The present invention is directed to recovery of gold from refractory and double refractory ores using a fungal agent and/or culture media.
100 FEED MATERIAL

104 SULFIDE OXIDATION

116 OXIDIZED RESIDUE

108 SOLID/ LIQUID SEPARATION

120 SEPARATED RESIDUE

112 WASH

140 BIO-ACTIVE AGENT

136 BASE

124 WASHED RESIDUE

128 NEUTRALIZATION/ CONDITIONING

144 NUTRIENTS

148 CONDITIONED MATERIAL

152 BIO-TREATMENT

A

B

FIG. 1A
156 **BO-TREATED MATERIAL**

132 **SOLID/LIQUID SEPARATION**

136 **BASE**

180 **GOLD PRODUCT**

188 **TAILINGS**

168 **LEACHING**

164 **NEUTRALIZED BO-TREATED MATERIAL**

160 **NEUTRALIZATION**

162 **NEUTRALIZED BO-TREATED MATERIAL**

152 **BIO-TREATED MATERIAL**

**FIG. 1B**
MICROBIAL PRE-TREATMENT OF DOUBLE REFRACATORY GOLD ORES

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefits of U.S. Provisional Application Ser. Nos. 60/990,805, filed Nov. 28, 2007, and 61/088,928, filed Aug. 14, 2008, both entitled “Microbial Pre-Treatment of Double Refractory Gold Ores”, both of which are incorporated herein by this reference in their entirities.

FIELD

[0002] The invention relates generally to hydrometallurgical gold recovery processes and particularly to biological processes for recovering gold from refractory and double refractory materials.

BACKGROUND

[0003] In carbonaceous gold bearing ores, preg robbing occurs when active carbon, indigenous to the ore, complexes with the gold dissolved in cyanide leach solutions, thereby reducing gold recovery. “Preg robbing” is a generic term and can refer to any of several phenomena related to an ore’s Total Carbonaceous Material (TCM). Not only can preg robbing be caused by activated carbon, but it can also be caused either by high molecular weight hydrocarbons usually associated with the activated carbon or by organic acids, such as humic acid, having functional groups capable of interacting with gold complexes to form organic gold compounds. (P. Afenya, Treatment of Carbonaceous Refractory Gold Ores, Minerals Engineering, Vol. 4, pp. 1043-1055, 1991. W. Guiry, The Treatment of Refractory Gold Ores Containing Carbonaceous Material and Sulfides, Society of Mining Engineers of AIME, 81-34, pp. 1-4, 1981). An additional problem in recovering gold from highly carbonaceous ores is that a significant quantity of the gold may have been adsorbed onto carbon during formation of the mineral deposit. Cyanide has shown varying degrees of success in leaching gold locked in carbonaceous material.

[0004] Many gold deposits currently processed throughout the world are sulfidic in nature and may contain the gold in a form that is inaccessible to lixiviants. Gold is frequently present in these ores as very finely disseminated particles encapsulated by a sulfide mineral structure. The inaccessibility of the gold to the lixiviant has been overcome by oxidizing the sulfides contained in the ore, thereby liberating gold particles from the sulfide matrix and rendering the gold amenable to cyanidation. Some ores are characterized as double refractory because they are both sulfide refractory and preg robbing carbonaceous refractory.

[0005] Several approaches to reduce the impact of carbonaceous preg robbing in sulfide ores have been employed with varying degrees of success depending on the feed ore’s refractory and mineralogical characteristics. These methods include: flotation, the addition of blanking agents, competitive loading onto commercial activated carbon, roasting, chemical oxidation and bioleaching.

[0006] Flotation is most successful when a small proportion of gold is associated with the preg robbing carbonaceous matter in the ore. The carbonaceous matter is floated off and discarded. The remaining ore is then processed using conventional cyanidation techniques. This technique, however, does not work for ores in which considerable quantities of gold are associated with the carbonaceous component.

[0007] The addition of blanking agents, such as kerosene, fuel oil, and RV-2 (para-nitro benzol azo salicylic acid), adsorb selectively onto the surface of activated carbon in carbonaceous ores, thereby deactivating some of the preg robbing character. Fuel oils exhibit a high affinity for carbonaceous material, particularly graphitic carbon, and adhere to hydrophobic surfaces of carbonaceous matter, thereby reducing its adsorptive capacity. Because fuel oil is lighter than water it will not separate readily from the ore solids in the slurry after leaching. This entrainment causes problems in subsequent operations, particularly liquid solid separation.

[0008] Carbonaceous matter can also be destroyed by roasting. This is the current industry standard for simultaneously destroying the carbonaceous matter while oxidizing sulfide minerals in double refractory gold ores. This process is generally, but not always, successful and depends upon the temperature of roasting. Very high temperatures are often required to combust some preg robbing carbon species. Roasting plants operate in a narrow range of temperature tolerance. Below optimum temperature, the carbon in the ore is not oxidized and remains actively preg robbing. Above the optimum temperature, the gold in the ore becomes increasingly less amenable to cyanidation or other extraction techniques. Because of the degrading gold recovery with higher roasting temperatures, many roasters are operated toward the lower side of the temperature range. Roaster efficiency in a plant environment tends to vary widely with variation in feed stock. Roasting may not be suitable or economical for ores that contain low levels of sulfide and high levels of carbonates, because the roasting is not autogenous.

[0009] Activated carbon or resin can be added to leach solutions to preferentially adsorb gold-cyanide. This process depends on the adsorbent having a stronger affinity for gold than the carbonaceous matter in the ore. This process is not effective when the ore contains large amounts of carbonaceous matter. It has also been been reported that native carbonaceous matter has the ability to adsorb the gold cyanide complex four times faster than activated carbon. (B. J. Scheiner, Relation of Mineralogy to Treatment Methods for Carbonaceous Gold Ores, Society of Mining Engineers, 87-96, pp 1-6, 1987).

[0010] U.S. Pat. No. 5,536,480 discloses a method for pressure oxidizing carbonaceous refractory ores. The method employs a combination of very fine zoning of the ore feed with severe pressure oxidation processing to oxidize and or passivate the preg robbing organic carbonaceous material. Although pressure oxidation can partially deactivate the indigenous carbon, it is often unable to deactivate the preg robbing carbon in highly preg robbing ores. Surprisingly, pressure oxidation has been shown, in some instances, to activate carbonaceous matter.

