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BENEFICIATION AND PROCESSING OF NATURAL AND TECHNOGENIC RAW MATERIALS

Research paper

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Comparative processing studies of the Arkachan deposit gold-bearing ores using dry separation and classical wet gravity separation methods

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Abstract
The use of dry methods of processing and beneficiation of mineral raw materials is one of the promising areas, as this approach to concentrate production is less energy-consuming, less labor-intensive, and economically beneficial. The paper presents experimental studies on preliminary dry separation of Arkachan deposit ores to determine the quality of beneficiation of the separation products. The studies on dressability were carried out on pilot plants for dry ore processing and beneficiation: combined impact crusher DKD-300, centrifugal mill TsMVU-800, pneumatic separator POS-2000. Processing of the obtained separation products by pneumatic separation and screening according to the sequential flow chart of crushing and grinding was carried out in laboratory conditions at a gravity concentration table SKO-0.5. The GRG test was performed at an ITOMAK-0.1 centrifugal concentrator using a sequential grinding circuit. The GRG test showed that for more efficient gravity separation of gold, up to total gold recovery of 73.91%, the degree of grinding up to 80% passing 0.071 mm was required, allowing obtaining a gravity concentrate graded at 70.28 g/t gold.

Keywords
crusher, mill, pneumatic separator, dry separation, screening, grinding, concentrator, gold, recovery, performance

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ОБОГАЩЕНИЕ, ПЕРЕРАБОТКА МИНЕРАЛЬНОГО И ТЕХНОГЕННОГО СЫРЬЯ

Научная статья

Сравнительные технологические исследования золотосодержащей руды месторождения Аркачан методами сухого обогащения и классической мокрой гравитации

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Аннотация
Использование сухих технологий переработки и обогащения минерального сырья является одним из перспективных направлений, так как данный способ производства концентрата менее энергозатратен, менее трудоемок и экономически выгоден. В работе приведены экспериментальные работы по предварительному сухому обогащению руд месторождения Аркачан для определения качества обо-

гащения продуктов разделения. Исследования на обогатимость проводились на опытных установках сухого метода переработки и обогащения руд: дробилке комбинированного ударного действия ДКД-300, центробежной мельнице ЦМВУ-800, пневмосепараторе ПОС-2000. Обработка полученных продуктов разделения пневмосепарацией и грохочением по последовательной схеме дробления и измельчения проводилась в лабораторных условиях на гравитационном концентрационном столе СКО-0,5. GRG-тест проходил на центробежном концентраторе ИТОМАК-0,1 по последовательной схеме измельчения. Анализ проведённого GRG-теста показал, что для более приемлемых условий гравитационного обогащения золота – до 73,91 % – необходима степень измельчения до 80 % класса −0,071 мм, для получения гравитационного концентрата с содержанием 70,28 г/т золота.

Ключевые слова

дробилка, мельница, пневмосепаратор, сухое обогащение, классификация, измельчение, концентратор, золото, извлечение, эффективность

Финансирование

Работа выполнена в рамках государственного задания Министерства науки и высшего образования Российской Федерации (тема № 0297-2021-0022, ЕГИСУ НИОКТР № 122011800089-2) с использованием оборудования ЦКП ФИЦ ЯНЦ СО РАН (грант №13.ЦКП.21.0016).

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Introduction

Reducing the cost of finished products by applying the most economically advantageous processes and technologies of mineral processing and beneficiation is one of the urgent tasks in the mining and processing industry. One of the promising areas is the use of dry methods of mineral raw materials beneficiation, as this approach to concentrate production has a number of significant advantages.

The purpose of this work is conducting experimental studies on preliminary dry separation of the Arkachan deposit ores and assessing the quality of the separation products with the recovery of gold from the pneumatic separation concentrate and tailings by gravity separation methods.

The ore samples from the Arkachan deposit by material composition are lumpy ore material of −150+40 mm in particle size, with veins of quartz-carbonate, quartz-carbonate-sulfide, quartz-goethite, and quartz-limonite composition.

The technology of the tests on dry ore separation provides for treatment of the separation products for maximum recovery of free gold from the products and correct accounting in determining the qualitative and quantitative indicators of the separation processes [1–3].

The technology involves two interrelated processes:

– ore preparation (crushing and grinding) to release and recover free gold up to 50 microns [4–6];

– pneumatic separation to produce concentrates with a high grade of free gold at a particle size of up to 100 microns.

The tested technology provides for the use of crusher DKD-300[1] [7, 8] based on the technique of multiple impact action [9, 10] with productivity up to 15 tph, centrifugal mill TsMVU-800[2] with productivity up to 6 tph, and pneumatic separator POS-2000 with productivity up to 6 tph.

Classical wet gravity separation was carried out using the GRG test methodology, which involves sequential release and recovery of gold as an ore is ground in stages. The GRG test consists of three successive stages of mineral disintegration and three stages of beneficiation.

