Developments in gold recovery equipment and their use in Greece

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ABSTRACT

Gravity separation techniques were used in the early years to extract native metal nuggets and flakes from placer gold deposits. This was relatively easy for visible metal grains. As the size of the grain becomes smaller traditional gravity separation techniques become inadequate to recover native gold. Cyanidation was invented as a solution to the problem. According to it, gold and other precious metals are dissolved in water by sodium cyanide. The result was a drastic increase of world gold production but at the same time environmental issues were raised. In Greece gold mining has become equivalent with the absolute destruction of the environment and is under extinction.

In the last years a new type of gravity equipment have been produced which create a gravitational field up to 200 G and can separate gold from gangue minerals at sizes below 50 μm. The strong gravitational field is created by centrifugal forces and the separation occurs in a fluidized bed, formed by water flow.

Accumulations of finely disseminated native gold are found in the sedimentary sequence of the Flysch of the Ionian Zone. The main gold minerals are gold and electrum present as free metal flakes and micro nuggets in the size range between 5-250 μm. Test work, using the Falcon SB40 centrifugal concentrator, at the Department of Mineral Resources Engineering at the Technical University of Crete, has shown that this particular type of gold ore can be processed by gravitational methods that require no reagents and are environmentally safe.

1. INTRODUCTION

Gold is a precious metal and has contributed to the artistic, cultural and economic development of mankind. It was probably the first metal used by humans because of its occurrence as a free metal in placer deposits, enabling its recovery without the requirement of complex separation techniques. The form in which gold exists in ore deposits implies the techniques to be used for its recovery.

Gravity separation techniques were used in the beginning to extract native metal nuggets and flakes. This was relatively easy for visible metal grains. As the size of the grain becomes smaller traditional gravity separation techniques become inadequate to recover native gold. Cyanidation was invented as a solution to the problem. According to it, gold and other precious metals are dissolved in water by sodium cyanide, separated from the remaining solids and recovered from the water solution in a concentrated form

In our days there is a strong opposition from different social groups against the use of sodium cyanide for the recovery of gold (Shawh and Constandinidis, 2001). New developments in gravity separation technology can allow the recovery of very fine free gold particles in sizes that were not possible by traditional machines. This is due to the creation of a fluidized bed under strong gravity field of the order of 200 G (gravity) caused by centrifugal forces. Fine gold can now be recovered from placer deposits.

The aim of this study is to examine the possibility to recover gold from rock samples of Western Greece, where there are indications for the existence of free fine gold. This is achieved by the use of gravity separation machines, which create centrifugal forces. The results of this test work show that this environmentally friendly technique can compete with cyanidation and give acceptable gold recoveries.

2. GRAVITY SEPARATION PARAMETERS

Gravity separation was the primary method to recover gold from placer sedimentary deposits. Its application is based on the different terminal velocities that heavy gold particles can achieve compared with light gangue minerals. For equi-dimensional particles the difference in settling velocity is due to their specific gravity, which for gold is 19.3 while for the majority of gangue minerals is of the order of 2.7. However, regardless of specific gravity the settling velocity is also affected by the particle size.

Assuming that the flow of particles in water is governed by Stokes' law (Stamboliadis, 2003), one can calculate the terminal velocity of quartz and gold particles as a function of their size.

$$u_t = \frac{(\rho_s - \rho_w) \cdot \gamma \cdot x^2}{18 \cdot n} \quad (1)$$

where:

u_t: terminal velocity (m/sec)
ρ_s: density of the solid (kg/m^3)
ρ_w: density of water (1000 kg/m^3)
γ: acceleration of gravity (m/sec^2)
n: viscosity of water (0.001 N.sec/m^2)
x: size of the particle (m).

The results, for gold and quartz particles, are plotted in Figure 1, together with the difference between the two materials for γ =g =9.81 m/esc^2 It is obvious, that below 100 μm the difference in terminal velocity is negligible and the differentiation by gravity is practically very difficult.

However, since the terminal velocity of a particle, in water, depends also on the acceleration of gravity one could affect the result by varying this acceleration.

