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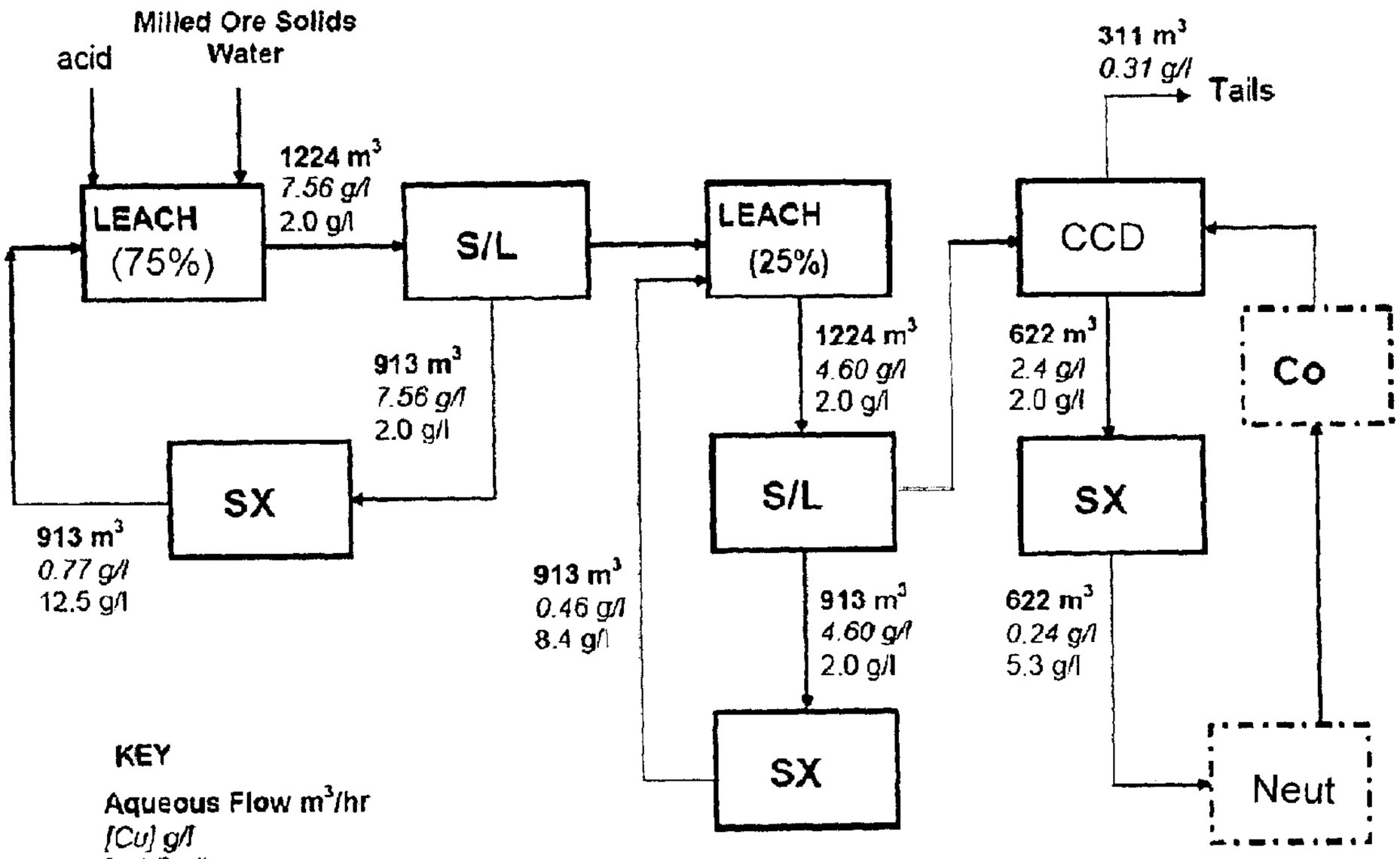
(72) **Inventeur/Inventor:**
NISBETT, ANDREW, US

(73) **Propriétaire/Owner:**
COGNIS IP MANAGEMENT GMBH, DE

(74) **Agent:** ROBIC

(54) **Titre : PROCEDE AMELIORE POUR LA RECUPERATION DE METAL ET RECYCLAGE D'AGENT DE LIXIVIATION DANS DES INSTALLATIONS A LIXIVIATION PAR AGITATION**

(54) **Title: IMPROVED METHOD FOR METAL RECOVERY AND LEACHING AGENT RECYCLE IN AGITATION LEACH PLANTS**



(57) **Abrégé/Abstract:**
Suggested is an improved process for metal recovery from ore using agitation leaching comprising dividing leaching of the crushed and mined ore into at least two sequential leaching-solids- liquid separation-solvent extraction sub-circuits, with no significant dilution during solids-liquid separation in these units, and the raffinate from solvent extraction being recycled back to the leaching, with the underflow pulp from the second liquid-solids separator being sent to a final solid-liquid separator, with water washing, from which the washed solids are sent to disposal and the clarified aqueous wash solution is sent to a final solvent extraction, with some or all of the metal-depleted aqueous raffinate from this final solvent extraction being optionally neutralized, and/or being circulated back to the third solid-liquid separation as wash solution and/or to recovery of other metals and/or to disposal to maximize metal recovery and maintain water balance.

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(71) Applicant *(for all designated States except US)*: **COGNIS IP MANAGEMENT GMBH** [DE/DE]; Henkelstrasse 67, 40589 Düsseldorf (DE).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **NISBETT, Andrew** [GB/US]; 10242 N. Cape Fear Lane, Tucson, AZ 85737 (US).

(74) Common Representative: **COGNIS IP MANAGEMENT GMBH**; Postfach 13 01 64, 40551 Düsseldorf (DE).

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(54) **Title:** IMPROVED METHOD FOR METAL RECOVERY AND LEACHING AGENT RECYCLE IN AGITATION LEACH PLANTS

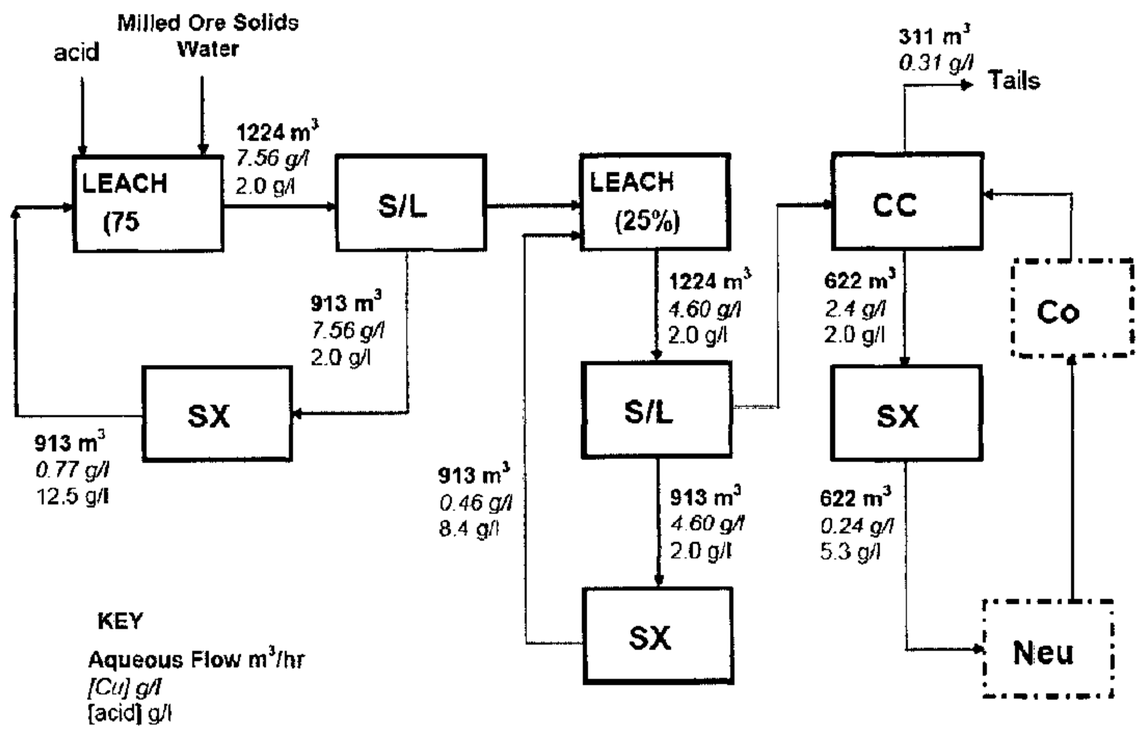


Figure 3:
Simple Leaching and Solvent Extraction Flow Sheet According to the Invention

(57) **Abstract:** Suggested is an improved process for metal recovery from ore using agitation leaching comprising dividing leaching of the crushed and mined ore into at least two sequential leaching-solids-liquid separation-solvent extraction sub-circuits, with no significant dilution during solids-liquid separation in these units, and the raffinate from solvent extraction being recycled back to the leaching, with the underflow pulp from the second liquid-solids separator being sent to a final solid-liquid separator, with water washing, from which the washed solids are sent to disposal and the clarified aqueous wash solution is sent to a final solvent extraction, with some or all of the metal-depleted aqueous raffinate from this final solvent extraction being optionally neutralized, and/or being circulated back to the third solid-liquid separation as wash solution and/or to recovery of other metals and/or to disposal to maximize metal recovery and maintain water balance.

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Improved method for metal recovery and leaching agent recycle in agitation leach plants

Field of the invention

The present invention relates to the design and operation of the leaching and solvent extraction steps in a metal recovery plant for recovering desired metal values from mined ores containing such metal values possibly commingled with other metal values.

Background of the invention

To obtain metals (e.g., copper, nickel, cobalt, zinc, uranium, and the like) in a pure, useful form, these metals must be removed and recovered from the ores in which they are found through a series of physical, hydrometallurgical and/or chemical steps.

Conventionally, the mined ore, containing a greater or lesser amount of the desired metal value, in addition to possibly one or more other more-or-less desirable metal values and a large amount of gangue and other more-or-less complicating minerals, is leached with an aqueous acidic (commonly sulphuric acid) or basic (commonly ammonium hydroxide) solution. This leaching is accomplished by either distributing the leaching agent over a pile or bed of mostly dry ore solids in dump leaching, heap leaching or vat leaching, wherein these ores are either leached as mined, or they may be crushed, but not ground or milled, to a size that gives higher metal recovery and/or faster metal recovery, or, as in agitation leaching, by mixing the leaching agent with an aqueous slurry of crushed and milled ore solids in one or more stirred tanks in an attempt to ensure optimal distribution of the leaching solution throughout the ore solids.

In heap, dump or vat leaching, dry ore is placed in a pile/bed leach system, or, where ore is agglomerated with moisture prior to being placed in a bed/heap, with only a small amount of added water. With these methods, there is often significant evaporation of any water from the pile/bed, and, so as not to depend solely on such evaporation to keep the ore dry, most plants using pile/bed leach systems employ at least one, and often several, large ponds in which to

hold water that may accumulate in a short event, such as a heavy rain. Thus, there is no need to bleed water on a continual basis from a heap/dump/vat leach system.

