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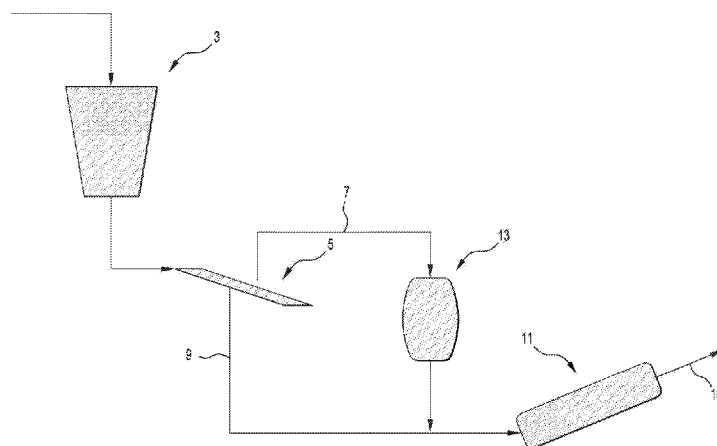


FIG. 1

(57) Abstract: A method of agglomerating mined ore for use in a heap leaching process includes exposing ore fragments to electromagnetic radiation and causing fractures to form in the fragments and thereafter agglomerating fragments.



HEAP LEACHING

TECHNICAL FIELD

5 The present invention relates to leaching a material containing a valuable metal.

 The present invention relates particularly, although by no means exclusively, to leaching a material in the form of a sulphidic ore containing a valuable metal.

 The present invention relates particularly, although by no means exclusively, to leaching a sulphidic copper-containing ore that includes copper-containing minerals.

10

BACKGROUND ART

 In conventional heap and dump leaching of copper sulphide containing minerals, mined ore is stacked into heaps, aerated through direct injection of air via
15 aeration pipes extending into the heap and/or by natural convection through exposed sides of the heap, irrigated with an acid solution for extraction of copper into solution, and the copper is subsequently recovered from solution by a range of recovery options including solvent extraction and electrowinning (SX/EW), cementation onto more active metals such as iron, hydrogen reduction, and direct electrowinning. Leaching
20 may be enhanced by the use of microorganisms.

 Generally, heap and dump leaching (hereinafter referred to as "heap leaching") provides lower metal recoveries than other metallurgical process options for recovering copper from copper-containing ores, such as milling and flotation that produces copper-containing concentrates that are then smelted to produce copper metal. Consequently,
25 heap leaching tends to be reserved for low grade ore types that have at least a proportion of readily recovered copper, but where crushing/milling costs per unit of copper (or copper equivalent – i.e. when taking into account by-product credits from, for example, gold and silver) are too high to support a concentrator approach, or where mineral liberation and other characteristics (e.g. arsenic content) will not support
30 production of directly useable or saleable concentrates.

 Standard best industry practice is to use agglomerates of mined and thereafter crushed ore in heaps. Typically, the mined ore is processed through multiple crushing

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steps, namely primary and secondary crushing steps and in some instances tertiary crushing steps, and the crushed ore is agglomerated in an agglomeration step, typically with the use of an acid as a binder.

A substantial amount of energy is required in the crushing steps, and this energy use is a significant concern. However, the industry view is that the use of agglomerates in heaps has advantages over the use of ore in an unagglomerated form in heaps from operational and valuable metal recovery perspectives and that these advantages outweigh energy cost considerations. In particular, the ore preparation steps of crushing and agglomeration make it possible to pre-condition material to a desired leaching pH and provide structural integrity and good liquor permeability within a heap.

The above description is equally applicable to other materials containing other valuable metals, such as by way of example, nickel.

The above description is not to be taken as an admission of the common general knowledge in Australia or elsewhere.

SUMMARY OF THE DISCLOSURE

The applicant, through a group company, has carried out research and development work on heap leaching copper-containing ores that include copper-containing minerals (such as chalcopyrite) and has made a number of findings in the course of this heap leaching work and in the course of work on other technology projects. The present invention is an outcome of those findings.

