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(54) Title: PROCESSES FOR RECOVERING METALS FROM ORES USING ORGANIC SOLVENT EXTRACTION AND
AQUEOUS STRIPPING AT SELECTED TEMPERATURE DIFFERENTIALS

(57) Abstract: The disclosed invention concerns a process comprising: (a) providing a pregnant leach solution comprising copper values; (b) contacting the pregnant leach solution with an organic phase comprising a copper extractant at an extraction temperature, T_{ext} , to form a loaded organic phase comprising the metal values; (c) contacting the loaded organic phase with an aqueous stripping solution at a stripping temperature, T_{strip} , to form a copper-enriched stripping solution; wherein the difference in temperature (ΔT) between the stripping temperature and the extraction temperature according to equation (I): $\Delta T = T_{strip} - T_{ext}$ is less than or equal to about 10°C. In other increasingly more preferred embodiments of the invention, the difference in temperature (ΔT) is less than or equal to about 5°C, less than or equal to about 2.5°C, less than or equal to about 0°C, less than or equal to about -5°C, and less than or equal to about -10°C. Also disclosed are economic means to manipulate the extraction, strip, and electrowinning temperatures to achieve these temperature differentials.

WO 2006/060305 A2

TITLE OF THE INVENTION

Processes for Recovering Metals From Ores Using Organic
Solvent Extraction and Aqueous Stripping at Selected Temperature Differentials

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. §119 from U.S. Provisional application No. 60/632,759, filed December 3, 2004.

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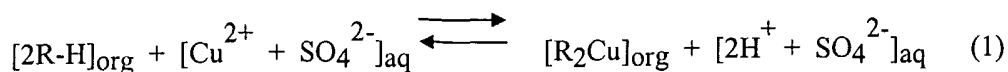
Not applicable.

BACKGROUND OF THE INVENTION

Most metals are obtained by removing those metals from the ores in which they are found in the ground. One method to initially separate metal from the ore is known as leaching. The first step in the leaching process is to contact the mined ore with an aqueous solution containing a leaching agent. For example, in copper leaching operations, sulfuric acid in an aqueous solution is contacted with the copper-containing ore. During this leaching process, acid in the leach solution is consumed and copper is dissolved, thereby increasing the copper content of the aqueous solution.

The aqueous solution then contains the leached metal in a dilute form together with other impurities, for example iron. This aqueous solution (also known as the Pregnant Leach Solution – PLS) can then be treated via a process referred to as solvent extraction in which the leach solution is contacted with a non-aqueous solution containing a metal extraction reagent. The metal extraction reagent extracts the metal from the aqueous phase into the non-aqueous phase.

For example, copper in a dilute aqueous sulfuric acid solution is commonly extracted in a solvent extraction process by an oxime based extractant in an organic medium according to the chemical reaction;



where R-H is the oxime extractant. The resultant aqueous solution (also known as raffinate), depleted in copper and enriched in sulfuric acid, is returned to the leaching process for further leaching of copper.

Since the above chemical reaction (1) is reversible, it follows that the copper
5 loaded onto the oxime reagent in the organic medium can then be re-extracted into another aqueous medium, provided there is sufficient acid in this aqueous medium to drive the reverse chemical reaction. This is accomplished in a stage in the overall process known as stripping. The stripping process involves contacting the organic phase with an aqueous solution (also referred to as the Lean Electrolyte – LE) having a high
10 sulfuric acid concentration with some copper. Copper is then re-extracted from the organic phase into the aqueous solution (also referred to as Rich Electrolyte – RE) which then has a relatively high concentration of copper and a lower level of sulfuric acid.

The Rich Electrolyte solution is then subjected to a process referred to as electrowinning, which takes place in what is called a tankhouse. In electrowinning, the
15 Rich Electrolyte solution is passed through an electrolytic cell between an anode and a cathode. The electrical potential placed between the two electrodes causes copper to be deposited on the surface of the cathode as copper metal. Sulfuric acid is generated in this process. The aqueous solution (now available for recycling as the Lean Electrolyte), somewhat depleted in copper and somewhat enriched in sulfuric acid, can be returned to
20 the solvent extraction strip stage to again strip more copper off the organic medium. The leaching, solvent extraction/stripping and electrowinning of copper is a common, continuous practice as a method to recovery copper from ores.

