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(54) Title: METHOD AND APPARATUS FOR MINERAL RECOVERY

(57) Abstract: A method of electrowinning a mineral from an ore body is disclosed, the method including recirculating a leaching solution [36] through leaching means [18] and solvent extraction means [58] whereby soluble mineral is leached from the ore body and dissolved into the leaching solution; recirculating a solvent [37] through the solvent extraction means [56] and stripping means [57] whereby selected soluble mineral dissolved in the leaching solution is extracted into the solvent from the leaching solution; recirculating an electrolyte [38] through the stripping means [57] and a mineral extraction cell assembly [10] whereby the selected soluble mineral is stripped from the

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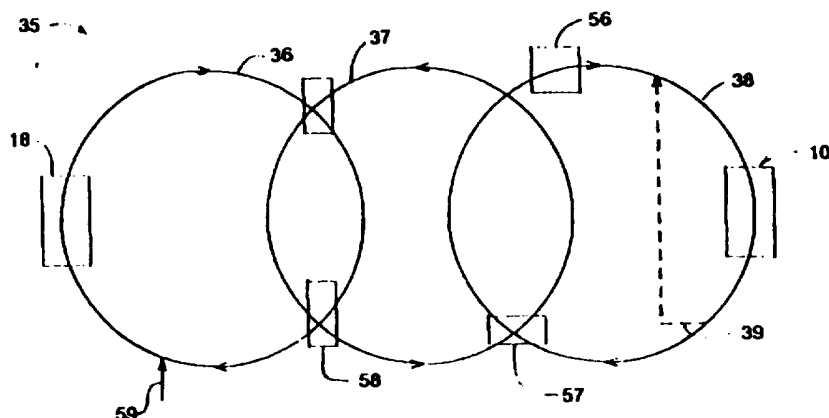


FIG. 1

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(56) Documents cited: AU 30338/84 (549797) (Elkem A/S)



## Abstract Continued

solvent into the electrolyte [38], and applying an electric current to the mineral extraction cell assembly [10] and wherein said mineral extraction cell assembly [10] includes a stationary elongate housing [11] having a conductive inner surface [12], closure assemblies [13, 14] removably mounted to each end of the stationary housing [11], an electrode [21] extending from at least one the closure assembly into the housing to form an annular cavity [24] between the housing and the electrode a fluid inlet to the annular cavity in one of the closure assemblies and formed whereby, in use, fluid is introduced to the mineral extraction cell assembly offset from the elongate axis of the stationary elongate housing, a fluid outlet to the cell assembly formed in the other of the closure assemblies, and electrical terminations for connecting the electrical current to the electrode and the conductive surface to cause the selected soluble mineral to be electro-deposited on the conductive surface. The mineral extraction cell assembly [10] preferably further includes separation means dividing the annular cavity into an electrolyte chamber with which the fluid inlet and the fluid outlet are in fluid connection and a process fluid chamber, a process inlet to the process fluid chamber a process outlet to the process fluid chamber, in which case the method includes circulating process fluid through the process inlet and the process outlet.



"METHOD AND APPARATUS FOR MINERAL RECOVERY"

This invention relates to a method and apparatus for mineral recovery.

This invention has particular but not exclusive  
5 application to electrowinning and/or electrofining of copper. However, it is to be understood that this invention could be used in other applications such as electrowinning or electrofining of other metals or the production of gases.

10 Many methods of extracting metals from ores leave small but significant proportions of the metals in the ore. Other methods cannot be utilised economically on low-grade ores. One established method of extracting residual metals from processed ores, or of extracting metals from low-grade  
15 ores, is known as "leaching". Leaching involves passing a fluid in which the metal to be extracted will dissolve through the ore, collecting the leachate, and separating the metal from the leachate. In the case of copper extraction, the leachate typically used is dilute sulfuric  
20 acid, which reacts with the copper to produce copper sulfate.

However, sulfate leachate is not suitable for many metals, or for some physical and/or mineral forms for metals usually leached by a sulfate leachate. Frequently,  
25 dissolving such materials may be achieved by forming a chloride salt either by chlorination, ferric or cupric chloride leaching, or hydrochloric acid leaching. Chloride systems are in the early stages of development, and have achieved only limited commercial acceptance not only  
30 because of technical difficulties and cost of engineering for the highly corrosive and/or highly reducing environment, but also due to difficulties in electrowinning from chloride solutions. Therefore, efforts have been directed towards the sulfate leaching system.

35 For the sulfate leachate system, copper may be removed from the copper sulfate drained from the ore by exposing it to metallic iron or steel, where iron sulfate and free

copper are formed. Unfortunately, the copper so produced contains significant impurities, and the acid is used up in the process, making the economics of the process poor.

Alternatively, the copper sulfate solution may be passed  
5 through an electrolytic cell, recovering both free copper and sulfuric acid. However, conventional electrolytic cells cannot generally be applied economically to the direct winning of metal from the low concentration leachates available from mining operations, a further  
10 concentration process being required before the leachate can be electrolysed.

One established method of further concentrating the metal in solution includes a first solvent extraction step whereby the metal moiety is extracted from the leachate  
15 into a solvent immiscible with the leachate and a second solvent extraction step whereby the metal moiety is extracted from the solvent into an electrolyte immiscible with the solvent. The leachate, solvent and electrolyte are recirculated.

20 The leachate loop includes a leaching stage where metal is dissolved into the leachate from an ore and a solvent extraction stage where metal to be won out of the leachate is preferentially extracted into a solvent which is usually an organic solvent. The solvent extraction loop includes a  
25 loading stage where the solvent is loaded with metal from the leachate and a stripping stage where the metal is stripped from the solvent into an electrolyte. The electrolyte and leachate are usually aqueous solutions.

The electrolyte is recirculated in a loop which includes  
30 the stripping stage of the solvent where the metal is stripped from the solvent into the electrolyte and an electrolysis stage where electric current is passed through the electrolyte to remove the metal from the electrolyte.

In such a process, strict controls are required on the  
35 behaviour of each of the three recirculating loops described above. In particular, a very limited quantity of solvent is permitted in the electrolyte, a consequence of the limits being exceeded being that the electrowinning

process becomes inefficient and/or unworkable. Therefore, a filter is required to remove undesirable quantities of solvent from the electrolyte which adds to the complexity and cost of the process.

5        Within the electrolyte recirculation loop, it is common practice to provide a short circuit of spent electrolyte from the electrowinning process back to the feed to the electrowinning process so as to maintain certain levels of metal in the electrolyte. Upon receiving metal in the  
10 stripping stage from the solvent, a filter is required to remove substantially all of the solvent from the electrolyte. The electrolyte may also need to be bled off and the volume made up with fresh electrolyte and the leaching fluid may also need to be bled off and made up due  
15 to a build up in concentration of contaminating metals such as, in the case of electrowinning copper, the presence of iron. These and other such complexities to the system add to the cost of the operation as well as the cost of design and installation of an electrowinning process plant.

20        It is normal practice to maintain substantially laminar flow through the electrowinning cells containing the electrolyte thereby limiting the current density applied to electrodes in the cells. One reason for this is so that the electro-deposited metal is not sloughed from the  
25 electrode. Furthermore, the tenor and flow of the electrolyte is required to be maintained within narrow limits due to the sensitivity of present electrowinning cells. Where chloride levels are high, corrosion may be a problem at the water line.

30        Generally speaking, the process of electrowinning metals from ores has developed as an application of the electrofining process where metals are refined to a high level of purity once they have been won by a metal winning process including smelting and electrowinning. Since the  
35 electrofining process involves the production of metal from a feedstock having fundamentally different characteristics to that in the case of the electrowinning process, many compromises have had to be made in adapting the

electrorefining process to electrowinning of metals from ores.