By comparison, in a plant employing agitation leaching, crushed ore that is to be agitation-leached is generally ground or wet-milled to a desired size distribution for achieving an acceptable metal recovery in leaching, with the resulting ore solids being added to the agitation leach unit(s) as aqueous slurry. Thus, in agitation leaching, a considerable amount of water is normally brought into the leaching system with the ore. This water must eventually leave or be removed from the system in order to maintain a water balance and it does so, mainly and continually, with the leached solids in the tailings or by intermittent bleeds from the circuit. Any desired metal or other valuable metals in the water leaving with the leached solids is lost (called the "soluble metal loss"). In addition, any leaching agent in this water is also lost and often has to be neutralized prior to the final disposal of the leached solids.

Selection of the type of leaching to be employed is based on several factors including the grade of the ore, the clay content of the ore, the hardness of the ore and the way the ore responds to the various leaching methods. A dump or heap leach system is generally much less costly in both capital (equipment) costs and operating (energy) expense, and is therefore selected for use with lower grade ores, where costs are critical, or with higher grade ores that respond well to heap leaching, permitting a high metal recovery. Agitation leaching, on the other hand, provides for a faster and more complete recovery of the desired metal(s), is easier to control, and often gives higher recovery of secondary valuable metals, such as cobalt, but it is also more expensive due to the capital cost of additional equipment, such as mills, leach tanks and clarifiers, and has a higher operating cost because of, for example, the energy required to mill the ore and the chemicals needed for the solids-liquid separation.

Following the leaching step in a circuit employing agitation leaching (such circuits being the focus of this invention), the resulting mix of aqueous leachate, now containing a high proportion of the desired metal values, as well as leached ore solids from which the desired metal values have been dissolved, is then normally sent to a solids-liquid separation process, such as by counter-current decantation ("CCD"), with washing, or by filtration, also with washing. Following this solids-liquid separation process, the clarified or partially-clarified aqueous phase is sent to one or more units in a solvent extraction process for transfer of the metal values from the aqueous leachate into an organic phase comprising one or more extraction reagents.

In that solvent extraction process, the particular desired metal value is extracted from the leach solution containing that metal value into an organic phase by one or more extraction

reagents specific for that desired metal, which reagent(s) is/are dissolved in an organic phase that comprises the extraction reagent(s), optionally with one or more equilibrium modifiers, kinetic additive(s) and/or other compounds, in a water-insoluble, water-immiscible organic solvent. During such extraction, hydrogen ions are released from the organic phase into the aqueous phase, now largely depleted of the desired metal values, as represented by the equation below for extraction when copper is the desired metal, sulphuric acid is the leaching agent, and where "RH" represents the copper-specific extraction reagent(s):

$$2RH + CuSO_4 \rightleftharpoons R_2Cu + H_2SO_4$$

In the extraction of 1 ton of copper, 1.54 tons of sulphuric acid (useful for further leaching of copper when the leach solution, depleted of copper values, is returned to the leaching unit(s)) is regenerated in the leach solution from which the copper was extracted. Thus, the greater the amount of copper extracted from an aqueous solution, the higher the concentration of sulphuric acid generated in that solution. In general, more of the leached copper can be extracted when the concentration of copper in the leach solution is higher, thus, the higher the copper concentration in the leach solution to be treated by solvent extraction, the greater is the potential to return more sulphuric acid back to the leaching unit. Other metals, such as Zn, Ni and Co, also show this behavior, depending on the leach solution and extraction reagent(s) employed.

Following the extraction, the metal-rich organic phase containing one or more complexes of the desired metal with the extraction reagent(s) is then possibly washed to reduce the level of undesired iron and/or other undesirable species, and stripped of its desired metal content with a stripping agent, such as a relatively concentrated acid solution (normally sulphuric acid) that breaks apart the complex(es), freeing the desired metal into the aqueous "pregnant stripping solution". That metal is then finally captured in a pure form from the desired metal-rich pregnant stripping solution, by electrodeposition in an electrowinning stage, or by one or more alternative metal recovery processes.

The great quantities of solids and the large volumes of leaching and stripping agents, extraction reagents, organic solvents and purified water involved in large-scale mining and metal recovery operations mandate efforts to use these resources most efficiently, both from a purely economic perspective, and in consideration of the potential environmental impact of accidental discharges and intentional disposal of no-longer-useful substances. Increased recycling of expensive agents and reagents, and the reduction of losses resulting both from the disposal of metal-depleted tailings slurry still containing some desired metal and other metal values dissolved in the water in the tailings slurry and from bleeds of the aqueous phase in order to

maintain the overall water balance and/or adjust/correct levels of undesirable metals or acid, as well as from other conservation measures, have become critical to the successful economic and environmentally-responsible operation of mining and metal recovery operations.

A particular issue addressed by this invention is the high cost both of replacing leaching agents lost or bled from the leaching-solvent extraction-electrowinning circuits and of purchasing substances used to neutralize excess leaching agents prior to further metal recovery activities and/or disposal of spent leaching and/or washing solutions containing these leaching agents. Another issue addressed is the need to recover a higher percentage of the desired metal values from the leached ores and thereby reduce the amount of valuable metal that is ultimately lost from the circuit in bleed streams or to tailings disposal, resulting in the loss of significant revenue that could be realized by the operator.

US 2005/0031512 A1 (Kordosky *et al*) showed that good metal extraction may be achieved while also significantly improving the recovery of the leaching agents by proposing a "split-circuit" arrangement of leachate solution flows that does not require as much fresh leaching agent to be added to supplement the recycling of the leachate solution back to the leaching stage. This method does not follow the conventional practice of washing, and thereby diluting, the entire solution flow from the one or more agitation leach units during the solids-liquid separation stage following leaching. Such washing is intended to minimize the loss of metal values with the disposal of the metal-depleted tailings slurry, but it also reduces the concentration of the desired metal in the clarified leach solution exiting solids-liquid separation and thereby reduces the leaching agent concentration which can build in this solution as the desired metal is extracted. Since only a portion of this leach solution, now depleted of desired metal values, but increased in leaching agent concentration, is recycled back to leaching, less leaching agent is recycled back to leaching than would be if the leaching solution had not been diluted.

Instead, the split circuit design involves subjecting the first leached pulp from the leach unit(s), comprising a mixture of metal-depleted leached solids and an aqueous leach solution containing dissolved salts of the desired metal, leaching agent, water, and possibly other metal values, to a first solids-liquid separation, without significant dilution. The solids pulp from that separation is then sent to a second solids-liquid separation, with significant washing/dilution, with the clarified metal-rich aqueous leach solutions from each solids-liquid being separation circulated to separate solvent extraction units. The solids, as aqueous slurry, from the second solids-liquid separation are then sent to disposal, with the metal-depleted raffinate from the solvent extraction unit(s) following the first solids-liquid separation, without dilution, being recycled as leach solution, possibly supplemented with additional fresh

leaching agent, to one or more of the leach unit(s). The raffinate, depleted of desired metal values, exiting the solvent extraction unit(s) following the second solids-liquid separation is neutralized, as necessary, and/or circulated to one or more additional units to possibly recover other metal values that may also have been present in the original ore in sufficient quantities, and/or recycled back to the second solids-liquid separation as wash solution, with the possibility that some of the neutralized solution may be bled to disposal in order to maintain a water balance.

Nevertheless, mineral industry is still interested in improved processes for the leaching of ores allowing significant reductions in leaching agent replacements and neutralizations, as well as further significant increases in the recovery of the desired metal from the original ore. The problem underlying the present invention has been to serve these needs.

Detailed description of the invention

The present invention is directed to a process for leaching desired metal values from crushed and milled ore solids and extracting those values into organic phases for further recovery efforts, in order to eventually obtain the desired metal in a usable form. This process initially comprises leaching crushed and milled ore solids with an acidic or basic leaching solution in one or more initial/"first" agitation leach units, to dissolve a significant portion of the desired metal values from the crushed and milled ore solids into an aqueous phase. The slurry of partially-leached solids with aqueous leach solution (called a "leach pulp") resulting from the initial leaching unit(s) proceeds to a first solids-liquid separation and clarification to produce two products, a first undiluted aqueous leach solution, rich in desired metal values, and a second leach pulp.

The first undiluted aqueous leach solution is then circulated, without significant dilution, to one or more "first" solvent extraction units for extracting the desired metal values from the aqueous solution into an organic phase. From the first solvent extraction unit(s), the aqueous solution ("raffinate"), depleted of desired metal values, is recycled as leaching solution, possibly augmented by fresh leaching agent and/or recycled raffinate from one or more other solvent extractions later in the process/circuit, back to the initial leach unit(s).

After the first solid-liquid separation and clarification, the second leach pulp is sent, without significant dilution, to one or more "final" agitation leach units for additional leaching, in order to dissolve another significant portion of the desired metal values remaining in the pulp. The leach pulp resulting from the "final" leach unit(s) is subjected to a second solids-liquid

separation and clarification to produce two products, a second undiluted aqueous leach solution, rich in desired metal values, and a third leach pulp. The second undiluted aqueous leach solution is circulated, without significant dilution, to one or more "second" solvent extraction units for extracting the desired metal values from the aqueous solution into an organic phase, with the aqueous solution ("raffinate"), depleted of desired metal values, exiting the second solvent extraction unit(s) being recycled as leaching solution, possibly augmented by fresh leaching agent and/or recycled raffinate from one or more other solvent extractions earlier and/or later in the process/circuit, back to the final agitation leach unit(s).

After the second solids-liquid separation and clarification, the third leach pulp, now largely depleted of desired metal values after two leachings, is sent to a last solids-liquid separation, with water washing and significant dilution for the first time, from which the washed solids slurry is sent to disposal, and the clarified aqueous wash solution is sent to one or more final solvent extraction units. From the final solvent extraction unit(s), the aqueous solution (raffinate), depleted of desired metal values, is optionally neutralized and then either possibly sent to one of more units to recover any other valuable metal values also present in the original ore, or recycled back to the last solid-liquid separation unit(s) as wash solution, or it may be split, with some portion sent to recovery of other metal values, and some portion sent to recycle back to the last solids-liquid separation unit(s) as wash solution, and perhaps even some to final disposal.

In some cases, depending on the grade of ore and the leaching characteristics of that ore, there may be one or more additional "intermediate" sub-circuits of leaching/solids-liquid separation/solvent extraction steps similar to the initial or first leaching/solids-liquid separation/solvent extraction sub-circuit, inserted between the first and "final" leaching/solids-liquid separation/solvent extraction sub-circuit.

By following this process and changing the current design and operation of the leaching and solvent extraction processes of current metal-recovery plants accordingly, the amount of leaching agent recycled to leach may be significantly increased, and both the amount of leached metal that is lost to tailings disposal and the quantities of additional fresh leaching agent purchased and the quantities of chemicals that must be expended to neutralize excess leaching agent in the circuits may be significantly decreased.