The solvent extraction process effectively concentrates the leached copper species into an aqueous solution (electrolyte) that is relatively high in copper and
25 relatively low in other impurities, for example iron. This allows the electrowinning process to produce high quality copper metal at a high electrical current efficiency.

Leaching of low grade copper ores is typically carried out in heap or dump leaching operations. In dump leaching operations, the ore is typically placed in a natural geological feature such as a canyon. The depth of the ore in the dump can range from
30 relatively shallow to a few hundred meters in thickness. Heap leaching is carried out on permanent pads or on on-off pads. In the case of permanent pads, the depth of the ore

can be similar to that in a dump. On-Off pads are designed so that the ore is placed on the prepared pad in a layer several meters thick, leached, allowed to drain and then removed from the pad. In these types of leaching systems, fresh aqueous leaching agent and/or recycled acidic raffinate solution is applied to the tops of the heaps or dump and
5 allowed to drain down through the ore. It is then collected at the bottom of the heap or dump and fed as PLS to the solvent extraction operation.

The temperature of the PLS exiting the copper leaching system will be dependent on the heat build up in the dump or heap. This in turn is dependent on the size of the dump or heap. The larger and deeper the size of the leaching system the less heat that
10 will be lost by radiation to the environment. Heat loss will also be dependent on the local climatic conditions. If sulfide ores are present, bioleaching of these sulfide minerals will contribute significant amounts of heat to the dump or heap. In general, the temperature of the PLS exiting the leaching system will typically vary from about 8° C to about 30°C.

15 In agitation leaching, which is commonly carried out in large vats where an ore is mixed with fresh aqueous leaching agent and/or recycled acidic raffinate solution, the resulting PLS can then be separated from the leached residue via a series of clarification operations and fed to solvent extraction. The ore grade is typically higher than in the case of ores fed to heap or dump leaching. Due to the nature of the operation, the
20 temperature of the copper PLS will typically vary from about 15°C to about 30°C. The solvent stripping step is normally carried out at temperatures above 30 deg. C. Therefore, existing solvent extraction plants generally operate with a lower temperature in the extraction stages than in the stripping stage(s).

Electrowinning of copper is typically maintained at temperatures in the 40°C to
25 50°C range to insure the production of high grade copper cathode. As a result, electrowinning tankhouses are typically outfitted with boilers to allow for some heat input into the electrolyte to insure that the electrolyte temperature is maintained in the correct range. To minimize heat loss from the electrowinning tankhouse, the Lean Electrolyte line going to stripping and the Rich Electrolyte return line from stripping are
30 passed through interconnected heat exchangers so that the warm Lean Electrolyte is used

to warm the Rich Electrolyte returning to the electrowinning tankhouse, thus minimizing energy losses from the tankhouse.

BRIEF SUMMARY OF THE INVENTION

It has now been surprisingly found that there are significant advantages in copper recovery operations with elevated temperatures during the extraction stage and/or lowered temperatures during the stripping stage. More particularly, advantages in copper recovery operations are realized according to the present invention by decreasing the temperature differential between the temperature during stripping and the temperature during extraction.

In general, the present invention can also be described in terms of the following equation:

$$T_{\text{Strip}} - T_{\text{Ext}} = \Delta T$$

where T stands for the temperature in °C. To maximize the advantages achieved in a solvent extraction process, the value of ΔT is minimized, or preferably driven to a negative value. ΔT is no more than 15°C. A preferred value of ΔT is $\leq 10^\circ\text{C}$, a more preferred value is $\leq 7.5^\circ\text{C}$, a still more preferred value is $\leq 5^\circ\text{C}$, a still more preferred value is $\leq 2.5^\circ\text{C}$, a still more preferred value is $\leq 0^\circ\text{C}$, a still more preferred value is $\leq -2.5^\circ\text{C}$, a still more preferred value is $\leq -5^\circ\text{C}$, a still more preferred value is $\leq -7.5^\circ\text{C}$, and the most preferred value is $\leq -10^\circ\text{C}$.

