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Yuri DEREVYANKIN, Irena VINOGRADOVA, Valentin MENSHIKOV
Belorussian State Geological Research Firm „BelGEO", Mińsk, Białoruś

GRAVEL SAND COMPLEX TREATMENT TECHNOLOGY AT BELARUSIAN PLANTS

Summary. The extraction of gold and heavy minerals from Belarusian gravel sands using gravity concentration method. The amount of gold in the gravel sand or sand material amounts to one to hundreds mg/m^3. The most effective concentration of heavy minerals out of classified sands was achieved with screw separator VS-250. It allows to extract up to 95-99% of all heavy minerals with average gold content of 128 g/m^3 of sand and its concentration ratio of 121.5.

KOMPLEKSOWA PRZERÓBKA BIAŁORUSKICH PIASKÓW ŻWIROWYCH

Streszczenie. Przeprowadzono próby wydzielenia złota i minerałów ciężkich z białoruskich piasków żwirowych metodami grawitacyjnymi. Zawartość złota w tych próbach wynosi od jednego do kilkuset mg/m^3 piasku.

Najbardziej efektywną metodą wydzielania ciężkiej koncentratów okazało się wzbogacanie przy użyciu wzbogacalników spiralnych VS-250. Osiągnięto uzysk minerałów ciężkich w granicach 95-99 %. Zawartość złota w koncentracie wynosiła 128 g/m^3, co odpowiada współczynnikowi wzbogacania 121.5.

Gravel sand (GS), now widely used as raw material in construction, has become an object of research as a potential additional source of precious metals.

The problem of by-extraction of heavy minerals out of GS is being purposefully studied in Russia and the Ukraine where large deposits of these raw materials are exploited. The head Russian scientific organisations (Central Geology Research Institute, Soviet Union Minerals Institute) produced special concentrators for technological analysis of gravel sand mixtures (GSM), carried out tests of extracted rocks and their treatment products, and also invented quality-quantitative methods of rocks concentration for gold by-extraction. Russian

specialists' research resulted in a fact that source gravel sand or sand material contains mainly fine-class gold in amount of one to hundreds mg/m^3. Centrifugal concentrators, screw separators and concentration tables were recognised as the most effective equipment for native gold by-extraction.

According to techno-economic calculations made by the specialists of CGRI, economic efficiency of gold by-extraction out of GSM on active mines starts at production level of at least 500 thousand m^3 a season and metal content in class 5mm treatment products about 50 mg/t (A. I. Romanchuk, A. I. Nikulin).

In the Republic of Belarus about 150 GS deposits have been explored. According to the specialists of "Belgeologia", the total reserve of the mineral is hundreds of millions cubic metres. Its mining is carried out by quarrying with rock classification on spot or on aggregate processing plants (APP). In order to get quality product the largest plants use production technology which includes wet screening and classification.

"BelGEO" specialists have been performing assessment of the auriferousness of the Belarus quaternary deposits and exploited GS mines since 1992. At the early stage (1992-1993) highly qualified Russian "SevGEO" specialists contributed a lot to the regional mineralogical research. During this period auriferousness tables of deposits of that age were made, regional features of native gold spreading were assessed, gold typomorphic characteristics and its chemical composition features were analysed. Rocks heavy fractions structure and average content of other minerals were also studied in that set of works.

During GS by-components complex analysis the following results were acquired:

1. In explored and exploited GS and construction sand mines constant presence of fine-class native gold is observed in dispersed mineralisation and local high-level concentration zones. Chemically this gold is of high standard (>900 ‰) and in some cases contains platinoid admixtures. Gold's content in source rocks varies from ones to dozens, rarely to hundreds mg/m^3.
2. Other valuable minerals of the GS and sand rocks heavy fraction include garnet, ilmenite, zircon and rutile. Garnet is raw material for abrasives and fine cleansing filters production, ilmenite and rutile are used for welding electrodes and titanic sponge production, zircon is one of the components of the fire-proof covering. These minerals, as well as gold, can be found in fine class grains. Their total amount in source rocks accounts for about 1-2 kg/m^3.

3. On active APPs there is accumulation of precious metals and other valuable minerals in some intermediate treatment products of source GS. The former content reaches a few grams per cubic metre, the heavy minerals total content is 10-12 kg/m^3.

