic field. The gaseous plasma therefore sees an effec- tive electric field whose lines of force make closed loops. Thus, if walls do not intersect these lines of force, the current produced by this electric force never has to leave the gaseous plasma. It is necessary to pro- vide axial symmetry for the structure containing the plasma so that the current flows freely.

The direction of the magnetic field in respect to the direction of flow of the plasma is significant to the sepa- ration process. A parallel magnetic field can be used to separate the ions from the neutral particles since charged particles spiral around magnetic field lines, whereas the neutral particles are uneffected. This works efficiently but very slowly because relatively low pressures are required to avoid deleterious particle col- lision. On the other hand, providing the effect of a mag- netic field at an angle to the flow generates a separating force that operates well at high plasma pressures and large flow velocities so that large throughput rates are possible.

For the purpose of illustrating the invention, there are shown in the drawings forms which are presently preferred; it being understood, however, that this in- vention is not limited to the precise arrangements and instrumentalities shown.

FIG. 1 is a longitudinal sectional view of an apparatus in accordance with the present invention.

FIG. 2 is a sectional view of the apparatus taken along the line 2—2 in FIG. 1.

FIG. 3 is a transverse sectional view of the apparatus taken along the line 3—3 in FIG. 1.

The principal aspects of the present invention are heating matter from which a constituent specie is to be separated until the matter dissociates into a gaseous state and is at a temperature at which that specie or a remaining constituent specie is partly ionized. At such temperature, there is no significant ionization of any species except one. The gas and plasma is passed at a high velocity through a magnetic field whose intensity varies in the direction in which the plasma is flowing. In particular, the intensity increases. As the gaseous material flows through the apparatus, the partly ionized specie is squeezed by the resultant forces into a fixed region of space from which it may be removed.

Referring now to the drawings, wherein like numerals indicate like elements, there is shown an apparatus **10** for accomplishing the process. The apparatus **10** includes a vessel **12** supported on a base **14.** The walls of vessel **12** are preferably cooled in any conventional manner so that it may withstand the relatively high temperatures within its confines.

The base **14,** in addition to supporting the vessel **12,** also supports apparatus **15** for preheating and vaporizing the matter from which the constituent species is to be removed. In the example given, aluminum is removed from alumina. It should be understood, however, that this is by way of example and other constituent species of matter may be removed by the same process.

A pair of cylindrical carbon electrodes **16** and **18** are concentrically mounted within the base **14** and define an annulus **20** between them. Appropriate vacuum seals **22, 24** and **26** are provided at the joints between base **14** and the carbon electrodes **16** and **18.** Each of the seals **22, 24** and **26** is surrounded by an inert gas maintained within the chamber **28** defined by the base **14.** The gas is at approximately **0.1** atmospheres and serves both as a coolant and to assist in completing the seal.

The annular inner support **30** for the electrode **16** as well as the top wall **32** of base **14** are preferably made of a refractory material such as alumina since these are the hottest regions of the entire apparatus and this material is capable of maintaining structural integrity and strength at temperatures in excess of **2000°K.** The remaining portions of the vessel are preferably made of stainless steel with appropriate cooling means (not shown).

The material from which a constituent specie is to be removed is introduced into the annulus **20,** preferably in a finely ground form so as to be able to readily heat the same. The electrodes **16** and **18** are connected to a source of electrical (A.C. or D.C.) power (not shown). Current flows between the electrodes and the temperature of the material is raised by ohmic heating. The amount of ohmic heating is sufficient to cause the material to vaporize when it reaches the annular space **36** formed by the inner support **30.** In the example shown, alumina is introduced into the annulus **20** and is vaporized when it reaches the annular space **36.**

Many electrodes **38** are mounted at equidistant points around the circumference of base **14** as best shown in FIG. **2.** An appropriate seal **40** is provided for each of the electrodes **38.** As shown in FIG. **1,** the electrodes extend up to a point spaced from the electrode **18.** Each of the electrodes **38** is connected to another source of alternating or direct current power and is opposite in phase or polarity to the electrode **18.** Accordingly, an arc **42** is struck between each of the electrodes **38** and the electrode **18.** This arc heats the vapors to a temperature where they are dissociated and the aluminum is partly ionized. Such partial ionization takes place at a temperature of approximately **5000°K** for alumina.