The electrowinning of metals has been applied directly to the matte phase in particular for the production of nickel. This technique has not been successful for copper mainly due to the effect of elemental sulfur coating onto the electrode(s). This leads either to passivation of the electrode so coated, or untimely break up of the anode due to copper being selectively removed from an unpassivated area.

The present invention aims to alleviate one or more of the above disadvantages and to provide mineral extraction apparatus which will be reliable and efficient in use.

With the foregoing in view, this invention in one aspect resides broadly in a method of electrowinning a mineral from an ore body by the process of:-

recirculating a leaching solution through leaching means and solvent extraction means whereby soluble mineral is leached from the ore body and dissolved into the leaching solution;

recirculating a solvent through the solvent extraction means and stripping means whereby selected soluble mineral dissolved in the leaching solution is extracted into the solvent from the leaching solution;

recirculating an electrolyte through the stripping means and a mineral extraction cell assembly whereby the selected soluble mineral is stripped from the solvent into the electrolyte, and

applying an electric current to the mineral extraction cell assembly and wherein said mineral extraction cell assembly includes:-

a stationary elongate housing having a conductive inner surface;

closure assemblies removably mounted to each end of the stationary housing;

an electrode extending from at least one the closure assembly into the housing to form an annular cavity between the housing and the electrode;



a fluid inlet to the annular cavity in one of the closure assemblies and formed whereby, in use, fluid is introduced to the mineral extraction cell assembly offset from the elongate axis of the stationary elongate housing;

5 a fluid outlet to the cell assembly formed in the other of the closure assemblies, and

electrical terminations for connecting the electrical current to the electrode and the conductive surface to cause the selected soluble mineral to be electro-deposited  
10 on the conductive surface.

Preferably, the cell assembly may be as disclosed in our co-pending International Patent Application No. PCT/AU92/00052 or it may include separation means dividing the annular cavity into an electrolyte chamber with which  
15 the fluid inlet and the fluid outlet are in fluid connection and a process fluid chamber, a process inlet to the process fluid chamber, a process outlet to the process fluid chamber, and the method includes circulating process fluid through the process inlet and the process outlet.

20 The electrolyte may be passed through the mineral extraction cell assembly in a relatively quiescent flow regime so as not to disturb the deposition of mineral on the conductive surface. Preferably, however, the electrolyte is recirculated through the mineral extraction  
25 cell assembly by passing the electrolyte through the housing between the fluid inlet and the fluid outlet whereby the electrolyte impinges on the conductive surface. Suitably, the electrode includes surface treatments for promoting impingement of the electrolyte upon the  
30 conductive surface and/or promotes or induces a desired flow regime in the fluid. The flow regime may be generating laminar flow, but is preferably turbulent flow, whether generating, established or fully developed turbulent flow whereby the electro-deposited mineral is  
35 maintained in suspension in the electrolyte.

The conductive surface may be of a material different from the mineral being deposited, and any mineral electro-deposited thereon is regularly removed. This process may



be accomplished by removing the housing and replacing it with a fresh one. Preferably, however, the conductive surface is the same material as the mineral to be deposited whereby the step of stripping of the electro-deposited mineral from the conductive surface may be eliminated. Additionally, the use of different phases fluids may be used to assist in ameliorating fouling of the separation means.

Where the electro-deposited mineral is maintained in suspension, at least some of the electro-deposited mineral deposited by the electrode is collected by use of particulate collection means. Additionally, the electrolyte chamber may be opened to remove the conductive surface.

Preferably, the electrode is utilised as an anode and the conductive surface is utilised as a cathode whereby the mineral is electro-deposited by the conductive by the application of the electrical current.

In another aspect this invention resides broadly in a mineral extraction cell assembly for extracting a mineral from a flowing solution containing mineral, the cell assembly including:-

a stationary elongate housing having a conductive inner surface;

closure assemblies removably mounted to each end of the stationary housing;

an electrode extending from at least one the closure assembly into the housing to form an annular cavity between the housing and the electrode;

a fluid inlet to the annular cavity in one of the closure assemblies and formed whereby, in use, fluid is introduced to the mineral extraction cell assembly offset from the elongate axis of the stationary elongate housing;

a fluid outlet to the cell assembly formed in the other of the closure assemblies;

separation means dividing the annular cavity into an electrolyte chamber with which the fluid inlet and the





fluid outlet are in fluid connection and a process fluid chamber;

a process inlet to the process fluid chamber;

a process outlet to the process fluid chamber, and  
5 wherein the method includes circulating process fluid through the process inlet and the process outlet, and

electrical terminations for connecting the electrical current to the electrode and the conductive surface to cause the mineral to be electro-deposited on the conductive  
10 surface. Suitably, the separation means is adapted to permit selected species to pass thereacross, such as an ion selective membrane. Other separation regimes may be used in conjunction with the ion selection, such as dialysis, ultrafiltration, microfiltration or such like in  
15 combination as desired. Suitably, such as for the electrowinning of a cationic species such as a metal, the separation means is a cationic selective membrane for electrowinning of cationic mineral from a corresponding anion in solution.

20 In a preferred embodiment, the separation means permits access to the cathode compartment for harvesting of the electrowon mineral and is a tubular membrane supported by its respective ends by the closure assemblies.

Preferably the elongate housing extends between end  
25 walls and the electrode is disposed within the housing and extends between the end walls. The electrode may be of any shape, but preferably is of a form or configuration which includes surface treatments such as projections or ribs for promoting a the impingement upon the conductive surface  
30 and/or a desired flow regime in the fluid. It is also preferred that the electrode is utilised as an anode and the conductive surface is utilised as a cathode such that mineral material produced by electrolysis of a liquid in contact with the anode and the cathode is deposited by the  
35 conductive surface. However, the electrode may be utilised as the cathode such that mineral material may be deposited thereon.

It is believed by the applicants that by the incorporation of a turbulent or non-quiescent flow regime in the electrolyte whereby impingement of the electrolyte onto the conductive surface occurs, the current density applied to the conductive surface may be increased above the current density applied in conventional electrolytic cells. Moreover, in a further preferred embodiment, the incorporation of a turbulent flow regime in the electrolyte may be utilised to maintain electrowon material in suspension in the electrolyte for recovery by filtration, settling, centrifugation, hydrocyclone chemical processing or such like, or any combination of these. Chemical processing may include the selective redissolving of impurities such as sulfur, unwanted metals or the like.

It is envisaged that the cell may be adapted for the electrowinning of minerals in particulate form by arranging the operating conditions of a cell, including fluid velocity and cathode current density, within desired limits such that at least some of the electrowon material, instead of being deposited onto the cathode is carried through the cell with the liquid flow whereby it may be collected at a convenient collection point remote from the cylindrical portion of the housing. The cell may be provided with metal particulate collection means whereby at least some of the electrowon material may be extracted from the cell as particles with minimal interruption to the electrowinning process.

Additionally or alternatively, the particulate collection means may be interposed between cells connected in series, and may be formed integrally with gas separation means. The particulate collection means may include separation means utilising gravitational effects or centrifugal effects for separation and a collection chamber or hopper. The latter may be selectively connectible to an external collection region by external valve means, and the collection chamber may itself be selectively isolated from the cell by further valve means such that particulate material may be extracted by permitting it to fall through



the open further valve means into the collection chamber with the external valve means closed, then closing the further valve means and opening the external valve means.

In a further embodiment, the collection means may include a collection chamber moveable between a collection location beneath a cell or separation chamber and a discharge location remote from the cell or separation chamber. Suitably, a plurality of collection chambers are provided, and are arranged around a rotary magazine, the latter being rotatable such that collection chambers may be moved between the collection location and a discharge location.