For the comparative characterization of these two technologies, optimal crushing process parameters of crushing and grinding apparatuses, fractional compositions of crushing and grinding products, release of gold-bearing minerals from the ore matrix, the results of the studies on dry beneficiation of the crushed fraction using POS-2000 pneumatic separator with the determination of the recovery of gold-bearing minerals by pneumatic separation, the degrees of reduction were determined and used [11, 12]. The quality of beneficiation and

1 Matveev A.I., Vinokurov V.P., Grigoriev A.N., Monastyrev A.M. Patent No. 2111055 of the Russian Federation. Combined impact crusher. Published on 20.05.1998.

2 Matveev A.I., Grigoriev A.N., Filippov V.E. Patent No. 2150323 7 B02 C 13/20. Counter Impact Centrifugal Pulverizer. SB RAS North Mining Institute. Published on 06/10/2000; Matveev A.I., Vinokurov V.R., Grigoriev A.N. Patent No. 2746502 B02C 7/00. Vertical Centrifugal Pulverizer. Federal State Budgetary Institution of Science Federal Research Center Yakutsk Research Center of the Siberian Branch of the Russian Academy of Sciences. Published on 14.04.2021.

the separation products was determined by particle size class. The technological assessment was given and the feasibility of using dry ore separation for obtaining gold concentrates at the preliminary stage of beneficiation were substantiated [13, 14].

General methodology of the performed studies on ore sample processing

The experimental sample processing was carried out in conjunction with basic sequential processing of an ore sample weighing at least 500 kg. A small portion of the initial sample was retained for umpire analytical studies.

The tests were carried out according to the flow chart, providing for the sequential processing of ore at the DKD-300 crusher, TsMVU-800 mill, and POS-2000 pneumatic separator (Fig. 1).

For end-to-end testing, the initial sample after each crushing cycle was separated by screening into particle size classes of +5 mm, −5 + 3 mm and −3 + 0 mm.

The +5 mm particle size classes formed in the crushing process were subjected to successive staged crushing at a DKD-300 crusher, and the number of crushing cycles was determined by sufficient degree of mass loss of +5 mm size classes after the latest crushing cycle.

The crushing products of −5 + 3 mm and −3 + 1 mm particle size classes were ground at a TsMVU-800 centrifugal mill. The grinding products were separated at POS-2000 pneumatic separator to obtain concentrate and tailings. For the end-to-end tests, grinding and pneumatic separation were performed sequentially.

The pneumatic separation concentrates were screened to separate into two particle size classes: −1 mm and +1 mm. The resulting −1 mm class was further concentrated at a SKO-0.5 table, then at a Moseley analyzer for free gold recovery by finishing (magnetic separation and washing in bromoform).

The −3 + 0 mm particle size class obtained after primary crushing was also screened to separate the +1 mm particle size class, which was sent for regrinding with following pneumatic separation. The screening products of +1 mm and −1 mm particle size classes were subjected to pneumatic separation at the POS-2000 to obtain concentrate and tailings.

Free gold was separated from the pneumatic separation concentrates using Moseley analyzer finishing, magnetic separation, and bromoform washing.