[0011] U.S. Pat. No. 4,729,788 employs bio-oxidation to treat double refractory sulfide and carbonaceous gold ores. The process uses bacteria to biologically degrade sulfide minerals and liberate precious metal values so that they can be recovered by conventional technologies. The most widely used and studied bacteria for this process is Acidithiobacillus ferrooxidans. As bio-oxidation has little effect on the preg robbing characteristics of an ore, a blinding agent, such as “Actinol FA” (a form of Toll Oil), is used to bind the preg robbing carbon to obtain satisfactory gold yields from carbonaceous ores.
[0012] U.S. Pat. Nos. 5,244,493 and 5,127,942 disclose a process for treating double refractory ores in which bio-oxidation of sulfidic minerals is followed by microbial treatment to reduce the effects of preg robbing carbon. This treatment uses a consortium of bacterial comprising at least two bacteria selected from the group consisting of *Pseudomonas maltophilia*, *Pseudomonas oryzihabitans*, *Pseudomonas putida*, *Pseudomonas fluorescens*, *Pseudomonas stutzeri*, *Achromobacter* species, *Arthrobacter* species, and *Rhodococcus* species. The bioactivating agent disclosed in this patent is a product of the above microbial consortium (column 2, line 17). The disadvantage of this patent is that the deactivation of preg robbing carbon is facilitated by addition of a chelating agent at very high dosages. The preferred dosage range quoted, 0.5 g to 5 g EDTA/20 g of ore or 25-250 kg EDTA per tonne of ore, is likely to be economically prohibitive.

[0013] There is therefore a need for an economical and practical method to treat the preg robbing component of single or double refractory ores.

**SUMMARY**

[0014] These and other needs are addressed by the various embodiments and configurations of the present invention. The present invention is directed generally to the recovery of gold and other precious metals from refractory and double refractory materials using bio-active agents, particularly fungal agents.

[0015] In a first embodiment, a method is provided for treating refractory and double refractory gold-containing materials containing preg robbing carbon-containing components using a fungal agent to deactivate the preg robbing components. The fungal agent can be any suitable fungus, including a white rot fungus, with any *Coriolaceae* cellular organism being preferred and any *Trametes* cellular organism, such as *Trametes versicolor* (formerly *Coriolus versicolor*), being even more preferred. Before or after inoculation by the fungal agent, any refractory sulfide sulfur may be oxidized by a suitable technique, including roasting, atmospheric oxidation, pressure oxidation, and bio-oxidation. This embodiment can provide an economical and practical method to treat not only refractory but also double refractory ores.

[0016] In a second embodiment, a method is provided for treating refractory and double refractory gold-containing materials containing sulfide sulfur using a fungal agent to decompose sulfides. The fungal agent can be any suitable fungus, including a white rot fungus, with any *Coriolaceae* cellular organism being preferred and any *Trametes* cellular organism, such as *Trametes versicolor* (formerly *Coriolus versicolor*), being even more preferred. Before or after inoculation by the fungal agent, any preg robbing carbon-containing components may be deactivated by a suitable technique. One preferred technique is bio-deactivation using fungal and/or bacterial microbes.

[0017] In a third embodiment, a method is provided for treating refractory and double refractory gold-containing sulfidic materials. A culture media, with or without a microbial agent, is applied at elevated temperature to the material to oxidize sulfidic sulfur. The culture media may be for a microbe that deactivates the preg robbing carbon-containing material. In that event, the gold-containing material may be inoculated with the microbe during or after sulfidic sulfur oxidation.

[0018] The second and third embodiments can oxidize sulfidic sulfur at an alkaline pH, thereby reducing base consumption compared to bacterial oxidation of sulfidic sulfur.

[0019] These and other advantages will be apparent from the disclosure of the invention(s) contained herein.

[0020] As used herein, "a" or "an" entity refers to one or more of that entity. As used herein, "one or more" and "at least one" can be used interchangeably herein. It is also to be noted that the terms "comprising", "including", and "having" can be used interchangeably.

[0021] As used herein, "acid consumer" refers to any material that reacts with sulfuric acid to form a new compound. Specific examples of acid consumers include carbonates, such as limestone, soda ash, trona, ankerite, dolomite, and calcite; alkaline earth metal oxides such as lime; other metal oxides such as zinc oxide and magnesium oxide; alkali metal hydroxides such as sodium hydroxide and potassium hydroxide; other metal hydroxides such as ferric hydroxide (e.g., limonite and goethite) and aluminum hydroxides such as laterite, gibbsite, and diaspor; ammonia; and various clays.

[0022] As used herein, "at least one", "one or more", and "and/or" are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions "at least one of A, B and C", "at least one of A, B, or C", "one or more of A, B, and C", "one or more of A, B, or C", and "A, B, and/or C" means A alone, B alone, C alone, A and B together, A and C together, B and C together, or A, B and C together.

[0023] As used herein, "carbonaceous material" refers to organic carbon-containing material. Examples of organic carbonaceous materials include humic acid, hydrocarbons, and naturally occurring activated carbon.

[0024] As used herein, "deactivation" refers to decomposition or alteration, such as by oxidation and/or reduction, of a selected compound and/or passivation of a selected material.

[0025] As used herein, "malt" refers to grains that have been partially germinated by artificial means. Malt normally contains dextrin, maltose, and amylase.

[0026] As used herein, "passivate" means to form a coating on a surface and reduce a selected chemical activity or function.

[0027] As used herein, "yeast" refers to unicellular organisms known as saccharomyces.

