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Processing of discard tailings and non-conventional raw materials using efficient upgrading processes

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ABSTRACT

At Russian alluvial deposits, precious metals are normally recovered with the aid of simple ore dressing units, such as washing sluices. Particles of precious metals with a size of less than 100 μm are not recovered by this method. Centrifugal apparatus and processing technology have been developed for recovery of fine and ultrafine particles of precious metals ensuring recoveries of up to 90-97% and producing a product containing 1-2% Au. This technology is environmentally sound and does not impose any negative impact on the ambient environment. The tailings generated by a DM-250 dredge have a gold content from 0.5 to 1.5 g/t, of which about 85% has a particle size of less than 50 μm. The use of proposed centrifugal equipment at an alluvial operation for processing of dredge tailings made it possible to produce concentrate with a gold content of 1.1 kg/ton with a gold recovery of 92.7%.

Key words : *Precious metals, Tailings, Centrifugal separators.*

INTRODUCTION

An immense resource for production of precious metals is processing of stockpiled tailings generated by mineral processing plants. This material has been already subjected to the most expensive processes of mining, crushing and grinding.

The recent changes in the structure of gold mines and less strict technological control have aggravated the situation of the gold mining industry, because the current increase in the volumes of material handled and processed occurs without adequate analysis of gold recovery levels and there is a trend towards using simplified ore upgrading techniques and less intricate equipment. Currently, most of dredges and washing plants use prehistoric sluice boxes with hard collecting coating which results in substantial losses of gold in fine size fractions.

We have studied tailings ponds of many gold mills in Bashkiria, South Urals, Rudny Altai, Krasnoyarsk Region, Khakasia, Chukotka, Kolyma, Central Kazakhstan, Uzbekistan, and Tadzhikistan. The gold content in tailings varies from 0.2 to 3 g/t and higher and in terms of quantities makes up hundreds of tonnes. The prevailing part of loss of precious metals occurs in fine size fractions, i.e., -44 μm (over 50%). These size fractions often have a gold content 5 to 6 times higher than in coarse fractions and 1.5 to 3 times higher than in initial tailings, which indicates that the upgrading of fine gold particles is rather inefficient. The difficulty of their recovery is attributed primarily to lower weight of particles and their larger specific surface area. Gold-containing raw materials are most commonly processed using environmentally safe gravity concentration processes. There is a large number of various gravity concentration equipment, such as heavy-media separators, jigs, cone and spiral concentrators, shaking tables, sluice boxes, Reichert cones, Bartles-Mosly separators, Bartles-crossbelt concentrators, etc.

The above types of gravity concentration units work with accelerations only insignificantly exceeding the free-fall acceleration. As a result the finer the particles to be separated, the less is the chance to separate them. Gravity concentration processes using the normal gravity forces are not able to separate fine particles with a size of -20 μm.

With an increase in the force applied to particles of different densities due to centrifugal forces, the separation efficiency improves in a proportional manner (the so called separation factor, F_p).

In gravity concentration units using the gravity force, F_p is equal to unity, while in centrifugal apparatus F_p increases by a factor of several tens. We will not discuss the designs of centrifugal equipment here, because they are rather well known. Below we will describe the specific features of our concentrator in comparison with analogous conventional units[1].

Tests aimed at development of a technology for processing of discard tailings using centrifugal equipment have been run at many mines in Russia, Kazakhstan, Uzbekistan and Tadzhikistan.

RESULTS

Processing of Stockpiled Tailings of An Amalgamation Plant at a Gold Mine in Kolyma

Table 1 presents some of the performance parameters processing of tailings using flotation and centrifugal separation techniques.

Table 1 : Results on processing of tailings by flotation and centrifugal separator

Description of products	Yield, %	Gold content g/t	Gold recovery %	Upgrading conditions
		Flotation		
Recleaner concentrate	1.01	95.0	52.7	Grinding to 60% µ74
Recleaner middling	4.22	4.6	10.8	Flotation:
Flotation tailings	94.77	0.7	36.5	Kx - 50 g/t
Feed material	100.0	1.82	100.0	T 80 - 60 g/t
		Centrifugal separation		
Recleaner concentrate	1.0	120.0	63.1	Without re-grinding
Recleaner middling	3.02	4.2	6.6	
Separation tailings	95,98	0.6	30.3	
Feed material	100.0	1.9	100.0	

Centrifugal separation of stockpiled tailings of the amalgamation plant ensures, without regrinding, recovery of 63% of gold into a concentrate containing 120 g/t gold, whereas regrinding is required for flotation and it produces a concentrate with 95 g/t gold with a recovery of only 52%, which is much below the performance values of the centrifugal separation process.