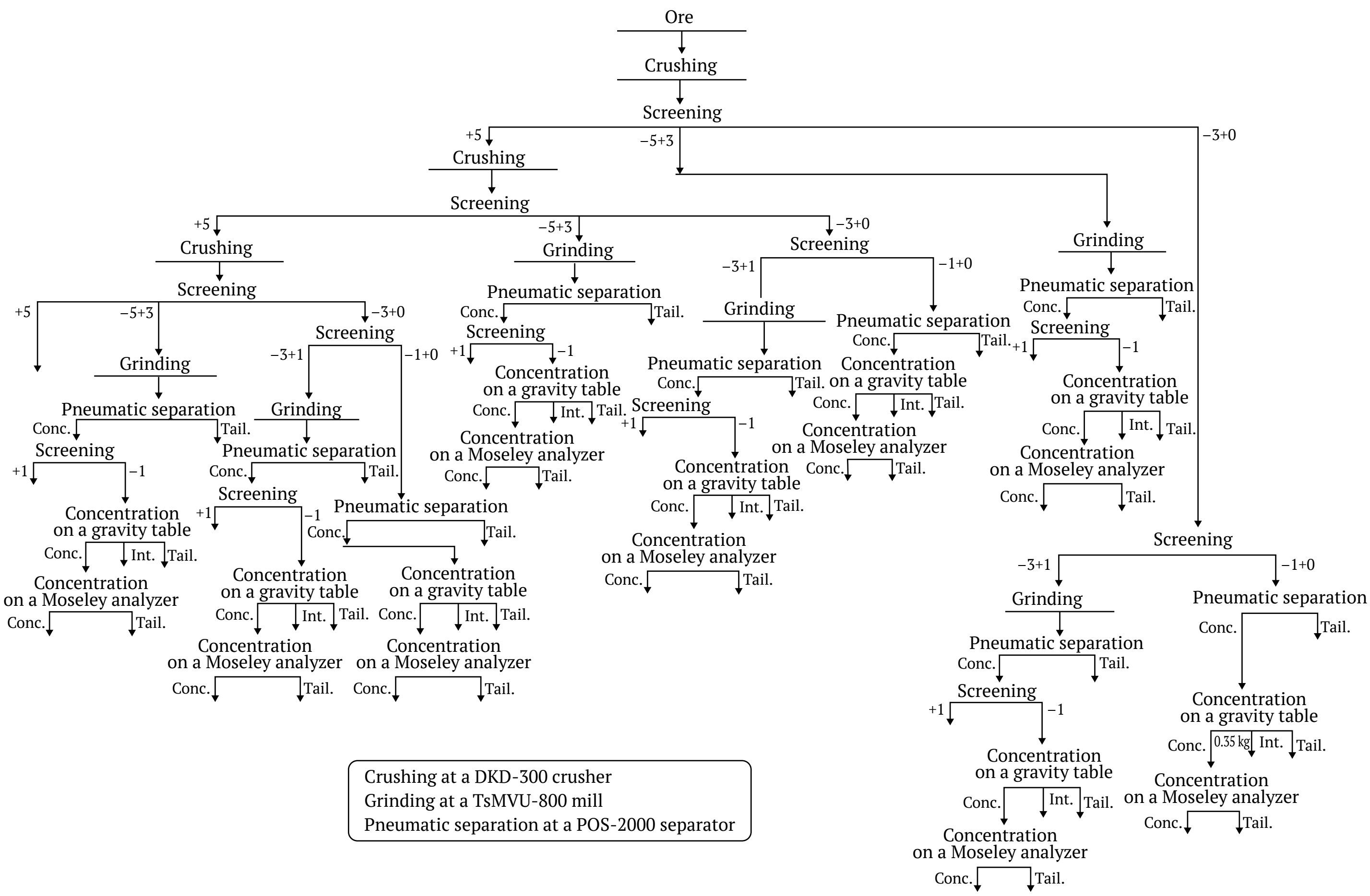

Fig. 1. Flow chart of sample processing: Conc. – concentrate; Tail. – tailings, Int. – intermediates

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All crushing and grinding products were subjected to particle size distribution analysis with appropriate sampling, and the separation products from the pneumatic separation, concentration table, and Moseley analyzer were analyzed by fire assay or atomic adsorption method for residual gold grade after complete recovery of free gold particles.

Based on the conducted research results, the qualitative and quantitative indicators of the sample processing flow chart were calculated. The quality of pneumatic separation was determined after analyzing the processing products taking into account the recovered amount of free gold.

As the final step, a balance calculation of the processing products in terms of gold grade and recovery by processing cycle (crushing-grinding-pneumatic separation) and for throughout sample processing was performed.

Methodology of the GRG test for assessing the gravity dressability of the gold-bearing ore

A study of the initial ore sample by GRG test was carried out to determine the deposit ore gold dressability based on the use of a Knelson centrifugal concentrator [15–17]. The GRG test technique is based on the sequential recovery of released gold by grinding stage, i.e. as gold is released, and excludes overgrinding and comminution of coarse gold particles [18, 19]. The GRG test involves three consecutive cycles of mineral disintegration and corresponding three cycles of subsequent beneficiation [20, 21].

The GRG test specifies the grinding degrees of the test materials:

Stage 1 – up to 100% passing 1 mm (P100 –1 mm);

Stage 2 – up to 80% passing 0.315 mm (P80 –0.315 mm);

Stage 3 – 88% passing 0.071 mm (P88 –0.071 mm).

At the first stage of grinding, DAU-250 active impact crusher was used, whose technical characteristics are given in Table 1.

The initial mass of a sample taken for the test was 65 kg, which was milled and beneficiated to produce concentrate and tailings.

The second stage received the ground tailings of the first stage, the third stage received the ground tailings of the second stage; the grinding was carried out at a MSHL-120 laboratory ball mill. General drawing of the laboratory ball mill is shown in Fig. 2, and its technical characteristics are given in Table 2.

The beneficiation was carried out at an ITOMAK-0.1 centrifugal concentrator (Fig. 3). This centrifugal concentrator is a Russian analog of a Knelson concentrator; technological characteristics of these facilities are comparable under equal operating conditions. Technical characteristics of the ITOMAK-0.1 are given in Table 3.

The flow chart of the GRG test using the DAU-250, MShL-120, ITOMAK-0.1 facilities is presented in Fig. 4.

