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Girard et al.

[11] **3,841,705**

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[54] **STIMULATION OF PRODUCTION WELL FOR IN SITU METAL MINING**

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[21] Appl. No.: **401,484**

[52] **U.S. Cl.** **299/4**, 166/247, 166/271

[51] **Int. Cl.** **E21b 43/28**

[58] **Field of Search** 299/4; 166/247, 271, 299

[56] **References Cited**

UNITED STATES PATENTS

3,278,233	10/1966	Hurd et al.	299/4
3,490,534	1/1970	Grady	166/271
3,542,131	11/1970	Walton et al.	166/299 X

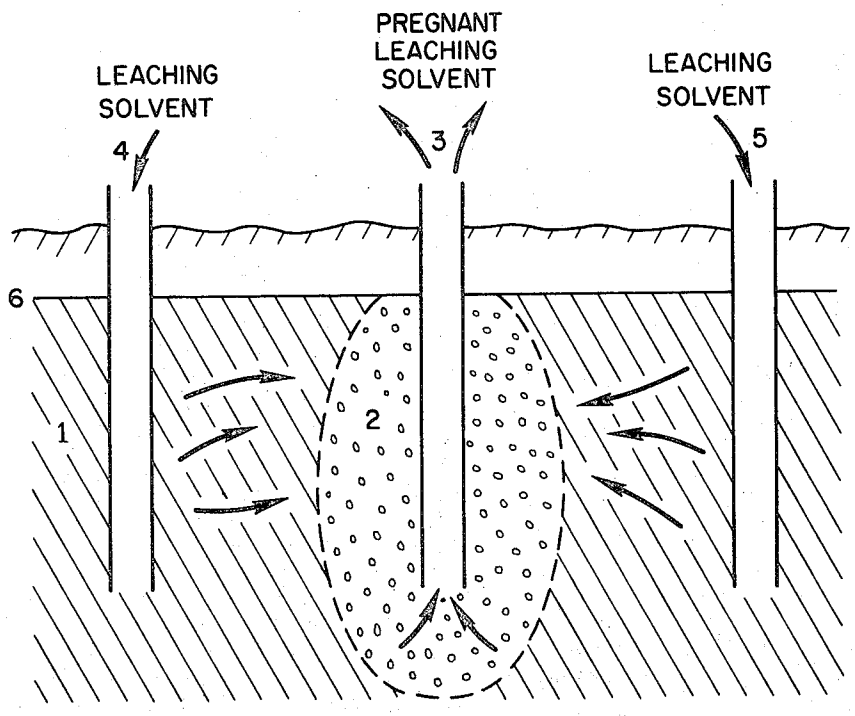
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[57] **ABSTRACT**

Metal values are economically leached in situ by rubblizing a portion of an ore body, injecting a lixiviant for the metal values through one or more injection wells in the ore body located adjacent to but outside the rubblized portion of the ore body, and collecting the lixiviant containing the dissolved metal values from one or more production wells located in a rubblized zone of the ore body.