One embodiment of the present invention includes a process comprising: (a) providing a pregnant leach solution comprising copper values; (b) contacting the pregnant leach solution with an organic phase comprising a copper extractant at an extraction temperature, T_{ext} , to form a loaded organic phase comprising the metal values; (c) contacting the loaded organic phase with an aqueous stripping solution at a stripping temperature, T_{strip} , to form a copper-enriched stripping solution; wherein the difference in temperature (ΔT) between the stripping temperature and the extraction temperature according to equation (I):

$$\Delta T = T_{\text{strip}} - T_{\text{ext}} \quad (\text{I})$$

is less than or equal to about 10°C. In other increasingly more preferred embodiments of the present invention, the difference in temperature (ΔT) is less than or equal to about

7.5°C, less than or equal to about 5°C, less than or equal to about 2.5°C, less than or equal to about 0°C, less than or equal to about -2.5°C, less than or equal to about -5°C, less than or equal to about -7.5°C, and less than or equal to about -10°C.

The phrases “difference in temperature”, “(ΔT)” and “temperature differential”,
5 as used herein, are synonymous and interchangeable with reference to the difference, in degrees Celsius, between the temperature during the stripping stage and the temperature during the extraction stage.

Lowering the temperature during the stripping stage results in more efficient stripping of the organic phase as evidenced by a lower copper concentration in the
10 stripped organic. On the other hand, increasing the temperature during the extraction stage results in more efficient use of the oxime extractant as evidenced by a higher copper concentration in the loaded organic. Lowering the temperature during the stripping stage and/or increasing the temperature during the extraction stage increases the net transfer of copper per unit time, assuming that flows are constant.

15 Thus, processes according to the present invention can be used to (1) increase overall copper production, (2) decrease overall oxime extractant concentration while maintaining copper production constant, or (3) decrease sulfuric acid concentration in the electrolyte while maintaining copper production constant or (4) some combination of two or more of these beneficial effects.

20 In another aspect, the invention provides economic means to manipulate the extraction, strip, and electrowinning temperatures.

DETAILED DESCRIPTION OF THE INVENTION

All numbers expressing quantities of ingredients or reaction conditions used
25 herein are to be understood as modified in all instances by the term “about”.

The following detailed description provides an explanation of the present invention in terms of certain preferred embodiments involving the recovery of copper from copper ores. However, it is to be understood that the present invention applies to various metal recovery processes employing leaching, extraction and stripping
30 operations, and may be advantageously employed in the recovery of various different metals from a variety of ores, and in metal recovery plants utilizing any configuration of

multiple extraction and stripping stages arranged in series, in parallel, nested, or any combination thereof.

In certain preferred embodiments of the present invention directed to processes for recovering copper from copper-containing ores, the ores may be either primarily
5 oxide type copper minerals, a mixture of oxide and sulfide type copper minerals, or sulfide type copper minerals. For a more complete description of the minerals including leaching chemistry, see the 1996 SME Short Course – Copper Heap Leach Notes, 1996 SME Annual Meeting, Phoenix, AZ.

The preferred copper extractants are those based on phenolic oximes (such as
10 those disclosed in US Patent Nos. 4,978,788, 5,176,843 and 6,395,062) including ketoximes such as 2-hydroxy-5-nonylacetophenone oxime and the aldoximes such as 5-nonylsalicylaldoxime, by themselves or as mixtures with one another or with a modifier (such as those modifiers and oxime combinations disclosed in US Patent No. 6,231,784). Also preferred would be mixtures of an aldoxime with a modifier present .

15 To illustrate some of the advantages of the present invention, as applied to copper recovery operations, one can first look at the effect of lowering the temperature during the stripping stage. A case study was carried out using the ISOCALC® Solvent Extraction Modeling Software developed by Cognis Corporation. Using this software allows one to predict with great accuracy the performance that can be achieved in a
20 continuous solvent extraction plant. The program is based on a very large set of actual isotherm data determined at 25°C for a variety of LIX® reagents, which are generally oxime-containing metal extraction reagents, from which an algorithm was determined which serves as a foundation for the modeling. The model was used to determine an extraction isotherm for a conventional plant consisting of 2 stages of extraction in series
25 and 1 stage of stripping. Using an average set of values from commercially operating plants, the PLS was assumed to contain 6 gpl of copper, 70 gpl of sulfate and have a pH of 1.9. Similarly, the organic phase was assumed to be 25% (v/v) LIX® 984N in a typical aliphatic hydrocarbon diluent. LIX® 984N is 0.77 M in 2-hydroxy-5-nonylacetophenone oxime and 0.88 M in 5-nonylsalicylaldoxime. The level of the
30 copper on the stripped organic at a given temperature was taken from a mathematical model derived from a collection of stripping isotherms determined at different

temperatures and reagent concentrations. The stripped organic value was plugged into the ISOCALC® Solvent Extraction Modeling Software and used to model the performance of a plant operating within these parameters.