Table 1

Technical characteristics of DAU-250 crusher

Parameter	Value
Max. particle size of feed material, mm	100
Relieve slot, mm	1–10
Motor power, kW	7.5
Motor speed, rpm	960–1,490
Feed throughput, tph	1.0
Weight with electric motor, t	0.8

Fig. 2. Laboratory MShL-120 ball mill

Table 2

Technical characteristics of MShL-120

Parameter	Value
Drum volume, l	120
Feed material particle size, mm, max	8
Drum speed, rpm	48–60
Final product particle size, mm	–0.071
Ball load, kg	Up to 80
Diameter of balls, mm, within	20–80
Installed power, kW	1.5
Operating mode	Intermittent, continuous
Grinding method	Dry

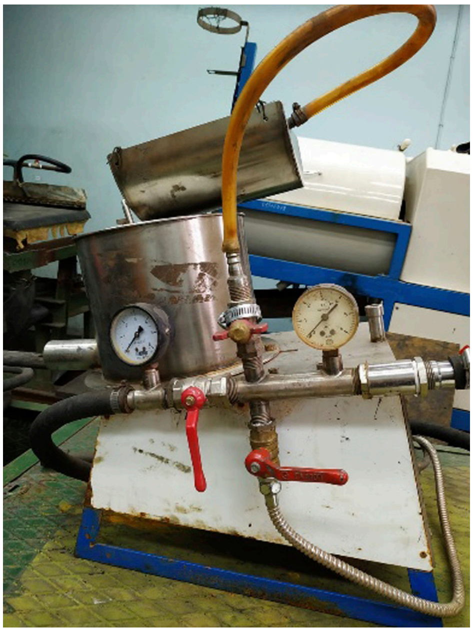

Fig. 3. ITOMAK-0.1 centrifugal concentrator

Table 3

Technical characteristics of ITOMAK-0.1

Parameter	Value
Motor power, W	250
Three-phase AC mains supply voltage*, V	380 ± 38
Solid sludge capacity, kg/h	100
Slurry capacity, m³/h	0.37
Maximum flushing water consumption, m³/h	2.5
Feed material particle size (for alluvium), mm, max	2.0
Feed material particle size (for ore), mm, max	0.5
Slurry solid content, %	Up to 75
Concentrate volume, ml, max	120
Facility weight, kg, max	55
Overall facility dimensions, mm, L × W × H, max	550 × 350 × 780

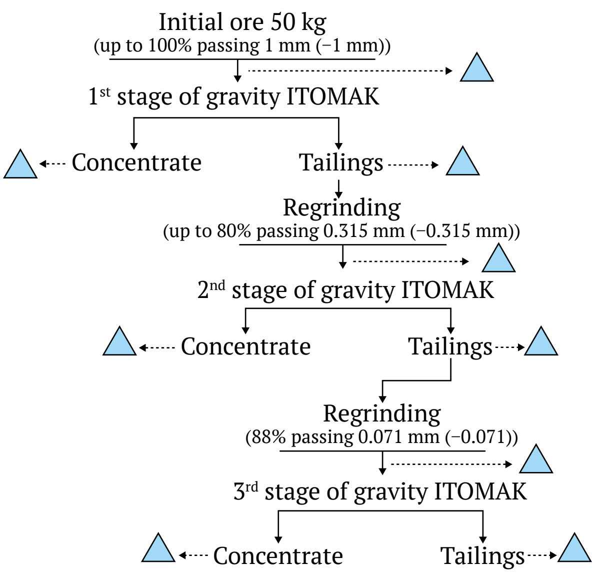

Fig. 4. GRG test design

Results of Arkachan deposit ore metallurgical sample investigations involving crushing, grinding, and pneumatic separation

According to the methodology of the conducted researches the tested flow chart of sample processing represents consecutive operations of gold release by staged crushing, grinding, and pneumatic separation of crushed materials passing 3 mm, carried out directly in the DKD-300 crusher, TsMVU-800 mill, and POS-2000 pneumatic separator.

The tests were carried out according to the flow chart presented in Fig. 1, according to the general methodology, providing sequential crushing of ore in the crusher.

A total of three crushing cycles were performed at a DKD-300 crusher during the sample processing (Table 4).

As shown in Table 4, the maximum degree of crushing by cycle was 9.35.

Grinding of ore samples was carried out in a centrifugal step mill TsMVU-800 according to the flow chart shown in Fig. 1. The crushing and screening products of the −5 + 3 mm and −3 + 1 mm particle size classes (Tables 5, 6) comprised the grinding feed. All the grinding products were subjected to pneumatic separation in POS-2000 pneumatic separator.