Surprisingly it has been observed that It surprisingly has now been found that further significant reductions in leaching agent replacements and neutralizations, as well as further significant increases in the recovery of the desired metal from the original ore, may be realized over the "split circuit" arrangement by dividing the duty of leaching the desired metal values from

the original crushed and milled ore solids among two or more agitation leach units in series. Each of these units then leaches desired metal values from the same ore solids, with each unit being followed by its own solids-liquid separator, without significant dilution, then its own solvent extraction unit(s), prior to a final solids-liquid separation, with washing, and a final solvent extraction on the clarified solution exiting the final solids-liquid separation, with washing, to try to recover any final amounts of valuable metal. The metal-depleted aqueous solution exiting the final solvent extraction unit is neutralized, as necessary, and/or circulated to one or more additional units to possibly recover other metal values that may also be present in the original ore, prior to disposal and/or recycle back to the final solid-liquid separation, with washing, as wash solution. The metal-depleted aqueous slurry of the leached solids exiting the final solids-liquid separation, with washing, is then sent to final disposal, which, in most cases, includes neutralization. With this new circuit design, raffinates from each solvent extraction unit, except the final solvent extraction unit, may be totally recycled to one or more of the preceding agitation leach unit(s), and, in doing so, much more leaching agent is recycled to leaching and, therefore, much less leaching agent is lost to final disposal as compared to the conventional and "split circuit" flow sheets. In addition, the desired metal lost to final disposal in the leached and washed solids is minimized when compared to either the conventional or “split circuit" flow sheets.

In particular, it has been found that by not depending on a single initial leach unit to dissolve all or mostly all of the desired metal values from the crushed and milled ore solids at one time, and breaking the leaching function into two or more units in a series or sequential arrangement, with accompanying solids-liquid separators, without dilution, and solvent extraction units, as described below, the amount of desired metal that may be recovered and the amount of leaching agent that may be recycled may be substantially increased. According to this invention, the crushed and milled ore solids are subjected to a sequence of leach units, each leach unit dissolving a portion of the desired metal values from, effectively, the same crushed ore solids (the original crushed and milled ore solids in the first agitation leach unit and progressively-more-leached solids pulps in subsequent agitation leach units in the series) with each such leaching unit being followed by its own solids-liquid separation without significant dilution, then one or more solvent extraction units to extract the desired metal value from the aqueous leach solution, rich in desired metal values, coming from the respective solids-liquid separation unit(s). In addition, all, or almost all, of the aqueous raffinates regenerated by the solvent extractions are recycled back to either their respective leach units, or recycled among two or more of the previous or following leach units in the circuit, for additional leaching, prior to a final solids-liquid separation, with washing. That final separation is applied to the crushed and milled leached solids exiting the last solids-liquid separation without significant

dilution, and is followed by a final solvent extraction on the clarified leach solution exiting the final solids-liquid separation.

To understand the significant benefits of the present invention over the conventional standard agitation leaching-solvent extraction operation, as well as over the "Split Circuit" agitation leaching-solvent extraction process, and not depend on any particular theory, involves closely comparing the flow diagrams and accompanying mass balances in Figures 1 through 3, with copper as the desired metal and sulphuric acid as the leaching agent, as later explained in the Examples.

For example, in any copper agitation leach-solvent extraction recovery process, all the sulphuric acid recycled back to leaching may be used to leach more copper, while all the acid taken to neutralization or contained in the tailings is lost, and, therefore, cannot be used to leach more copper. The more acid that can be recycled, the less acid that needs to be purchased, and the less the amount of acid that must be neutralized and/or that would be lost to disposal.

In each flow sheet, copper recovery from leaching is set at a realistic 90% and copper recovery from solvent extraction is also assumed to be a realistic 90%, even though copper recovery in an agitation leaching process can be up to nearly 100% in some cases and copper recovery across a copper solvent extraction unit can be more than 90% in some cases.

In one aspect, the instant invention provides a process for recovering metal values from crushed and milled ore solids comprising desired metal values that may be commingled with one or more other metal values, which process comprises:

(a) mixing a first aqueous leach solution with a body of the crushed and milled ore solids in a first agitated tank leach unit in order to dissolve at least a significant portion of the desired metal values formerly in the ore solids into the first aqueous leach solution and to obtain a first aqueous leach pulp, which pulp comprises a mixture of leached solids and first aqueous leach solution, rich in the desired metal values;

(b) subjecting the first aqueous leach pulp to a first solids-liquid separation, without significant water dilution, to provide a first clarified aqueous leach solution and a second aqueous leach pulp, which pulp comprises leached solids at a per cent solids level that is greater than that in the first aqueous leach pulp;

(c) sending the second aqueous leach pulp to a final agitated tank leach unit, and circulating the first clarified aqueous leach solution to a first solvent extraction, wherein, in such solvent extraction, at least a significant portion of the desired metal values are extracted into a first organic phase by one or more extraction reagent(s) specific for the desired metal, which extraction reagent(s) is/are dissolved in an organic formulation that comprises such extraction reagent(s), optionally with one or more equilibrium modifiers, kinetic additives and/or other compounds in a water-insoluble, water-immiscible organic solvent, creating a first organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complexes, that is sent to further metal recovery processes, and a first aqueous raffinate, depleted of desired metal values, up to all of which raffinate may be recycled/circulated back to the first agitated tank leach unit as at least a part of the first aqueous leach solution, which solution may be supplemented by fresh leaching agent and/or one or more other raffinates from later in the process;

(d) mixing a second aqueous leach solution with the second aqueous leach pulp in the final agitated tank leach unit in order to dissolve another portion of the desired metal values formerly in the partially leached crushed and milled ore solids (now comprising the second aqueous leach pulp) into the second aqueous leach solution and to obtain a third aqueous leach pulp, which pulp comprises a mixture of twice-leached solids and a second aqueous leach solution, rich in desired metal values;

(e) subjecting the third aqueous leach pulp to a second solids-liquid separation, without significant water dilution, to provide a second clarified aqueous leach solution and a fourth aqueous leach pulp, which pulp comprises leached solids at a per cent solids level that is greater than that in the third aqueous leach pulp;

(f) sending the fourth aqueous leach pulp to a third solids-liquid separation, and circulating the second clarified aqueous leach solution to a second solvent extraction, wherein, in such solvent extraction, at least a significant portion of the desired metal values are extracted into a second organic phase by one or more extraction reagent(s) specific for the desired metal, which extraction reagent(s) is/are dissolved in an organic formulation that comprises such extraction reagent(s), optionally with one or more equilibrium modifiers, kinetic additives and/or other compounds in a water-insoluble, water-immiscible organic solvent, creating a second organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complexes, that is sent to further metal recovery processes, and a second aqueous raffinate, depleted of desired metal values, up to all of which raffinate may be recycled/circulated back to the final agitated

tank leach unit as at least a part of the second aqueous leach solution, which solution may be supplemented by fresh leaching agent and/or one or more other raffinates from earlier or later in the process;

(g) subjecting the fourth aqueous leach pulp to a third solids-liquid separation, with significant dilution via an aqueous stream, in order to obtain a third clarified aqueous leach solution, wherein the concentration of desired metal values in the third clarified aqueous leach solution is less than the concentration of desired metal values in the second clarified aqueous leach solution, and a fifth aqueous pulp, which pulp comprises a mixture of leached solids and aqueous leach solution; and

(h) sending the fifth aqueous pulp to disposal and circulating the third clarified aqueous leach solution to a third solvent extraction unit, wherein, in such solvent extraction, a third organic phase of water-insoluble, water-immiscible organic solvent formulation comprising one or more extraction reagents extract at least a portion of the desired metal values from the third clarified aqueous leach solution creating a third organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complex(es), that is sent to further metal recovery processes, and a third aqueous raffinate, depleted of desired metal values, that is optionally neutralized and circulated back to the third solids-liquid separation as at least a part of the aqueous washing solution to recover at least a portion of any remaining desired metal values from the fifth aqueous pulp, or is optionally neutralized and sent to disposal, or is optionally neutralized and treated to recover one or more other metal values, if present in sufficient amounts, that may be present in the mined ore solids, or is optionally neutralized with portions circulating back to the third solid-liquid separation and/ or to further metal recovery and/or to disposal.

In one aspect, the instant invention provides a process for recovering metal values from crushed and milled ore solids containing a desired metal as desired metal values that may be commingled with one or more other metal values, which process comprises:

(a) mixing a first aqueous leach solution with a body of the crushed and milled ore solids in a first agitated tank leach unit in order to dissolve at least a significant portion

of the desired metal values formerly in the ore solids into the first aqueous leach solution and to obtain a first aqueous leach pulp, which first aqueous leach pulp comprises a mixture of leached solids and first aqueous leach solution, rich in the desired metal values;

(b) subjecting the first aqueous leach pulp to a first solids-liquid separation, without significant water dilution, to provide a first clarified aqueous leach solution and a second aqueous leach pulp, which second aqueous leach pulp comprises leached solids at a per cent solids level that is greater than that in the first aqueous leach pulp;

(c) sending the second aqueous leach pulp to a final agitated tank leach unit, and circulating the first clarified aqueous leach solution to a first solvent extraction, wherein, in such solvent extraction, at least a significant portion of the desired metal values are extracted into a first organic phase by one or more extraction reagents specific for the desired metal, which extraction reagent(s) is/are dissolved in an organic formulation that comprises such extraction reagent(s), optionally with one or more members selected from equilibrium modifiers, kinetic additives and a mixture of two or more thereof, in a water-insoluble, water-immiscible organic solvent, creating said first organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complexes, that is sent to further metal recovery processes, and a first aqueous raffinate, depleted of desired metal values, up to all of which raffinate may be recycled back to the first agitated tank leach unit as at least a part of the first aqueous leach solution, which solution may be supplemented by fresh leaching agent, one or more other raffinates from later in the process, or a mixture of both;

(d) mixing a second aqueous leach solution with the second aqueous leach pulp in the final agitated tank leach unit in order to dissolve another portion of the desired metal values formerly in the second aqueous leach pulp into the second aqueous leach solution and to obtain a third aqueous leach pulp, which third aqueous leach pulp comprises a mixture of twice-leached solids and the second aqueous leach solution, rich in desired metal values;

(e) subjecting the third aqueous leach pulp to a second solids-liquid separation, without significant water dilution, to provide a second clarified aqueous leach solution and a fourth aqueous leach pulp, which fourth aqueous leach pulp comprises leached solids at a per cent solids level that is greater than that in the third aqueous leach pulp;

(f) sending the fourth aqueous leach pulp to a third solids-liquid separation, and circulating the second clarified aqueous leach solution to a second solvent extraction, wherein, in such solvent extraction, at least a significant portion of the desired metal values are extracted into a second organic phase by one or more extraction reagent(s) specific for the desired metal, which extraction reagent(s) is/are dissolved in an organic formulation that comprises such extraction reagent(s), optionally with one or more members selected from equilibrium modifiers, kinetic additives, and a mixture of two or more thereof, in a water-insoluble, water-immiscible organic solvent, creating said second organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complexes, that is sent to further metal recovery processes, and a second aqueous raffinate, depleted of desired metal values, up to all of which raffinate may be recycled/circulated back to the final agitated tank leach unit as at least a part of the second aqueous leach solution, which solution may be supplemented by fresh leaching agent and/or one or more other raffinates from earlier or later in the process;

(g) subjecting the fourth aqueous leach pulp to said third solids-liquid separation, with significant dilution via an aqueous stream, in order to obtain a third clarified aqueous leach solution, wherein the concentration of desired metal values in the third clarified aqueous leach solution is less than the concentration of desired metal values in the second clarified aqueous leach solution, and a fifth aqueous pulp, which pulp comprises a mixture of leached solids and aqueous leach solution; and

(h) sending the fifth aqueous pulp to disposal and circulating the third clarified aqueous leach solution to a third solvent extraction, wherein, in such solvent extraction, a third organic phase of water-insoluble, water-immiscible organic solvent formulation comprising one or more extraction reagents extract at least a portion

of the desired metal values from the third clarified aqueous leach solution creating a third organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complex(es), that is sent to further metal recovery processes, and a third aqueous raffinate, depleted of desired metal values, that is either neutralized and circulated back to the third solids-liquid separation as at least a part of the third clarified aqueous leach solution to recover at least a portion of any remaining desired metal values from the fifth aqueous pulp, neutralized and sent to disposal, neutralized and treated to recover one or more other metal values, if present in sufficient amounts, that may be present in the mined ore solids, or neutralized with portions circulating back to the third solid-liquid separation, to further metal recovery, to disposal, or to a combination of two or more thereof.