[0028] The preceding is a simplified summary of the invention to provide an understanding of some aspects of the invention. This summary is neither an extensive nor exhaustive overview of the invention and its various embodiments. It is intended neither to identify key or critical elements of the invention nor to delineate the scope of the invention but to present selected concepts of the invention in a simplified form as an introduction to the more detailed description presented below. As will be appreciated, other embodiments of the invention are possible utilizing, alone or in combination, one or more of the features set forth above or described in detail below.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0029] The accompanying drawings are incorporated into and form a part of the specification to illustrate several examples of the present invention(s). These drawings, together with the description, explain the principles of the invention(s). The drawings simply illustrate preferred and alternative examples of how the invention(s) can be made and
used and are not to be construed as limiting the invention(s) to only the illustrated and described examples. Further features and advantages will become apparent from the following, more detailed, description of the various embodiments of the invention(s), as illustrated by the drawings referenced below.

**[0030]** FIG. 1A is a flowsheet of a process according to an embodiment; and

**[0031]** FIG. 1B is a flow sheet continuation of the process of the embodiment.

**DETAILED DESCRIPTION**

**[0032]** Refractory carbonaceous material is contacted with a heterotrophic bio-active agent, particularly a fungal agent, to deactivate preg robbing carbonaceous components. Although any suitable fungi may be employed, a preferred heterotrophic agent is an Aspergillus fungal organism, more preferably a Cordyceps fungal organism, even more preferably white rot fungi and mutants thereof, with a Trametes fungal organism (e.g., Trametes trogi, Trametes hirsuta, and Trametes versicolor (formerly Cordyceps sp.)), a Phanerochaete fungal organism (e.g., Phanerochaete chrysosporium and Phanerochaete sordida), a Bjerkandera fungal organism, a Phlebia fungal organism (e.g., Phlebia brevipes), a Cyathus fungal organism (e.g., Cyathus stercoreus), and a Tyromyces fungal organism (e.g., Tyromyces palustris) and mutants thereof being even more preferred and a Trametes species and mutants thereof being even more preferred. In one configuration, the bio-active agent can not only deactivate carbonaceous components but also oxidize sulfide minerals. These fungi are commonly active at temperatures in the range of about 15 to about 45° C, and at a pH of at least about pH 3, even more commonly in the range of about pH 5 to about pH 12, and even more commonly in the range of about pH 8 to about pH 10.

**[0033]** While not wishing to be bound by any theory, the fungi are believed to secrete a number of enzymes, particularly peroxidases and laccases with unique properties. The enzymes can catalyze a wide variety of oxidations and both indirect oxidations and reductions. The fungi synthesize and secrete hydrogen peroxide to activate the peroxidases and laccases, veratryl alcohol to serve as a free radical intermediate for indirect oxidations, and/or electron donors, such as oxalate, which, with veratryl alcohol, catalyze reductions. Reductions are often required for subsequent oxidation of chemicals by the peroxidases and laccases. It is believed that some carbonaceous materials are converted into carbon dioxide by some fungi while other fungi passivate the pre-robbing capacity of carbonaceous materials.

**[0034]** A process according to a first embodiment will be discussed with reference to FIGS. 1A and 1B. The process oxidizes sulfides and bio-deactivates carbonaceous components in different stages and by different means.

**[0035]** A feed material 100 contains gold and can be in any suitable form, such as ore, concentrate, tailings, calcine, and residue of an extractive metallurgical process. The gold content of the feed material 100 depends on the form of the material and typically ranges from about 0.1 to about 5 oz/tonne and even more typically from about 0.2 to about 2 oz/tonne. The material 100 includes a preg robbing carbonaceous component, such as humic acid, hydrocarbons, and surface active carbon, in an amount ranging from about 0.3 to about 10 wt. %. The material 100 can also include other components, including one or more of silver in an amount typically ranging from about 1 to about 10 oz/tonne and even more typically ranging from about 1 to about 5 oz/tonne, sulfide sulfur in an amount typically ranging from about 0.1 to about 15 wt. %, and acid consumers in an amount typically ranging from about 0.1 to about 30 wt. %. Depending on the mineralogy of the material, the sulfide minerals are commonly in the form of pyrite, marcasite, arsenopyrite, and chalcopyrite while the acid consumers are commonly present as carbonates, ankerite, calcite, siderite, and dolomite.

**[0036]** The particle size of the feed material 100 depends on subsequent processing steps and mineralogy. For example, when the feed material 100 particles will be bio-treated in a vat or other container the P80 size of the material will be about 75 µm. Commonly, the feed material 100 will have a median, average, and/or P80 size in the range of about 10 µm to about 25 µm.

**[0037]** Optional steps 104, 108 and 112 are performed, when the feed material 100 is sulfide refractory, to oxidize sulfide sulfur sufficiently to liberate most of the gold from the sulfide matrix. Sulfide oxidation may be performed by any technique, including alkaline or acid atmospheric or pressure oxidation, roasting, and bio-oxidation. Preferably, oxidation is performed by bio-oxidation in a tank. In bio-oxidation, the material 100 is inoculated with a chemolithotrophic autotrophic bacterial consortium, typically including Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans and Leptospirillum ferrooxidans. Alternately or additionally, the bacteria used for oxidative leaching comprise at least one bacteria selected from the group consisting of Thiobacillus thiooxidans, Acidithiobacillus ferrooxidans, Leptospirillum spp., Thiomonas acidocaldarius, Sulfolobus BC and Sulfolobus solfataricus. Thiobacillus ferrooxidans bacteria are suitable for sulfide oxidation within the temperature range of about 15 to about 40° C. The facultative-thermophilic iron-oxidizing bacteria oxidize sulfides at a temperature range of about 35 to about 55° C. The Sulfolobus and Acidimans species are active from about 50 to about 90° C.

**[0038]** The various reactions occurring during bio-oxidation are believed to be:

\[
\begin{align*}
2\text{Fe}_2\text{S}_3 + 7\text{O}_2 + 2\text{H}_2\text{O} & \rightarrow 4\text{Fe}^{3+} + 6\text{H}^{+} \\
4\text{Fe}^{3+} + 4\text{O}_2 + 2\text{H}_2\text{SO}_4 & \rightarrow 2\text{Fe}_2\text{SO}_4 + 2\text{H}_2\text{O} \\
\text{Fe}^{3+} + \text{Fe}^{3+} + 3\text{SO}_4^{2-} & \rightarrow 3\text{Fe}^{3+} + 3\text{S} \\
2\text{S} + 3\text{O}_2 + 2\text{H}_2\text{O} & \rightarrow 2\text{H}_2\text{SO}_4
\end{align*}
\]

Reactions (1) and (3) are believed to be mainly chemical reactions and occur with little or no bacterial involvement. Reactions (2) and (4) are believed to rely entirely on bacterial catalysis and will not proceed to any appreciable degree in the absence of active bacteria under ambient conditions. The final oxidation products of sulfide minerals should be ferric sulfate and sulfuric acid.