As can be seen from the results obtained (see Table 5), when grinding the particle size classes −3 + 1 mm, the minimum fineness number was 2.01 mm and the maximum one was 2.17 mm. When grinding coarser classes of −5 + 3 mm, the fineness number ranged from 3.05 to 3.59 mm (see Table 6), being significantly higher. This is due to the peculiarity of impact grinding in centrifugal mills, where

Table 4

Particle size distributions of the DKD-300 crusher crushing products

Particle size class (mm)	Yield, %		
	1st cycle	2nd cycle	3rd cycle
−0.071	3.57	2.44	2.18
−0.1 + 0.071	1.99	0.62	0.76
−0.2 + 0.1	2.82	1.66	2.27
−0.315 + 0.2	1.15	1.07	1.47
−0.63 + 0.315	3.61	1.93	2.58
−1 + 0.63	4.92	2.86	3.44
−2 + 1	8.78	5.92	7.22
−5 + 2	22.93	32.07	37.40
−10 + 5	14.59	24.63	23.03
−20 + 10	21.23	22.44	17.34
−40 + 20	8.83	4.34	2.31
+40	5.59	0.00	0.00
Degree of crushing	9.35	2.28	2.02

the effect of the mass of a broken piece manifests itself. The more massive and coarser a particle, the greater the energy of dynamic impact when the particles collide with the mill's working bodies; correspondingly, the higher the fineness number.

POS-2000 pneumatic separator was tested in two operating modes. The first mode consisted in the sequential combined operation with centrifugal mill TsMVU-800, and the second one, in separate pneumatic separation of passing 1 mm screening products. The resulting pneumatic separation concentrate was divided into two classes, −1 mm and +1 mm. The particle size class −1 mm was concentrated at a SKO-0.5 concentration table to produce a rough concentrate. The table concentrate was further processed in a Moseley analyzer until a "primary concentrate" – ultra concentrate – was obtained.

Gold grade in the +1 mm particle size classes and in the pneumatic separation tailings was determined by fire assay.

In the second mode of operation, i.e. at pneumatic separation of screening products of −1 mm particle size class, the obtained pneumatic separation concentrate was also concentrated at the SKO-0.5 concentration table to assess the quality of separation. The concentrate was then processed at a Moseley table to separate the primary gold concentrate.

The beneficiation results at three different pneumatic separator productivities after processing the separation products by concentration at the SKO and at the Moseley analyzer with the corresponding results of gold grades assays in the separation products are shown in Table 7.

The highest gold recovery, 35.25%, was observed at the lowest productivity, 1.8 tph (i.e. in the most quiet option of separation), but the rational level of productivity in this case was 3 tph. The gold grade in the pneumatic separation tailings is higher than in the concentrate in all cases, indicating the transfer of fine and bound gold into the tailings.

Table 5

Particle size distributions of −3+1 mm particle size class crushing cycles products

Particle size class (mm)	1st cycle		2nd cycle		3rd cycle	
	Initial	After grinding	Initial	After grinding	Initial	After grinding
−0.071+0	0.00	4.11	0.00	4.10	0.00	2.64
−0.1+0.071	0.00	2.85	0.00	2.25	0.00	2.58
−0.2+0.1	0.00	14.24	0.00	14.13	0.00	15.10
−0.315+0.2	0.00	9.49	0.00	8.71	0.00	7.82
−0.5+0.315	0.00	9.18	0.00	10.39	0.00	10.57
−1+0.5	0.00	26.58	0.00	28.35	0.00	31.26
−1.6+1	64.06	25.95	68.66	25.61	70.35	24.73
−2.5+1.6	19.93	7.59	17.31	6.46	16.40	5.29
−3.2+2.5	16.01	0.00	14.03	0.00	13.25	0.00
Grinding degree	–	2.17	–	2.15	–	2.01

Table 6

Particle size distribution characteristics of grinding of crushing cycle products of −5+3 mm particle size class

Particle size class (mm)	1st cycle		2nd cycle		3rd cycle	
	Initial	After grinding	Initial	After grinding	Initial	After grinding
−0.071+0	0.00	16.71	0.00	10.25	0.00	8.74
−0.1+0.071	0.00	6.48	0.00	4.30	0.00	4.14
−0.2+0.1	0.00	15.46	0.00	14.75	0.00	14.25
−0.315+0.2	0.00	7.23	0.00	9.22	0.00	9.20
−0.5+0.315	0.00	5.49	0.00	8.81	0.00	8.05
−1+0.5	0.00	13.72	0.00	18.03	0.00	17.24
−1.6+1	0.00	16.71	0.00	17.83	0.00	20.00
−2.5+1.6	0.00	6.73	0.00	6.35	0.00	6.90
−3.2+2.5	78.97	11.47	86.52	9.22	74.40	10.34
−5+3.2	21.04	0.00	13.48	1.23	25.60	1.15
Grinding degree	–	3.59	–	3.34	–	3.05

Results of the GRG test

GRG test was conducted with the initial ore sample weighing 65 kg at the ITOMAK-0.1 centrifugal concentrator in the following modes: solid sludge productivity – 100 kg/h; pulp productivity – 0.37 m^3/h; maximum consumption of flushing water – 2.5 m^3/h.