Based upon these results three alternative concentration modules were worked out and built for studying the possibility of by-extraction of valuable minerals out of GS treatment products on two active APPs which belong to JC "Nerudprom" and utilise wet classification technology. Module 1 used screw separators and small productivity centrifugal concentrators, module 2 utilised an industrial centrifugal concentrator Knelson 30 (KN-30). Industrial screw separators SV2-1000 were the main concentration unit of module 3. Final concentration of the rough concentrates of modules 2 and 3 was performed on the concentration table Gemeni 60.

Rough gravitation concentrates were treated by the magnetic, electromagnetic and electrostatic separators producing magnetite, ilmenite, garnet and zircon concentrates.

All GS material goes through the following treatment stages on APP: phasic dry screening depending on fineness class (20 mm and 5 mm); crushing of the boulder part in a jaw crusher; wet sieving on 5mm-cell sieves.

Mainly small-grained material with the size of 5mm and less was tested and analysed because fine-sized gold grains and other valuable minerals are concentrated after sieving of GS in under-sieve products. During the research at APPs the following products were analysed:

- source gravel-sand rocks;
- GS after classification into size classes of 20 mm and 5 mm;
- spiral classifier's products: washed sands, discharge sands and sub-ground sands with heavy minerals concentration.

Conditioned technological research was carried out at APP on module 1 using small-sized concentration units KCV 0.6 and VS-250. Two aims were pursued during the research:

- to assess concentration level of gold and other minerals in GS treatment products on APPs;
- to determine the efficiency of artificial sands concentration on chosen concentration units.

In the course of the research on the small-sized units the most effective concentration of heavy minerals out of classified sands was achieved on screw separator VS-250. Double or triple scouring of sands on that unit allows to extract up to 95-99% of all heavy minerals with average gold's content 128 g/m^3 and its concentration coefficient 121.5. On small-sized centrifugal separator KCV-0.6 the same result can be achieved only after five scours.

However, after the first scour gold extraction level exceeds 80% on the latter unit with average metal content 524.5 g/m^3 and concentration coefficient 605.9.

When using centrifugal separator KCV-0.6 only precious metals were effectively collected while the rest heavy rock fractions were lost with tailings. This was caused by the design of the unit which was designed for gold extraction only.

When using screw separator, magnetite, ilmenite, zircon, garnet and other minerals were effectively extracted along with gold.

Experiments carried out on small productivity screw and centrifugal units proved principal possibility of the use of ecology-friendly gravitational methods for gold-containing concentrate by-extraction out of GS.

These results allowed to continue the research at industrial enterprises. Together with JSC "Nerudprom" staff production work bays were chosen and the most effective variants to plug industrial modules into APP manufacturing line were developed. The source feed for module with KN-30 was 5mm classified product of screens CMD-121, the source feed for the module with SB2-1000 were spiral classifier's sands.

Concentration modules were tested in two steps. During the first step work modes of main and auxiliary equipment were tried out, the second step was aimed at statistic analysis of concentration samples on all stages of the technologic cycle. Work modes tryout for both modules involved optimal density feed generation and creating conditions of uniform water supply in all parts of the unit as well as determination of the optimal work modes which provide the most effective concentration.

The test of concentration module working system with KN-30 was carried out with additional classification of the feed on a screen with a 0.5mm flexible synthetic sieve and on an arch screen with 2mm distance between the openings. With 0.5mm feed grade the gold extraction rate was at 97.3%, whereas with 2mm feed grade it was possible to extract 90.5% of gold. However, 52% of gold was lost with the retained feed in the first case and only 4% in the second one.

For better segregation of the feed in the working system of a module with screw separators the processed sands were additionally classified on a 3mm screen.

Optimal proportion of solid material and water in feed and uniformity of its feeding to the processing units was ensured by intermediate tanks, pumps and hydrocyclones.

During work mode test it was determined that optimal feed density for module with KN-30 was 40% of solid and 25-30% for module with SB2-1000. Additional pre-classification allowed to lessen the volume of the feed and to increase concentration of gold and other

minerals in under-sieve product on 10-50% which resulted in growth of the concentration figures.