Whether the impingement of electrolyte onto the conductive surface removes at least some of the electrowon material or substantially all of the electrowon material remains on the conductive surface, the conductive surface may be chosen from a material such that it differs in its surface properties from the mineral to be electrowon to the extent that a layer of the mineral built up on the conductive material may be conveniently separated therefrom. The separated mineral may be in the form of a thin-walled tube which itself may be utilised as a "starter" tube for the deposition of successive layers of the same mineral after its separation from the conductive material. For instance, in the electrowinning of copper, a large number of copper starter tubes for other cells may be produced from a relatively small number of cells using stainless-steel tubes.

The housing preferably includes an elongate cylindrical portion formed from conductive material such that the conductive surface may be integral therewith. The cathode and in particular the conductive material may be chosen to be the same as the mineral to be deposited. For instance, in the electrowinning of copper, the cylindrical portion may take the form of a thin-walled copper tube within which a thick layer of copper may be deposited, and the cylindrical portion may then be replaced with a fresh



copper tube whereby stripping of the deposited material from the tube may be eliminated.

The fluid inlet and the fluid outlet may be disposed in any direction relative to the housing, such as parallel to the elongate dimension of the housing. However, it is preferred that the fluid inlet be disposed adjacent to a first end of the housing, aligned substantially perpendicular to the axis of the elongate housing, and/or tangential to the annular cavity formed between the housing and the electrode whereby spiral flow through the annular cavity of the liquor is induced. Such spiral flow is considered to promote even deposition of the electrowon material. Suitably, the fluid outlet is disposed in a similar configuration to the fluid inlet and remote therefrom such that spiral flow of the liquor is further enhanced.

The fluid inlet may be connected to the fluid outlet of a second mineral extraction cell such that fluid may pass in series through both cells, permitting the progressive extraction of minerals from the fluid. An extraction battery may be formed from a plurality of cells connected in series such that mineral extraction may occur from a given volume of fluid over a sustained time period whereby a significant proportion of the total initial concentration of the desired mineral may be extracted.

Where the extraction process results in the generation of gaseous by-products, gas separation apparatus may be interposed between cells such that gas generated in an upstream cell may be removed from the liquid by differential density techniques or the like before entering a downstream cell. Alternatively or additionally, the upper ends of the cells may be provided with vent openings whereby generated gas may be vented from a cell before the liquid passes to a downstream cell. The gaseous separation effect may be enhanced by providing a gas separation chamber above the liquid outlet. Suitably, for the desired level of effectiveness, the separation chamber should be approximately the same diameter as the outside diameter of

the annular cavity, and have a minimum height equal to half of that diameter.

One embodiment of this invention includes an ion selective membrane to select anolyte and catholyte flow. Suitably, and in particular for the electrowinning of metal from a chloride solution, a cation selective membrane may be provided. By dividing the electrowinning cell into two compartments with the membrane, the anode and cathode reactions are able to proceed without interference, with only selected species being able to pass across the membrane. The function of the membrane is to enable open access to the cathode compartment for harvesting of the plated metal. The membrane prevents the chlorine formed at the anode from crossing to the cathode side of the cell, but is also selected to be of the type which permits the sodium cation to cross the membrane to complete the electrical circuit and maintain stoichiometry. The chlorine gas is removed only from the anode compartment.

The spent catholyte may be recirculated from the cathode compartment to the anode compartment as anolyte to maintain the chloride balance, which is reused directly in the leaching process, or to reform the leachate. Reformation of the leachate may be achieved by the reoxidation of cuprous and/or ferrous chloride to cupric and ferric chloride respectively, as well as the formation of hydrochloric acid.

In another aspect, this invention resides broadly in in a mineral extraction cell including:-

an elongate housing having a conductive surface disposed about its elongate internal periphery;

an electrode electrically isolated from the conductive surface and extending into the housing;

a fluid inlet to the housing;

a fluid outlet from the housing remote from the fluid inlet;

electrical terminations for connecting an electrical circuit to the electrode and the conductive surface, and



barrier means interposed between the electrode and the conductive surface. The barrier means may be in the form of a diaphragm or such like, but preferably the barrier means is a membrane. In a further preferred embodiment, the membrane is an ion exchange membrane and fluid flow through the cell includes at least some impingement upon the conductive surface. Other membrane separation regimes, or combinations of regimes may be utilised, such as dialysis, ultrafiltration electrodialysis and such like.

10 The mineral extraction cell is preferably adapted to operate with one or more membranes in aqueous electrolytes. Such membrane(s) may be in the form of tubular membranes supported at their ends by the end caps of the cell. Preferably, the membrane is spaced remote from the anode at  
15 a distance of the order of 2 or 3 mm. The flow regime, including the use of different phases, and/or membrane separation regimes may be used to assist in ameliorating fouling of the membrane.

In another embodiment of this invention, chloride  
20 electrolytes may be adapted to the mineral extraction cell in the electrowinning of noble metals from their cyanide complexes in alkaline aqueous solution.

In a further embodiment of this invention, the mineral extraction cell of this invention ameliorates the  
25 depositing of sulfur onto an electrode whereby the cell may be used for the direct winning of metals from the matte phase. Additionally, the system may be adapted to produce crystalline sulfur or other desired allotropes of sulfur and/or an abrasive material may be added to the circuit to  
30 enhance the effect of the flow regime in the cell. The mineral may be removed from the system as either a powder or in plate form, and the sulfur may be removed by a filtration or other separation step. The abrasive material may be retained and recirculated.

35 In another aspect, this invention resides broadly in a method of electrowinning a mineral, including:-

providing mineral extraction apparatus including an elongate housing having a conductive surface disposed about



the internal periphery thereof, an elongate electrode disposed within the housing, a fluid inlet to the housing, a fluid outlet from the housing remote from the fluid inlet, and a pair of electrical terminations for connecting  
5 an electrical circuit to the electrode and the conductive circuit;

connecting a source of electric current between the conductive surface and the electrode;

and,

10 passing a fluid containing a dissolved salt of the mineral through the housing between the fluid inlet and the fluid outlet.

The method may further include the addition of a leaching process to the electrowinning process, the fluid  
15 containing suitably comminuted ore including the metal to be electrowon, such that the process of dissolving the metal may be carried out concurrently with the electrowinning process, rather than requiring the two separate steps of leaching and electrowinning. For  
20 instance, in the electrowinning of copper from its ores, finely-crushed ore may be introduced into a dilute solution of sulfuric acid passing through a cell or plurality of cells. The copper is dissolved in the acid and may thence be electrowon from solution, being precipitated as a free  
25 metal, during which the sulfuric acid is preferably regenerated. The undissolved remainder of the ore may be separated from the liquid in a separation step such as settling, filtration or centrifugal effects and such like.

The further concentration process usually includes two  
30 solvent extraction steps as described above - the first solvent extraction where metallic cations are loaded into a liquid solvent substantially immiscible with the leachate and the second solvent extraction where metallic cations are stripped from the solvent into an electrolyte  
35 substantially immiscible with the solvent. The leachate and electrolyte are preferably aqueous solutions and the solvent is preferably a non-aqueous liquid. The



electrowinning stage of this invention is preferably applied to electrowinning of metal from the electrolyte.