The solids content in the slurry fed to gravity separation was 25–30%. This test was performed in three stages. At the 1st stage, ore sample weighing 65 kg was crushed in the impact crusher DAU-250 to 100% passing 1.0 mm, and the crushed ore was passed through ITOMAK-0.1 concentrator. Next, the tailings of the first stage were re-ground to 80% passing 0.315 mm and processed at the ITOMAK concentrator. At the 3rd stage, the tailings of the 2nd stage were re-ground to 88% passing 0.071 mm. During the process at all stages, samples were taken from the tailings for particle size distribution analysis. All gravity concentrates and tailings of the ITOMAK centrifugal concentrator were sampled for particle size distribution determination as well as for gold fire assay.

The initial 65 kg sample was initially crushed to a particle size of −1 mm. For determining initial gold distribution by size class, sieving was carried out on sieves with mesh 0.63, 0.5, 0.315, 0.2, 0.1, 0.071 mm. From each resulting particle size class, subsamples were taken for fire assay. Based on the results of the assay, a table of gold distribution by particle size class was compiled (Table 8). The table shows that gold is unevenly distributed by size class. The highest gold grades were found in the fine −0.2 mm particle size classes, while the highest proportion of gold was contained in the −0.2+0.1 mm and −0.071 mm classes, 27.35% and 23.46%, respectively.

Beneficiation of this sample in the ITOMAK centrifugal concentrator produced concentrate weighing 2.573 kg and tailings weighing 61.327 kg. The resulting products were screened into particle size classes: −1+0.63 mm; −0.63+0.5 mm; −0.5+0.315 mm; −0.315+0.2 mm; −0.2+0.1 mm; −0.1+0.071 mm; −0.071 mm. The material from each particle size class was subjected to fire assay. The assay results and gold distribution in the first stage are presented in Table 9.

Table 7

Pneumatic separation results

No.	Product	Productivity, tph	Weight, g	Yield, %	Gold grade		Recovery E, %
					g	g/t	
	POS-9-1 separation	6	**54,950**	**100.00**	**0.91**	**16.61**	**100.00**
1	POS-9-1 concentrate		16,600	30.21	0.29	17.47	31.76
2	POS-9-1 tailings		30,107.5	54.79	0.55	18.20	60.02
3	POS-9-1 losses		8,242.5	15.00	0.08	9.10	8.22
	POS-9-2 separation	3	**52,500**	**100.00**	**0.88**	**16.73**	**100.00**
1	POS-9-2 concentrate		22,200	42.29	0.30	13.65	34.50
2	POS-9-2 tailings		22,425	42.71	0.38	17.10	43.66
3	POS-9-2 losses		7,875	15.00	0.19	8.55	21.83
	POS-9-3 separation	1.8	**43,050**	**100.00**	**0.59**	**13.75**	**100.00**
1	POS-9-3 concentrate		16,600	38.56	0.21	12.57	35.25
2	POS-9-3 tailings		19,992.5	46.44	0.33	16.50	55.75
3	POS-9-3 losses		6,457.5	15.00	0.05	8.25	9.00

Table 8

Distribution of gold by particle size class in the initial sample of −1.0 mm particle size

Particle size class (mm)	Yield, %	Weight, g	Au Grade (g/t)	Au proportion, %
−1+0.63	32.20	20,575.8	2.12	14.74
−0.63+0.5	6.80	4345.2	3.52	5.17
−0.5+0.315	13.20	8,434.8	3.78	10.77
−0.315+0.2	9.00	5751	3.48	6.76
−0.2+0.1	12.30	7,859.7	10.3	27.35
−0.1+0.071	6.30	4,025.7	8.64	11.75
−0.071+0	20.20	12,907.8	5.38	23.46
Total	100	63,900	4.63	100.00

The table shows that in the 1st stage of gravity separation of ore crushed to −1 mm particle size class, high proportions of gold belonged to the concentrates in the finer particle size classes (−0.2 + 0.1 mm; −0.1 + 0.071 mm; −0.071 mm), with a noticeable redistribution of gold into these classes with a total proportion of 83.72% in the −0.2 mm particle size class. As for tailings, all particle size classes showed roughly similar gold grades, but the coarse classes +0.2 mm demonstrated higher gold grades. The highest grade was found in −0.315 + 0.2 mm class, 8.8 g/t. This may be due to the presence of unreleased gold in these size class.

Further, the tailings obtained at the 1st stage of gravity separation were further milled in the laboratory ball mill (see Fig. 2) to 80% passing 0.315 mm and became the feed for the 2nd stage of gravity separation at the ITOMAK.

From this product, a 1,000 g subsample was taken for sieving and sampling for gold fire assay. The assay results and gold distribution are presented in Table 10.

As can be seen from the results presented in Table 10, after grinding the tailings of the 1st stage of gravity separation to 80% passing 0.315 mm, the residual gold grade in the tailings of the first stage of concentration is redistributed evenly by size class. The gold grades range from 3.44 g/t (−0.5 + 0.315 mm class) to 6.66 g/t (for −0.1 + 0.071 mm class). The highest proportion of redistributed gold was found in the −0.2 + 0.1 and −0.071 mm classes, 26.19 and 25.79%, respectively.