In general terms the invention provides a method of agglomerating mined ore for use in a heap leaching process which includes exposing ore fragments to electromagnetic radiation and causing fractures to form in the fragments and thereafter agglomerating fragments.

The invention provides a method of agglomerating mined ore for use in a heap leaching process which includes the steps of:

- (a) exposing ore fragments to electromagnetic radiation and causing fractures to form in the fragments; and
- (b) agglomerating fragments after exposure to electromagnetic radiation in step (a), with agglomeration step (b) including mixing fragments so that fragments that

have fractures break down into smaller fragments and these smaller fragments subsequently form agglomerates during the agglomeration step.

The method provides an opportunity to use energy required for the agglomeration step to break down fractured fragments from the electromagnetic radiation exposure step (a). This provides an opportunity to avoid secondary and tertiary crushing (assuming tertiary crushing would be otherwise required) of mined ore prior to agglomeration step (b) and to reduce the overall energy requirements to produce agglomerates from mined ore. The method also makes it possible to take larger fragments into the agglomeration step – this is a considerable advantage in terms of upstream materials handling of fragments.

The term “fragment” is understood herein to mean any suitable size of mined material having regard to materials handling and processing capabilities of the apparatus used to carry out the method. It is also noted that the term “fragment” as used herein may be understood by some persons skilled in the art to be better described as “particles”. The intention is to use both terms as synonyms.

The term “mined” ore is understood herein to include metalliferous material and non-metalliferous material. Iron-containing and copper-containing ores are examples of metalliferous material. Coal is an example of a non-metalliferous material. The term “mined” ore is understood herein to include, but is not limited to, (a) run-of-mine material and (b) run-of-mine material that has been subjected to at least primary crushing or similar size reduction after the material has been mined and prior to being sorted. The term “mined” material includes mined material that is in stockpiles.

The smaller fragments may form agglomerates with other smaller fragments in agglomeration step (b).

The smaller fragments may form agglomerates with other fragments in agglomeration step (b).

The agglomeration step (b) may include simultaneously mixing and agglomerating fragments.

The agglomeration step (b) may include mixing fragments in one step and then agglomerating the mixed fragments in a subsequent step. There may be overlap between the mixing and agglomeration steps.

The method may include crushing mined ore prior to processing the crushed mined ore in the electromagnetic radiation exposure step (a).

The method may include crushing mined ore in a primary crushing step prior to processing the crushed mined ore in the electromagnetic radiation exposure step (a).

5 The term “primary crushing” is understood herein to mean crushing ore to a top size of 250 to 150 mm in the case of copper-containing ores where the copper is in the form of sulphides. It is noted that the top size may be different for ores containing different valuable metals.

10 The term “secondary crushing” is understood herein to mean crushing ore to a top size of 50 to 20 mm in the case of copper-containing ores where the copper is in the form of sulphides. It is noted that the top size may be different for ores containing different valuable metals.

15 The term “tertiary crushing” is understood herein to mean crushing ore to a top size of 15 to 5 mm in the case of copper-containing ores where the copper is in the form of sulphides. It is noted that the top size may be different for ores containing different valuable metals.

The method may include separating crushed ore into at least two fractions based on fragment size prior to the electromagnetic radiation exposure step (a) and supplying one of the fractions to step (a).

20 One fraction may be a coarse fraction and another fraction may be a fines fraction. In the context of a size separation step, for example using a screen, “coarse” and “fine” refer to “oversize” and “undersize” respectively in relation to a screen. The split could occur in a range of 12 to 50mm. Typically, the split is 25 mm in the case of the copper mining sector. The split may be any suitable size depending on factors as
25 the ore type and the downstream processing requirements.

The method may include processing the coarse fraction in electromagnetic radiation exposure step (a) and forming a fractured coarse fraction.

The method may include supplying the fines fraction and the fractured coarse fraction produced in step (a) to the agglomeration step (b).