**[0039]** Sulfide bio-oxidation takes place at a pH of less than about pH 2.5, with an operable range being from about pH 1.1 to about pH 3.0. To attain or maintain this pH, the material 100 may need to be contacted, before bio-oxidation, with an acid to destroy acid consumers.

**[0040]** To promote microbial activity, nutrients, such as soluble Fe²⁺; ammonium sulfate, and phosphate, are contacted with the material 100, during and after inoculation. Bio-oxidation is further discussed in U.S. Pat. Nos. 4,729,788, 5,089,412, 5,127,942, and 6,696,283.
Sulfide bio-oxidation may be carried out prior to or subsequent to the carbon deactivation by the bio-active (fungal) agent disclosed herein. In some cases, this reversal of steps is desirable to prevent liberated gold from being lost to preg robbing carbon before the preg robbing carbon is deactivated.

Through oxidation, commonly 25% or more, even more commonly more than 50%, and even more commonly 85% of the sulfide sulfur in the feed material 100 is oxidized in step 104.

The oxidized residue 116, when in the form of a slurry, is subjected to solid/liquid separation in step 108, such as using a counter current decantation circuit, to produce a separated residue 120. The oxidized and separated residue 116 and 120, respectively, contain most of the gold. The liquid component may be recycled to step 104.

In step 112, the residue is washed in a wash circuit to reduce acid levels, remove bacteria, and form a washed residue 124.

In step 128, the residue 124, which is typically in the form of a slurry, is neutralized, as needed, using base 136 to produce the desired pH range (discussed above), conditioned to produce a desired pulp density, and inoculated. The base 136 can be any acid consumer, such as lime and limestone, with lime being preferred. The pulp density is adjusted with solution from step 132 to a preferred range of about 10 to about 50% and even more preferably of about 20 to about 30%.

The bio-active (fungal) agent 140, commonly in the form of an inoculant or culture media, are contacted with the neutralized and conditioned slurry during step 128 and/or during bio-treatment step 152. The inoculant preferably contains from about 10^4 to about 10^6 colony-forming units per milliliter, preferably as a suspension in a nutrient solution. Preferably, the colony forming units are grown for a suitable period on a culture medium before inoculation. Commonly, the bio-active agent 140 does not include heterotrophic carbon deactivating bacteria, such as Pseudomonas maltophilia, Pseudomonas oryzihabitans, Pseudomonas putida, Pseudomonas fluorescens, Pseudomonas stutzeri, Streptomyces setonii, Arthrobacter species, Achromobacter species, and Rhodococcus species.

The inoculant or culture media includes nutrients 144 to promote growth and reproduction of the bio-active agent. Nutrients generally include a carbon source and one or more inducers to encourage or enhance production by the bio-active agent of one or more selected enzymes that effect the desired deactivation of the preg robbing carbonaceous materials. In one formulation, the nutrients 144 are a glucose-malt-yeast extract medium preferably including, in each liter of nutrient solution, from about 5 to about 50 g/L glucose, from about 1 to about 25 g/L malt extract, from about 0.5 to about 25 g/L yeast extract, and from about 0.1 to about 10 g/L of an alkaline earth metal sulfate, particularly hydrated magnesium sulfate, with the remainder of the solution being (preferably distilled) water. In another formulation, the nutrient-containing solution is an aqueous mixture including from about 10 to about 20 parts Kirk’s medium, from about 1 to about 1.5 parts polysaccharide (e.g., a phycocollloid, particularly agar (which is a mixture of agarose and agaropectin)) and from about 2.5 to about 3 parts malt extract or maltine, with the remainder being (preferably distilled) water. One liter of Kirk’s medium preferably includes about 10 grams glucose or dextrose, from about 0.44 to about 0.80 grams ammonium tartrate, about 0.05 gram of a transition metal sulfate, particularly hydrated manganese sulfate, about 0.1 gram of an alkaline earth metal chloride, particularly hydrated calcium chloride, about 100 µmol thiamine, about 100 µmol trace minerals, and about 3 gram 2,2 dimethylsucinate supplement. Unlike U.S. Pat. No. 5,244,493, the inoculating solution or culture media excludes, and bio-treatment step 152 is performed in the complete or substantial absence of, a chelating agent, particularly ethylene diamine tetraacetic acid.

The conditioned material 148 is bio-treated in step 152 to deactivate most and even more preferably from about 75 to about 95% of the preg robbing carbonaceous material. During bio-treatment, nutrients 144 and, as needed, additional bio-active agent 140, are contacted with the conditioned material 148. While not wishing to be bound by any theory, the bio-active agent, using the particles of conditioned material 148 as a substrate, metabolizes, multiplies, and produces biomass. During the growth process, the fungus is believed to attach to the carbonaceous components of the conditioned material 148. Fungal deactivation of carbonaceous components to a non-preg robbing form is believed to result from coating the carbonaceous components with the fungal-produced biomass. The biomass may block or “blind” the carbonaceous material from reacting with dissolved gold.

To maintain desired growth and reproductive rates of the bio-active agent, further inoculations of the bio-active agent and nutrient solution are done during bio-treatment. This can be done either on a continuous or discontinuous basis. The pulp density is preferably maintained in the range set forth above.

Typically, neutralization/conditioning and bio-treatment will take place in a series of vessels, such as tanks, columns, or vats. The vessels are preferably continuous or semi-continuous stirred tank vessels. Commonly, the series includes a neutralization/conditioning vessel followed by one or more reactor vessels (in which bio-treatment occurs).

Molecular oxygen is generally provided to support fungal growth. Molecular oxygen is commonly provided by sparging air through the neutralization/conditioning and/or bio-treatment vessels.