In order that this invention may be more easily understood and put into practical effect, reference will  
5 now be made to the accompanying drawings which illustrate a preferred embodiment of the invention, wherein:-

FIG. 1 is a diagrammatic representation of an electrowinning process using solvent extraction;

10 FIG. 2 is a cross-sectional side view of an electrolytic cell for use with a process according to the invention;

FIG. 3 is a cross-sectional plan view of the electrolytic cell shown in FIG. 2;

FIG. 4 is a cross-sectional side view of a further embodiment of the invention;

15 FIG. 5 is a cross-sectional side view of a separation apparatus according to the invention;

FIG. 6 is a diagrammatic representation of an electrowinning cell assembly using a separative membrane, and

20 FIG. 7 is a diagrammatic representation of a metal winning process including electrowinning from a matte phase.

Referring to FIG. 1, a mineral recovery process 35 includes three recirculation loops for leaching a mineral  
25 from an ore body 18. The mineral recovery process 35 includes a leaching loop 36, a solvent extraction loop 37 and an electrolysis loop 38. The mineral to be extracted from the ore body 18 is electrolysed in an electrolytic cell 10 in the electrolysis loop 38.

30 Leachate recirculates around the leaching loop 36 through the ore body 18 whereby the leachate is replenished with mineral. For example, for winning copper, the replenished leachate contains of the order of three grams per litre of copper and five grams per litre sulfuric acid.

35 The leachate then passes through a loading step 58 wherein the mineral is extracted from the leachate into a solvent which recirculates through the solvent extraction loop 37. The leachate exiting from the loading stage 58 is typically

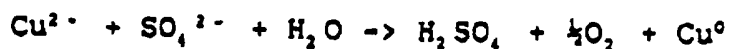


reduced to a mineral concentration, in the case of copper, of the order of 0.3 grams per litre copper. In order to allow for loss of leachate strength, a leachate makeup 59 is provided to maintain the acid concentration at the level 5 of the order of 15 grams per litre sulfuric acid.

The solvent extraction loop 37 includes a loading step 58 and a stripping step 57. In the loading step 58, the solvent is contacted with the leachate and the mineral is loaded from the leachate into the solvent recirculating 10 around the solvent extraction loop 37. In the stripping step 57, the solvent is contacted with an electrolyte which recirculates around the electrolysis loop 38.

The mineral is extracted from the solvent to the electrolyte to a relatively concentrated level such as for 15 example 50 grams per litre copper from the stripping step 57 and recirculates through a filter 56 for removing any solvent and/or other unwanted material. The electrolyte then passes through an electrolytic cell 10 in which at least some of the mineral is extracted to produce a spent 20 electrolyte having a concentration for example of the order of 35 grams per litre of copper and 180 grams per litre sulfuric acid.

In a typical application using a copper sulfate system, in the electrolytic cell 10, the copper sulfate is 25 dissociated in water, and one water molecule takes part in the electrolysis reaction as follows:



with the half oxygen molecule being formed at the anode and the copper metal being deposited at the cathode. At the 30 cathode, electrolysis of water takes place as:



Alternatively, a typical copper chloride system may be used with copper being deposited at the cathode and inter alia chlorine gas being liberated at the anode. With the 35 copper chloride system, the oxydation state of cuprous and cupric copper may also be used in the electrowinning process to provide a convenient process stoichiometry.



It is common practice to include an electrolyte by-pass 39 in conjunction with the electrolysis loop 38 whereby a portion of the spent solvent from the electrolytic cell 10 is returned to the electrolysis loop 38 after the filter 56 and before the electrolytic cell 10.

It is believed that the application of this invention to the mineral recovery process 35 described substantially by FIG. 1 may be simplified. For example, it is believed that the filter 56 and/or the electrolyte by-pass 39 may be eliminated. It is believed that the application of the invention to the process described in FIG. 1 is not so sensitive in respect of maintaining the concentration of the mineral to be electrowon from the electrolysis loop 38 within as close a range of concentrations as is required by the prior art. It is believed that the invention of the present application reduces or eliminates losses of solvent in the electrolytic cell whereby filtration of strong electrolyte is not required.

The electrolytic cell 10 shown in FIGS. 2 and 3 includes a housing assembly 11 which comprises a metal tube 12 to the external periphery of which an upper end cap 13 and a lower end cap 14 are sealed by sealing rings 15. The housing assembly 11 is held together by through bolts 16 which are clamped to flanges 17 formed in the end caps 13 and 14.

Sealing glands 20 are formed centrally in the end caps 13 and 14, and a cylindrical electrode 21 passes through them. If desired, only one sealing gland may be provided, and the electrode 21 may be terminated at its other end around a boss or within a tubular recess projecting inward from an end cap, the tubular electrode 21 being sealed to the boss or recess by sealing means, or otherwise blocked to minimized loss of fluid through the electrode 21. A liquid outlet 22 is formed in the upper end cap 13, and a liquid inlet 23 is formed in the lower end cap 14. The outlet 22 and the inlet 23 are aligned with their axes perpendicular to the axis of the housing assembly 11 and tangential to the annular cavity 24 formed between the

housing assembly 11 and the electrode 21. The upward flow of liquid induced by locating the inlet 23 in the lower end cap 14 will tend to scour gas deposited on the electrode 21 upwards towards a gas vent 32 formed in the upper end cap 13, and the gas flow acts as a bubble pump to enhance the flow of liquid and reduce external pumping requirements. Of course, if desired, the inlet 23 could be formed in the upper end cap 13 and the outlet 22 in the lower end cap 14 to induce downward liquid flow.

10 In the region between the inlet 22 and the lower end of the tube 12, the inner diameter of the lower end cap 14 is formed to match closely the inside diameter of the tube 12 such that a relatively smooth cylindrical surface is provided to enhance spiral flow of the incoming liquid.

15 The same process of diameter-matching is applied to the upper end cap 13 and the tube 12 for further enhancement of smooth spiral flow within the annular cavity 24.

Each of the end caps 13 and 14 is formed from an assembly of PVC plastic pipe fittings, including a flange adaptor 25, a length of pipe 26, a pipe cap 27, a compression fitting 30 and a further length of smaller-diameter pipe 31, these components being welded or glued together. Of course, if desired, the end caps could be formed integrally by a plastics moulding process. If

25 desired, the gas vent 32 may be provided with a float valve or the like which opens when gas has collected within the upper end cap 13, and closes after the gas has been vented.

Where it is desired to win electrolytic copper from a liquor containing sulfuric acid and copper sulfate, a copper tube may be utilised as the metal tube 12, and the tubular electrode 21 may be formed from titanium with a surface coating of precious metal oxides (known as dimensionally-stable anodes), or other materials which are insoluble in acid and non-passivating under operating

30 conditions, such as lead/antimony alloys. Alternatively, the metal tube 12 may be formed from an inert material such as stainless steel from which the deposited material may be readily removed.

35



In use, a source of DC electric power is connected to the cell 10 with its positive terminal joined to the tubular electrode 21, which becomes the anode, and its negative terminal joined to the metal tube 12, which becomes the cathode, clip-on connectors being preferred for this purpose to facilitate ease of assembly and disassembly and particularly removal and replacement of the housing 12. Current passing between the electrode 21 and the tube 12 deposits copper on the latter, and oxygen released from solution by the process is vented to atmosphere through the gas vent 32. When a desired thickness of copper has built up on the inside of the tube 12, it may be removed for sale as refined copper, or for such uses as electrical bus bars, and replaced with a fresh tube.

If desired, an array of cells 10 may be built up, and the liquor may be pumped through a plurality of cells in series, such that the copper content of the liquor is progressively reduced. Of course, any desired configuration of series and parallel flow between an array of cells may be configured such that flow conditions in the cells are optimised. Similarly, the electrical supply to the cells may be arranged in any desired series, parallel or series/parallel configuration to match cell currents and voltages to the available power supply.