Upgrading of Tailings at the Semyonovskaya Gold Mill (Bashkiria)

At the Semyonovskaya gold mill, the feed ore is treated using cyanide technology. Discard tailings with a size of 55% -74 µm contain 1.2-1.8 g/t gold in the form of free grains and intergrowths with iron sulfides and host rock [1].

Tailings from the dump located near the mill were re-slurried and fed to a centrifugal concentrator with a bowl diameter of 500 mm. In the process of long tests using centrifugal separation without regrinding a product was produced containing 50 to 70 g/t gold with an average recovery of 50% (the initial gold content of tailings was 1.5 g/t). The productivity of the concentrator was 11 t/hr of solids or up to 35 m^3/hr.

Treatment of Tailings from Artyom Mill (AO "Yuzhuralzoloto")

The size fraction of the tailings is 50% -74 µm, with the gold content from 1 to 2.5 g/t depending on the area. Gold is in the form of intergrowths with rock and sulfides, as well as unleached free gold. The process of tailings re-grinding does not improve the separation results to any appreciable extent. The concentrate produced contained 28-34 g/t gold and the recovery was about 68%. It has been found that in order to efficiently treat the material by cyanidization technique it is necessary to regrind the concentrate to achieve gold recoveries into the solution of more than 85% (it is only 73% without regrinding).

Treatment of Tailings at the ArtyomOvskaya Gold Mill (Krasnoyarsk Region)

Gold in tailings samples analyzed was in the form of fine grains represented both by free gold and associated with sulfides (mainly iron sulfides). Grains larger than 0.1 mm account for about 15-20%, the rest of gold varies in size from 2 to 100 μm.

The tests conducted have indicated that it is advisable to regrind the tailings to 65% -74 μm. A series of experiments using centrifugal separation was carried out with tailings from different zones of the tailings dumps located along the Olkhovka river and having different gold contents, in g/t: 1.5, 2.5, and 6.6. As a result concentrates were produced with the following gold contents, in g/t: 32.0, 48.5 and 70, respectively, and the following recoveries achieved, in %: 61, 71, and 87[1].

At the Artyomovskaya gold mill the required circuits are available for cyanidization and gold precipitation on zinc, which can be used for processing of concentrates produced from tailings.

Processing of Secondary Raw Materials Containing Platinum Group Metals, Gold and Silver

Waste products of refineries, such as furnace breakage, smelting slag, recyclable slag, broken crucibles, etc. were processed by centrifugal separation. The concentrate produced with a yield of about 10% was subjected to thorough treatment using the technology developed in the Gintsvetmet Institute to produce precious metals with contents of 98-99% of the respective main constituent.

For example, furnace breakage containing 0.4% Au, 1.2% Ag, 0.6% Pt, and 0.3% Pd, was treated to produce underflow containing 4.1% Au, 5.0% Ag, 6.3% Pt, and 2.1% Pd. The recoveries of the above precious metals was 94.9, 56.8, 82.8 and 70.4%, respectively. Re-cleaner separation of underflow from the main separation upgraded the gold content up to 23%. Similar results were obtained when treating broken crucibles. The concentration degree of metals was 15-17 with the following recoveries: 92.6% Au, 98% Pt, and 74.5% Pd. Centrifugal separation of the above wastes of precious metals refineries reduces their total amounts by tens of times and more with high recoveries and contents of precious metals in concentrates produced. As a consequence, the expenses for their final treatment to produce fine metals are accordingly reduced.

Processing of Discard Tailings at the Norilsk Ore Processing Plant

In 1988-1989 commercial-scale tests of a centrifugal separators with 500 mm diameter were carried out to process discard tailings at Section IV of the Norilsk ore processing plant. This was a prototype of the separator manufactured at the Ryazan experimental plant of the Gintsvetmet Institute. Despite some drawbacks revealed in the process of the tests, the separator achieved rather satisfactory results: the platinum, palladium, rhodium, gold and silver contents in the underflow was as high as 100 g/t, 18 g/t, 0.17 g/t, 10 g/t, and 70 g/t, respectively.

Gold Recovery at Gravel Crushing and Sorting Plants

It is of acute interest to produce gold as a by-product from sand and gravel deposits in the process of sand, crushed stone and gravel production (in gold-bearing regions). Such materials occur in various areas in Stavropol, Ivanovo, Kostroma, and Moscow regions, along the valley of the Chirchik river in Uzbekistan, etc. They have a low gold content (about 100 mg/m^3; in some specific areas up to 700 mg/m^3), fine grain size (85% -25 µm), and the presence of so called "floating" gold. In general, this material is produced when washing gravel to remove clay. Normally it is discharged into a dump and is of special interest from the viewpoint of gold recovery. Positive results are obtained when using centrifugal concentrators; other gravity concentration techniques are not suitable. Final concentration of sands is effected using flotation and the "gold pot". In one of the gravel quarries in the Ivanovo region, the gold content of concentrate was 20 kg/t; it was further processed to obtain heavy concentrate.