Using an average set of values from commercially operating plants, the Lean Electrolyte composition was assumed to be 170 gpl sulfuric acid and 36 gpl copper. The Rich Electrolyte likewise contained 45 gpl copper and the temperature in stripping was assumed to be 45 °C. For the base case, the targeted copper recovery was assumed to be 90% to achieve a total annual copper production of 40,000 metric tons per year. The results summarized in Table 1 illustrate the benefits in copper production afforded by the invention simply by lowering the temperature in the strip stage while keeping all the other process parameters the same.

Table 1

Case	T _{Strip} (°C)	Stripped Org (gpl Cu)	Cu Recovery (%)	Cu NT* (gpl Cu/%(v/v) Extract)	Δ T (°C)	Cu Prod (tons/yr)
1	45	5.36	90.08	0.216	+20	40,000
2	40	5.18	90.75	0.218	+15	40,306
3	35	4.99	91.43	0.219	+10	40,608
4	30	4.80	92.08	0.221	+5	40,897
5	25	4.58	92.75	0.223	0	41,195
6	20	4.36	93.36	0.224	-5	41,466

* NT is net transfer by the organic phase. The greater the value of NT, the more efficiently the extractant is being used and the greater the copper recovery.

According to the invention, lowering the stripping temperature from 45°C to 40°C (Table 1, Case 1 vs. Case 2) results in an increase of 306 tons of copper. At current copper prices of ~\$1.30/lb, this represents an additional \$876,751 of revenue.

Depending on the site specific circumstances of a copper solvent extraction plant, it may not be feasible to produce more copper as described in the above paragraph. As can be seen in Table 1, lowering the temperature in strip results in an increase in copper NT. If it is not feasible to increase the amount of copper transferred to electrowinning, according to the invention one is alternatively able to lower the concentration of the oxime extractant in the organic phase while still maintaining the overall copper recovery at 90%. This is a significant advantage in terms of cost of the organic phase.

Example 1

Using the ISOCALC® Solvent Extraction Modeling Software one can also evaluate the effect of lowering the reagent concentration and strip temperature while maintaining copper recovery and all other factors constant. The results are summarized in Table 2.

Table 2

Case	T _{Strip} (°C)	Stripped Org (gpl Cu)	Cu Recovery (%)	Cu NT* (gpl Cu/%(v/v) Extract)	Δ T (°C)	[Oxime] (% (v/v))
1	45	5.36	90.08	0.216	+20	25
2	40	5.03	90.08	0.223	+15	24.2
3	35	4.70	90.07	0.231	+10	23.4
4	30	4.38	90.03	0.239	+5	22.6
5	25	4.07	90.08	0.247	0	21.9
6	20	3.75	90.04	0.256	-5	21.1

Every 5°C decrease in the strip temperature allows one to reduce the extractant concentration by 0.8% (v/v), a reduction of ~ 3.2-3.8% relative.

According to the invention, there is another potential benefit to lowering the temperature during the stripping stage. Since the organic strips more readily at lower temperature, one can also effectively lower the acid concentration and still achieve the desired copper recovery. Lowering the acid concentration in the electrolyte has a couple of benefits. Due to the build up of impurities in the electrolyte, it is necessary to bleed a portion of the electrolyte from the tankhouse periodically to control the level of these impurities. The acid lost in the bleed must be replaced with fresh acid representing a cost. Lowering the acid content of the electrolyte lowers this cost. Additionally, one can produce higher quality copper cathode when plating is carried out at lower acid concentrations.

Example 2

To further illustrate the invention, one can look at an additional set of case studies using the ISOCALC® Solvent Extraction Modeling Software with actual extraction isotherm data and experimentally determined strip data. Two sets of extraction isotherm data were determined at 25°C and 45°C along with the corresponding strip points at these temperatures.