10 Claims, 2 Drawing Figures



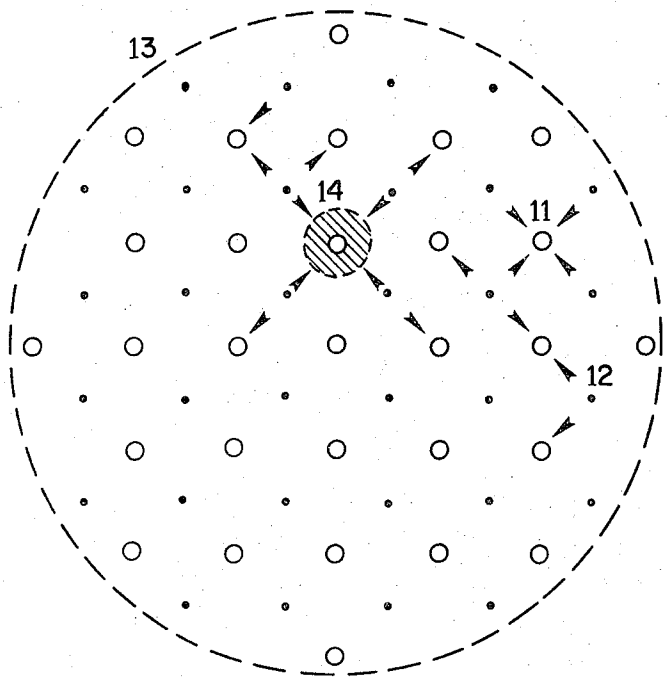


FIGURE 1

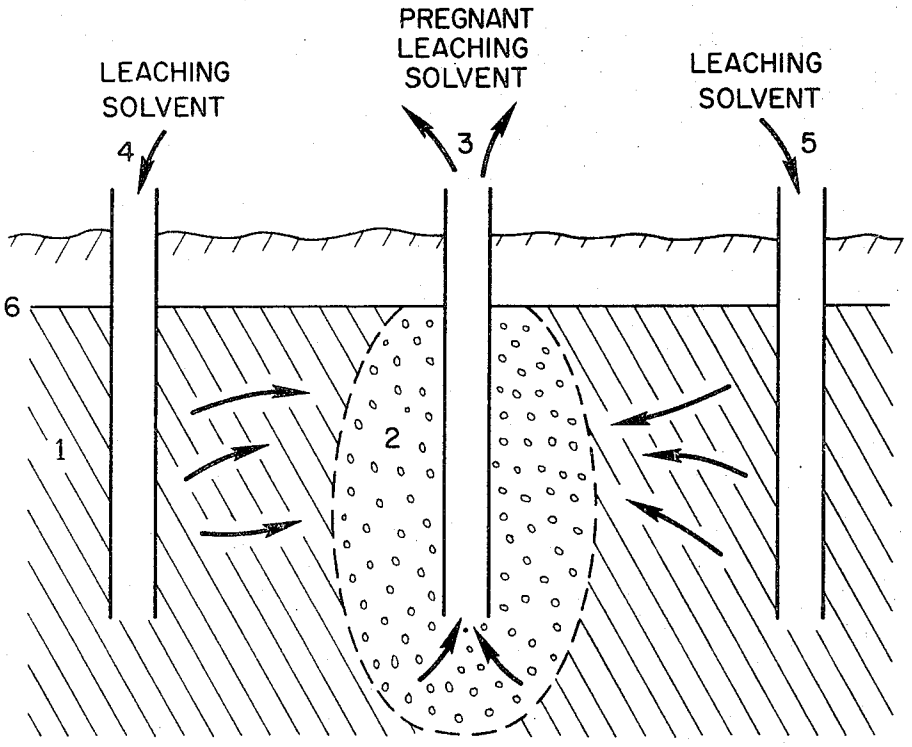


FIGURE 2

STIMULATION OF PRODUCTION WELL FOR IN SITU METAL MINING

FIELD OF INVENTION

In situ mining of valuable minerals has been explored as a means of economically recovering the metal values from low grade ores or otherwise inaccessible ore bodies. Recent work in the area has, in general, dealt with pumping of a leaching liquid or lixiviant into an ore formation, allowing sufficient residence time and removing the pregnant liquid from the formation. Many problems have surfaced with respect to the movement of fluids in the subsurface ore bodies and some investigation has been accomplished. U.S. Pat. Nos. 3,278,233 and 3,574,599 are cited as showing the present state of in situ leaching art.

Other recent investigatory work has been done in the area of nuclear explosive applications in forming lixiviation cavities in subsurface formations. Very recent art in this area, however, teaches the use of the explosive to create a closed system or series of closed systems in the ore body in which to introduce the lixiviant. Adelmann, Canadian Pat. No. 855,525 and Lewis, U.S. Pat. No. 3,640,579, demonstrate this use of the nuclear blast. This use of a closed system may well lead to efficient leaching within the rubblized zone but as Lewis indicates, the blast area is confined and, therefore, so is the leaching liquid. The quantity of ore which can be thus contacted and leached is thereby limited to the rubblized region. The present invention proposes to increase the volume of ore which can be contacted and leached effectively, without increasing the rubblized region.