The residence time is the time required to substantially reduce, or deactivate, the preg robbing characteristic of the ore and commonly depends on the characteristics of the conditioned material 148 and processing conditions, such as feed rate, temperature, particle size, and pulp density. The residence time of the conditioned material 148 in the reactor tank(s) typically ranges from about one to about 3 weeks.

The bio-treated material 156 includes most, if not all, of the gold in the feed material 100.

In optional step 132, the bio-treated material 156, which is in the form of a slurry, is subjected to solid/liquid separation, such as in a counter current decantation circuit, to separate a portion of the liquid phase from the solid phase (or bio-treated material 156).

In optional step 160, the separated bio-treated material 156 is neutralized using a suitable base 136. The base 136 is preferably lime.

The neutralized bio-treated material 164, in step 168, is leached using a lixiviant to form a pregnant leach solution 172 containing most of the gold in the material 164 and a barren material 176. The lixiviant can be any suitable gold-dissolving leaching agent, such as cyanide, thiocyanate, or thiourea, with cyanide being preferred.
In step 180, dissolved gold in the pregnant leach solution 172 is recovered by suitable techniques to form a gold product 184. Gold recovery and leaching can be performed sequentially or simultaneously. In a preferred configuration, dissolved gold is concentrated by adsorption onto activated carbon either in adsorption columns, in carbon added to the leaching process (known as Carbon-in-Leach ("CIL") or Carbon-in-Pulp ("CIP") techniques), or in resin added to the leaching process (known as Resin-In-Leach ("RIL") techniques). Adsorbed gold is eluted from the sorbent by stripping with ammonia, nitric acid, caustic, steam and/or other stripping solutions. Gold is then isolated and converted to a solid from the eluate by electrowinning (electroplating of gold onto cathodes), precipitation and filtration, or cementation.

In step 188, the barren material 176 is subjected to solid/liquid separation to form tailings 192, which may be discharged into a tailings pond or otherwise disposed of.

Because treatment of feed material 100 with a bio-oxidizing consortium occurs at an acid pH and cyanidation of the bio-treated material 156 occurs at an alkaline pH, it is desirable, after bio-oxidation (step 104) and before bio-treatment of carbonaceous components and cyanidation, to raise the pH of the oxidized residue 116 into the alkaline regime. It is, however, possible to bio-treat the carbonaceous components before sulfide oxidation (step 104). This configuration is practical when the ore contains a high amount of carbonate and other acid consumers and is subjected to alkaline pressure oxidation. As will be appreciated, in alkaline pressure oxidation the autoclave discharge has a neutral to alkaline pH as described by Mason in U.S. Pat. No. 4,979,987.

In one alternative embodiment, the feed material 100 is processed by heap leaching techniques. The feed material 100 is comminuted to a coarse size and/or formed into agglomerates. In heap leaching, the particles of feed material 100, for example, typically have a P_{80} size of less than about 2 inches and even more typically less than about 0.5 inches. The heap is inoculated with, and sprayed with nutrients for, the chemolithotrophic bacteria. When sulfide oxidation is at a selected degree of completion, the heap is dismantled and the particles/agglomerates neutralized with soda ash or limestone. The neutralized particles/agglomerates are re-formed into a heap and bio-treatment performed to deactivate the preg robbing carbon components. When bio-treatment is at a selected degree of completion, the heap, if necessary, is dismantled and the particles/agglomerates neutralized with lime. The heap is re-formed again. The gold is recovered by contacting the heap with an alkaline lixiviant, such as cyanide, thiourea, and thiourea.

In another embodiment, sulfide oxidation is effected at elevated temperature using a nutrient-containing solution or culture media in the substantial absence of a fungal or bacterial agent. The microbe-barren nutrient solution is contacted with the feed material 100 in a stirred tank for a time sufficient to oxidize a substantial portion of the sulfides. The contacting temperature is typically about 30°C or higher and even more typically ranges from about 40°C to about 45°C. and the pH is about pH 9 or more and even more typically ranges from about pH 9.5 to about pH 10.5. The nutrient solution can have the composition set forth above in connection with fungal agents. As will be appreciated, the byproducts of sulfide oxidation (e.g., sulfuric acid) may cause the pH of the culture media to decrease during the course of sulfide oxidation. Consequently, base is added, as needed, to maintain the pH of the culture media at the desired level. Before or after oxidation, preg robbing carbon-containing component deactivation by fungal or bacterial microbes is effected as set forth above.

In another alternative embodiment, the sulfide destruction capability of the bio-active agent 140 and the oxidative ability of the nutrient solution are jointly used to effect bio-oxidation (step 104). It is well established that white rot fungus decomposes dibenzyl sulfide to dibenzyl sulfone and dibenzyl sulfone. Van Hamme, *Dibenzyld Sulfide Metabolism by White Rot Fungi*, Applied and Environmental Microbiology, February 2005, pages 1320 to 1324 (2003). Accordingly, white rot fungus and the nutrient solution are applied, together or separately, to the feed material 100, either by heap or tank leaching techniques, to decompose commonly at least about 25 wt. %, even more commonly more than about 50 wt. %, and even more commonly at least about 65 wt. % of sulfide sulfur. Preferably, step 104 is conducted at the elevated temperature and pH ranges set forth in the prior paragraph. Because white rot fungus also deactivates preg robbing carbon, both sulfide oxidation and preg robbing carbon deactivation (step 152) can be effected in a single stage. In this embodiment, sulfide oxidizing and/or carbon consuming bacteria may or may not be applied to the feed material 100 along with the fungal agent.

In yet another embodiment, sulfide destruction is effected using white rot fungus as the bioactive agent 140 and the culture media at the temperature and pH ranges set forth above, and a different microbial agent is used to effect deactivation of the preg robbing carbon. The preg robbing carbon deactivation microbe is preferably bacterial but may be fungal. Exemplary bacteria include *Pseudomonas maltophilia*, *Pseudomonas oryzihabitans*, *Pseudomonas putida*, *Pseudomonas fluorescens*, *Pseudomonas stutzeri*, *Stenotrophomonas setonii*, *Arthrobacter species*, *Achromobacter species*, and *Rhodococcus species*. Because the fungal agent, during sulfide oxidation, can mobilize the gold for collection on the preg robbing carbon, it is preferred that preg robbing carbon deactivation (step 152) be performed before sulfide oxidation (step 104). In this embodiment, sulfide oxidizing bacteria may or may not be applied to the feed material 100 along with the fungal agent.