The organic solution was 0.093 M in 5-nonylsalicylaldoxime and 0.189 M in 2-hydroxy-5-nonylacetophenone oxime in a typical aliphatic hydrocarbon diluent. The PLS contained 3.08 gpl Cu at a pH of 1.8. The above organic solution was contacted vigorously with the PLS solution at various organic to aqueous ratios for sufficient time to achieve equilibrium. The resulting equilibrated organic phases and the corresponding aqueous phases were analyzed for copper by atomic absorption spectroscopy. The results are summarized in Tables 3 and 4.

The copper max load against the PLS was determined by successively contacting the organic phase 3 times with fresh volumes of PLS at an O/A = 1 at the desired temperature. The organic was assayed for copper by atomic absorption spectroscopy. The stripped organic representing 1 stage of stripping was determined in a similar fashion by equilibrating the organic with a synthetic rich electrolyte containing 55 gpl of copper and 157 gpl of sulfuric acid. The data is summarized in Table 5.

15

Table 3 Extraction isotherm at 25°C

Organic/Aqueous	[Cu] _{Aq} (gpl Cu)	[Cu] _{Org} (gpl Cu)
7/1	0.05	1.98
2/1	0.08	3.13
1/1	0.16	4.66
1/1.5	0.32	6.08
1/2	0.54	6.83
1/2.5	0.80	7.31
1/3.5	1.27	7.97
1/6	1.94	8.37

Table 4 Extraction isotherm at 45°C

Organic/Aqueous	[Cu] _{Aq} (gpl Cu)	[Cu] _{Org} (gpl Cu)
7/1	0.04	1.98
2/1	0.05	3.10
1/1	0.10	4.66
1/1.5	0.22	6.07
1/2	0.44	7.16
1/2.5	0.75	7.83
1/3.5	1.30	8.41
1/6	2.01	8.89

Table 5 Summary of Copper Max Load and Stripped Organic Values

Temperature (°C)	Cu Max Load (gpl Cu)	Stripped Organic (gpl Cu)
25	8.76	2.21
45	9.46	2.91

Example 3

Using the above data in the ISOCALC® Solvent Extraction Modeling Software,
 5 the performance of a copper solvent extraction plant consisting of 2 stages of extraction in series (counter-current), 1 stage of extraction in parallel and 1 stage of stripping. The results are summarized in Table 6.

Table 6

Case	T _{Strip} (°C)	T _{Extract}	Cu Recovery (%)	Cu NT* (gpl Cu/%(v/v) Extract)	Δ T (°C)	Cu Production (tons/yr)
1	45	25	84.87	0.299	+20	40,000
2	25	25	90.02	0.317	0	42,408
3	45	45	89.54	0.316	0	42,274
4	25	45	93.01	0.328	-20	43,879

Case 1 represents the base case which is typical of current practice. Cooling the strip
 10 from 45°C to 25°C while maintaining the extraction temperature 25°C (Case 1 vs Case 2) results in an additional 2,408 tons of copper production (a 6% increase) similar to what was seen in the first example. Increasing the temperature of extraction from 25°C to 45°C while maintaining the strip temperature at 45°C (Case 1 vs Case 3) results in a similar increase in production as in Case 1 vs Case 2.

15 The effect of lowering the strip temperature from 45°C to 25°C and at the same time increasing the temperature of extraction from 25°C to 45°C is seen in comparing Case 1 with Case 4. results in a 3,879 ton (9.7% relative) increase in copper production. Clearly, there are significant benefits associated with minimizing the value of ΔT to the point of driving it towards a negative value.

20

As previously discussed, manipulating the temperatures in stripping can provide the overall copper recovery operation with the flexibility to operate with lower reagent concentrations or with lower acid concentrations in the Lean Electrolyte while maintaining copper recovery/production constant. Increasing the temperature in

extraction also provides the operation with the flexibility to operate at lower reagent concentrations. It also offers the possibility of treating a PLS with a higher acid concentration while maintaining copper recovery/production constant. It also provides the flexibility to permit treating a PLS with a higher copper content without increasing reagent concentration while maintaining copper recovery constant.

Another aspect of the invention provides economic means to manipulate the extraction temperature (T_{Ext}) and the strip temperature (T_{Strip}). The exact processes by which one lowers the temperature of the electrolyte prior to the stripping stage or increases the temperature of the PLS prior to the extraction stage will depend on site specific considerations. Some suitable mechanisms include, but are not limited to the following.