The electrolytic cell 40 shown in FIG. 4 is similar in construction to that shown in FIGS. 2 and 3, but in the upper end cap 41, a vertical gap greater than one-half of the internal diameter of the tube 42 is left between the top of the liquid outlet 43 and the gas vent 44 such that gas entrained in the fluid rising through the tube 42 may separate from the liquid before the latter passes out of the cell 40. The lower end cap 45 is also formed with a vertical gap greater than one-half of the internal diameter of the tube 42 between the bottom of the liquid inlet 46 and the base 47 of the lower end cap 45. The anode 50 terminates above the liquid inlet 46, but its cylindrical shape is continued downward beyond the liquid inlet 46 by means of a non-conducting anode mount 51 attached to the

base 47 such that the inlet flow pattern is not significantly disturbed. These features ensure that a moderate buildup of metal particles falling to the bottom of the cell 40 neither impedes the flow of liquid through the inlet 46 nor creates an electrical short between the anode 50 and the tube 42.

The circumferential joint between the lower end cap 45 and the lower end of the tube 42 is also placed at least one-half of the inside diameter of the tube 42 above the top of the inlet 46 such that erosion of the end of the tube 42 in the turbulent flow conditions near the inlet may be minimised. The circumferential joint between the upper end cap 41 and the upper end of the tube 42 is configured in a similar manner such that smoothness of the spiral exit flow is enhanced and such that erosion of the upper end of the tube 42 is minimised.

The separation apparatus 60 illustrated in FIG. 5 is utilized to recover mineral particles formed in the cell 10 but not deposited on the cathode and for this purpose includes a vertical tubular separation chamber 61 closed at its top end and separated into two parts by a vertical baffle 62, the latter separating the inlet pipe 63 from the outlet pipe 64. Gas vents 65, which may include float valves if desired, are formed in the upper portion of the separation chamber 61. At its lower end, the separation chamber 61 tapers inward conically and terminates in an upper valve 66, the lower face of which a tubular collection chamber 67 is attached. The latter is terminated at its lower end by a lower valve 70.

In use, liquor carrying gas bubbles and metal particles may enter the separation apparatus 60 from the liquid outlet 22 of a cell 10 through the inlet pipe 63. The volume of the separation chamber 61 is made many times the volume of the volume of a cell 10 such that the liquor will have a relatively long retention time within the separation chamber 61. The baffle 62 prevents the short-circuiting of liquor flow directly from inlet 63 to outlet 64. Gas rises out of the liquor 71 and escapes through the gas vents 65,



while metal particles fall through the liquor 71 and the open upper valve 66 into the collection chamber 67, resting on the closed lower valve 70.

When it is desired to collect the accumulated metal particles, the upper valve 66 is closed, allowing the pressurised liquor flow loop to continue in operation while the lower valve 70 is opened to allow the metal particles to drop out. If desired sensing electrodes may be placed in spaced relationship along the side wall of the collection chamber 67, and remote sensing means, such as a resistance meter, may be utilised to sense when the level of metal particles has reached the desired level for collection.

From the above, it will be seen that the present invention may offer the advantages of simplifying the arrangement and/or operation of a tank farm, associated pipework and equipment and such like frequently used in conjunction with a typical electrowinning facility. Furthermore it may be possible to eliminate the need for a heat exchanger to recover heat in the electrolysis loop since the temperature of the electrolyte passing through the electrolytic cell is less critical than with the prior art.

Because the electrolytic cell of this invention is less sensitive to tenor and flow variation, the solvent extraction control requirements can be relaxed and may also allow variation in the tenor of the electrolyte without loss in efficiency. It is also believed that the strip mixer settler could be used as a powder recovery system for ultrafine particles. From the above, it can be seen that the invention of the present application has no water line in the electrolytic cell whereby corrosion can take place, the product and process of present invention are less sensitive to corrosion contaminant such as chloride. Also, it is believed that the circuit will require a lower iron bleed rate than conventional systems, which may lead to less acid makeup into the electrolyte and may also allow the use of the less selective and/or cheaper extractant.



Referring to FIG. 6, an electrowinning process includes an electrowinning cell 28 having an anode 19, a cathode 29 and a recirculation loop 33. Abrasive material and/or sulfur crystal catalyst is injected into the recirculation  
5 loop via an injection port 34. Positive electrical potential is applied to an anode terminal 48 and negative electrical potential is applied to a cathode terminal 49 to cause metal cations to migrate in the direction of arrows  
10 52 and be deposited upon the cathode 29 as free metal. The flow regime of electrolyte through the electrowinning cell 28 may be adapted to induce free metal to be dislodged from the cathode 29 for removal from the electrowinning process 28 in a separation step not shown. The sulfur is removed as  $S^0$  at 53a from the system in a desulfurisation unit 53.

15 Referring to FIG. 7, a smelting process 54 includes a concentrator 75 which feeds crushed ore to a reverberatory furnace 72 in which the ore is fused for the removal of impurities such as silica in the form of a slag 76. Molten matte phase material 55 is then converted for the removal  
20 of further impurities such as iron and sulfur at 77 with the addition of oxygen at 78 in a conversion furnace 73. In the production of copper, the matte 55 is principally copper sulfide. Through an anode furnace 74 and refining step 69, the copper metal is produced.

25 In an application of the present invention, an electrowinning cell 68 is used to electrowin metal directly from the matte 55. Although used to a limited extent in the production of nickel from nickel sulfide, the application of the electrowinning cell of this invention to  
30 the electrowinning of products from the matte phase will be more efficient.

It will of course be realised that while the above has been given by way of illustrative example of this invention, all such and other modifications and variations  
35 thereto as would be apparent to persons skilled in the art are deemed to fall within the broad scope and ambit of this invention as claimed in the following claims.

-- CLAIMS --

1. A method of electrowinning a mineral from an ore body by the process of:-

recirculating a leaching solution through leaching means and solvent extraction means whereby soluble mineral is leached from said ore body and dissolved into said leaching solution;

recirculating a solvent through said solvent extraction means and stripping means whereby selected soluble mineral dissolved in said leaching solution is extracted into said solvent from said leaching solution;

recirculating an electrolyte through said stripping means and a mineral extraction cell assembly whereby said selected soluble mineral is stripped from said solvent into said electrolyte, and

applying an electric current to said mineral extraction cell assembly and wherein said mineral extraction cell assembly includes:-

a stationary elongate housing having a conductive inner surface;

closure assemblies removably mounted to each end of said stationary housing;

an electrode extending from at least one said closure assembly into said housing to form an annular cavity between said housing and said electrode;

a fluid inlet to said annular cavity in one of said closure assemblies and formed whereby, in use, fluid is introduced to said mineral extraction cell assembly offset from the elongate axis of said stationary elongate housing;

a fluid outlet to said cell assembly formed in the other of said closure assemblies, and

electrical terminations for connecting the electrical current to said electrode and said conductive surface to cause said selected soluble mineral to be electro-deposited on said conductive surface.

2. A method as claimed in claim 1, wherein said cell



assembly includes:-

separation means dividing said annular cavity into an electrolyte chamber with which said fluid inlet and said fluid outlet are in fluid connection and a process fluid chamber;

a process inlet to said process fluid chamber;

a process outlet to said process fluid chamber, and wherein the method includes circulating process fluid through said process inlet and said process outlet.

3. A method as claimed in claim 1 or claim 2, wherein said electrolyte is recirculated through said mineral extraction cell assembly by passing said electrolyte through said housing between said fluid inlet and said fluid outlet whereby said electrolyte impinges on said conductive surface.

4. A method as claimed in any one of the preceding claims, wherein said electrode includes surface treatments for promoting impingement of said electrolyte upon said conductive surface and/or a desired flow regime in the fluid.

5. A method as claimed in any one of the preceding claims, wherein fluid flow through the cell is a turbulent flow regime whereby said electro-deposited mineral is maintained in suspension in said electrolyte.