The crushed tailings were sent to Stage 2 gravity separation at the ITOMAK concentrator. The concentrate weighing 2,210 kg and tailings weighing 57.117 kg were obtained. The obtained products were subjected to particle size analysis by particle size class: +0.315 mm; −0.315 + 0.2 mm; −0.2 + 0.1 mm; −0.1 + 0.071 mm; −0.071 mm. Gold grades were determined for each size class of each product obtained. The results are presented in Table 11.

The data presented in Table 11 shows that the proportion of gold in the concentrate (particle size class) passing 0.071 mm is 38.33%, while the maximum proportion of gold in the tailings belongs to the particle size class 0.2+0.1 mm and amounts to 30.98%. This is due to the fact that the ore is hard-dressable to a certain extent in terms of gold release, just as in the case of crushing the ore to −1 mm particle size, grinding to −0.315 mm did not release much of the gold present in the ore.

Table 9

Results of the GRG test Stage 1

Particle size class (mm)	Concentrate				Tailings			
	Yield, %	Weight, g	Au Grade (g/t)	Au distribution, %	Yield, %	Weight, g	Au Grade (g/t)	Au proportion, %
−1 + 0.63	21.72	558.93	13.0	3.35	12.30	7,543.22	4.12	9.64
−0.63 + 0.5	17.07	439.09	8.80	1.78	8.80	5,396.78	5.20	8.70
−0.5 + 0.315	17.02	438.03	21.6	4.36	12.60	7,727.20	5.08	12.18
−0.315 + 0.2	13.89	357.42	41.1	6.78	13.40	8,217.82	8.80	22.43
−0.2 + 0.1	21.39	550.45	115	29.20	22.60	13,859.90	4.96	21.32
−0.1 + 0.071	4.70	120.91	284	15.84	9.40	5,764.74	4.96	8.87
−0.071 + 0	4.20	108.18	775	38.68	20.90	12,817.34	4.24	16.86
Total	100	2573	84.24	100	100	61,327.00	5.26	100

Table 10

Particle size distribution and gold grades and proportions in ground tailings from Stage 1 gravity separation at ITOMAK concentrator

Particle size class (mm)	Yield, %	Weight, g	Au Grade (g/t)	Au proportion, %
−0.5 + 0.315	20.00	12,065.4	3.44	14.24
−0.315 + 0.2	17.10	10,315.917	4.40	15.58
−0.2 + 0.1	26.80	16,167.636	4.72	26.19
−0.1 + 0.071	13.20	7,963.164	6.66	18.20
−0.071 + 0	22.90	13,814.883	5.44	25.79
Total	100	60,327	4.83	100.00

The tailings obtained after the 2nd stage of gravity separation were ground to 88% passing 0.071 mm using the laboratory ball mill. As with the feed for the 2nd stage gravity separation at ITOMAK, the ground tailings became the feed for the 3rd gravity separation stage at the ITOMAK. A sample weighing 517 g was taken from the crushed tailings and subjected to particle size distribution analysis. The gold grade was assayed in each obtained particle size class.

As can be seen from the table, after grinding the tailings of the 2nd stage of gravity concentration to 88% passing 0.071 mm, most of the contained gold (89.27%) goes to the −0.071 mm particle size class.

The ground tailings were sent to Stage 3 gravity separation in the ITOMAK concentrator. A concentrate weighing 1.479 kg and tailings weighing 55.121 kg were obtained. Gold grades were assayed in each size class of each product obtained. The results are presented in Table 13.

Table 14 summarizes the GRG test results for the three ITOMAK gravity separation stages.

The table shows that the maximum gold content in the concentrate is in the −0.071 mm size class, and the minimum value of gold content is in the tailings, while the distribution of gold in the concentrate and in the tailings is almost the same, with the maximum value belonging to the finer class passing 0.071 mm.

The test results established the initial ore grade at 8.44 g/t, which is consistent with the value for sample #1 (trench 500) obtained from through sample processing.

The highest gold recovery was achieved at the 1st stage of gravity separation (ore ground to −1 mm particle size class), in which 40.20% of released free gold were recovered into the concentrate, with 38.68% of which belonged to −0.071 mm particle size class. This indicates that gold contained in the ore is mainly represented by fine free gold particles of less than 71 microns in size that is confirmed by the test results presented in Table 9.

Grinding of tailings of the 1st stage to 80% passing 0.315 mm made it possible to extract additionally into concentrate 14.46% of released gold, which is also mainly represented by particle size class −0.071 mm and amounts to 38.33% (see Table 11).