For purposes of clarity, in each instance in this process, when reference is made to a single "unit", it should be understood that such "unit" may actually be several units in parallel or in series. Specifically, each leaching "unit" may consist of several agitated leaching tanks in parallel or in series, and each solvent extraction "unit" may consist of a single stage or a multiple number of stages, either extraction only or extraction and stripping in a typical arrangement, such as solvent extraction units or stages in parallel or series. It is also possible that all of the solvent extraction units are actually just different stages in a single solvent extraction plant. Generally, the solvent extraction process is highly flexible and the particular arrangement of solvent extraction units or stages for any given leach solution is done in order to optimize recovery of the desired metal and to optimize regeneration of the leaching agent for recycle.

In the present inventive process, the leached-solids pulp from each solids-liquid separator, prior to the final one that does involve a final washing/dilution, becomes the leachable body of the following leach unit (the leach unit next in the series/sequence). It should also be understood that each solids-liquid separation, with or without dilution/washing, may be conducted in any manner capable of separating solids from liquids; the method of such separations is not critical. For example, solids may be separated from liquids by methods including, but not limited to, decantation and/or filtration. In the final solids-liquid separation, with significant washing/dilution, according to the invention, counter-current decantation is preferred, but is not mandatory.

The term, "significant dilution" or "significant washing/dilution", when used in the process in accordance with the instant invention, refers to the addition of a measurable amount of water or other aqueous solution. Dilution of any of the clarified leach solutions prior to circulation of them to solvent extraction could cause a build-up of the volume of aqueous phase in one of the loops, and as such, would be undesirable and could decrease leaching agent recovery. Significant dilution of such aqueous leach solution is only used in the instant process in the final solids-liquid separation as part of the final solids- liquid separation wash process to try to recover the last vestiges of the desired metal values from the pulp prior to disposal of the metal-depleted ore solids.

Additionally, the solvent extractions in accordance with the processes of the present invention may also be carried out in any known manner, wherein aqueous leach solution is contacted with an organic phase containing an extraction reagent, specific to the desired metal. For example, these solvent extractions may be carried out using mixer- settler solvent extraction units, wherein the organic phase and the aqueous leach solution are vigorously intermixed in a mixer, and the resulting dispersion of organic and aqueous is then passed to a settler where the two phases settle, and from which there exits a clear organic phase and a clear aqueous phase.

Also, the "further metal recovery processes" to which the organic phases, rich in the desired metal values, may be subjected might comprise additional metal extraction followed by washing with a solution designed to remove undesirable species prior to contacting the organic phase, rich in desired metal values, with a suitable stripping agent that breaks apart the desired metal-extraction reagent complex and allows passage of the desired metal into an aqueous phase containing the desired metal in a concentrated and purified state from which final metal recovery takes place by electrowinning, or one or more other final metal recovery methods. With certain metals is may also be possible to recover the desired metal directly from the organic phase, rich in desired metal values, even though this is not a common technique.

And all solutions, phases, raffinates, and pulps may be conveyed within the circuits of the process by pipes or any other natural or man-made conduit.

The process according to the instant invention may be practiced in a new plant designed specifically for the instant invention, or it may be practiced in an existing plant by reconfiguring existing equipment, and pulp and solution flows, without necessarily adding a great deal of handling and/or process equipment.

In a preferred application of the process according to the instant invention, a majority of the desired metal values in the mined ore is intended to be leached from the crushed and milled ore solids in an initial leach unit, at least a majority of the desired metal values remaining in the solids pulp from the solids-liquid separator following the initial leach unit is leached in the next leach unit, and, in embodiments of the instant process comprising more than two leach units, the number of such units being limited by the economics of diminishing returns, the desired metal values in the mined ore are leached in sequential leach units progressively from a majority in the initial leach unit in the total circuit, a majority of the metal values remaining being leached in the next leach unit, and so on, until the last reasonably-recoverable amount of the remaining desired metal values from the original crushed and milled ore solids are leached by the final leach unit in the process/circuit.

For example, in a preferred application of the instant process, which comprises leaching with two leach units, 60 to 75% of the desired metal values in the original ore might be preferably leached in the first leach unit, and the remaining 25 to 40% of such desired metal values would then be leached in the second leach unit. In a preferred application of the instant process, which comprises leaching the desired metal values with three leach units, 45 to 55% of such desired metal values in the original ore might be preferably leached in the first leach unit, 25 to 35% of such desired metal values might be preferably leached in the second leach unit, and the remaining 10-30% of such desired metal values might preferably be leached in the third leach unit. In a particularly preferred aspect of the process according to the instant invention, at least a majority of the original or remaining desired metal values from the ore solids or pulp, as the case may be, is removed in the initial and each successive leach unit-solvent extraction unit combination, in order to maximize the regeneration of the leaching agent during the process and thereby maximize the recycling of such leaching agent to the leaching process. This sequential leaching practice generally results in the concentration of desired metal in the first clarified aqueous leach solution being at least 30% greater than the concentration of the desired metal in the second clarified aqueous leach solution, preferably this difference is at

least 50%, more preferably this difference is at least 70%, and still more preferably this difference is 100%.

In another embodiment of the instant invention, one or more intermediate agitation tank leach units may be inserted after the first solid-liquid separation and before the final agitated tank leach unit in step (c), such intermediate agitated tank leach unit sending an aqueous leach pulp, resulting from an aqueous leach solution being distributed through an aqueous leach pulp coming from the first solids-liquid separation, to an intermediate solids-liquid separation, from which an intermediate aqueous leach pulp is sent to the final agitated tank leach unit, and an intermediate clarified aqueous leach solution is circulated to an intermediate solvent extraction, from which an intermediate aqueous raffinate up to all of which raffinate may be recycled/circulated back to the intermediate agitated tank leach unit as at least a part of the aqueous leach solution for such leach unit, which solution may be supplemented by fresh leaching agent, and an intermediate desired metal-rich organic phase, rich in desired metal values, is sent to further metal recovery processes. It being readily understood by the skilled practitioner that the number of additional such sub-circuits would be determined by economic practicality, i.e., the capital and operating cost of the sub-circuit will be measured against the diminishing returns that may be realized in further recovery of desired metal and reduction in leaching agent and neutralization substances.

For purposes of illustration, one such additional sub-circuit may comprise a leach unit, labelled an "intermediate agitation leach unit", a solids-liquid separator labelled an "intermediate solids-liquid separation", following this agitation leach unit, and a solvent extraction following the intermediate solids-liquid separation, this solvent extraction labelled an "intermediate solvent extraction". Such an intermediate agitation leach unit might be inserted after the first solids-liquid separation and before the final agitated tank leach unit in step (c) in the process described above, such intermediate agitation leach unit sending an aqueous leach pulp, resulting from an aqueous leach solution being distributed through an aqueous leach pulp coming from the first solids-liquid separation, to an intermediate solids-liquid separation, from which an intermediate aqueous leach pulp is sent to the next agitation leach unit, and an intermediate clarified aqueous leach solution is circulated to an intermediate solvent extraction, from which exits an intermediate aqueous raffinate, up to all of which raffinate may be recycled/circulated back to the intermediate leach unit, or an earlier or later agitation leach unit, as at least a part of the aqueous leach solution for such leach unit, which solution may be supplemented by fresh leaching agent, and an intermediate organic phase, rich in the desired metal as a desired metal-extraction reagent(s) complex(es), is sent to further metal recovery processing.

The process according to the instant invention may be used in any metal recovery operation which employs an aqueous agitation leaching operation, where the leaching agent is regenerated in the solvent extraction process, and essentially with any leaching agent that is water-miscible, capable of leaching the desired metal from the mined ore into the desired metal leaching solution. Such leaching agents include, but are not limited to acids, including sulphuric acid, hydrochloric acid, nitric acid, organic acids, and combinations of two or more thereof, and basic substances, including gaseous ammonia and ammonium hydroxide. In certain preferred embodiments of the present invention, the leaching agent is sulphuric acid, resulting in each aqueous leach solution, i.e., the first aqueous leach solution, the second aqueous leach solution, the third aqueous solution, any intermediate aqueous leach solution, and so on, as well as each raffinate, i.e., the first aqueous raffinate, the second aqueous raffinate, the third aqueous raffinate, and so on, being sulphuric acid solutions. In other certain preferred embodiments of the instant invention, the preferred leaching agent is gaseous ammonia or ammonium hydroxide, resulting in each of the leach solutions, i.e., the first aqueous leach solution, the second aqueous leach solution, the third aqueous solution, any intermediate aqueous leach solution, and so on, as well as each raffinate, i.e., the first aqueous raffinate, the second aqueous raffinate, the third aqueous raffinate, and so on, being ammonia/ammonium hydroxide solutions.

The process of the invention is preferably used in the leaching and solvent extraction of desired metals that occur naturally as oxide and/or sulphide ores, preferably in the leaching and solvent extraction of divalent metals, such as copper, zinc, nickel and cobalt, and including, for example, transition metals. In a preferred embodiment of the invention, the desired metal is copper, and, particularly, when the desired metal is copper, the preferred leaching agent is sulphuric acid. In another preferred embodiment of the invention, the desired metal is copper, and the preferred leaching agent is gaseous ammonia or ammonium hydroxide. In still another preferred embodiment, the desired metal is zinc, and particularly, when the desired metal is zinc, the leaching agent is sulphuric acid or gaseous ammonia or ammonium hydroxide. In yet another preferred embodiment of the invention, the desired metal is nickel, and, particularly, when the desired metal is nickel, the preferred leaching agent is sulphuric acid or gaseous ammonia or ammonium hydroxide. In another preferred embodiment of the invention, the desired metal is cobalt and the preferred leaching agent is sulphuric acid.

The aqueous raffinate from each solvent extraction process is generally recycled back to the leach unit from which the clarified aqueous leach solution that was circulated to that vessel originated most recently in order to leach more desired metal from the crushed and milled ore solids or a subsequent leach pulp. However, a portion of the first aqueous raffinate, a portion of the second aqueous raffinate, a portion of the third aqueous raffinate, a portion of any in-

termediate aqueous raffinate(s), or a mixture of two or more thereof, may be circulated to any of the leach units and/or the third solids-liquid separator in the process according to the present invention if needed to maintain a water balance or to more efficiently distribute leaching agent.