The effect that such an action has on the terminal velocity difference between gold and gangue particles is shown on Figure 2. The acceleration G used in this figure is the relative

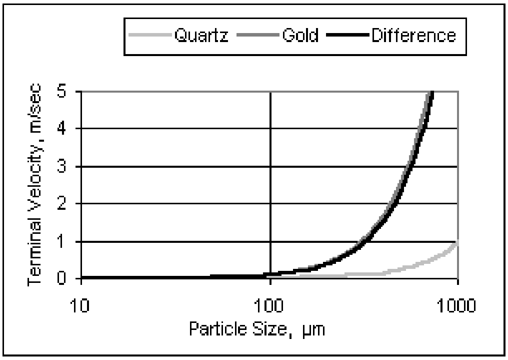

Figure 1: Effect of size

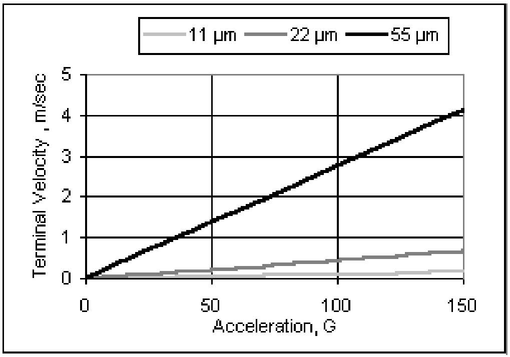

Figure 2: Effect of Gravity.

one G=γ/g. One can see that the difference in terminal velocity increases proportionally with the acceleration

Traditional equipment used for gravity separation operates under conditions of the earth gravity acceleration 1 G.

New technological developments have produce separation equipment that create gravitational fields, which are multiples of earth gravity acceleration (McAlister and Armstrong, 1998).

The principle of operation of such equipment is shown in Figure 3. The separation vessel consists of a bowl, which rotates around a vertical axis. The pulp is fed at the center and due to centrifugal forces it flows to the top of the bowl where a series of riffles are provided.

The material "drops" into the riffles, where there is a back flow of pressurized water that keeps the material in the riffles in the form of a fluidized bed.

Due to the fluidized bed action in the riffles

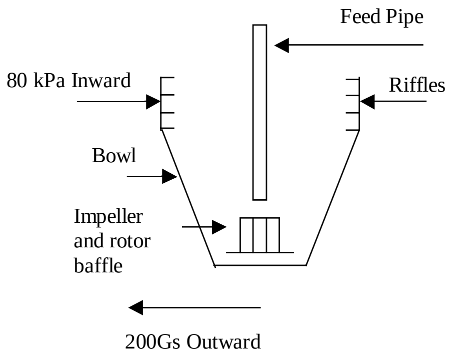

Figure 3: Centrifugal equipment outline

the heavy gold particles go deeper into it while the lighter gangue particles overflow to the top of the bowl where they exit (Sprake, 1998).

The gravitational forces, which are created, can be calculated as a function of the rotation frequency N (rpm) for a bowl of given diameter D (m). The peripheral velocity v of the bowl is given by:

$$v = \pi \cdot D \cdot N/60 \text{ , m/sec} \quad (2)$$

The acceleration γ, which can be achieved, is calculated by

$$\gamma = 2.v^2/D \text{ , m/sec}^2 \quad (3)$$

The graphical representation of (3) is given on Figure 4 for a laboratory size unit, again the relative acceleration G is used and D= 0.10 m

3. GEOLOGICAL INDICATIONS FOR FREE GOLD

Systematic investigations within the sedimentary rocks of the Ionean zone (Western mainland of Greece) showed, for the fist time, the presence of placer gold minerals, mainly native gold and electrum, which are concentrated together with other heavy minerals into placers (Pantelaki, 2001). The Western mainland of Greece is situated in the External Hellenides. Geologically this area includes the Ionian Zone, which on its stratigraphic top has a thick exposed sedimentary sequence, mainly composed of monotonous clays, marls, sandy marls and conglomerates, called West Hellenic flysch (I.F.P./I.G.S.R., 1966) The flysch

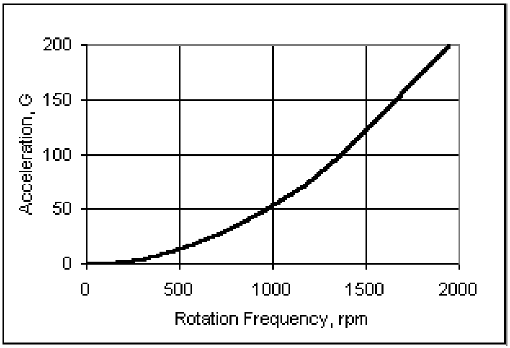

Figure 4: The effect of rotation.

sediments are the products of the uplift and subsequent erosion of the cordillera situated to the east of the Ionian Zone. The size of the gold grains (in form of flakes and micro-nuggets) ranges between 5-250 μm.