Thus a gaseous mixture consisting of partly ionized aluminum **(0.2–20%)** and oxygen which is essentially un-ionized enters the vessel **12.**

Supported within the vessel **12,** is a collecting structure which includes conical wall **46** and **48** which define an aperture **50** opening into annulus **47** into which the ionized specie is directed. Walls **46** and **48** diverge and are connected to duct **52** through which the ionized specie of the constituent material is exhausted. In order that the flow of plasma be unimpeded by the magnetic field in annulus **47** fins **44** are located so as to prevent the occurrence of the closed current loops which previously confied the plasma in lower section **45.** Duct **52** is connected to an appropriate pump for maintaining the flow of the ionized specie through the duct. The inner side of wall **48** provides communication with the duct **54** through which the un-ionized specie may flow. The un-ionized specie also flows between the walls **46** and the walls of the vessel **12** as shown. The un-ionized specie is exhausted from the vessel **12** through the duct **56** which also is connected to an appropriate pumping means for maintaining the flow of such un-ionized species. By way of example, by not limitation, the pressure within the vessel **12** is maintained at approximately **0.01** atmospheres by the aforementioned pumping means.

The vessel **12** is surrounded by an electromagnet **58** which preferably is of the superconductive type so as to be capable of generating an appropriate magnetic field. Electromagnet **58** is designed so as to provide a magnetic field B whose intensity varies along the axis of the vessel **12.** A magnetic field of significant intensity extends from just below the arc **42** up to a level beyond aperture **50.** Its intensity increases in the direction such that it is a maximum (saddle point) at level near **50.**

The pumping action at the ducts **52** and **56** allows the mixture of gas and plasma to flow through the vessel **12.** Thus, the example given, a mixture of partly ionized aluminum and substantially un-ionized oxygen atoms are now within the magnetic field. Partly ionized aluminum tends to follow the magnetic field lines and thus retain its annular shape as it flows past the arcs **42.** On the other hand, the un-ionized oxygen or other constituent species is unaffected by the magnetic field and hence diffuses away from the plasma **60** into the much larger volumes **43** and **45** available to it within chamber **12.**

As the mixture of aluminum and aluminum ions within the plasma **60** flows toward the aperture **50,** the magnetic field strength increases. This tends to squeeze the plasma since the force is acting on both sides of the plasma. The squeezing force is developed because the plasma does not rigorously follow the magnetic field lines. Rather, it tends to slip across the field. In doing so, it is moving at a velocity $\vec{v}$ having a vector that has an angle β with respect to the direction of the magnetic field $\vec{B}$. The electrons within the plasma **60** flow around the axis of the vessel **12** within section **45** by reason of the fact that they are being forced to move at right angles to the perpendicular component of the magnetic field $\vec{B}_{\perp}$. This motion produces electron current densities $\vec{J}$ circulating around the axis of the machine. These circulating currents, close upon themselves, and interact with the parallel component of the magnetic field $\vec{B}_{\parallel}$, producing another force on the electrons. This force density F is the squeezing force acting upon the plasma.

As the electrons are squeezed together, an electric field arises due to the separation between the ions and the electrons. This field pulls the ions after the electrons.

The magnetic force acting on the plasma varies depending upon the direction in which it slips. However, in greatly simplified form, it can be stated as follows:

$$F = \frac{Mv_s B^2 \beta}{\eta}$$

where:

M = Mach No.

v_s = speed of sound

B = magnetic field of any particular point in the plasma

β = the angle between the direction of flow and the magnetic field B at any particular point

η = plasma resistivity

F = the force density.

The forces acting upon the plasma tend to squeeze it, that is, they tend to act laterally with respect to the direction of flow. This squeezing effect enhances the rapid diffusion of the oxygen away from the plasma. By properly shaping the magnetic field $\vec{B}$, the plasma is caused to enter the aperture **50.** It should be noted that although the ions tend to slip across the magnetic field $\vec{B}$, this natural diffusion is offset by the effect of the convergence of the "lines" of magnetic field.

As used herein, the term "plasma" is intended to mean that portion of a partly ionized gas or vapor of such extent that within it static charges are statistically screened by charges of opposite sign with a distance small compared to the extent of the gas.