DISCUSSION

Some Issues Relating to the Design of Centrifugal Separators and Their Cost

According to the information published in the Tsvetnye Metally Journal, 1998, No.10-11, the Norilsk mine had purchased five Knelson separators with 48" bowls at the 1997 price of $ 135,000 each, as well as 20" and 12" separators at $84,000 and $53,000, respectively. The tests of these separators indicated that it was reasonable to use these separators for gold recovery at the head of the process from the product of the first-stage ore grinding to produce rough concentrate to be sent to the smelting process.

The issue whether it is reasonable to recover precious metals at the head of the process is disputable and requires further comparative investigations.

It is planned to increase the number of operating concentrators. The cost of the purchased units exceeded US $1 million which is affordable only for such a large mining company as the Norilsk Mining and Metallurgical Complex.

One of the main advantages of the Knelson separators, in addition to their mechanical reliability and high level of automation, is the use of a fluidized bed process ensuring additional upgrading of the feed material in the riffles increasing thereby the duration of a washing cycle to 1-2 hours. The question is whether it is always needed?

The research conducted to determine the distribution of gold by the levels of riffles and throughout their depth have shown a significant difference (up to 6 times) in the gold content in different zones. A unit has been tested which generates hydraulic pulses in the corresponding zones of the working member resulting in a substantial increase in the grade of sands collected in the riffles without any special modifications of the design.

In a Knelson separator, water from the fluidized bed is injected tangentially through special openings in the bowl at the internal side of the product located within rings in the direction opposite to the rotor rotation direction. The positive effect of this solution is obvious. However, this results in a significantly more complicated apparatus design and requires treatment of the injected water in filters.

Our patented design implies special manifolds located inside a bowl and loosening the sand in riffles. It ensures simple design of the concentrator providing the same effect that is obtained in a Knelson separator, but the cost of such a unit is lower by several times[2].

There are some well known examples when the purchase of an expensive Knelson concentrator had no sense and did not justify the expenses. For example, a gold mining artel operating in the Magadan region used a 48" Knelson separator (the price see above) during an entire mining season to treat sluice tailings with gold contents of about 2.4 g/t with prevailing gold combined with sulfides (more than 90%).

The time of concentrate removal cycle was set at 2 hours. As a result, the bulk of gold bound by sulfides was discharged with tailings. The gold production during the operating season did not pay for all the expenses, the major part of which was for the purchase of this equipment.

All this indicates that it is necessary to reasonably justify the use of centrifugal units of different designs and modifications with due consideration of technological and economic aspects, site-specific conditions and material treated.

Currently, the most common centrifugal separators are manufactured by the Knelson company. The widely advertised Falcon concentrator (Canada) has a smooth rotor surface and continuous discharge of the heavy fraction. A specific feature of the Orocon concentrator (Australia) is the availability of devices for loosening sands designed in the form of steel bars fixed horizontally on unmovable brackets.

Out of the Russian-made equipment it is worthwhile to mention a finishing centrifugal separator of RS-400 type with a complex bowl movement pattern. An interesting development is a low-rate separator manufactured by TulNIIGPe Institute with centrifugal bowl and fine riffles which operate in combination with UORZ concentrating plants.

Another centrifugal separator design is offered by NPO ITOMAK (Novosibirsk). ZAO Redtsvetmet has developed and produces at the Tula Rifle Factory centrifugal separators of different sizes. Some apparatus designs are also produced by other industrial facilities.

It should be pointed out that recovery of ultrafine precious metals is of a very significant importance for the industry which arouses a sharp interest for centrifugal separators. Despite the continuing stagnant economic situation and the unreasonable industrial policy pursued by the government it is necessary to organize production of centrifugal separators in Russia which would be not inferior to imported equipment. It appears to be wise to centralize their manufacture using advantages of individual assemblies produced by different manufacturers. At least some of the hard-currency expenses spent currently for imported units should be used for establishing domestic production of similar equipment. By the way, this alternative was proposed in the past by the Norilsk Complex after the tests of our separators.

Prototypes of concentrators of new generation should be tested using materials from different mines to prove their mechanical and technological reliability. After successful completion of such tests it is necessary to organize their commercial production. The cost of such apparatus would be lower by 5 or more times as compared with Knelson concentrators.

Our estimates made for the mines where we had tested our centrifugal separators using available floor areas, electric power and utilities supply (i.e. the minimum required expenses) indicate that it would be possible to produce 1,100 kg of gold per year.