SUMMARY

The invention is a process of in situ mining comprising the steps of rubblizing a portion of an ore body by detonating one or more strategically placed explosive devices to form a rubblized zone or chimney, injecting a leach solution into one or more injection wells, the injection well or wells being located in the ore body adjacent to but outside of the rubblized chimney, such that the leach solution will pass through the non-rubblized ore body removing the metal values therefrom and into the rubblized chimney, and recovering a pregnant leach solution from one or more production wells located within the rubblized zone or chimney.

In an alternate method an ore body is solution mined in-situ by first injecting a lixiviant into the ore formation under pressure through an array of injection wells. The pregnant solution is then recovered from the formation through one or more production wells that has been stimulated with a nuclear or chemical explosion subsequent to the injection of the leaching solution. The explosive charge causes rubblization in the area of the production well, but not in the immediate area of the injection wells, such that the rubblization reduces the resistance to lixiviant flow into the production well to the extent that the pregnant solution can be withdrawn from the production well nearly as fast as leaching liquid can be injected into the ore formation.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 shows one possible array for well placement, commonly known as the 5-spot pattern.

FIG. 2 shows the rubblization around the centrally located production well and the flow of leaching solvent from the distant injection wells into the rubblized zone.

DESCRIPTION OF INVENTION

In situ solution mining of a metal value requires injection of a leaching solution into the ore body, contact with the mineral containing the metal values to be extracted, and recovery of the pregnant solution from the ore formation. The problem to be overcome in the process is the restricted flow rates of leaching solution between the injection and the production wells, especially in igneous rock systems, due to the relatively low permeability of the igneous rocks. This restriction to fluid flow means that the leaching solution can be injected into the formation faster than it can be withdrawn.

The above situation is termed a production limited system because overall recovery of pregnant solution, and therefore recovery of leached metallic element, is dependent on how fast solution can be withdrawn from the production well. The present invention is an attempt to reach an injection limited system such that recovery of pregnant solution is limited by the amount of solution which can be injected into the formation. This situation would typically result in much greater productivity than the production limited system.

Referring now to FIG. 1, the ore body 13 is located and an array of injection wells 12 and production wells 11 are bored. The particular pattern shown in FIG. 1 is commonly known as a 5-spot pattern which allows the nearest neighbor of any injection well to be a production well and vice versa. It is within the scope of the invention described herein that any other desired pattern of wells may be used.

In a preferred embodiment all the production wells 11 will be rubblized with a chemical or nuclear explosive device to provide a rubblized zone 14 around each production well. The area of rubblization 14 indicates the relative extent of the blast area with respect to the placement of the injection wells. It will be noticed here, and in greater detail in FIG. 2, that there remains relatively undisturbed regions between the rubblized area and the injection well. The arrows around the rubblized area 14 indicate the direction of fluid flow from nearby injection wells. The injection wells may be between about 50 feet up to about 700 feet from the boundaries of the rubblized chimney area 14. The distance between production and injection wells will depend on permeability profile of the rock mass surrounding the chimney.

The rubblized area surrounding the production wells 11 creates a of lower permeability thus resulting in the flow of fluid from the high permeability igneous rock surrounding the injection wells 12 toward the production wells 11 rather than a fluid flow into other areas of the ore body where the fluid may be lost.

From FIG. 2 it can be seen that the rubblized zone 2, caused by the nuclear or chemical explosion, does not extend to the injection wells 4 and 5. However the nuclear chimney from the blast may extend upward from the ore formation 1 to a point above the water table 6. In this respect the invention relates to the recovery of metal values found in mineral formations located beneath the water table and, hence, the rubblized zone of the production well will be below the water table. This fact, in turn, means that the hydrostatic pressures be-

neath the water table contribute integrally to the flow properties of leaching solution into the production well.