In the above alternative embodiments, the use of an overlapping pH range to perform both sulfide oxidation and preg robbing carbon deactivation can provide significant reductions in operating and capital costs and increases in throughput compared to the two-step leaching processes set forth above.

**EXPERIMENTAL**

The following examples are provided to illustrate certain embodiments of the invention and are not to be construed as limitations on the invention, as set forth in the appended claims. All parts and percentages are by weight unless otherwise specified.

**Example 1**

Baseline Cyanidation

Three different ore samples were employed to investigate the two stage bio-oxidation-bio-treatment process. The analysis is shown in Table 1. Sample A is a flotation concentrate. Samples B and C are run-of-mine ore samples.
TABLE 1

<table>
<thead>
<tr>
<th>Sample</th>
<th>Au g/t</th>
<th>Ag g/t</th>
<th>C (graphitic) %</th>
<th>S %</th>
<th>Fe %</th>
<th>As %</th>
<th>Robbing %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>76.1</td>
<td>6.00</td>
<td>7.03</td>
<td>13.30</td>
<td>15.30</td>
<td>11.25</td>
<td>51.8</td>
</tr>
<tr>
<td>B</td>
<td>4.80</td>
<td>0.24</td>
<td>3.00</td>
<td>0.69</td>
<td>2.25</td>
<td>0.62</td>
<td>68.9</td>
</tr>
<tr>
<td>C</td>
<td>2.91</td>
<td>0.10</td>
<td>2.36</td>
<td>3.79</td>
<td>6.36</td>
<td>1.49</td>
<td>80.3</td>
</tr>
</tbody>
</table>

[0067] Conventional bottle roll cyanidation tests were conducted using (75% minus 75 micron ore), 0.5 g/l NaCN, at a pH of 10.5, for 24 hours. The results presented in Table 2 show that gold extractions for each sample were less than 22%. The sulfide and inorganic carbon contents of the ore and the low gold recovery by cyanidation indicate the samples are double refractory ores.

TABLE 2

<table>
<thead>
<tr>
<th>Sample</th>
<th>% Au</th>
<th>Residue</th>
<th>Consumption, kg/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Extraction g/l,Au</td>
<td>NaCN</td>
<td>CaO</td>
</tr>
<tr>
<td>A</td>
<td>21.5</td>
<td>59.74</td>
<td>5.62</td>
</tr>
<tr>
<td>B</td>
<td>17.7</td>
<td>3.95</td>
<td>1.84</td>
</tr>
<tr>
<td>C</td>
<td>15.0</td>
<td>2.47</td>
<td>1.74</td>
</tr>
</tbody>
</table>

Example 2

Bio-Oxidation

[0068] The same seed samples employed in Example 1 were pre-treated using microbial bio-oxidation for the treatment of the refractory sulfide component of the ore. The pretreatment consisted of grinding the ores to 90% minus 200 mesh (74 μm) and forming a slurry of about 20% solids in a 2 liter Erlenmeyer flask. The pH's of the slurries were adjusted to about pH 1.5 with sulfuric acid. The chemolithotrophic bacteria used for sulfide oxidation was a mixture of equal parts Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans and Leptospirillum ferrooxidans. These chemolithotrophes were grown together to form a mixed culture and maintained in a medium containing about 0.5 g/l of (NH₄)₂SO₄, K₂HPO₄, MgSO₄.7H₂O, 0.1 g/l KC1 and 0.01 g/l Ca(NO₃)₂, 15.0 g/l FeSO₄.7H₂O, 1.0 g/l sulfur and 0.25 ml/l of Wolfe's solution. A 10% v/v microbial culture was added into the flask containing the pH adjusted slurry, and was agitated using an orbital shaker at 180 rpm for 14 days. At the end of microbial pre-treatment, the slurry was filtered, washed and pulped to about 33% solids for bottle roll cyanidation as outlined in Example 1. The pregnant cyanide solution and leach residue were both assayed for gold.

[0069] Table 3 shows that gold extraction from the ore samples pre-treated with chemolithotrophic bacteria ranged from about 71% to 81%. This improvement is consistent with the liberation of gold after oxidation of the sulfide refractory components of the ore.

TABLE 3

<table>
<thead>
<tr>
<th>Sample</th>
<th>Au g/t</th>
<th>Ag g/t</th>
<th>C (graphitic) %</th>
<th>S %</th>
<th>Fe %</th>
<th>As %</th>
<th>Robbing %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>81.1</td>
<td>14.83</td>
<td>1.04</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>71.1</td>
<td>1.42</td>
<td>0.55</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>73.7</td>
<td>0.77</td>
<td>0.54</td>
<td>0.31</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example 3

Bio-Treatment of Carbonaceous Preg Robbing Material

[0070] The same feed samples used in Examples 1 and 2 were pre-treated with one stage microbial oxidation for treatment of preg robbing carbonaceous materials, followed by the conventional bottle roll cyanidation as described in Example 1. White rot fungus was used for desactivation of the carbonaceous material.

[0071] The white rot fungus, Trametes versicolor, was cultured in a medium containing Kirk's medium, agar and malt extract. The 1,000 ml Kirk's solution contained about 10.1 grams glucose, 0.44–0.80 grams ammonium tartrate, 0.05 gram NaSO₄.7H₂O, 0.01 gram CaCl₂.2H₂O, 10 μl thiamine, 100 μl trace minerals and 2.92 grams 2,2 dimethylsuccinate supplement.

[0072] Pretreatment of the samples included grinding the ore to 90% minus 200 mesh (74 μm) and forming a slurry of 20% solids in a 2 liter Erlenmeyer flask. A 10% v/v microbial culture of Trametes versicolor was added into the flask containing the pH 9.5 slurry, which was agitated using an orbital shaker set at 180 rpm for 14 days at ambient temperature. At the end of microbial pre-treatment, the slurry was filtered, washed and pulped to 33% solids for bottle roll cyanidation as outlined in Example 1. The pregnant cyanide solution and leach residue were both assayed for gold.