The test also allowed to determine the optimal technological parameters of concentration units performance. The most effective gold extraction (more than 90%) on KN-30 concentrator can be achieved if its continuous work duration does not exceed 3 hours, water pressure is between 3 to 12 psi and the unit's productivity is under 15 m^3 per hour. If the source feed consists mostly of small particles (less than 0.5 mm) and clay, the most effective pressure is 4-6 psi, whereas the pressure level of 10-12 psi is more preferable when the particles are larger than 1mm and there is little clay in the source feed.

The total productivity of the module with SV2-1000 was 6 m^3/h, i. e. 1.5 m^3/h per one trough, the optimal width of rough concentrate and intermediate product output zones were 20-40 mm.

The test of retreating operation on concentration table Gemeni-60 included choosing amplitude and deck vibration frequency, adjustment of the water flow and its distribution over the deck. During the experiment the following conclusions were made: optimal table productivity is 45-50 kg/h, feed density as to solid partial is 70% , optimal feed grade is under 0.8 mm.

Full technologic cycle treatment of GS on industrial units confirmed the efficiency of the selected concentration equipment as well.

According to the results of the quantitative mineralogical analysis, gold extraction out of source class –5mm GS feed on the module with KN-30 varied from 87.2% to 92.1%. In experiments with equipment work duration of 1 hour and average gold's content of source GS 19.8 mg/m^3, its content in the Gemeni-60 concentrate accounted for 2.7 kg/ m^3 with concentration coefficient 136531. In similar experiments with 3-hour duration and lower initial gold's content (13.9 mg/ m^3) the overall concentration coefficient increased 5 times more (k=677365) while output gold's content ran at 9.4 kg/m^3. Check measurement of gold by test-tube spectrum analysis determined its content in source sands at 28.2 mg/m^3 and 4.96 kg/m^3 in Gemeni-60 concentrate with average concentration coefficient 223988. Besides gold, platinum and palladium in small quantities were found in the table's concentrates.

The module with a screw separator (SS) testing through the whole technologic cycle was performed by processing washed and concentrated ground classifier's sands.

According to the results of the quantitative mineralogical analysis, average gold extraction out of washed sands amounted to 87.2%. The metal content in the source feed varied from 1.3 to 189.5 mg/m^3 with an average amount of 30,8 mg/m^3. In rough concentrates

of SS and concentration table its amount gradually increases reaching industrial levels of 2.94 g/m^3 and 977.8 g/m^3 respectively. According to the analysis' results, the average coefficient of gold concentration in output product was 31748.

Average gold's content figure (31.7 mg/m^3), which is very close to that of the mineralogical analysis, was reaffirmed by the test-tube spectrum test. Gold's content is higher in SS and Gemeni-60 table concentrates amounting to 3.6 g/m^3 and 1300 g/m^3 respectively. Platinum (1.6 g/m^3) and palladium (0.3 g/m^3) were also observed in the latter concentrate.

The module test with processing concentrated ground classifier's sands resulted in higher and more stable gold extraction into rough concentrates of SS (varying from 90.5% to 99.3%, or 94.7% on average). Gold's content in the SS source feed varied from 201 to 1505 mg/m^3 (586.3 mg/ m^3 on average).

In SS and Gemeni-60 table concentrates gold's content rapidly increased amounting to 8.2 and 2508.7 g/m^3 respectively with total average concentration coefficient 4277.

Integrating data about SS module work allowed to see the straight relation of gold extraction from particles size and gold's content in the source feed. With its average content growth from 4.9 to 732.9 mg/m^3 its extraction level increases from 71 to 94.8%. Particles sized 25 to 100 micron contribute most to the metal's loss which is due to the prevailing flat and plate shape of such particles causing their "soarability".

On the module with SS total extraction of all minerals out of washed and concentrated artificial sands reached 89.9 and 91.2% respectively. Heavy minerals' content in washed sands varied from 0.5 to 4.7 kg/m^3 (1.2 kg/m^3 on average) and in concentrated sands it accounted for 3.3 to 20.3 kg/m^3 (10 kg/m^3 on average). After processing these sands on the module the output content of zircon, ilmenite and garnet varied from 85 to 95%.