The first aqueous raffinate produced in accordance with the processes of the present invention will generally have a leaching agent concentration which is greater than the concentration of leaching agent present in the second aqueous raffinate, the second aqueous raffinate produced in accordance with the processes of the present invention will generally have a leaching agent concentration which is greater than the concentration of leaching agent present in the third aqueous raffinate, and so on, with the aqueous raffinate from a solvent extraction component of any additional "intermediate" sub-circuit in accordance with the processes of the present invention generally having a leaching agent concentration which is greater than the concentration of leaching agent present in the aqueous raffinate from the solvent extraction vessel next following in the instant process. In preferred embodiments of the present invention, the first aqueous raffinate will have a leaching agent concentration which is at least 10% greater than the concentration of leaching agent present in the second aqueous raffinate, while in increasingly more preferred embodiments of the present invention, the first aqueous raffinate will have a leaching agent concentration which is at least 20% greater, preferably at least 50% greater, more preferably at least 75% greater and most preferably 100% greater. Such differentials of concentrations of leaching agents in second aqueous raffinates over the concentration of leaching agent in the third aqueous raffinate are similar to those between the first and second aqueous raffinates. The concentration of leaching agent in any intermediate aqueous raffinate over the concentration of leaching agent is the aqueous raffinate from the next-following solvent extraction vessel in the present process are also similar to those between the first and second aqueous raffinates. The aqueous stream for diluting the fourth aqueous leach pulp (step (g)) is normally the raffinate from the final solvent extraction process, optionally with neutralization or optionally following metal recovery of a second valuable metal value, but it may comprise fresh water introduced into the process and/or a portion of other aqueous process streams to maintain a water balance. Where the leaching agent comprises an acid, any of the aqueous raffinate(s) may be at least partly neutralized (e.g., to any pH up to about 8) with any basic substance (e.g., lime when the leaching agent is sulphuric acid) prior to its use for diluting the fourth aqueous leach pulp in the third solid-liquid separation.

While the invention has been described in connection with specific embodiments thereof, it will be understood that the scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

A computer simulation, based on mass balance principles and using iterative Excel spreadsheets, was run to compare the economics of the conventional leaching and solvent extraction circuits in widespread use (illustrated in Figure 1), against the economics of the split circuit configuration of the leaching and solvent extraction stages currently in use in some plants (illustrated in Figure 2), and against the economics of the simplest configuration of the instant invention (illustrated in Figure 3). In this non-limiting simulation, copper was used as the desired metal to be recovered, sulphuric acid was used as the leaching agent, and all numbers expressing quantities or concentrations are to be understood as approximations (to be understood, where not already present, as modified by "about"), not representations, for comparison purposes only, and affected by the ore grade, the water content of the crushed ore solids, the metal recovery achieved in leaching, the desired pulp density in leaching, desired wash ratios and thickener flow densities achievable in a CCD solid-liquid separation, the response of the leached solids to solid-liquid separation, the total flow of leach solution to be treated, the design of the solvent extraction process, and other parameters determined by the plant operators. The simulation is intended to be illustrative of the instant invention's advantages, but should not be interpreted to limit the scope of the current invention in any way. For purposes of the simulation, the following conditions were used:

Table 1
Case Study Basis

Ore treated (tons per day)	8,700
Ore grade (% Cu)	3.5
Ore Specific Gravity	2.8
Pre-leach thickener U/F (% solids)	55
% Solids in Leach	22
% Recovery in Leach	90
All CCD thickener U/F (% solids)	50
Number of CCD stages	6
Wash ratio in CCD	2:1
Copper recovery in each SX unit (%)	90

The economic benefits of the Sequential Circuit flow sheet relative to both the Split Circuit flow sheet and the conventional flow sheet are detailed in Table 2.

Brief description of the figures

- **Figure 1** is a flow diagram, containing pertinent components of the mass balance for the circuit, representing the flows in a standard conventional agitation leaching-solvent extraction flow sheet, wherein all of the aqueous leach solution is treated in the same manner.

- **Figure 2** is a flow diagram, with pertinent mass balance values, representing a "Split Circuit" flow sheet, wherein an aqueous leach solution is divided into two portions- one portion without significant dilution and the other with water dilution- prior to being subjected to solvent extraction.

- **Figure 3** is a flow diagram, with pertinent mass balance values, representing an embodiment of the "Sequential Circuit" flow sheet according to the present invention.

Optional units/operations are shown in dashed lines, with a cobalt recovery unit representing one or more units for recovering other metal values that may be present in sufficient quantities in the incoming ore.

Examples

Comparative Example A

Comparative Example A is based on Figure 1, which depicts a process flow diagram of a standard conventional copper agitation leaching and solvent extraction circuit, with pertinent mass balance numbers included for aqueous flows, copper concentrations and acid concentrations.

The leach pulp exiting the leach unit/train ("LEACH"), consisting of about 1224 cubic meters/hour of aqueous leach solution, comprising 9.92 g/l of copper and 2.0 g/l of sulphuric acid, and about 362.5 tonnes/hour of crushed and milled ore less the mass leached, is mixed/washed, in a counter-current decantation ("CCD"), with about 622 cubic meters/hour of recycled aqueous raffinate from the copper solvent extraction unit/train ("SX1"). For modelling purposes, the 622 cubic meters/hour of raffinate containing 0.80 g/l Cu was assumed to be neutralized to contain 2 g/l sulphuric acid before addition to the CCD circuit as wash solution, thus diluting the copper concentration of the aqueous leach solution exiting the CCD circuit from about 9.92 g/l copper to about 8.05 g/l copper prior to this solution being fed to the solvent extraction. An aqueous leach solution obtained from the CCD of about 1535 cubic meters/hour, comprising 8.05 g/l copper and 2.0 g/l sulphuric acid, is circulated to SX1, and an aqueous raffinate, comprising 0.80 g/l copper and 13.2 g/l sulphuric acid, exiting from the SX1, is split, with about 913 cubic meters/hour being recycled back to the leaching operation, where the acid is used to dissolve more copper, and about 622 cubic meters/hour that is recycled to neutralization and then to the CCD. The about 622 cubic meters/hour of raffinate, which is recycled to the CCD operation, is used to wash the leach solution from the leached solids, in order to minimize soluble metal losses in the aqueous phase portion of the leached pulp that is eventually disposed to tailings. A small portion of fresh water may be added to the overall leach/wash system or a small portion of aqueous solution may be bled from the overall leach/wash system to maintain a water balance.

In Comparative Example A, 913 cubic meters per hour of raffinate containing 13.2 g/l sulphuric acid would be returned to leaching, about 622 cubic meters per hour of raffinate containing 13.2 g/l sulphuric acid is neutralized to 2.0 g/l sulphuric acid prior to recycle back to the CCD circuit, and about 311 cubic meters per hour of aqueous solution containing 0.91 g/l copper is lost in tailings.

Comparative Example B

Comparative Example B is based on Figure 2, which depicts a process flow diagram of a "Split Circuit" copper leaching and solvent extraction system, with pertinent mass balance numbers included for aqueous flows, copper concentrations and acid concentrations. The leach pulp exiting the leach unit/train ("LEACH"), consisting of about 1224 cubic meters/hour of aqueous leach solution, comprising 9.92 g/l of copper and 2.0 g/l of sulphuric acid, and about 362.5 tonnes/hour of crushed and milled ore, less the mass leached, is passed to an initial solids-liquid separation (S/L), comprising a clarifier using decantation. Then about 913 cubic meters/hour of this solution, containing about 10.07 g/l Cu and about 2.0 g/l sulphuric acid, is taken directly to solvent extraction (SX 1), where the copper is extracted and sulphuric acid is regenerated. SX 1 will reasonably produce a raffinate containing about 1.01 g/l copper and about 15.95 g/l sulphuric acid, which solution is then recycled back to leaching. The leach pulp exiting the initial solid-liquid separation, which contains about 311 cubic meters/hour of leach solution, is taken to a counter-current decantation wash circuit (CCD) where it is mixed with about 622 cubic meters/hour of raffinate from SX 2 that has been, optionally, partially neutralized to 2.0 g/l sulphuric acid. About 622 cubic meters/hour of leach solution from the CCD circuit, comprising 5.21 g/l copper and 2.0 g/l sulphuric acid, is taken to SX 2 to give a raffinate containing 0.52 g/l copper and 9.2 g/l sulphuric acid. A small portion of fresh water may be added to the overall leach/wash system or a small portion of aqueous solution may be bled from the overall leach/wash system to maintain a water balance.

In Comparative Example B, 913 cubic meters/hour of raffinate containing 15.95 g/l sulphuric acid is returned to leaching, about 622 cubic meters/hour of raffinate from SX 2 containing 9.2 g/l acid is neutralized to 2.0 g/l sulphuric acid and about 311 cubic meters per hour of aqueous solution containing 0.67 g/L copper is lost to Tails.

The amount of acid in any aqueous stream at a particular time is the stream flow at that time multiplied by the acid concentration in the stream. A simple calculation shows that for this particular case about 2.51 more metric tons of acid/hour, or about 60.3 more metric tons of acid/day, is recycled to leaching using the "Split Circuit" flow sheet of Comparative Example B over the standard conventional flow sheet of Comparative Example A. Acid costs vary widely from, currently, about US$60/ton to above US$250/ton depending on the location. For low-cost acid, the savings in acid using the "Split Circuit" flow sheet instead of the conventional standard flow sheet would be about US$3618/day, while for high-cost acid, the savings in acid would be about US$15,075/day or greater.

A second simple calculation shows that for these Comparative Examples, about 2.49 less metric tonnes of acid per hour, or about 59.8 less metric tonnes acid per day, are neutralized using the "Split Circuit" of Comparative Example B over the standard conventional circuit of Comparative Example A. This is well within rounding error, since the greater amount of acid recycled to leaching using the "Split Circuit" flow sheet of Comparative Example B, over the conventional circuit flow sheet of Comparative Example A, should equal the lesser amount of acid that is neutralized using the "Split Circuit" flow sheet of Comparative Example B compared to the acid that is neutralized using the conventional circuit flow sheet of Comparative Example A.

Savings in neutralization can vary widely, depending on the cost of the neutralizing agent (typically lime or limestone), the capital required to build a larger neutralization plant and the cost to dispose of the greater amount of gypsum formed.

The amount of copper in any aqueous stream at a particular time is the stream flow at that time multiplied by the copper concentration in the stream. A third simple calculation shows that the total copper recovered using the "Split Circuit" flow sheet of Comparative Example B is greater than the total copper recovered using the standard conventional flow sheet of Comparative Example A by 74.64 kilograms/hour or about 1.79 tonnes/day. At a copper price of, currently, US$2.50/pound, this additional copper has a value of US$9,866/day or about US$3.55M annually.