It should be recognized that it is not necessary to entirely ionize the specie which is to be separated. There is a rapid (resonant) charge exchange between neutral atoms of the partly ionized specie and the ions of that specie. An electron may jump from an atom to an ion tens of angstroms distant, thus converting that ion back into an atom. For example, electrons may jump from aluminum atoms to aluminum ions more rapidly than those atoms collide with oxygen atoms. An atom that just lost an electron is now an ion which feels the pull of the electrons being acted upon by the magnetic field. By averaging out this exchange between neutral atoms and ions over a given time scale, any given atom appears to have a positive charge which is less than the electron's charge. Thus, all of the atoms can be regarded as "partial ions". The electric field created by the electrons pulls all of the partly ionized specie. Stated otherwise, the resonant charge exchange is important to the fulfillment of the process. Typically, the resonant charge transfer cross section is approximately $10^{-14}cm^2$. This means that at several percent ionization a given atom changes its ionization state approximately 10^7 to 10^8 times per second at a temperature of several thousand degrees K and a pressure of the order of 1 atmosphere. Accordingly, an aluminum atom, for example, can move only about a tenth of a millimeter before changing its ionization state. This fact means that the whole body of a plasma having a very small percentage of ionization can be moved.

The atoms and ions within the plasma **60** are guided into aperture **50** by the magnetic field $\vec{B}$ and flow through the duct **52** to a point where they are condensed into aluminum. The oxygen passes through the duct **54** and through the channel defined by the wall **46** and vessel **12** into the duct **56** where it is collected.

In the operation of the process, some of the alumina may not be fully dissociated. Accordingly, it may condense on the walls of the vessel **12.** Such liquid alumina is permitted to flow down the walls and onto the base **32.** From there, it is exhausted through the conduit **64.** From that point, it may be recirculated to be mixed with the incoming alumina within the annulus **20** and thus act as a preheater.

The duct **52** is preferably cooled so as to rapidly lower the temperature of the aluminum or other constituent species within its interior and thus permit the aluminum or other constituent specie to de-ionize.

A high intensity magnetic field is desirable. Current technology permits the production of a magnetic field of approximately up to **12** telsa. Accordingly, that should be the strength of the magnetic field above the aperture **50** at the level **51.**

There are several advantages to operating a separation process in accordance with the foregoing. The primary advantage is that the plasma is remotely positioned with respect to the walls of the apparatus. The temperature outside the plasma decreases rapidly to levels below 3000°K. Accordingly, the problem of walls capable of withstanding plasma temperatures is avoided. Rather, the structural walls can be cooled using conventional cooling means.

The process of the present invention has been described in connection with the direct reduction of alumina to aluminum and oxygen and has been explained that other materials can be similarly directly reduced. However, such direct reduction of metallic ores is not entirely necessary. To further reduce the operating temperatures of the process, it is entirely possible to first chemically reduce the matter and then separate the products of such chemical reduction.

There are several methods employed for the extraction of metals from the ores, in more or less pure condition. The choice of process in any particular instance depends upon the chemical nature of the ore and the properties of the metal concerned. Some metals, such as iron, are readily reduced by the application of heat in the presence of carbon, a classical oxidation-reduction process. Aluminum and certain other metals, unfortunately, are not so readily reduced. The problem is that certain metals, particularly those in the III and IV columns of the periodic table tend to form carbides. Accordingly, any attempt to reduce the ores of those metals with carbon means that there must be some further process to separate the metal from the carbide to obtain pure metal. Such processes are usually quite disadvantageous in that they require the consumption of large amounts of energy.

Just the same, there are advantages to reducing alumina and certain other metal ores, such as titanium dioxide by classical reduction processes. Among these would be reducing a large amount of electrical power required by, for example, the Hall process for converting alumina into aluminum. Another advantage would be increase throughput rates. These advantages can be realized if pure aluminum or other metals can be separated from the products in a chemical reduction process.

The present invention can accomplish the foregoing result. At high temperatures, carbon can be reacted with alumina to produce aluminum and carbon monoxide in a gaseous state. Aluminum carbides are produced only if the carbon reacts with the alumina at

lower temperatures. Given the foregoing, it becomes possible to produce pure aluminum if a gaseous aluminum can be separated from the gaseous carbon monoxide. The same applies to other high temperature reduction reactions which result in a gaseous vapor of the metal and the products of reduction or can be converted to such gaseous state.