Example 4

(A) The temperature of the electrolyte can be lowered using an external cooling source. Current practice involves using interconnected heat exchangers to transfer heat from the Lean Electrolyte as it exits the electrowinning tank house to the incoming Rich Electrolyte coming from stripping to minimize heat loss from the electrowinning tank house. This results in cooling the Lean Electrolyte a few degrees. The Lean Electrolyte can be cooled more effectively by either coupling the current heat exchanger with an external cooling source such as an evaporative cooler, a compressor based refrigeration unit or using a low temperature fluid stream, for example, the PLS or makeup water. Since heat must be returned to the tank house, it may be advantageous to install a second heat exchanger on the Lean Electrolyte line downstream from that used to transfer heat to the Rich Electrolyte. This second heat exchanger would then be coupled with an external cooling source such as an evaporative cooler, a mechanical refrigeration unit, or using a low temperature fluid stream such as PLS or makeup water. The Rich Electrolyte must be reheated prior to return to the electrowinning tank house. This can be done partially by passing through a heat exchanger coupled to the Lean Electrolyte as previously discussed. It can be reheated using an external energy source such as a boiler, solar heating, or alternatively by interchanging heat between a high temperature fluid stream such as an stream from a copper concentrate leach system, for example, an

autoclave or a bioreactor leach system. The advantage of using the autoclave leach system or the bioreactor leach system is that it also produces additional copper that can be recovered in addition to the heat. One could also use the waste heat from a sulfur burner, which would also allow one to produce sulfuric acid for use in the process.

5 (B) The temperature of the PLS can be increased by using it as the cooling fluid in a heat exchanger with the Lean Electrolyte before passing it to extraction. It can be heated using an external energy source such as a boiler, solar heating, or alternatively by interchanging heat between a high temperature fluid stream such as an stream from a copper concentrate leach system, for example, an autoclave or a bioreactor leach system.

10 The advantage of using the autoclave leach system or the bioreactor leach system is that it also produces additional copper that can be recovered in addition to the heat. One could simply dilute cold PLS from a heap or dump leaching operation with the hot discharge from a copper concentrate leach system. One could also use the waste heat from a sulfur burner, which would also allow one to produce sulfuric acid for use in the

15 process.

(C) One could also take steps to minimize heat loss from the PLS by covering PLS ponds and catchments to minimize evaporation and radiant heat loss.

Clearly, as described above, there are a number of potential ways to alter the temperature balance in a solvent extraction plant. There are undoubtedly others that

20 would be understood by one of ordinary skill in the art based upon the foregoing description.

A further extension of this invention is the concept of simply replacing the current boilers used to heat the electrolyte by use of the waste heat from copper concentrate leaching systems such as autoclave leach systems or bioreactor leach

25 systems. One could also use the waste heat from a sulfur burner.

It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and

30 scope of the present invention as defined by the appended claims.

CLAIMS

What is claimed is:

Claim 1: A copper recovery process comprising:

- (a) providing a pregnant leach solution comprising copper values;
 - (b) contacting the pregnant leach solution with an organic phase comprising a copper extractant at an extraction temperature, T_{ext} , to form a loaded organic phase comprising the copper values;
 - (c) contacting the resulting loaded organic phase with an aqueous stripping solution at a stripping temperature, T_{strip} , to form a copper-enriched stripping solution;
- wherein the difference in temperature (ΔT) between the stripping temperature and the extraction temperature according to equation (I):

$$\Delta T = T_{\text{strip}} - T_{\text{ext}} \quad (\text{I})$$

is less than or equal to about 10°C.

Claim 2: The copper recovery process according to claim 1, wherein the difference in temperature (ΔT) is less than or equal to about 7.5°C.

Claim 3: The copper recovery process according to claim 1, wherein the difference in temperature (ΔT) is less than or equal to about 5°C.

Claim 4: The copper recovery process according to claim 1, wherein the difference in temperature (ΔT) is less than or equal to about 2.5°C.

Claim 5: The copper recovery process according to claim 1, wherein the difference in temperature (ΔT) is less than or equal to about 0°C.

Claim 6: The copper recovery process according to claim 1, wherein the difference in temperature (ΔT) is less than or equal to about -2.5°C.

Claim 7: The copper recovery process according to claim 1, wherein the difference in temperature (ΔT) is less than or equal to about -5°C .