Example 1

Example 1 illustrating the present invention is based on Figure 3, which depicts a process flow diagram of a simple example of a copper leaching and solvent extraction process according to the instant invention (denominated “Sequential Circuit”), with pertinent mass balance numbers included for aqueous flows, copper concentrations and acid concentrations. In this Example 1, a leach pulp consisting of about 1224 cubic meters/hour of aqueous leach solution, comprising 7.56 g/l of copper and 2.0 g/l of sulphuric acid, and about 362.5 tonnes/hour of crushed and milled ore less the mass leached, flows directly without dilution from this first leach unit (Leach 1), where about 75% of the copper from the crushed, mined ore has been dissolved into an aqueous acidic leach solution, to a solid-liquid separator (S/L1). From separator S/L1 about 913 cubic meters/hour of an aqueous leach solution, comprising 7.56 g/l copper and 2.0 g/l sulphuric acid, is circulated to a solvent extraction unit/train (SX1), and a pulp, consisting of about 311 cubic meters/hour of leach solution and about 362.5 tonnes/hour of partially leached crushed and milled ore less the small mass of ore leached in Leach 1, is

sent to a second leach unit. The entire 913 cubic meters/hour of metal-depleted aqueous leach solution, comprising 12.5 g/l sulphuric acid and 0.77 g/l copper, exiting SX1 is recycled to LEACH 1 where the acid contained in this first raffinate is used to leach copper from more fresh crushed and milled ore solids.

The remaining amount of copper in the partially leached crushed and milled ore solids exiting Leach 1, (25% of the original amount in the crushed and milled ore solids entering Leach 1) is then dissolved from the solids in LEACH 2, from which 1224 cubic meters/hour of aqueous leach solution, comprising 4.6g/l copper and 2.0 g/l sulphuric acid, and about 362.5 tonnes/hour of solids less the total mass leached, is sent to another solid-liquid separator (S/L2), again, without dilution. About 913 g/l of a second aqueous leach solution, comprising about 4.6 g/l copper and 2.0 g/l sulphuric acid emerges from S/L2 and is circulated to a second solvent extraction unit (SX2), and a pulp, consisting of about 331 cubic meters/hour of leach solution and about 362.5 tonnes/hour of almost totally leached solids less the mass leached, is sent to a third solid-liquid separator (CCD) where the pulp is diluted and washed The entire 913 cubic meters/hour of metal-depleted aqueous leach solution, comprising 8.4 g/l sulphuric acid and 0.46 g/l copper, are recycled from SX2 to LEACH 2 where the acid contained in this second raffinate is used to leach copper from the partially leached crushed and milled ore solids entering Leach 2 from S/L1.

Exiting the CCD wash process is a pulp, consisting of 311 cubic meters/hour of aqueous solution, comprising 0.31 g/l copper and 2 g/l sulphuric acid, and 362.5 tonnes/hour of almost totally leached solids, which is sent to tails and 622 cubic meters/hour of a third aqueous leach solution, comprising 2.4 g/l copper and 2.0 g/l sulphuric acid, which is sent to a final solvent extraction unit (SX3). From SX3, 622 cubic meters/hour of metal depleted aqueous leach solution, comprising 0.24 g/l copper and 5.3 g/l sulphuric acid, emerge as an aqueous raffinate for possible neutralization ("Neut") of excess acid before possible recovery of additional metal ("Co"), and recycle to the CCD as wash solution or supplemental wash solution.

In Example 1, about 913 cubic meters/hour of raffinate containing 12.5 g/l acid and about 913 cubic meters/hour of raffinate containing 8.4 g/l acid are returned to Leach 1 and 2, respectively. About 622 cubic meters/hour raffinate from SX 3 containing 5.3 g/l acid is neutralized to 2 g/l acid and about 311 cubic meters/hour of aqueous solution containing 0.31 g/l copper is lost to tailings

Example 3

Economic benefit calculation

Table 2:

Economic Benefits of the Sequential Circuit and Split Circuit Flowsheets over the Conventional Flowsheet in a One Year Period of Time

	Conventional	Split Circuit	Sequential Circuit
Operating days per year	360	360	360
Neutralization Cost ($/ton acid)	200	200	200
Cu price ($/lb)	2.50	2.50	2.50
Acid to neutralization (MT / day)	167.2	107.5	49.7
Neutralization cost ($ million/yr)	12.04	7.74	3.58
Benefit ($ million/yr)		4.30 (A)	**8.46 (A)**
Cu soluble loss (ton / day)	6.80	5.00	2.31
Revenue loss ($ million/yr)	13.45	9.90	4.57
Benefit ($ million/yr)		3.55 (B)	**8.88 (B)**
Total benefit ($ million/yr)		7.85 (A+B)	**17.34 (A+B)**

Calculation of the financial savings the invention offers when compared to the conventional flow sheet and the split circuit flow sheet are based on three advantages of the invention: the total greater amount of leaching agent recycled to Leach 1 and Leach 2, the decrease in acid neutralized and the decrease in the concentration of the desired metal in the aqueous solution leaving the circuit to the tailings with the washed leach pulp exiting the CCD wash circuit (called the "copper soluble loss").

In Table 2, the neutralization cost/year is calculated by multiplying the acid neutralized/day by the cost of neutralization times 360 days/year. The acid neutralized/day is the flow of the respective steam being neutralized multiplied by the g/l acid neutralized, for example, the acid neutralized/day for the conventional circuit is [622 cubic meters/hour times (13.2 g/l acid - 2 g/l acid) times 24 = 167.2]. The cost of neutralization, assumed to be US$ 200/tonne acid, is the total cost of the acid plus the cost of the base needed to neutralize the acid plus a small operating cost. A neutralization cost of US$ 200 tonne acid is used for this example and such cost is reasonable for neutralization and well within the range of today's costs for neutralization. The benefit of the acid savings on an annual basis for the Sequential Circuit flow sheet according to the instant invention over the Split Circuit flow sheet and over the conventional standard flow sheet is calculated from the difference in the neutralization cost for each of the three flow sheets.

Also in Table 2, the benefit on an annual basis associated with the lower soluble copper loss offered by the by the Sequential Circuit flow sheet according to this instant invention over the "Split Circuit" flow sheet and over the conventional standard flow sheet is determined from the differences in the economic value of the soluble copper lost on an annual basis (the concentration of the copper in the respective streams exiting the CCD wash circuit to Tails times the flow calculated on an annual basis times the copper price) for each of the three flow sheets.

From Table 2 it can be seen that the use of the Sequential Circuit flow sheet according to the instant invention offers an annual savings of US$17.34 million over the conventional leaching-solvent extraction flow sheet and a savings of US$ 9.49 million over the use of the Split Circuit flow sheet (which Split Circuit flow sheet has shown an annual savings US$7.85 million over the conventional flow sheet).

Clearly, the use of the process according to the present invention would result in much more leaching agent (in these Examples, acid) being returned to additional leaching than would be recycled with the conventional standard flow sheet or with the split circuit flow sheet. Also clearly the use of the process according to the instant invention would result in more copper being produced, and less copper lost as soluble copper, when compared to the conventional standard flow sheet and the split circuit flow sheet.

Since the amount of ore and copper content of the ore being treated is the same for the Conventional Circuit (Comparative Example A), the Split Circuit (Comparative Example B) and the Sequential Circuit according to this invention (Example 1), a direct and valid comparison can be made for the amount of acid neutralized and the soluble copper loss using each flow sheet.

The values calculated in Table 2 are both realistic and reasonable considering that, in December, 2007; the price of acid varies between US$ 60/tonne to over 250/tonne, depending on location and logistics, with most acid prices well above the low figure of US$ 60/tonne. Also at the present time the price of copper is about US$ 3.00/pound.

No matter what values are used to calculate the annual total benefit in US$, some benefit in less acid neutralized and more copper produced is always present for the Sequential Circuit flow sheet according to this instant invention over the Split Circuit flow sheet and the conventional standard flow sheet.

In addition to the benefits of more acid recycled to leaching, less acid being neutralized and less copper being lost as soluble copper in the pulp exiting the CCD process, a fourth advantage of the Sequential Circuit flow sheet pertains to the leaching efficiency. When the leaching process is divided into a first leach, where a majority of the copper is leached, and a second leach, where the remainder of the copper is leached, the copper concentration in the aqueous phase in contact with the almost-totally-leached, crushed and milled ore solids in the last leach unit is considerably lower (4.60 g/l Cu) than when all the leaching is done in one leaching unit/train (10.07 g/l Cu in the case of the split circuit flow sheet and 9.92 g/l Cu in the case of the standard conventional flow sheet). A lower copper concentration in the leach solution in contact with the final leached solids should allow a very slightly higher overall leach recovery because the diffusion of leached copper from the pores in the ore particles is faster. In addition, the acid to leach can be better controlled and thus made more efficient.

A fifth benefit may occur in those cases where the acid in the stream being recycled to the CCD wash process does not need to be neutralized, but the bleed of this stream from which a component of value in the bleed is recovered, for example cobalt, must be neutralized prior to cobalt recovery. Neutralization with a soluble base, such as caustic or ammonia, is very expensive, thus the lower the acid content of the bleed stream, the lower the amount of expensive base needed for neutralization. Furthermore, the use of a solution of caustic for neutralization adds water to the bleed stream, thereby diluting the valuable cobalt stream. Alternatively, neutralization can take place with lime or limestone, which is a less costly base. In this case, a lesser amount of acid in the bleed stream requires less lime or limestone for neutralization, and in the process, a lesser amount of gypsum precipitate, that must be removed from the system, is produced. A lesser amount of gypsum allows the use of smaller equipment for this particular solid-liquid separation. Since, when finely-divided solids separated from a liquid, the solids will always contain some of the liquid, a lesser amount of gypsum will contain a lower volume of the neutralized bleed stream that contains the valuable second component, for example, cobalt. Thus, the ultimate recovery of the secondary valuable component in the bleed stream is higher when using the process according to the invention.