30 The ore may be a copper-containing ore.

The ore may be a copper-containing ore that includes copper-containing minerals.

The ore may be any suitable ore containing a valuable metal. Nickel is another example of a valuable metal.

The operating conditions for the electromagnetic radiation exposure step (a) may be selected to form fractures in fragments without causing significant breakdown of fragments into smaller fragments. From a materials handling viewpoint, it is preferable to have minimal breakdown of fragments between the electromagnetic radiation exposure step (a) and the agglomeration step (b).

By way of example, the operating conditions for the electromagnetic radiation exposure step (a) may be selected to form fractures in fragments with minimal breakdown of the fragments into smaller fragments.

By way of example, the operating conditions for the electromagnetic radiation exposure step (a) may be selected to form fractures in fragments without causing breakdown of more than 25%, typically no more than 15%, more typically no more than 10%, by weight of the fragments into smaller fragments.

The operating conditions for the electromagnetic radiation exposure step (a) may be selected to form fractures that ultimately result in a preferred particle size distribution of fragments for forming agglomerates that have required characteristics, such as porosity and/or mechanical strength, for heap leaching.

The electromagnetic radiation may be selected to be high power density. For example, the power density applied in step (a) may be selected to be at least 1×10^{10} W/m³, typically at least 1×10^{10} W/m³, and more typically at least 1×10^{11} W/m³.

The electromagnetic radiation exposure times may be selected to be very short exposure times. By way of further example, the exposure time applied in step (a) may be less than 1s, typically less than 0.5s, more typically less than 0.1s, more typically less than 0.05s.

The electromagnetic radiation may be continuous radiation, and step (a) may include moving ore fragments through an electromagnetic radiation exposure space at a rate to provide a required exposure time.

The electromagnetic radiation may be pulsed radiation, and step (a) may include moving ore fragments through an electromagnetic radiation exposure space at a rate to provide a required exposure time.

The electromagnetic radiation may be any suitable radiation.

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For example, the electromagnetic radiation may be microwave radiation. The microwave radiation may have any suitable wavelength in the range of 300 MHz – 300 GHz, 500 MHz – 30 GHz or 600 MHz – 3 GHz, for example 2450 MHz or 915 MHz.

By way of further example, the electromagnetic radiation may be radio
5 frequency radiation.

The invention also provides agglomerates formed in the above-described method of agglomerating mined ore.

The invention also provides a heap of material, with the material including agglomerates formed in the above-described method of agglomerating mined ore.

10 The invention also includes a method of heap leaching that includes:

- (a) forming a heap of material, with the material including agglomerates formed in the above-described method of agglomerating mined ore; and
- (b) leaching valuable metal from the ore in the heap.

The method may also include recovering the leached metal as a metal product.
15 Typically, this step includes recovering the leached metal from solution in pregnant leach liquor.

BRIEF DESCRIPTION OF THE DRAWING

20 The present invention is described further with reference to the accompanying drawing which illustrates the steps in one embodiment of a method of agglomerating mined ore for use in a heap leaching process in accordance with the present invention.

DESCRIPTION OF EMBODIMENT

25

The method of agglomerating mined ore illustrated in the Figure is described in the context of copper-containing ore. However, it is understood that the invention is not limited to this type of ore and extends to mined ore generally. Other examples of a mined ore are nickel-containing ores.

30

The method of agglomerating mined ore illustrated in the Figure is suitable for forming standard heaps in terms of the basic shape and size of the heaps. More specifically, the present invention does not extend to particular shapes and sizes of

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heaps and to particular methods of constructing heaps from agglomerated ore. By way of example only, the heap may be a heap of the type described in International publication WO2012/031317 in the name of the applicant and the disclosure in the International publication is incorporated herein by cross-reference.

5 With reference to the drawing, run-of-mine copper-containing ore is crushed in a primary crusher 3, and the crushed ore fragments are transferred to a screen 5 and separated into a coarse fraction 7 of at least 25 mm and a fines fraction 9 of less than 25 mm.

 The fines fraction 9 is supplied to an agglomeration station 11.