Processing of Heavy Concentrates Produced by DM-250 Dredges

The technology used for upgrading alluvial material at dredges manufactured by the Irkutsk heavy machine-building factory with 250-litre buckets comprises classification of feed material in a sizing trommel into different size fractions: +40mm fraction discharged into a dump; -40+20mm fraction sent to a nugget recovery unit, and -20mm fraction upgraded in sluice boxes. An analysis of sluice tailings indicated the presence of ultrafine gold (so called "floating" gold) with contents of 0.7 to 1.5 g/t and a size of up to 10 µm. The present processing technology does not ensure recovery of such fine gold.

Tests were run with a centrifugal concentrator of CK-300 type installed directly in the stream of sluice tailings on a dredge having a capacity of up to 300 t/hr. Prior to this process, the pulp was classified to a 3 mm size fraction, the bulk of gold was contained in the -0.1mm size fraction (90%). The concentrate produced contained 100 to 600 g/t gold; after re-cleaner separation the gold content was 1,000-1,500 g/t with a recovery of 80-90%.

It has been demonstrated that it is feasible to recover fine gold with the aid of centrifugal concentrators from dredge tailings.

Processing of Discard Tailings in the Process of Hydraulic Transport

The authors have developed a technique for removal of upgraded portion of tailings from a tailings pipeline in the process of slurry handling directly at processing plants. This technique is based on segregation and gravitational effects in the process of transportation of polymineral slurry in pipelines. This makes it possible to remove an upgraded portion of tailings without any substantial additional capital and operating expenses (pumps, pipelines, hydrocyclones, etc.). This technology has been patented in Russia and Uzbekistan[3].

When transporting slurries the fluid phase flows around solid particles which results in frontal drag and hydrodynamic lift forces. The average flow rate of slurry stream at which the hydraulic resistance forces are virtually equal to hydraulic resistance forces of water stream in the pipeline is called critical. At such a flow rate, mineral particles move in a suspended condition and due to the heterogeneity of the solid phase (different particle sizes and density) the lower layers of the stream become enriched with courser and heavier particles. At flow rates below the critical rate, the solid component of the slurry is transported mainly in the lower portion of the cross-section of the stream corresponding to 1/5 to 1/4 of the pipeline diameter. The quantity of course and heavy fractions increases downward, while the largest and heaviest particles move on the bottom of the pipeline. Research was carried out in this respect at a pilot plant in the Moscow Civil-Engineering Institute.

Based on the results of the work performed at the Almalyk Copper Ore Processing Plant, a plant was constructed comprising a feeding device, a mill for regrinding the separated upgraded fraction and equipment for final upgrading process. After this plant had been commissioned it became possible to treat the upgraded portion recovered from tailings at a rate of about 60 t/hr (the limitation being the throughput of the grinding mill) and recover additionally 200 to 250 kg of gold and 370 to 400 t of copper[4]. Processing technology has been also developed for treating discard tailings at the Dzhezkazgan ore processing plants.

CONCLUSION

1. Due to the trend toward lower grades of ores, higher mining costs, development of more advanced techniques and technologies it becomes reasonable to process old tailings accumulated in tailings ponds and dumps at the available ore processing plants.
2. The main losses of precious metals are attributed to the very fine size of gold grains which can be recovered by centrifugal separation, the feasibility of which has been proven at mines in Norilsk, South Urals, Bashkiria, Rudny Altai, Krasnoyarsk region, Khakasia, Chukotka, Kolyma, Kazakhstan, and Uzbekistan.
3. With minimum expenses it is possible to use the available floor areas for installation of apparatus and utility lines for production of additional 1,100 kg of gold per year.
4. Processing of secondary raw materials by centrifugal separation facilitates a tenfold or even more reduction in the amounts of materials to be subjected to subsequent final hydrometallurgical treatment to produce pure metals with high recoveries which implies a proportional reduction in the costs of treatment.
5. The feasibility of recovery of ultrafine gold (down to 10 μm) by means of centrifugal separation from dredge tailings has been proven (normally these tailings cannot be treated by conventional technology). This process ensures high recoveries of gold (up to 90%) and production of high-grade concentrates (to 0,5%).
6. An additional source for gold production is sand and gravel quarries. The economic feasibility of gold recovery by means of centrifugal separators is determined by the probable concentration of gold at certain points of the construction material production flow-sheet (crushed stone, gravel, sand).
7. To reduce expenditures in terms of foreign currency for purchase of imported centrifugal apparatus it is proposed to establish centralized manufacturing of such units utilizing the available domestic experience.
8. It is economically justifiable to recover precious metals in the process of hydraulic transportation of discard tailings slurries under certain conditions.

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