Claims

1. A process for recovering metal values from crushed and milled ore solids containing a desired metal as desired metal values that may be commingled with one or more other metal values, which process comprises:

(a) mixing a first aqueous leach solution with a body of the crushed and milled ore solids in a first agitated tank leach unit in order to dissolve at least a significant portion of the desired metal values formerly in the ore solids into the first aqueous leach solution and to obtain a first aqueous leach pulp, which first aqueous leach pulp comprises a mixture of leached solids and first aqueous leach solution, rich in the desired metal values;

(b) subjecting the first aqueous leach pulp to a first solids-liquid separation, without significant water dilution, to provide a first clarified aqueous leach solution and a second aqueous leach pulp, which second aqueous leach pulp comprises leached solids at a per cent solids level that is greater than that in the first aqueous leach pulp;

(c) sending the second aqueous leach pulp to a final agitated tank leach unit, and circulating the first clarified aqueous leach solution to a first solvent extraction, wherein, in such solvent extraction, at least a significant portion of the desired metal values are extracted into a first organic phase by one or more extraction reagents specific for the desired metal, which extraction reagent(s) is/are dissolved in an organic formulation that comprises such extraction reagent(s), optionally with one or more members selected from equilibrium modifiers, kinetic additives and a mixture of two or more thereof, in a water-insoluble, water-immiscible organic solvent, creating said first organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complexes, that is sent to further metal recovery processes, and a first aqueous raffinate, depleted of desired metal values, up to all of which raffinate may be recycled back to the first agitated tank leach unit as at least a part of the first aqueous leach solution, which solution may be supplemented by fresh leaching agent, one or more other raffinates from later in the process, or a mixture of both;

(d) mixing a second aqueous leach solution with the second aqueous leach pulp in the final agitated tank leach unit in order to dissolve another portion of the desired metal values formerly in the second aqueous leach pulp into the second aqueous leach solution and to obtain a third aqueous leach pulp, which third aqueous leach pulp comprises a mixture of twice-leached solids and the second aqueous leach solution, rich in desired metal values;

(e) subjecting the third aqueous leach pulp to a second solids-liquid separation, without significant water dilution, to provide a second clarified aqueous leach solution and a fourth aqueous leach pulp, which fourth aqueous leach pulp comprises leached solids at a per cent solids level that is greater than that in the third aqueous leach pulp;

(f) sending the fourth aqueous leach pulp to a third solids-liquid separation, and circulating the second clarified aqueous leach solution to a second solvent extraction, wherein, in such solvent extraction, at least a significant portion of the desired metal values are extracted into a second organic phase by one or more extraction reagent(s) specific for the desired metal, which extraction reagent(s) is/are dissolved in an organic formulation that comprises such extraction reagent(s), optionally with one or more members selected from equilibrium modifiers, kinetic additives, and a mixture of two or more thereof, in a water-insoluble, water-immiscible organic solvent, creating said second organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complexes, that is sent to further metal recovery processes, and a second aqueous raffinate, depleted of desired metal values, up to all of which raffinate may be recycled/circulated back to the final agitated tank leach unit as at least a part of the second aqueous leach solution, which solution may be supplemented by fresh leaching agent and/or one or more other raffinates from earlier or later in the process;

(g) subjecting the fourth aqueous leach pulp to said third solids-liquid separation, with significant dilution via an aqueous stream, in order to obtain a third clarified aqueous leach solution, wherein the concentration of desired metal values in the third clarified aqueous leach solution is less than the concentration of desired metal values in the second clarified aqueous leach solution, and a fifth aqueous pulp, which pulp comprises a mixture of leached solids and aqueous leach solution; and

(h) sending the fifth aqueous pulp to disposal and circulating the third clarified aqueous leach solution to a third solvent extraction, wherein, in such solvent extraction, a third organic phase of water-insoluble, water-immiscible organic solvent formulation comprising one or more extraction reagents extract at least a portion of the desired metal values from the third clarified aqueous leach solution creating a third organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complex(es), that is sent to further metal recovery processes, and a third aqueous raffinate, depleted of desired metal values, that is either neutralized and circulated back to the third solids-liquid separation as at least a part of the third clarified aqueous leach solution to recover at least a portion of any remaining desired metal values from the fifth aqueous pulp, neutralized and sent to disposal, neutralized and treated to recover one or more other metal values, if present in sufficient amounts, that may be present in the mined ore solids, or neutralized with portions circulating back to the third solid-liquid separation, to further metal recovery, to disposal, or to a combination of two or more thereof.

2. The process according to Claim 1, further **characterised in** that an intermediate agitated tank leach unit is inserted after the first solid-liquid separation and before the final agitated tank leach unit in step (c), such intermediate agitated tank leach unit sending an aqueous leach pulp, resulting' from an aqueous leach solution being distributed through an aqueous leach pulp coming from the first solid-liquid separation, to an intermediate solid-liquid separation, from which an intermediate aqueous leach pulp is sent to the intermediate agitated tank leach unit, and an intermediate clarified aqueous leach solution is circulated to an intermediate solvent extraction, from which an intermediate aqueous raffinate up to all of which raffinate may be recycled back to the intermediate agitated tank leach unit, or to an agitated tank leach unit earlier or later in the process, as at least a part of the aqueous leach solution for such leach unit, which solution may be supplemented by fresh leaching agent, and an intermediate organic phase, rich in the desired metal as one or more desired metal-extraction reagent(s) complexes, is sent to further metal recovery processes.

3. The process according to Claim 1 or 2, **characterised in** that the desired metal is selected from the group consisting of copper, zinc, nickel and cobalt.

4. The process according to any one of Claims 1 to 3, **characterised in** that the first aqueous leach solution and the second aqueous leach solution are sulphuric acid solutions and the fresh leaching agent is sulphuric acid.

5. The process according to any one of Claims 1 to 3, **characterised in** that the first aqueous leach solution and the second aqueous leach solution are ammonia solutions and the fresh leaching agent is gaseous ammonia or ammonium hydroxide.

6. The process according to any one of Claims 1 to 5, **characterised in** that the third solid-liquid separation comprises counter-current decantation.

7. The process according to any one of Claims 1 to 6, **characterised in** that the concentration of the desired metal in the first clarified aqueous leach solution is at least 30% greater than the concentration of the desired metal in the second clarified aqueous leach solution.

8. The process according to any one of Claims 1 to 7, **characterised in** that the concentration of the desired metal in the first clarified aqueous leach solution is at least 50% greater than the concentration of the desired metal in the second clarified aqueous leach solution.

9. The process according to any one of Claims 1 to 8, **characterised in** that the concentration of the desired metal in the first clarified aqueous leach solution is at least 70% greater than the concentration of the desired metal in the second clarified aqueous leach solution.

10. The process according to any one of Claims 1 to 3, **characterised in** that the concentration of the metal in the first clarified aqueous leach solution is at least 100% greater than the concentration of the desired metal in the second clarified aqueous leach solution.