4. PROCESSING OF SEDIMENTARY GOLD

For native gold gravity concentration is used to preconcentrate the ore followed by cyanidation. For very fine gold, which cannot be recovered by gravity concentration, cyanidation is the only method used. The traditional gravity equipment used to recover relatively coarse gold are jigs, cones, spiral classifiers, shaking tables and shutes (Wills, 1988).

Run of mine ore is wet ground for better gold liberation. The coarse fraction is usually treated by gravity concentration to recover any liberated gold while the fine fraction is pumped to cyanidation (Yannopoulos, 1990). Sodium cyanide is added to the pulp at a concentration about 400-ppm and pH 10.5-11.0, adjusted by calcium hydroxide. The pulp is agitated for at least 24h in the presence of active carbon. Cyanide dissolves gold and forms soluble complexes, which are adsorbed by the active carbon. The loaded carbon is screened from the finely ground ore and is processed to recover gold. The barren pulp is treated to destroy the remaining cyanide and then is rejected into the tailings pond where the solids settle and the water is recycled into the process. The main processes used to destroy cyanide are the alkaline chlorination, oxidation by sulfur dioxide, (INCO process), oxidation by hydrogen peroxide (DEGUSSA process) and biological degradation. Regardless of the cyanide destruction, cyanidation tailings disposal arises a lot of protest and gold processing is under severe environmental terms, which increase the cost of production and some times do not allow the erection of new plants.

5. NEW DEVELOPMENTS IN GOLD RECOVERY EQUIPMENT

For native gold deposits gravity concentration by traditional techniques is restricted to sizes above 50 μm. At smaller sizes the drug force by water overcomes the difference in specific gravity between gold and the gangue minerals and separation is not effective. In the last years a new type of gravity equipment have been produced which create a gravitational field up to 200 G and can separate gold from gangue minerals at sizes below 50 μm. The strong gravitational field is created by centrifugal forces and the separation occurs is a fluidized bed formed by water flow. The specific equipment can handle large throughputs of ore because the quantity of the heavy fraction produced is very small in volume compared to the volume of light gangue mineral fraction. Experimental results of samples from the West Greece flysch treated by such equipment are presented bellow.

6. TEST WORK

6.1 Sample Preparation

Two different combined samples, A and B, were formed out of about 60 collected from the flysch sediments of the Ionian Zone in Western Greece. Each sample was broken to –4 mm using a laboratory jaw crusher. The –4 mm product was further ground to –1 mm using a rotating disk mill. At this size the liberation of gold is expected to be satisfactory. The ground product was divided in two fractions by screening at 0.250 mm. The fine –0.250 mm fraction was washed with water and classified at 10 μm by the use of a hydrocyclone.

6.2 Gravity Separation

The equipment used for gravity separation tests was a centrifugal Falcon concentrator model SB40. The objective of these tests was to concentrate the gold that was contained in the samples.

Three tests were made with the following samples:

- Test 1: Sample A fraction 10-250 μm.
- Test 2: Sample B fraction 250-1000 μm.
- Test 3: Sample B fraction 10-250 μm.

The operating conditions of gravity separation (Pantelaki, 2001) on each of the three tests, as well as the recovery of weight for the corresponding separations appear in Table 1.

The separation products, heavy concentrate and light gangue, were weighted and assayed for gold. The heavy fraction was also examined by optical microscopy in order to determine the free gold.