Completed technologic research of GS complex treatment allowed to get commercial concentrates of ilmenite, garnet, zircon, magnetite and gold. Zircon concentrate passed tests as a component of the heat-resistant covering in casting. It was approved for further use. The gold concentrate was cast into an alloying ingot and deposited to Republic of Belarus State Storage.

According to the results of analysis of Russian and other enterprises work concerning extraction of rare minerals and gold out of GS and comparison of technical parameters of up-to-date equipment, various alternatives of concentration quality-quantitative methods were developed. These methods allowed to analyse the output, extraction rate and content of minerals after each operation, and economic efficiency of GS processing. Each alternative included two concentration stages: during the main stage rough collective concentrates of

heavy minerals were obtained and during the retreating stage final products were obtained. Taking into account actual data on valuable minerals' content in source rocks two kinds of –5 class intermediate products of GS treatment were selected as the source feed: 1) gravel sand mixture obtained in the beginning of the technologic cycle after wet screening; 2) sands of the wet classification unit obtained after scouring the material from clay. Those sands were taken from the bottom zone of spiral classifiers where constant accumulation of heavy minerals was observed.

Six systems running different gravitational equipment are designed to obtain rough concentrates out of that feed. System 1 is designed for concentrating gravel sand material on constricting sand sluice boxes. In system 2 highly productive conical separator Reichert runs as the main concentration unit. In system 3 screw separators are used for obtaining rough concentrates. Concentration parameters in system 4 are calculated for centrifugal concentrators. System 5 is based upon the heavy minerals separation technology which suggests natural segregation of the material in the stream during the flow of the feed through the pipeline. System 6 is designed for processing concentrated bottom-zone sands of the spiral classifier using centrifugal units.

The second stage, i. e. retreating rough concentrates is the final operation in all concentration processes aimed at obtaining final gold-containing product and mono-mineral concentrates of heavy minerals. Systems to obtain gold and heavy minerals concentrates running concentration tables, magnetic and electromagnetic separators were designed for this stage specially. All concentration units used in these systems are industrial production equipment.

For calculating quality-quantitative schemes of –5mm class GSM concentration the following initial parameters were taken: the volume of processed material 500 000 m^3 per season; precious metals' content 26.0 mg/m^3; total amount of ilmenite, garnet, magnetite and zircon 1,6 kg/m^3. For concentrated classifier's sands the initial parameters were different: the volume of processed material 13 440 m^3 per season; heavy minerals' content 15 kg/m^3; precious metals' content 340 mg/m^3.

Concentration units in the designed systems worked in the following mode: 7 months a year, 20 working days a month, 2 shifts a day, 8 hours each shift.

-5mm class GSM treatment on system 1 using constricting sand sluice boxes with two-staged concentration followed by conversion results in final gold extraction into a commercial ingot amounting to 38% which allows to obtain approximately 5 kg of gold a year. Heavy minerals extraction is estimated at 49%. Electromagnetic and electrostatic separation of rough

collective concentrates allows to obtain 25.7 t of magnetite concentrate, 76.4 t of ilmenite concentrate, 8.2 t of zircon concentrate and 75.9 t of garnet concentrate with the mineral's content at 95-97%.

-5mm class GSM treatment on the system running conical separator Reichert allows to obtain 7.4 kg of gold in a commercial ingot, 64 t of magnetite concentrate, 17.6 t of zircon concentrate, 183 t of ilmenite concentrate and 291 t of garnet concentrate per season. Final extraction of precious metals is estimated at 57%, and heavy minerals at 80%.

The system with screw separators allows to obtain 7.6 kg of gold, 66 t of magnetite concentrate, 18.3 t of zircon concentrate, 190 t of ilmenite concentrate and 302 t of garnet concentrate per season. Final gold extraction into a commercial ingot is estimated at 58.9%, and heavy minerals at approximately 80%.

-5mm class GSM treatment on the system running centrifugal separators allows to by-extract 8.9 kg of gold per season with final extraction rate into a commercial ingot at 68.4% of gold's content in the processed feed.

Usage of conical and screw separators and centrifugal concentrators requires additional classification of the feed by –2mm size. This technological operation increases the efficiency of extraction of native gold and other heavy minerals of fine-size class and also allows to obtain new products: classified gravel for producing vibration-moulded items and for poultry farms and filter sands for water cleaning works in amount of 12 500 m^3 and 2 800 t per season respectively.