10 The coarse fraction 7 is supplied to an electromagnetic radiation treatment station 13. The station 13 may be any suitable construction. By way of example, the station 13 may be of the type described in International publication WO2014/066941 in the name of the applicant and the disclosure in the International publication is incorporated herein by cross-reference. The coarse fragments are exposed to high
15 power density radio frequency radiation (or any other suitable electromagnetic radiation) at the station 13. The operating conditions, including frequency, residence (i.e. exposure) time, and power density, etc. are selected so that fractures (i.e. cracks) form in the coarse fragments, preferably with minimal break down into smaller fragments at this point. Typically, the operating conditions are selected so that fractures
20 form in the coarse fragments without causing any more than 10% by weight of the fragments to break down at this point into smaller fragments.

 In any given situation, the selection of the operating conditions at the station 13 is dependent on the downstream agglomeration requirements and operating conditions for the agglomeration step. In some situations it may be preferred to cause extensive
25 cracking of the fragments. For example, it may be preferred to cause significant fracturing of all of the fragments. In other situations, it may be preferred to cause fracturing of a proportion of the fragments. The proportion may be fragments that have particular characteristics, such as a copper concentration above a threshold concentration. In other situations, less extreme structural alteration of the fragments
30 may be sufficient. It is noted that the actual extent to which individual fragments will be altered structurally will vary depending on the mineralogy of individual fragments. In some situations, it may be preferred to form fractures that ultimately result in a

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preferred particle size distribution of fragments for forming agglomerates that have required characteristics, such as porosity and/or mechanical strength, for heap leaching.

Structural alteration, i.e. fracturing, of the fragments at the station 13 may be the result of differences in thermal expansion of minerals within fragments, as a
5 consequence of heating of minerals due to exposure to electromagnetic radiation, resulting in regions of high stress/strain within the fragments and leading to cracking or other physical changes within the fragments.

The fragments from the electromagnetic radiation treatment station 13 are supplied to the agglomeration station 11. The agglomeration station 11 may be any
10 suitable construction that includes a drum (or other device) for mixing the fragments and agglomerating the fragments during the agglomeration step. The mixing conditions are selected to cause fragments that have fractures to break down into smaller fragments in the mixing drum. These smaller fragments subsequently form agglomerates with other smaller fragments and fines during the agglomeration step. The agglomeration
15 step may include the addition of a suitable binder, such as an acid. The mixing and agglomeration may occur simultaneously. Alternatively, mixing may be carried out first and agglomeration (for example initiated by the addition of a binder) may be carried out after mixing has been completed to a required extent.

In a situation where the mixing is carried out separately, the mixing may include
20 subjecting fragments to impact forces that cause breaking of at least a portion of the fractured fragments. International application PCT/AU2014/000648 in the name of the applicant describes an apparatus for subjecting fragments to impact forces and the disclosure in the specification of the International application is incorporated herein by cross-reference.

25 The agglomerates produced in the agglomeration station 11 are transferred via a conveyor 15 (or any other suitable materials transfer option) to a heap site (not shown) for use in the construction of a heap on the site.

The method provides an opportunity to use energy that is required in any event for agglomerating fragments in the agglomeration step (b) to break down fractured
30 fragments from the electromagnetic radiation exposure step (a). This provides an opportunity to avoid secondary and tertiary crushing (assuming tertiary crushing would be otherwise required) of mined ore prior to agglomeration step (b) and consequently to

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reduce the overall energy requirements to produce agglomerates from mined ore. The method also makes it possible to take larger fragments into the agglomeration step – this is a considerable advantage in terms of upstream materials handling of fragments.

Many modifications may be made to the embodiments of the present invention
5 described above without departing from the spirit and scope of the invention.

By way of example, the embodiment is described as a series of successive steps with fragments from the electromagnetic radiation station 13 being transferred directly to the agglomeration station 13 and thereafter directly to form a heap. The invention is not limited to this embodiment and there may be stockpiling of fragments and
10 agglomerates after each of the stations 13, 11. In addition, the stations 13, 11 and the heap may not be located in the same area and it may be necessary to transport fragments and agglomerates between stations and heaps that are in different locations.