If desired it is possible to have more than one explosive detonation. For example, rubblized chimneys of desired geometric configurations can be formed by strategically placing and detonating the explosives in proper sequence. See U.S. Pat. No. 3,470,953. Explosive reaction mixtures may be formed in concentric regions in the ore body around the wellbore by alternately injecting a propping agent and then an explosive reaction mixture. Upon detonation of the concentric regions of explosive reaction mixtures, the resulting fractures propagate both outwardly into the ore body and inwardly toward the wellbore so as to enhance the subsequent recovery of metal values from both the fractured areas and the areas between the injection well or wells and the centrally located production well. For further details, see U.S. Pat. No. 3,593,793.

The present invention of an in situ leaching process has particular application to copper ore deposits, for example chalcopyrite, chalcocite, covellite and bornite. However the process is not limited to recovering copper but can be used in recovering many other metallic elements from their ores. Of interest would be nickel, zinc, molybdenum, silver, gold and other valuable metals.

With respect to recovery of copper from primary sulfide deposits, the leaching solvent injected into the formation would typically be water, sulfuric acid, and ferrous sulfate, in various proportions, together with an oxidizing agent. The oxidizing agent is preferably an oxygen-bearing gas such as air, oxygen and any and all mixtures thereof. The oxygen-bearing gas may be introduced into the ore body prior to, during, or subsequent to the leaching solution. On contact with the leaching solution the copper is leached from the ore as a sulfate, and is later recovered from the solution by electrolysis, or in a precipitation process using de-tinned iron to replace the copper in solution.

More particularly, for instance, when a soluble substance such as copper is to be recovered from an ore, which contains either metallic copper or copper oxide in igneous rock, the present invention provides for very efficient in situ leaching by an appropriate acid or alkaline liquid extractant, such as aqueous sulfuric acid of moderate strength, e.g., acid containing 0.5 to 30 percent, and preferably 2 to 10 percent, H_2SO_4 by weight. Such sulfuric acid is pumped into the injection well in the copper ore in quantity sufficient to provide therein about 20 to 80 pounds H_2SO_4 per ton of ore to be treated when such ore contains between about 0.5 and 2 percent copper by weight. The pressures developed in pumping the leach solution into the ore body may vary over a wide range. Preferably the injection pressure will be below the formation fracture pressure. Recovery of copper from the formation by such leaching should be between about 40 and 85 percent or more, e.g. 70 percent somewhat depending on proportion and strength of acid used, permeability of the formation, concentration of copper therein, etc.

When the metal is in the ore as a sulfide, arsenide, telluride or a sulfo-salt, it can be recovered from such a sulfide-type ore either by converting it by in situ oxidation to the oxide by blowing air underground and then extracting the oxide as described above.

If nuclear stimulation of the production well is selected as the rubblizing agent, the nuclear explosives useable may range in yield from as little as **10** kiloton up to 2,000 kilotons, it being noted that the cost of such explosives is relatively independent of the energy yield. Consequently, the largest size device that can be employed at the given depth appropriate for a particular job is generally the most economical one.

The following examples illustrate the invention with reference to copper containing ore bodies. It is to be understood that this is done solely by way of example and is intended neither to delineate the scope of the invention nor limit the ambit of the appended claims, since the invention is applicable to the in situ recovery of other lixiviant soluble metal values from ore bodies.

EXAMPLE I

An embodiment of the invention as applied to the recovery of copper from a formation which contains copper oxide will next be described. The Copper ore deposit to be treated is a stratum 1,000 feet thick and has 2,000 feet of overburden above it. This stratum contains copper in a concentration of about 1 percent in igneous gangue.

At the beginning of the operation a 50 kiloton thermo-nuclear explosive is placed in the formation through a well at a depth of 3,200 feet. When the well is sealed and the device detonated, a chimney approximately 650 feet high is created above the shot point. It is estimated that the chimney will have a diameter of about 265 feet and contain about 2 million tons of rubble. If it is found that additional copper ore need be caved down, this may be produced by placing or detonating a further nuclear device in the formation.