[0073] The pH of the slurry to be leached with chemolithotrophic bacteria was about pH 1.5 compared to the pH used for Trametes versicolor, which was about pH 9.5.

[0074] Table 4 shows the gold extraction from the ore samples pre-treated with the white rot fungus was between about 54.1 and 64.5%, which is lower than that treated with the chemolithotrophic bacteria in Example 2, but significantly higher than the gold recovery by cyanidation alone as shown in Example 1.

TABLE 4

<table>
<thead>
<tr>
<th>Sample</th>
<th>Bio-oxidation</th>
<th>% Au</th>
<th>Residue</th>
<th>Consumption, kg/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Species</td>
<td>Extraction g/l,Au</td>
<td>NaCN</td>
<td>CaO</td>
</tr>
<tr>
<td>A</td>
<td>Trametes versicolor</td>
<td>64.5</td>
<td>27.02</td>
<td>1.09</td>
</tr>
<tr>
<td>B</td>
<td>Trametes versicolor</td>
<td>57.1</td>
<td>2.06</td>
<td>0.56</td>
</tr>
<tr>
<td>C</td>
<td>Trametes versicolor</td>
<td>54.1</td>
<td>1.34</td>
<td>0.57</td>
</tr>
</tbody>
</table>
Table 4 shows that the gold extraction from the samples pre-treated with white rot fungus was in the range of about 54 to 65%.

Example 4
Bio-Treatment of Preg Robbing Carbonaceous Ore Followed by Bio-Oxidation

A two stage pretreatment was then conducted on the three ore samples using the procedure outlined in Example 3 for the mitigation of preg robbing, followed by a washing step and treatment using the process for sulfide oxidation shown in Example 2. The two-stage pre-treatment used Trametes versicolor preg robbing deactivation followed by chemolithotrophic bacteria sulfide oxidation.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Extraction Au</th>
<th>Residue g/t</th>
<th>CaO</th>
<th>NaCN Consumption</th>
<th>kg/t</th>
<th>Au, %</th>
<th>Consumption, kg/t, CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>90.8</td>
<td>7.00</td>
<td>1.01</td>
<td>1.01</td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>91.5</td>
<td>0.41</td>
<td>0.56</td>
<td>0.29</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>87.4</td>
<td>0.37</td>
<td>0.53</td>
<td>0.29</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results of Table 5 indicate that gold extraction after treatment using Trametes versicolor was relatively high.

Example 5
Bio-Oxidation and Biotreatment with Trametes versicolor

A test was performed to determine whether Trametes versicolor culture media (without the fungal agent) could decompose sulfides followed by deactivation by the fungal agent of the preg robbing carbonaceous components of the ore. Samples A, B, and C were conditioned with the Trametes versicolor culture media (without the fungal agent) at 30°C for 14 days followed by bio-oxidation with Trametes versicolor at ambient temperature for 7 days. Table 6 shows that approximately 95% of gold was extracted from sample A and approximately 87% from samples B and C. By oxidizing sulfides with culture media alone at about 30°C and about pH 9 for 28 days followed by deactivation of the preg robbing carbon using Trametes versicolor, the same gold extraction results were also obtained.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Extraction Au</th>
<th>Residue g/t</th>
<th>CaO</th>
<th>NaCN Consumption</th>
<th>kg/t</th>
<th>Au, %</th>
<th>Consumption, kg/t, CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>21.5</td>
<td>81.1</td>
<td>64.5</td>
<td>90.8</td>
<td>95.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>17.7</td>
<td>71.1</td>
<td>57.1</td>
<td>91.5</td>
<td>87.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>15.0</td>
<td>73.7</td>
<td>54.1</td>
<td>87.4</td>
<td>87.60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As can be seen from Table 7, the two stage pretreatment using Trametes versicolor yielded the highest gold recovery for sample B while the one-stage pretreatment using the Trametes versicolor culture media (without the fungal agent) for preg robbing carbon decomposition yielded the highest gold recovery for samples A and C. These results indicate that the increases in gold recovery observed from bio-oxidation and bio-treatment are cumulative and due to the reduction of both sulfide refractory and preg robbing refractory components in the ore.

As can be seen from Table 6, the process produced the highest gold yield of any test for samples A and C and the third highest for sample B. The highest gold yields for sample B were from two-stage sulfide oxidation and bio-treatment processes.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Extraction Au</th>
<th>Residue g/t</th>
<th>CaO</th>
<th>NaCN Consumption</th>
<th>kg/t</th>
<th>Au, %</th>
<th>Consumption, kg/t, CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>95.25</td>
<td>3.62</td>
<td>0.98</td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>87.00</td>
<td>0.62</td>
<td>0.41</td>
<td>0.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>87.60</td>
<td>0.36</td>
<td>0.40</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The foregoing discussion of the invention has been presented for purposes of illustration and description. The foregoing is not intended to limit the invention to the form or forms disclosed herein. In the foregoing Detailed Description for example, various features of the invention are grouped together in one or more embodiments, configurations, or aspects for the purpose of streamlining the disclosure. The features of the embodiments, configurations, or aspects of the invention may be combined in alternate embodiments, configurations, or aspects other than those discussed above. This method of disclosure is not to be interpreted as reflecting an intention that the claimed invention requires more features.
than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment, configuration, or aspect. Thus, the following claims are hereby incorporated into this Detailed Description, with each claim standing on its own as a separate preferred embodiment of the invention.

Moreover, though the description of the invention has included description of one or more embodiments, configurations, or aspects and certain variations and modifications, other variations, combinations, and modifications are within the scope of the invention, e.g., as may be within the skill and knowledge of those in the art, after understanding the present disclosure. It is intended to obtain rights which include alternative embodiments, configurations, or aspects to the extent permitted, including alternate, interchangeable and/or equivalent structures, functions, ranges or steps to those claimed, whether or not such alternate, interchangeable and/or equivalent structures, functions, ranges or steps are disclosed herein, and without intending to publicly dedicate any patentable subject matter.