The foregoing process can be accomplished by introducing a mixture of alumina (Al_2O_3) and carbon (C) in the annulus **20.** This mixture is forced through the annulus and the carbon is reacted with the alumina in the arc **42.** The reduction of aluminum with carbon produces aluminum and carbon monoxide. Greatly simplified, the equation (reversible) is:

$$3C + Al_2O_3 \rightleftarrows 2Al + 3CO$$

Carbon monoxide is a very stable molecule at high temperatures and does not dissociate easily. Hence, the process can be operated as close to the boiling point of aluminum as possible without getting much reaction between the aluminum and the carbon monoxide. High temperatures favor the reaction towards the right and low temperatures favor the reaction toward the left. It is only when the reaction moves toward the left that carbides such as Al_4C_3 are formed. Upon completion of the reaction, the aluminum will be partly ionized and can be separated from the carbon monoxide in accordance with the process described above with respect to the separation of the aluminum from oxygen.

In operating the apparatus, it may be necessary, at least at start-up, to use a neutral carrier gas until the compound being treated has vaporized and the neutral species thereof can be substituted for the carrier gas. In some instances, it may be necessary to maintain the flow of the carrier gas which may be helium, argon or some other relatively stable and neutral gas. At startup, the carrier gas provides a means for striking the arcs as required.

The carrier gas may be inserted between the electrodes **16** and **18** from an appropriate source or, if desired, may flow in through appropriate conduits **80** and **81** as shown. Still further, the carrier gas could be brought in at a still different position and velocity than the plasma. For example, it could be brought in through the walls of the vessel **12.** This would drive the plasma at the requisite angle to the magnetic field thus initiating the separating force. In other words, the carrier gas can be used as yet another means for providing a flow of the plasma at an angle to a magnetic field to effect separation between dissociated species.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification as indicating the scope of the invention.

We claim:

1. A process for separating a constituent specie from the remaining species in a gas, said gas being at a temperature where the specie is partly ionized and the remaining species are insignificantly ionized, comprising:

a. flowing said gas along a magnetic field $\vec{B}$ whose field intensity increases in the general direction of gaseous flow, and the direction of said magnetic field also being in the general direction of said gaseous flow;

b. spacing the plasma of partly ionized specie at a position remote from the wall structure of a containing vessel as it flows along said magnetic field $\vec{B}$;

c. applying a force $\vec{F}$ to said plasma to confine it to a region of space, said force being created by the movement of the plasma at an angle β relative to the magnetic field;

d. permitting the current $\vec{J}$ created by the interaction of the moving electrons of the ionized specie with the perpendicular component of the magnetic field $\vec{B}_\perp$ to flow in a closed path;

e. using said current $\vec{J}$ flowing in a closed path to interact with the parallel component $\vec{B}_\parallel$ of the magnetic field $\vec{B}$ to generate the confining force $\vec{F}$ acting upon the partly ionized specie; and

f. collecting the partly ionized specie apart from the remaining species.

2. A process in accordance with claim **1** including collecting the specie in a region of maximum field intensity.

3. The process of claim **1** wherein said plasma generally follows said magnetic field and the movement of the plasma at an angle B relative to the magnetic field is created by a random drift.

4. The process of claim **1** wherein said gas is a dissociated compound and the ionized specie is a metal.

5. The process of claim **4** wherein the compound is alumina and the metal is aluminum.

6. The process of claim **4** wherein the dissociated compound includes iron and the ionized specie is the iron.

7. The process of claim **4** wherein the dissociated compound includes titanium and the ionized specie is the titanium.

8. The process of claim **4** wherein the dissociated compound includes tin and the ionized specie is the tin.

9. The process of claim **4** wherein the dissociated compound includes nickel and the ionized specie is the nickel.

10. The process of separating from each other a consituent specie and the remaining species in a composition of matter, comprising:

a. heating said composition of matter to a temperature where it is in a gaseous state and a constituent specie is partly ionized;

b. flowing said gas along a magnetic field $\vec{B}$ whose field intensity increases in the general direction of gaseous flow, and the direction of said magnetic field also being in the general direction of said gaseous flow;

c. spacing the plasma of partly ionized constituent specie at a position remote from the wall structure of a containing vessel as it flows along said magnetic field $\vec{B}$;

d. applying a force $\vec{F}$ to said plasma to confine it to a region of space, said force being created by movement of parts of the plasma at a variety of angles β relative to the magnetic field;

e. permitting the current $\vec{J}$ created by the interaction of the moving electrons of the ionized specie with the perpendicular component of the magnetic field $\vec{B}_\perp$ to flow in a closed path;

f. using said current $\vec{J}$ flowing in a closed path to interact with the parallel component $\vec{B}_\parallel$ of the magnetic field $\vec{B}$ to generate the confining force $\vec{F}$ acting upon the partly ionized specie; and

g. collecting the partly ionized specie apart from the remaining species.

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