6. A method as claimed in any one of the preceding claims, wherein said conductive surface is the same material as the mineral to be deposited whereby the step of stripping of the electro-deposited mineral from the conductive surface may be eliminated.

7. A method as claimed in any one of the preceding claims wherein said electrode is utilised as an anode and said conductive surface is utilised as a cathode whereby said mineral is electro-deposited by the conductive by said

application of the electrical current.

8. A method as claimed in any one of the preceding claims, and including the step of collecting at least some of the electro-deposited mineral deposited by the electrode by use of particulate collection means.

9. A method as claimed in any one of claims 2 to 8, wherein said electrolyte chamber may be opened to remove said conductive surface.

10. A method as claimed in any one of claims 2 to 9, wherein fluid flow includes the use of different phase fluids to assist in ameliorating fouling of the separation means.

11. A mineral extraction cell assembly for extracting a mineral from a flowing solution containing mineral, said cell assembly including:-

- a stationary elongate housing having a conductive inner surface;

- closure assemblies removably mounted to each end of said stationary housing;

- an electrode extending from at least one said closure assembly into said housing to form an annular cavity between said housing and said electrode;

- a fluid inlet to said annular cavity in one of said closure assemblies and formed whereby, in use, fluid is introduced to said mineral extraction cell assembly offset from the elongate axis of said stationary elongate housing;

- a fluid outlet to said cell assembly formed in the other of said closure assemblies;

- separation means dividing said annular cavity into an electrolyte chamber with which said fluid inlet and said fluid outlet are in fluid connection and a process fluid chamber;

- a process inlet to said process fluid chamber;

- a process outlet to said process fluid chamber, and



wherein the method includes circulating process fluid through said process inlet and said process outlet, and

electrical terminations for connecting the electrical current to said electrode and said conductive surface to cause said mineral to be electro-deposited on said conductive surface.

12. A mineral extraction cell assembly as claimed in claim 11, wherein said separation means is adapted to permit selected species to pass thereacross.

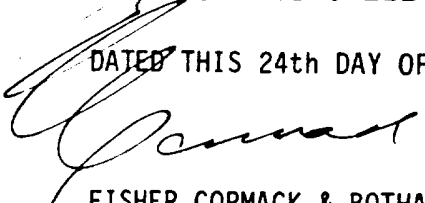
13. A mineral extraction cell assembly as claimed in claim 11 or 12, wherein said separation means includes an ion selective membrane.

14. A mineral extraction cell assembly as claimed in any one of claims 11 to 13, wherein said separation means is a cation selective membrane for electrowinning of cationic mineral from a corresponding anion in solution.

15. A mineral extraction cell assembly as claimed in any one of claims 11 to 14, wherein said ion selective separation means permits access to the cathode compartment for harvesting of the electrowon mineral.

16. A mineral extraction cell assembly as claimed in any one of claims 11 to 15, wherein said separation means is a tubular membrane supported by its respective ends by said closure assemblies.

DATED THIS 24th DAY OF August 1993

  
FISHER CORMACK & BOTHA  
Patent Agents for the Applicants

## ABSTRACT

A method of electrowinning a mineral from an ore body is disclosed, the method including recirculating a leaching solution [36] through leaching means [18] and solvent extraction means [58] whereby soluble mineral is leached from the ore body and dissolved into the leaching solution; recirculating a solvent [37] through the solvent extraction means [56] and stripping means [57] whereby selected soluble mineral dissolved in the leaching solution is extracted into the solvent from the leaching solution; recirculating an electrolyte [38] through the stripping means [57] and a mineral extraction cell assembly [10] whereby the selected soluble mineral is stripped from the solvent into the electrolyte [38], and applying an electric current to the mineral extraction cell assembly [10] and wherein said mineral extraction cell assembly [10] includes a stationary elongate housing [11] having a conductive inner surface [12], closure assemblies [13, 14] removably mounted to each end of the stationary housing [11], an electrode [21] extending from at least one the closure assembly into the housing to form an annular cavity [24] between the housing and the electrode a fluid inlet to the annular cavity in one of the closure assemblies and formed whereby, in use, fluid is introduced to the mineral extraction cell assembly offset from the elongate axis of the stationary elongate housing, a fluid outlet to the cell assembly formed in the other of the closure assemblies, and electrical terminations for connecting the electrical current to the electrode and the conductive surface to cause the selected soluble mineral to be electro-deposited on the conductive surface. The mineral extraction cell assembly [10] preferably further includes separation means dividing the annular cavity into an electrolyte chamber with which the fluid inlet and the fluid outlet are in fluid connection and a process fluid chamber, a process inlet to the process fluid chamber a process outlet to the process fluid chamber, in which case the method includes circulating process fluid through the process inlet and the process outlet.



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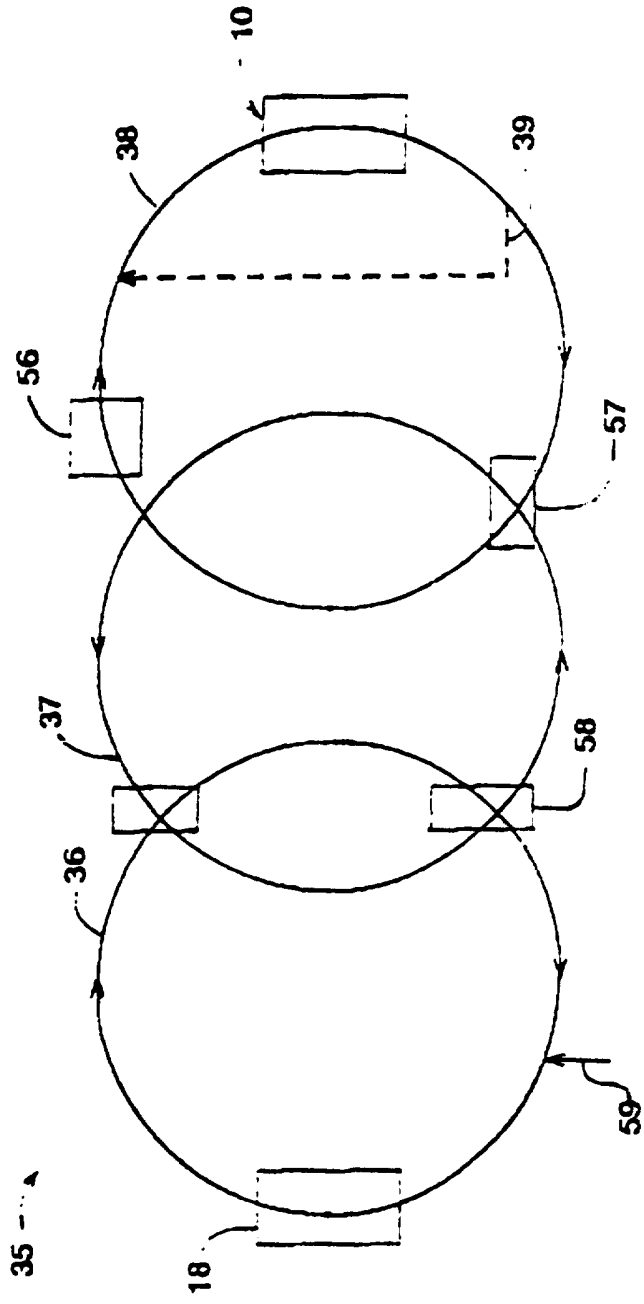