What is claimed is:

1. A method, comprising:
   providing a refractory gold-containing feed material, the feed material comprising a preg robbing carbon-containing component;
   inoculating the feed material with a fungal agent to passivate the preg robbing carbon-containing component, whereby at least most of the preg robbing ability of the carbon-containing component is deactivated; and
   thereafter recovering the gold from the inoculated feed material.

2. The method of claim 1, wherein the fungal agent is at least one of a white rot fungus and mutant thereof.

3. The method of claim 2, wherein the fungal agent is at least one of a Coriolaceae cellular organism and a mutant thereof.

4. The method of claim 3, wherein the fungal agent is at least one of a *Fusarium* species and a mutant thereof.

5. The method of claim 1, wherein the inoculating step occurs at a temperature of from about 15 to about 45°C, and a pH ranging from about pH 5 to about pH 10, wherein the feed material comprises from about 0.1 to about 5 oz/tonne gold, from about 0.3 to about 10 wt. % preg robbing carbon-containing component, and from about 0.1 to about 15 wt. % sulfidic sulfur, and further comprising:
   bio-oxidizing at least about 25% of the sulfidic sulfur in the feed material; and
   after and/or during inoculation, contacting the feed material with nutrients for the fungal agent, the nutrients comprising a carbon source and one or more inducers to enhance production by the fungal agent of one or more selected enzymes to cause passivation of the feed material.

6. A method, comprising:
   providing a refractory gold-containing feed material, the feed material comprising sulfidic sulfur;
   inoculating the feed material with a fungal agent to decompose at least some of the sulfidic sulfur, whereby at least a portion of the gold is released from a sulfidic matrix; and
   thereafter recovering the gold from the inoculated feed material.

7. The method of claim 6, wherein the fungal agent is at least one of white rot fungus and a mutant thereof.

8. The method of claim 7, wherein the feed material comprises a preg robbing carbon-containing component and wherein the fungal agent deactivates at least some of the preg robbing carbon-containing component.

9. The method of claim 8, wherein the inoculating step occurs at a temperature of from about 15 to about 45°C, and a pH ranging from about pH 5 to about pH 10, wherein the feed material comprises from about 0.1 to about 5 oz/tonne gold, from about 0.3 to about 10 wt. % preg robbing carbon-containing component, and from about 0.1 to about 15 wt. % sulfidic sulfur, wherein at least about 25 wt. % of the sulfidic sulfur is decomposed by the fungal agent and further comprising:
   after and/or during inoculation, contacting the feed material with nutrients for the fungal agent, the nutrients comprising a carbon source and one or more inducers to enhance production by the fungal agent of one or more selected enzymes to cause decomposition of the sulfidic sulfur.

10. The method of claim 9, wherein the nutrients comprise glucose, malt, and *Saccharomycetaceae*.

11. A method, comprising:
   providing a refractory gold-containing feed material, the feed material comprising sulfidic sulfur and a preg robbing carbon-containing component;
   contacting the feed material with a culture media, in the substantial absence of a microbe, to decompose at least some of the sulfidic sulfur, whereby at least a portion of the gold is released from a sulfidic matrix;
   thereafter inoculating the oxidized feed material with a microbial agent and the culture media to deactivate at least some of the preg robbing carbon containing component; and
   thereafter recovering the gold from the inoculated feed material.

12. The method of claim 11, wherein the microbial agent is selected from the group consisting essentially of white rot fungus, *Pseudomonas maltophilia*, *Pseudomonas oryzihabitans*, *Pseudomonas putida*, *Pseudomonas fluorescens*, *Pseudomonas stutzeri*, *Septomycetes setonii*, *Arthrobacter* species, *Achromobacter* species, and *Rhodococcus* species, and mutants and consortia thereof.

13. The method of claim 11, wherein the fungal agent deactivates at least some of the preg robbing carbon-containing component.

14. The method of claim 13, wherein the contacting step occurs at elevated temperature, wherein the inoculating step occurs at a temperature of from about 15 to about 45°C, wherein the contacting and inoculating steps occur at a pH ranging from about pH 5 to about pH 10, wherein the feed material comprises from about 0.1 to about 5 oz/tonne gold, from about 0.3 to about 10 wt. % preg robbing carbon-containing component, and from about 0.1 to about 15 wt. % sulfidic sulfur, wherein at least about 25 wt. % of the sulfidic sulfur is decomposed by the contacting step and wherein the culture media comprises a carbon source and one or more inducers to enhance production by the microbial agent of one or more selected enzymes to cause decomposition of the preg robbing carboxenous component.

15. The method of claim 11, wherein the culture media comprises glucose, malt, and *Saccharomycetaceae*. 
16. A method, comprising:
providing a refractory gold-containing feed material, the
feed material comprising a preg robbing carbon-con-
taining component;
inoculating the feed material with a fungal agent other than
a Phanerochaete cellular organism to deactivate the preg
robbing carbon-containing component, whereby at least
most of the preg robbing ability of the carbon-containing
component is deactivated; and
thereafter recovering the gold from the inoculated feed
material.
17. The method of claim 16, wherein the fungal agent is at
least one of a white rot fungus and mutant thereof.
18. The method of claim 17, wherein the fungal agent is at
least one of a Coriolaceae cellular organism and a mutant
thereof.
19. The method of claim 18, wherein the fungal agent is at
last one of a Trametes species and a mutant thereof.
20. The method of claim 16, wherein the inoculating step
occurs at a temperature of from about 15 to about 45°C. and
a pH ranging from about pH 5 to about pH 10, wherein the
feed material comprises from about 0.1 to about 5 oz/tonne
gold, from about 0.3 to about 10 wt.% preg robbing carbon-
containing component, and from about 0.1 to about 15 wt.%
sulfidic sulfur, and further comprising:
bio-oxidizing at least about 25% of the sulfidic sulfur in the
feed material; and
after and/or during inoculation, contacting the feed mate-
rial with nutrients for the fungal agent, the nutrients
comprising a carbon source and one or more inducers to
enhance production by the fungal agent of one or more
selected enzymes to cause passivation of the feed
material.