Aqueous sulfuric acid having an H_2SO_4 content of about 5 weight per cent is then pumped into the injection wells located some distance outside the rubblized chimney. Sufficient volume of acid of proper strength should be introduced into the injection wells to allow for the ultimate consumption of about 40 pounds H_2SO_4 per ton of broken rock treated in the process. After the acid is introduced in the injection wells it will percolate through the ore body and take some copper oxide into solution, which will accumulate as a body of liquid in the lower part of the chimney.

After a period of time the accumulation of pregnant leach solution in the chimney cavity can be pumped out through the production well located in the chimney. The copper is then recovered from the pregnant leach solution by known methods.

EXAMPLE II

An ore body 100 acres in area and averaging 100 feet in thickness lies at an average depth of 3,000 feet below the surface of the earth. Samples of the ore shows that it is composed primarily of granitic igenous rock and that it contains chalcopyrite as the principle copper mineral. The ore samples also show that it contains approximately 1.4 weight percent chalcopyrite and that the total copper content of the ore averages 0.5 percent. The volume of ore in the deposit is, therefore, 10^4 acre-feet, or 4.356×10^8 cubic feet. The specific gravity of the granitic ore is 2.6. Therefore the total weight of the ore in the deposit is 3.54×10^7 tons, and the copper content of the ore body is 3.54×10^8 pounds.

Wells are drilled into the body in an array such that the well density is one per acre. Position of production wells is determined. Liquid slurry or nuclear explosives are strategically placed and detonated such that the injection well positions remain outside of the rubblized chimney area. By measurements on core samples and by injection and production tests on individual wells, it is determined that the void volume within the randomly oriented fracture system is equivalent to 2 percent of the bulk ore volume, that the fracture spacing averages 6 inches, and that the permeability of the ore body to liquid averages about 25 millidarcys.

Petrographic examination of core samples taken from the ore body shows that about 2 percent of the rock surface area exposed by the fractures is covered by the chalcopyrite mineral and that the rock matrix bounded by the fracture system is substantially cubical in configuration.

Thus the surface-to-volume ratio of the ore blocks bounded by the fractures is approximately equal to that for cubically shaped blocks, and the surface area to volume ratio for the ore blocks is equal to 6/L, where L is the length of the side of a cube. In this case L = 0.5 feet, and the surface area to volume ratio is equal to 12 square feet/cubic foot.

The total surface area of ore exposed by the fracture network is equal to $12 \times 4.356 \times 10^8$, or 5.227×10^9 square feet. The surface area of the chalcopyrite mineral exposed by the fracture system is equal to 2 percent of the total surface area, or 1.045×10^8 square feet.

Laboratory tests with the ore samples showed that ferric sulfate solutions will dissolve copper from the chalcopyrite of the ore body at a rate equal to 0.002 pound of copper per square foot of chalcopyrite surface area per day. The initial maximum rate of copper production attainable from the ore body by in situ leaching with ferric sulfate would be $0.002 \times 1.045 \times 10^8 = 209{,}000$ pounds of copper per day. The laboratory tests also showed that by allowing a 0.4 molar solution of ferric sulfate to react completely with the chalcopyrite, and other minerals in the ore, a pregnant leach solution containing 3.0 pounds of copper per barrel (42 gallons) could be obtained. Therefore in order to supply 0.4 molar ferric sulfate solution to the ore body at the optimum rate, i.e., at the rate sufficient to produce the maximum amount of copper and at the same time allow total reaction of the ferric iron, the 0.4 molar ferric sulfate solution must be injected initially at a rate of 69,700 barrels/day. The required average residence time for the solution within the ore body is fixed by the injection rate and the void volume of the ore body:

$$\text{Average Residence Time} = \text{void volume/injection rate}$$

$$= (0.02)\ (4.34 \times 10^8) \text{ cubic feet}/(69{,}700 \text{ bbl./day})\ (5.615 \text{ cu.ft./bbl.}) = 22.2 \text{ days}$$

The injection and withdrawal rates of the wells are thus regulated to permit the ferric sulfate solution to remain in the ore body for approximately 22 days.