Figures

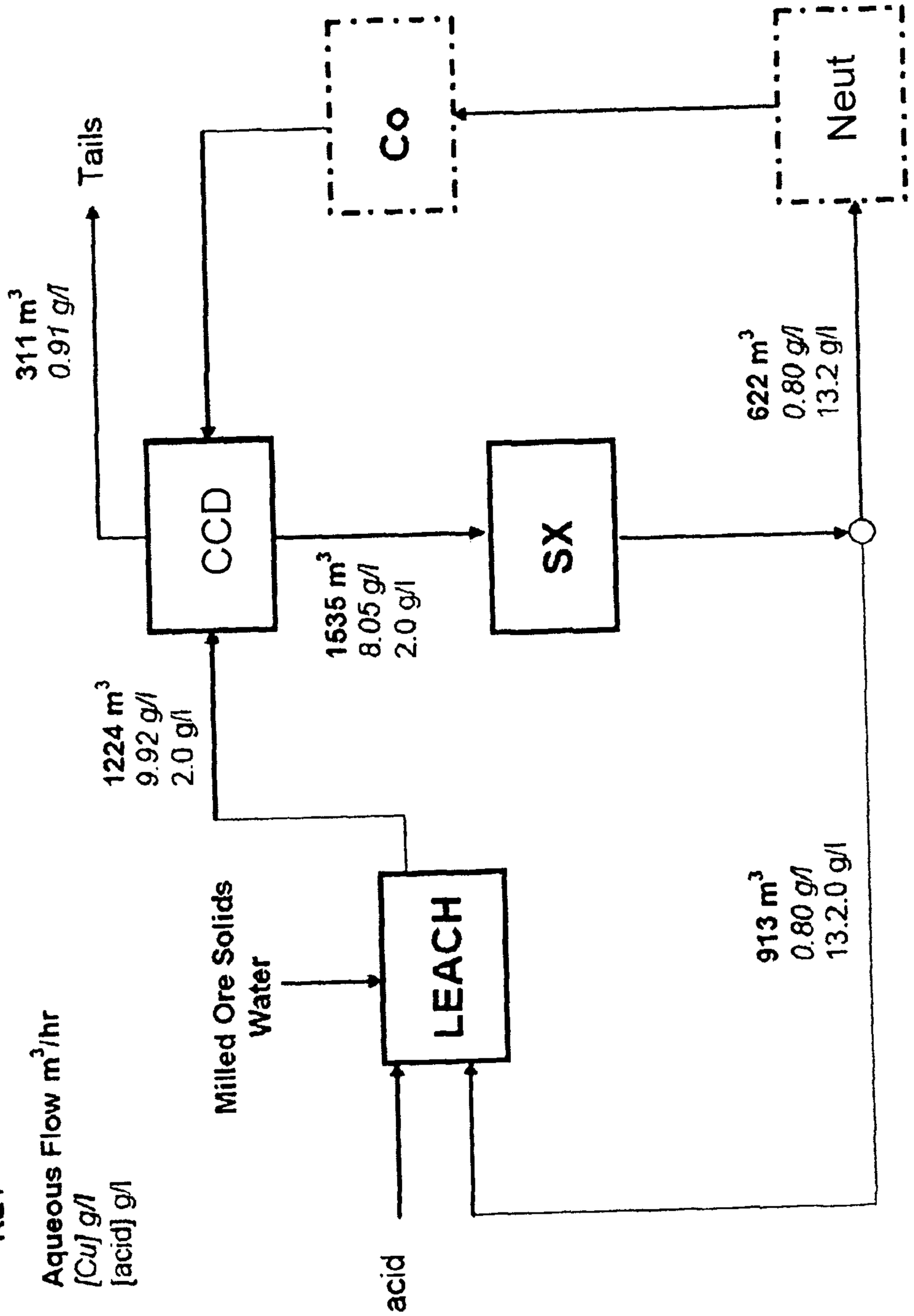


Figure 1

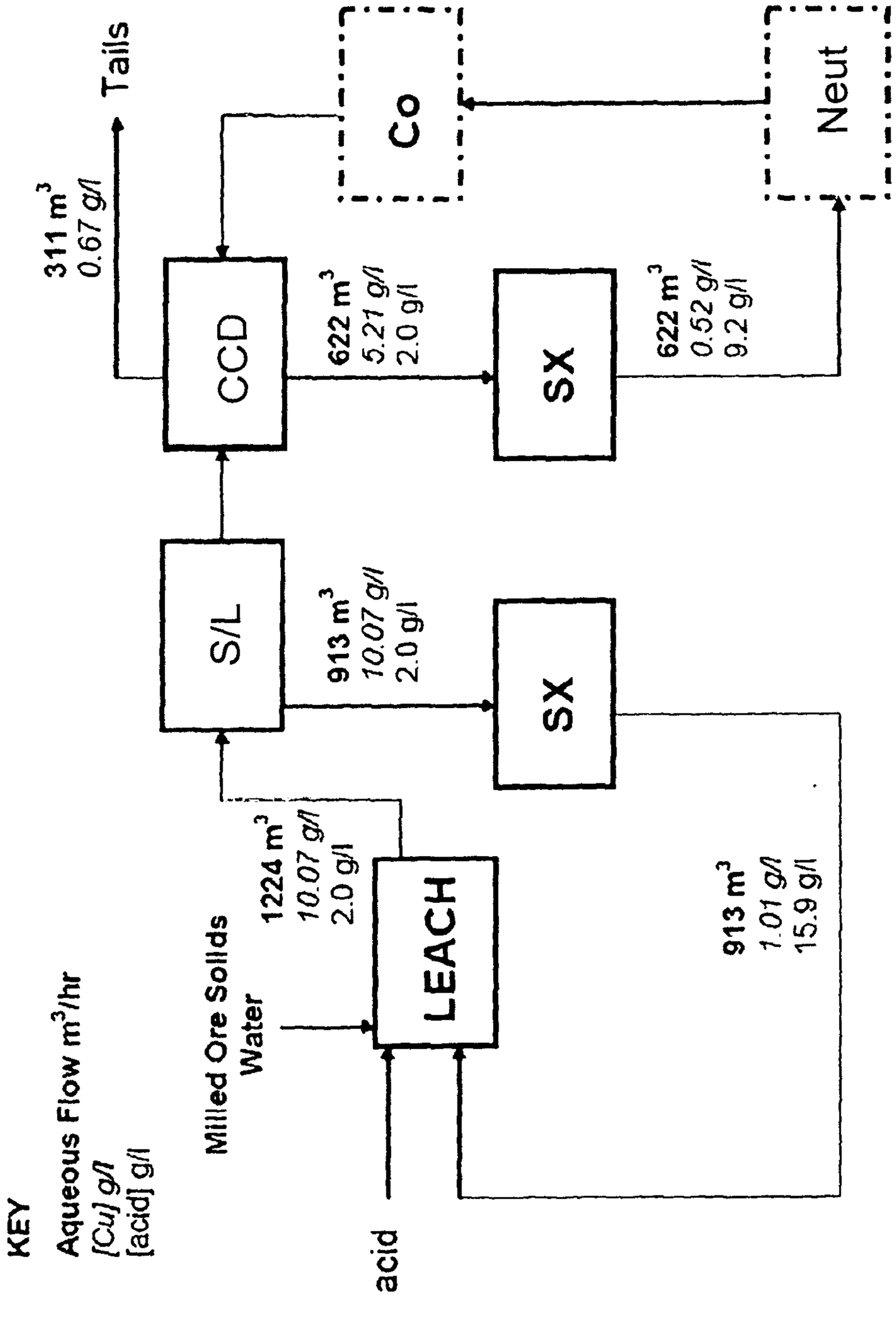

KEY
Aqueous Flow m³/hr
[Cu] g/l
[acid] g/l
Milled Ore Sollds
Water
acid
1224 m³
10.07 g/l
2.0 g/l
LEACH
913 m³
10.07 g/l
2.0 g/l
S/L
913 m³
1.01 g/l
15.9 g/l
SX
622 m³
5.21 g/l
2.0 g/l
CCD
311 m³
0.67 g/l
Tails
SX
622 m³
0.52 g/l
9.2 g/l
Co
Neut

Figure 2

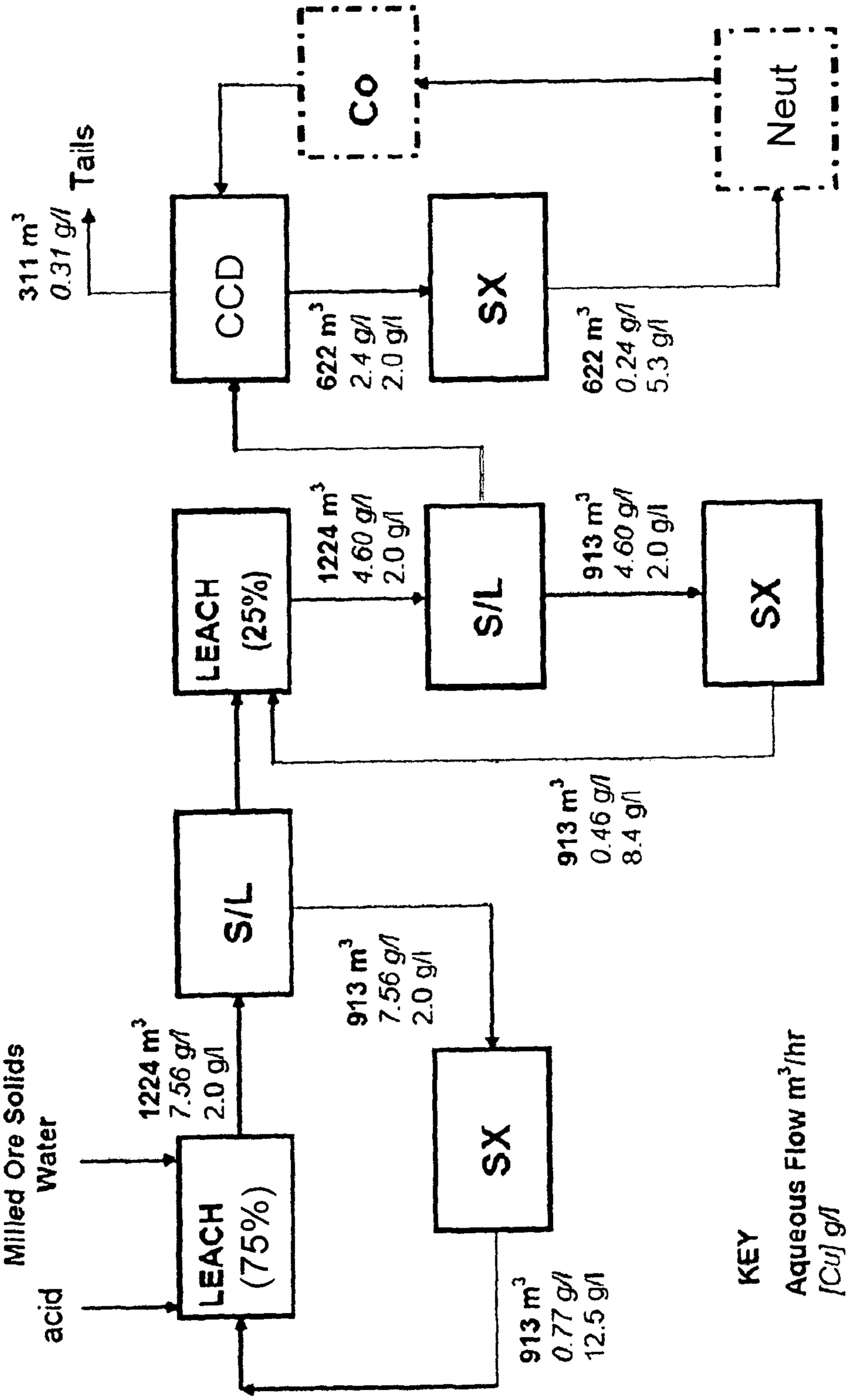
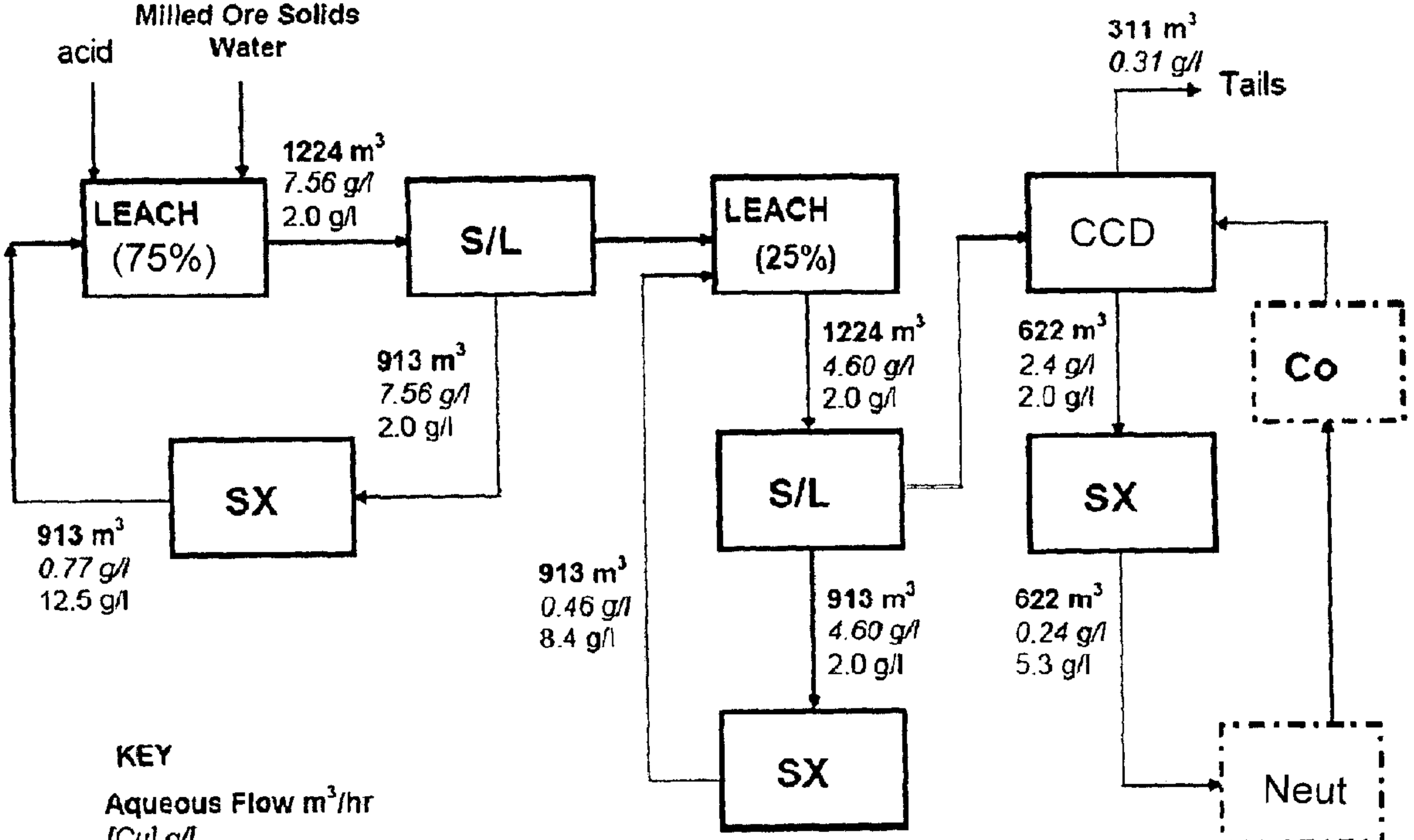

Co
Neut
Tails
311 m3
0.31 g/l
CCD
622 m3
2.4 g/l
2.0 g/l
SX
622 m3
0.24 g/l
5.3 g/l
LEACH
(25%)
1224 m3
4.60 g/l
2.0 g/l
S/L
913 m3
4.60 g/l
2.0 g/l
SX
913 m3
0.46 g/l
8.4 g/l
S/L
913 m3
7.56 g/l
2.0 g/l
1224 m3
7.56 g/l
2.0 g/l
SX
Milled Ore Solids
Water
acid
LEACH
(75%)
913 m3
0.77 g/l
12.5 g/l
KEY
Aqueous Flows m3/hr
[Cu] g/l
[acid] g/l

Figure 3


Milled Ore Solids
acid
Water
LEACH
(75%)
1224 m3
7.56 g/l
2.0 g/l
S/L
913 m3
7.56 g/l
2.0 g/l
SX
913 m3
0.77 g/l
12.5 g/l
LEACH
(25%)
1224 m3
4.60 g/l
2.0 g/l
S/L
913 m3
0.46 g/l
8.4 g/l
913 m3
4.60 g/l
2.0 g/l
SX
311 m3
0.31 g/l
Tails
CCD
622 m3
2.4 g/l
2.0 g/l
SX
622 m3
0.24 g/l
5.3 g/l
Co
Neut
KEY
Aqueous Flow m3/hr
[Cu] g/l
[acid] g/l