FIG. 1





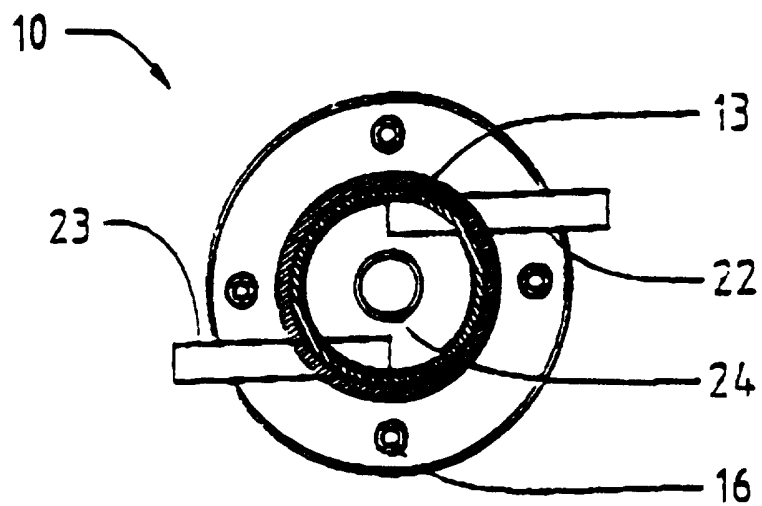


FIG. 3



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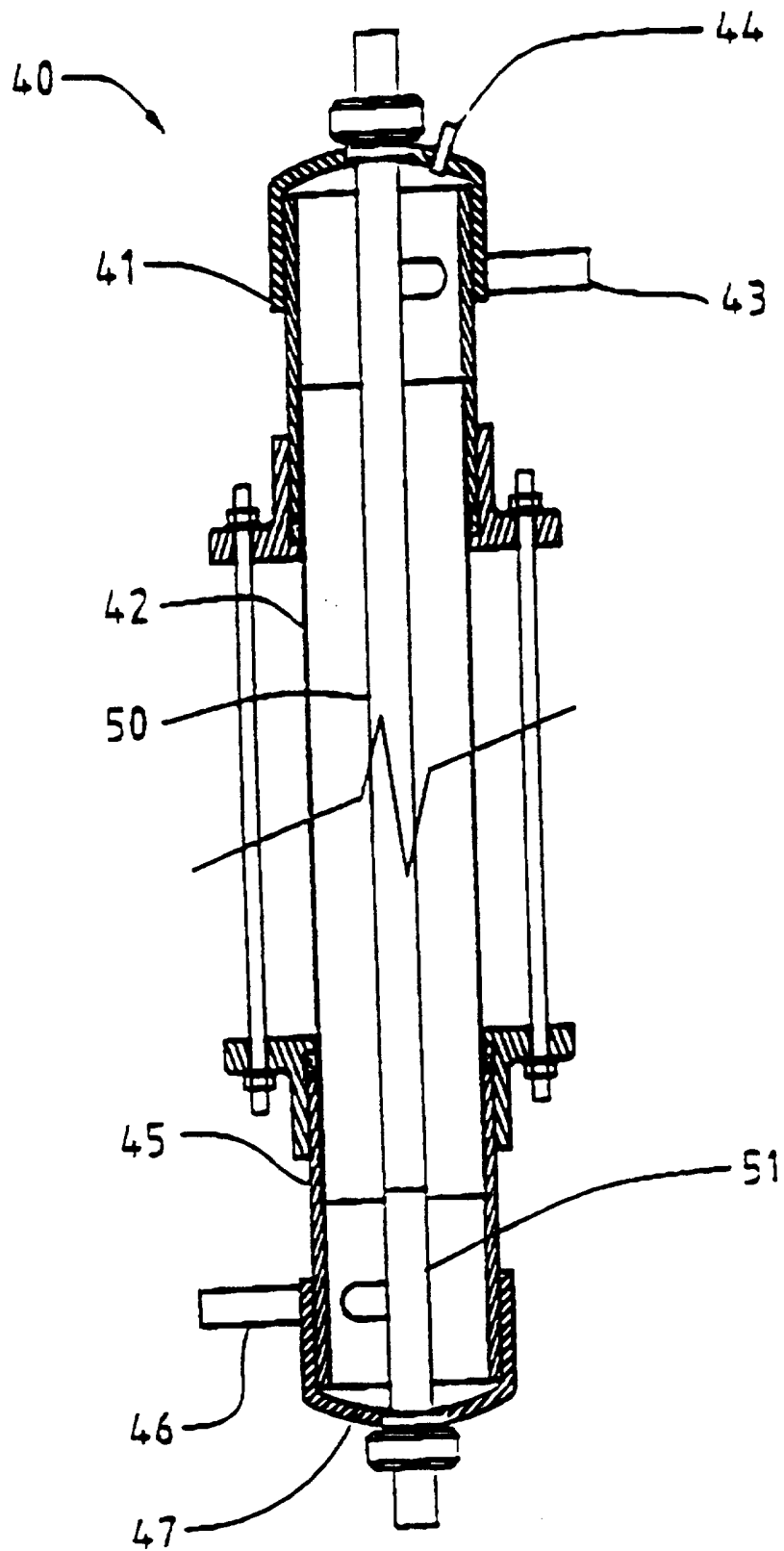