This average residence time, or the average time required for the fluid to traverse the ore body between injection and production wells, must be increased as the chalcopyrite mineral is depleted and the surface area of chalcopyrite exposed to the leaching solution diminishes. Over the useful life of the in situ leaching operation, the optimum average residence time for the 0.4 molar ferric sulfate solution will be continuously increasing and may be substantially greater than the 22.2 days calculated as the optimum average residence time at the start of the operation.

In most cases, the injection and production rates should be approximately equal in order to minimize migration of fluids into or away from the ore body being subjected to the solution mining process. In this example if half of the wells are used as injection wells, and the other half of the wells are used as production wells, the average injection and production rates will be initially:

$$69{,}700 \text{ barrels/day}/50 \text{ wells} = 1{,}394 \text{ barrels/(day)(well)}$$

The injection and production rates at individual wells may be varied as necessary to maintain an approximate overall balance between total injection and total production, and to maintain the residence time required for essentially complete reaction of the ferric iron in the leaching solution with the ore minerals.

As noted above, it will be necessary to adjust the residence time of the leaching solution within the ore body to maintain the optimum residence time as the ore minerals are depleted. The need for such adjustment will be indicated by the appearance of ferric iron in increasing concentrations in the fluids produced from the production wells. When ferric iron is observed in the fluid produced from a production well, the rate of fluid withdrawal from that well should be adjusted until ferric iron is no longer found in the fluid produced from the well. The injection rates at nearby injection wells should then be correspondingly reduced to maintain an overall balance between injection and production. This operation should be repeated as necessary to maintain the optimum residence time for the leaching fluid.

We claim:

1. An improved process for recovering metal values by in-situ leaching an ore body located below the water table which comprises:
   a. forming a rubblized zone in an ore body whereby the rubblized zone contains fractured metal bearing ore particles;
   b. injecting a leach solution through one or more injection wells located in the ore body adjacent to but outside the rubblized zone, the leach solution solubilizing metal values in the ore body and in the rubblized zone; and
   c. recovering a metal containing leach solution through one or more production wells located in the rubblized zone.

2. The process of claim 1 wherein the rubblized zone is produced by detonating one or more strategically placed explosives in the ore body, said explosive selected from nuclear and chemical explosives.

3. The process of claim 1 wherein the one or more injection wells are located between at least about 50 feet and up to about 700 feet from the one or more production wells.

4. The process of claim 1 wherein the ore body contains a copper bearing ore.

5. The process of claim 4 wherein the leach solution is injected through the one or more injection wells at a pressure less than the formation fracture pressure.

6. The process of claim 5 wherein the leach solution contains a dispersion of an oxygen bearing gas.

7. The method of leaching a metal bearing ore in place which comprises:

a. injecting a leach solution at a pressure below the formation fracturing pressure through at least one injection well located in a non-rubblized zone of a metal bearing ore body located below the water table;

b. allowing the leach solution to remain in the ore body to solubilize metallic ions present in the ore body, and

c. recovering metallic ion containing leach solution from at least one production well located in a rubblized zone in the ore body.

8. The process of claim 7 wherein the ore body contains copper bearing ore.

9. The process of claim 8 wherein the leach solution is aqueous sulfuric acid containing an oxygen bearing gas.

10. The process of claim 9 wherein at least one injection well is located between about 50 feet and about 700 feet from at least one production well.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,841,705 Dated October 15, 1974

Inventor(s) Lucien Girard et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 53, "a of lower" should read -- a zone of higher --; line 54, "high" should read -- low --. Column 4, line 57, "shows" should read -- show --; line 58, "igenous" should read -- igneous --

Signed and sealed this 18th day of February 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

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Notice of Adverse Decision in Interference

In Interference No. 99,293, involving Patent No. 3,841,705, L. Girard and R. A. Hard, STIMULATION OF PRODUCTION WELL FOR IN SITU METAL MINING, final judgment adverse to the patentees was rendered Jan. 10, 1980, as to Claims 1, 2, 4–9.

[*Official Gazette, April 29, 1980.*]