Claim 8: The copper recovery process according to claim 1, wherein the difference in temperature (ΔT) is less than or equal to about -7.5°C .

Claim 9: The copper recovery process according to claim 1, wherein the difference in temperature (ΔT) is less than or equal to about -10°C .

Claim 10: The copper recovery process according to claim 1, wherein one or more heat exchangers are utilized to lower the stripping temperature of the aqueous stripping solution.

Claim 11: The copper recovery process according to claim 10, wherein the one or more heat exchangers transfer heat from a lean electrolyte exiting an electrowinning stage to the copper-enriched stripping solution such that a cooled lean electrolyte is formed and the cooled lean electrolyte is used as at least a portion of the aqueous stripping solution.

Claim 12: The copper recovery process according to claim 10, wherein the one or more heat exchangers transfer heat from a lean electrolyte exiting an electrowinning stage to a water source such that a cooled lean electrolyte is formed and the cooled lean electrolyte is used as at least a portion of the aqueous stripping solution.

Claim 13: The copper recovery process according to claim 1, wherein one or more heat exchangers are utilized to raise the extraction temperature of the pregnant leach solution.

Claim 14: The copper recovery process according to claim 13, wherein the one or more heat exchangers transfer heat from a lean electrolyte exiting an electrowinning stage to the pregnant leach solution.

Claim 15: The copper recovery process according to claim 12, wherein the one or more heat exchangers transfer heat from a heat source selected from the group consisting of boilers and waste heat gases to the pregnant leach solution.

Claim 16: A copper recovery process comprising:

- (a) providing a pregnant leach solution comprising copper values;
 - (b) contacting the pregnant leach solution with an organic phase comprising a copper extractant at an extraction temperature, T_{ext} , to form a loaded organic phase comprising the copper values;
 - (c) contacting the resulting loaded organic phase with an aqueous stripping solution at a stripping temperature, T_{strip} , to form a copper-enriched stripping solution;
- wherein the difference in temperature (ΔT) between the stripping temperature and the extraction temperature according to equation (I):

$$\Delta T = T_{\text{strip}} - T_{\text{ext}} \quad (\text{I})$$

is less than or equal to about 10°C,

wherein one or more heat exchangers are utilized to lower the stripping temperature of the aqueous stripping solution.

Claim 17: The copper recovery process according to claim 16, wherein the difference in temperature (ΔT) is less than or equal to about -2.5°C.

Claim 18: The copper recovery process according to claim 16, wherein the one or more heat exchangers transfer heat from a lean electrolyte exiting an electrowinning stage to the copper-enriched stripping solution such that a cooled lean electrolyte is formed and the cooled lean electrolyte is used as at least a portion of the aqueous stripping solution.

Claim 19: The copper recovery process according to claim 16, wherein the one or more heat exchangers transfer heat from a lean electrolyte exiting an electrowinning

stage to a water source such that a cooled lean electrolyte is formed and the cooled lean electrolyte is used as at least a portion of the aqueous stripping solution.

Claim 20: A copper recovery process comprising:

- (a) providing a pregnant leach solution comprising copper values;
 - (b) contacting the pregnant leach solution with an organic phase comprising a copper extractant at an extraction temperature, T_{ext} , to form a loaded organic phase comprising the copper values;
 - (c) contacting the resulting loaded organic phase with an aqueous stripping solution at a stripping temperature, T_{strip} , to form a copper-enriched stripping solution;
- wherein the difference in temperature (ΔT) between the stripping temperature and the extraction temperature according to equation (I):

$$\Delta T = T_{\text{strip}} - T_{\text{ext}} \quad (\text{I})$$

is less than or equal to about 10°C,

wherein one or more heat exchangers are utilized to raise the extraction temperature of the pregnant leach solution.

Claim 21: The copper recovery process according to claim 20, wherein the difference in temperature (ΔT) is less than or equal to about -2.5°C.

Claim 22: The copper recovery process according to claim 20, wherein the one or more heat exchangers transfer heat from a lean electrolyte exiting an electrowinning stage to the pregnant leach solution.

Claim 23: The copper recovery process according to claim 20, wherein the one or more heat exchangers transfer heat from a heat source selected from the group consisting of boilers and waste heat gases to the pregnant leach solution.