CLAIMS

1. A method of agglomerating mined ore for use in a heap leaching process which includes the steps of:
 - (a) exposing ore fragments to electromagnetic radiation and causing
5 fractures to form in the fragments; and
 - (b) agglomerating fragments after exposure to electromagnetic radiation, in step (a), with agglomeration step (b) including mixing fragments so that fragments that have fractures break down into smaller fragments and these smaller fragments subsequently form agglomerates during the agglomeration step.
- 10 2. The method defined in claim 1 wherein the agglomeration step (b) includes simultaneously mixing and agglomerating fragments.
3. The method defined in claim 1 wherein the agglomeration step (b) includes mixing fragments in one step and agglomerating the mixed fragments in a separate step.
- 15 4. The method defined in any one of the preceding claims includes crushing mined ore in a primary crushing step and processing the crushed ore in the electromagnetic radiation exposure step (a).
5. The method defined in any one of the preceding claims includes separating crushed ore into at least two fractions based on fragment size prior to the
20 electromagnetic radiation exposure step (a), with one fraction being a coarse fraction and another fraction being a fines fraction.
6. The method defined in claim 5 includes processing the coarse fraction in the electromagnetic radiation exposure step (a).
7. The method defined in claim 6 includes supplying the fines fraction and
25 the fractured coarse fraction produced in step (a) to the agglomeration step (b).
8. The method defined in any one of the preceding claims wherein the ore is a copper-containing ore that includes copper-containing minerals.
9. The method defined in any one of the preceding claims wherein the electromagnetic radiation is microwave radiation or radio frequency radiation.
- 30 10. The method defined in any one of the preceding claims wherein the operating conditions for the electromagnetic radiation exposure step (a) are selected to

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form fractures in fragments without causing significant breakdown of fragments into smaller fragments.

11. The method defined in any one of the preceding claims wherein the operating conditions for the electromagnetic radiation exposure step (a) are selected to form fractures in fragments with minimal breakdown of the fragments into smaller fragments.

12. The method defined in any one of the preceding claims wherein the operating conditions for the electromagnetic radiation exposure step (a) are selected to form fractures in fragments without causing breakdown of more than 25%, typically no more than 15%, more typically no more than 10%, by weight of the fragments into smaller fragments.

13. The method defined in any one of the preceding claims wherein the operating conditions for the electromagnetic radiation exposure step (a) are selected to form fractures that ultimately result in a preferred particle size distribution of fragments for forming agglomerates that have required characteristics, such as porosity and/or mechanical strength, for heap leaching.

14. The method defined in any one of the preceding claims wherein the electromagnetic radiation is selected to be high power density and the exposure times are selected to be very short exposure times.

15. The method defined in claim 14 wherein the power density applied in electromagnetic radiation exposure step (a) is selected to be at least $1 \times 10^9 \text{ W/m}^3$.

16. The method defined in claim 14 wherein the power density applied in electromagnetic radiation exposure step (a) is selected to be at least $1 \times 10^{10} \text{ W/m}^3$.

17. The method defined in claim 14 wherein the power density is selected to be at least $1 \times 10^{11} \text{ W/m}^3$.

18. The method defined in any one of claims 14 to 17 wherein the exposure time in electromagnetic radiation exposure step (a) is less than 1s.

19. The method defined in any one of claims 14 to 18 wherein the exposure time is less than 0.05s.

20. Agglomerates formed in the method defined in any one of the preceding claims.

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21. A heap of material, with the material including agglomerates formed in the method of agglomerating mined ore defined in any one of the preceding claims.

22. A method of heap leaching that includes:

(a) forming a heap of material, with the material including agglomerates
5 formed in the method of agglomerating mined ore defined in any one of claims 1-20;
and

(b) leaching valuable metal from the ore in the heap.