FIG. 4





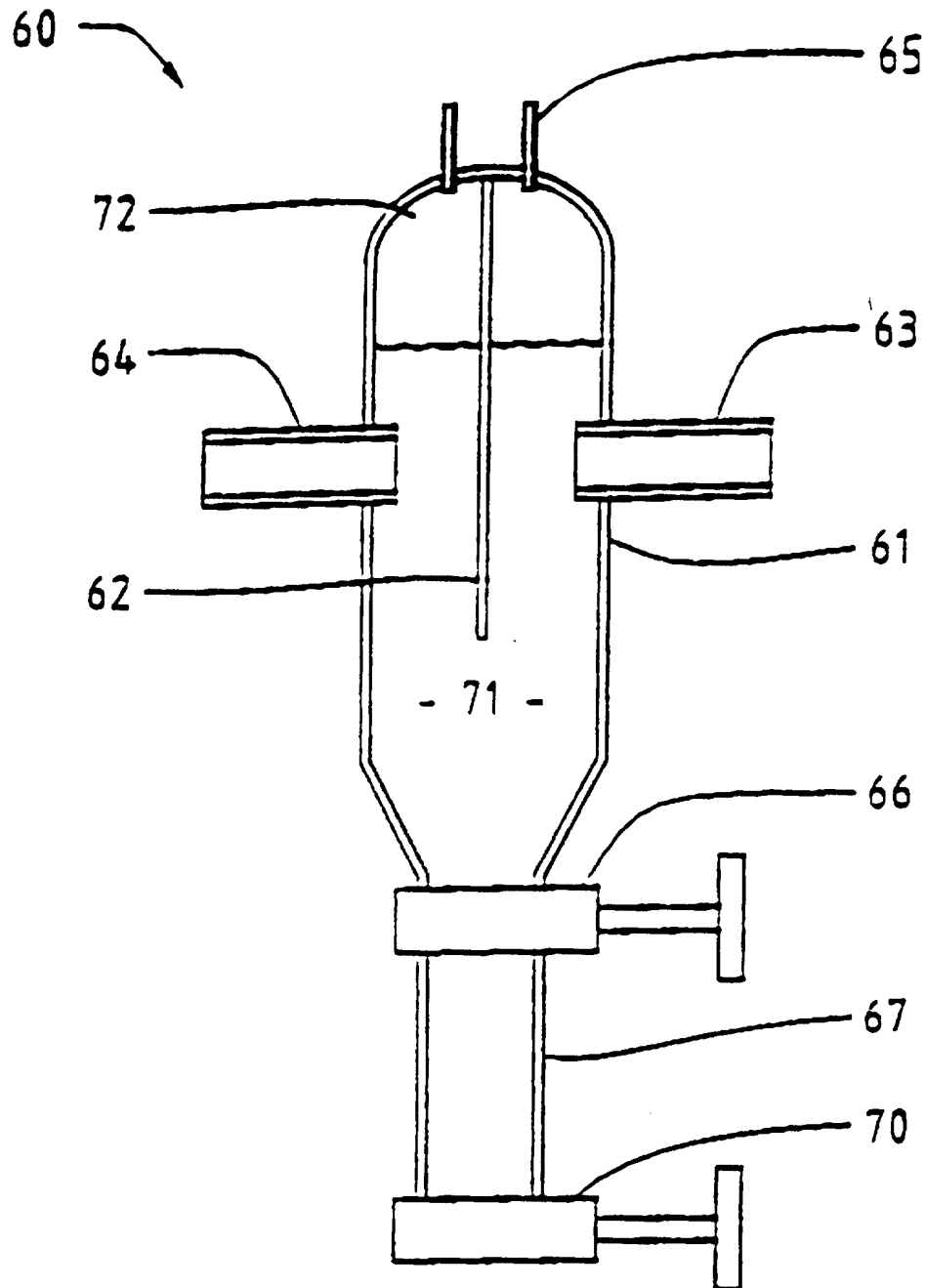


FIG. 5



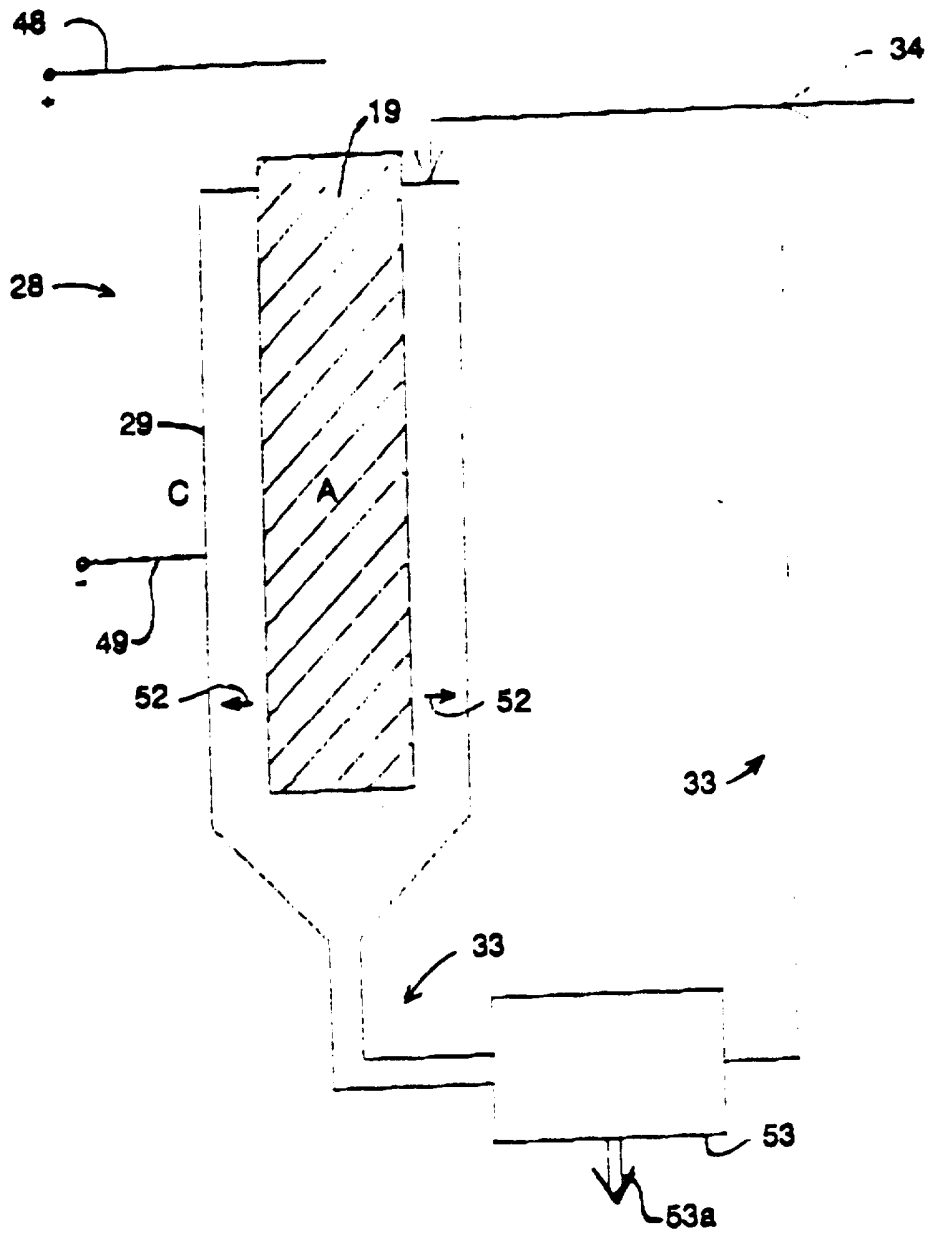


FIG. 6



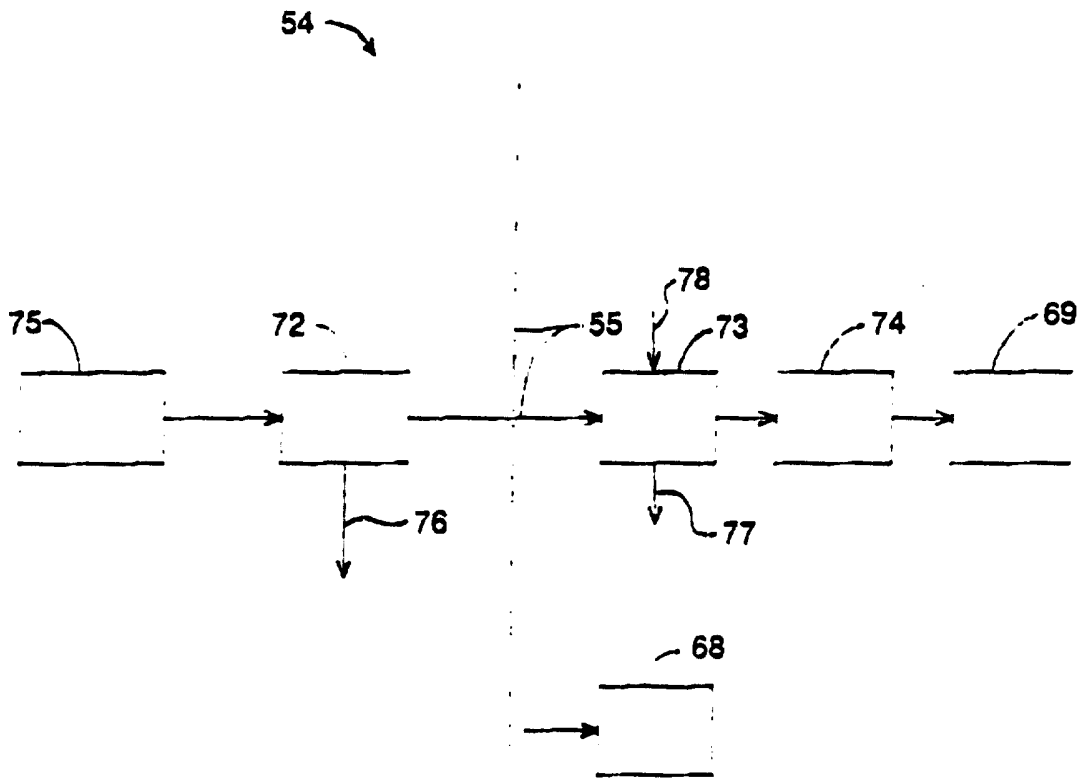


FIG. 7