6.3 Cyanidation

For comparison purposes cyanidation tests were also performed using the two size fractions of sample B. The operating conditions were the same for both cyanidation tests and the technique was the one of rolling bottle. The pulp contained 1 kg of sample, 3 lt of water and the following reagents were added:

- 7,5 g $Ca(OH)2$ for the adjustment of pH in the desirable level, (pH 11),
- 4,5 g NaCN, that corresponds to concent-ration 1500 ppm NaCN in the leaching solution or 4,5 kg NaCN per ton of ore.
- 50 g active carbon (+ 1.7 mm), for the adsorption of the dissolved gold.

The pulp was placed in a cylindrical bottle and was rolled for 48 hours. At the end of the reaction period the pulp was screened at 1.00

Table 1: Separation conditions

	Test 1 Sample A 10-250 μm	Test 2 Sample B 250-1000 μm	Test 3 Sample B 10-250 μm
Rotation frequency	35 Hz	30 Hz	35 Hz
Water pressure	6 psi	8 psi	6 psi
Feeding rate	6.33 kg/h	11.04 kg/h	7.50 kg/h
Water flow	2.0 l/min	1.8 l/min	2.0 l/min
Pulp density	5.0 %	9.3 %	5.9 %
Weight recovery	1.52 %	1.99 %	0.51 %

Table 2: Test Work Results

Sample	Gravity Separation					Cyanidation	
	Product	Weight %	Gold Assay g/ton	Gold Distri-bution %	Degree of Concent-ration	Product	Gold Distri-bution %
Sample A 10-250 μm	Concentrate	1.52	6.43	70.71	45.9	Active carbon	-
	Tailings	98.48	0.04	29.29		Tailings	-
	Total	100.00	0.14	100.00		Total	-
Sample B 250-1000 μm	Concentrate	1.99	906.90	71.75	36.1	Active carbon	91.2
	Tailings	98.01	7.25	28.25		Tailings	8.8
	Total	100.00	25.15	100.00		Total	100.00
Sample B 10-250 μm	Concentrate	0.51	7,847.3	82.76	162.3	Active carbon	99.74
	Tailings	99.49	8.38	17.24		Tailings	0.26
	Total	100.00	48.36	100.00		Total	100.00

mm, to remove the active carbon that was assayed for gold and the remaining pulp was sampled and rejected.

6.4 Fire Assay

The products from gravity separation and cyanidation were assayed using the fire assay technique. According to this method a certain quantity of the sample to be assayed, 30g from mineral samples and 1g from active carbon samples, were mixed with the appropriate quantities of Na_2CO_3, PbO, $CaCO_3$, SiO_2 and $Na_2O.2B_2O_3.10H_2O$ and were fired at about 950^oC to obtain the gold nugget. This nugget was consequently dissolved in aqua regia and assayed for gold by atomic absorption spectrometry.

6.5 Results

Using the assays of the products and the weights from the separation tests one can calculate the recoveries (distribution of gold) and the mass balance of each test, which is presented in Table 2. The degree of concentration for gravity concentration is calculated as the ratio of the gold assay in the concentrate to the assay in the feed. No cyanidation test was made for the sample A, 10-250 μm. The comparison of gold recovery obtained by the two methods is made between the distribution of gold in the concentrate of the gravity separation and the active carbon of the cyanidation. From the results obtained by gravity concentration and the optical microscopy observations it is obvious that better results can be obtained by finer grinding. However optimization of the process is beyond the scope of the present work.

7. CONCLUSIONS

Based on the above test work the following conclusions can be made:

- The gold present in the flysch of West Greece is in the form of native metal and can be recovered by high gravity equipment.
- The degree of concentration obtained by gravity separation is very high.
- The results of table 2 suggest that although concentration of gold can be obtained at relatively large sizes (0.25-1.00 mm) the recovery is better at lower sizes. The optimum size of grinding must be determined by further research work. Optical microscopy has shown that gold nuggets are smaller in size than the associated gangue minerals.
- The concentrate grade obtained by gravity separation can be possibly increased after regrinding and second pass.
- Pilot plan size test work is required to optimize the process and evaluate the results.
- Although cyanidation gives relatively better metallurgical recoveries the advantage of the

gravity separation is surpassing because it eliminates environmental concerns.

- The recovery of gold obtained by gravity separation is comparable with the one obtained by cyanidation. This means that gravity separation can replace cyanidation without an appreciable metal loss.

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