23. The method defined in claim 22 includes recovering the leached metal as a metal product.

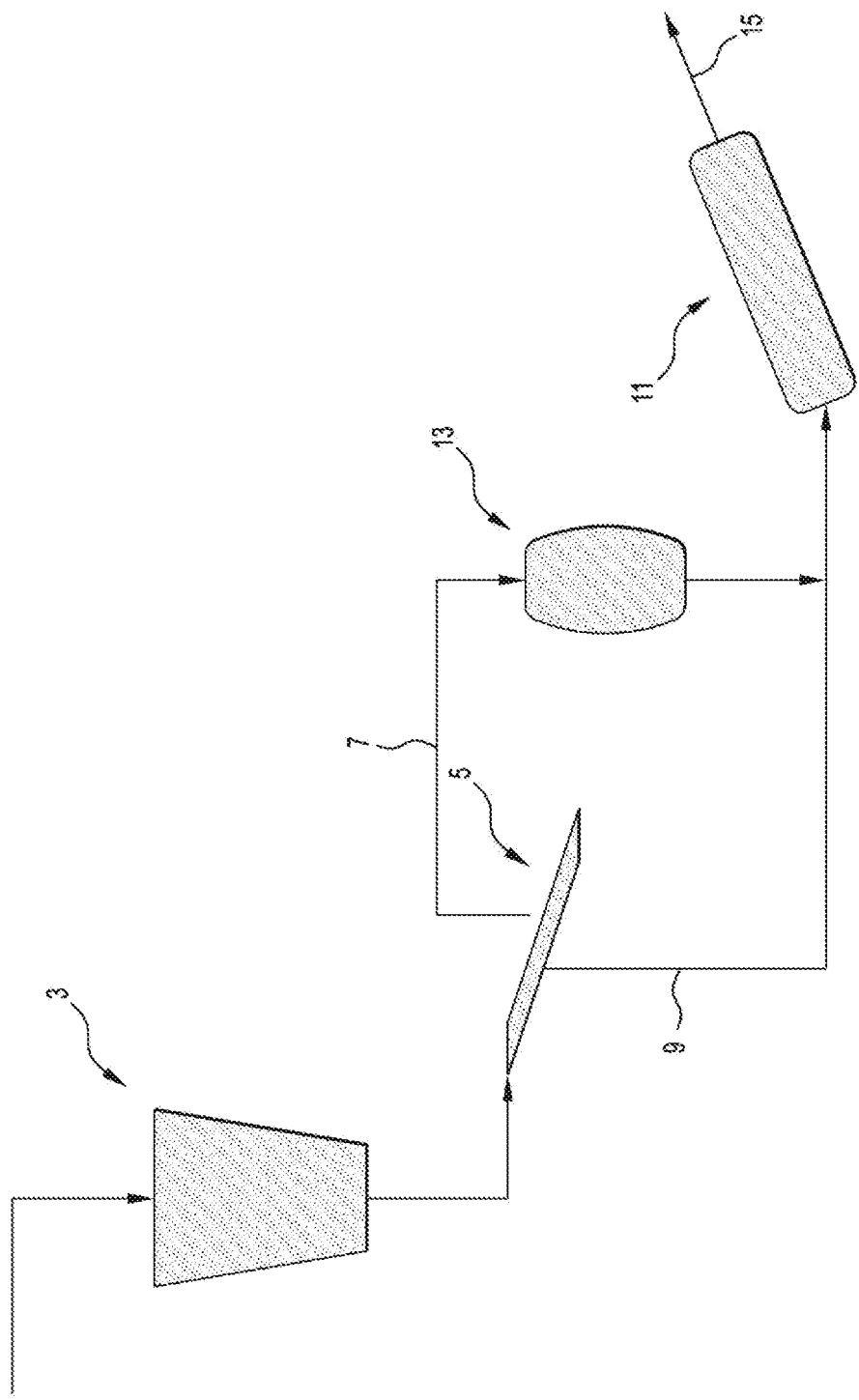


FIG. 1