Technology based upon natural segregation of heavy minerals in the bottom zone of the pipeline during the flow of the feed has been tested and is used by some works in Russia and Uzbekistan. The first tests we carried out at active APPs corroborate accumulation of heavy minerals in the bottom zone of the feed stream even on a small distance. Using that technology on an APP it is possible to extract 3.9 kg of gold, 48 t of magnetite concentrate, 13 t of zircon concentrate, 138 t of ilmenite concentrate and 219 t of garnet concentrate per season. This process can be characterised by the lowest extraction figures (30% for gold and 58% for other heavy minerals), but it is simpler in operation and less expensive.

The system of concentrated sands by-extraction out of the classifier's bottom zone involves usage of a centrifugal concentrator as a main concentration unit. Using this system it is possible to obtain 2.6 kg of gold per season while only 20% of the metal in the source feed will be extracted . The low extraction rate is caused by considerable losses of gold with discharge of clayey substance and washed sands during scouring the feed.

Analysis of the calculations of quality-qualitative schemes of GS complex treatment shows that all the schemes have low coefficients of extraction. This is caused by technical parameters of the equipment which does not ensure effective extraction of fine-sized heavy minerals as well as by the technology of GS treatment at APPs, which is not designed for by-extraction of other valuable components.

Considering the aforementioned figures for all variants of GS complex treatment systems techno-economic analysis of expediency of creating additional production including by-components extraction and new products development was carried out. The analysis was based upon estimation of investments, exploitation costs and manufacturing costs. The economic analysis of all the project variants was performed taking into account predicted cash flow in each year of the new production activity, net discount income, profitability, internal profitability rate and investments recoupment term.

These and other techno-economic parameters indicate that organising additional production on active APPs for by-extraction of gold and other valuable minerals is profitable in all variants on condition of the correct work mode. However, economic efficiency of work of the concentration units in all the systems is different. Systems with screw separators and those using the technology of concentration of the bottom-zone feed flowing through the pipeline show the best results. Internal profitability rate for these systems accounts for 37.1% and 37.4% respectively, investments recoupment takes up 3 years.

Analysis of the possibility of the complex GS treatment on active APPs allowed to come to the following conclusions:

1. In gravel sand material and its treatment products valuable minerals are constantly present. These minerals can be potential useful by-components.
2. Technologic research results, design of the concentration systems running different equipment and economic analysis of the systems proved principal possibility of effective GS complex treatment with valuable minerals by-extraction and production of new goods.
3. Efficiency of GS complex treatment on active APPs depends upon the following conditions: by-components' content in the processed material and their size class; volume of GS processed with wet classification treatment technology and its efficiency rate regarding by-components extraction; technical parameters of the concentration units used in fine-class heavy minerals extraction.
4. Further technologic research of the GS complex treatment must be oriented towards development of the major wet classification equipment of APPs aiming at creating

controlled concentration of heavy minerals in the final product; towards designing effective industrial units for valuable minerals by-extraction and new goods production within existing technologic process of the works; towards development of the technology of artificial mineral placers creating during GS mines exploitation. The last direction is actual because most active APPs cannot process necessary amount of GS (400 000 - 500 000 m^3), which should ensure profitable heavy minerals by-extraction considering their low content in the initial rocks.

Recenzent: Dr hab. inż. Andrzej Ślączka, prof. nzw. Pol. Śl.

Streszczenie

Przeprowadzono próby wydzielenia złota i minerałów ciężkich z białoruskich piasków żwirowych metodami grawitacyjnymi. Zawartość złota w tych próbach wynosi od jednego do kilkuset mg/m^3 piasku.

Wzbogacanie prowadzono dla klasy ziarnowej poniżej 5 mm, albowiem w tej klasie występuje największa koncentracja złota. Do wzbogacania zastosowano wzbogacalnik spiralny VS-250, wirówkę Knelson 30 i stół koncentracyjny Gemini 60. Najlepsze rezultaty osiągnięto przy zastosowaniu wzbogacalników spiralnych VS-250. Osiągnięto uzysk minerałów ciężkich w granicach 95-99 %. Zawartość złota w koncentracie wynosiła 128 g/m^3, co odpowiada współczynnikowi wzbogacania 121.5.