Table 11

Results of the GRG test Stage 2

Particle size class (mm)	Concentrate				Tailings			
	Yield, %	Weight, g	Au Grade (g/t)	Au proportion, %	Yield, %	Weight, g	Au Grade (g/t)	Au proportion, %
−0.5+0.315	12.66	279.79	12.7	4.71	5.54	3,164.28	4.56	4.73
−0.315+0.2	32.97	728.64	21.1	20.38	18.90	10,795.11	7.80	27.58
−0.2+0.1	38.30	846.43	23.2	26.03	29.05	16,592.49	5.70	30.98
−0.1+0.071	8.92	197.13	40.4	10.56	16.43	9,384.32	4.40	13.53
−0.071+0	7.15	158.02	183	38.33	30.08	17,180.79	4.12	23.19
Total	100	2,210	34.14	100	100.00	57,117.00	5.34	100

Table 12

Particle size distribution and gold grades in the ground tailings of the 2nd stage of gravity separation at the ITOMAK concentrator

Particle size class (mm)	Yield, %	Weight, g	Au Grade (g/t)	Au distribution, %
−0.1+0.071	12.00	6,792	4.00	10.73
−0.071+0	88.00	49,808	4.54	89.27
Total	100	56,600	4.48	100.00

Table 13

Results of the GRG test Stage 3

Particle size class (mm)	Concentrate				Tailings			
	Yield, %	Weight, g	Au Grade (g/t)	Au proportion, %	Yield, %	Weight, g	Au Grade (g/t)	Au proportion, %
−0.1+0.071	32.14	475.35	35.40	16.19	11.46	6,316.87	2.32	11.29
−0.071+0	67.86	1,003.65	86.80	83.81	88.54	48,804.13	2.36	88.71
Total	100	1,479	70.28	100.00	100	55121.00	2.36	100

Table 14

Summary table of GRG test results

Product	Yield, %	Weight, g	Au Grade (g/t)	Au distribution (Au proportion), %
Stage 1 – 100% passing 1 mm				
Concentrate 1	4.03	2,573.00	84.24	40.20
Tailings 1	95.97	61,327.00	5.26	59.80
Feed (ore)	100.00	63,900.00	8.44	100.00
Stage 2 – 80% passing 0.315 mm				
Concentrate 2	3.73	2,210	34.14	19.82
Tailings 2	96.27	57,117	5.34	80.18
Feed (tailings 1)	100	59,327	6.42	100.00
Stage 3 – 88% passing 0.071 mm				
Concentrate 3	2.61	1,479	70.28	44.46
Tailings 3	97.39	55,121	2.36	55.54
Feed (tailings 2)	100	56,600	4.13	100.00
Total				
Concentrate 1	4.19	2,573.00	84.24	38.57
Concentrate 2	3.60	2,210.00	34.14	14.46
Concentrate 3	2.41	14,79.00	70.28	20.88
Tailings 3	89.80	55,121.00	2.36	26.08
Feed – ore	100.00	61,383.00	8.79	100.00

When the 2nd stage tailings were milled to 88% passing 0.071 mm, 20.88% of the released gold was additionally recovered into the concentrate, which is also mostly in the −0.071 mm particle size class and amounts to 83.81% (see Table 13).

Thus, the results of the standard GRG test showed the following: from the ore milled to 100% passing 1 mm, 38.57% of gold are recovered into the concentrate; from the tailings of the 1st stage after regrinding to 80% passing 0.315 mm, 14.46% of gold are recovered into the concentrate.

The total recovery to the gravity concentrate obtained after the first and second stages of grinding was 53.03%. Grinding of 2nd stage gravity separation tailings to 88% passing 0.071 mm enabled obtaining additionally a gravity concentrate 3 containing 70.28 g/t gold at a recovery of 20.88%. The total gold recovery into the three gravity concentrates (1 + 2 + 3) amounted to 73.91%.

Discussion of the test results

Au grade in ore samples from Arkachan deposit provided for the study, namely, sample No. 1 (trench 500), 7.95 g/t and No. 2 (trench 600), 11.28 g/t was redetermined based on the results of processing and balance calculations.

Ore quality in terms of gold grade in the tested samples is high, but in contrast to the data of the geological report, the polydispersity of gold is not confirmed, i.e. we are talking only about dispersed gold particles passing 100 µm or impregnated gold, presumably in pyrite. For this ore the existing technology of dry separation is inefficient, as the applied technology of dry grinding in a step centrifugal mill does not release such dispersed gold; in addition, the process of pneumatic separation doesn't provide required beneficiation, despite the fact that the process of gold release and its redistribution into fine particle size classes is observed to some extent.

A detailed study of the feasibility of pneumatic dry ore separation requires more thorough post-fine grinding studies at the laboratory level rather than at the bulk test level.

The processing of the pneumatic separation products by gravity separation methods showed the feasibility of gold recovery, which requires a high degree of grinding, 80% passing 0.071 mm. This conclusion is confirmed by historical GRG tests performed in TsNIGRI.

Conclusions

The research on the processing of the Arkachan deposit ore samples for assessing efficiency of dry separation technology to obtain highly concentrated gold-containing products allowed establishing the following:

– the experimental studies and balance calculations determined the gold grade in the studied samples: in sample No. 1 (trench 500), 7.95 g/t and in sample No. 2 (trench 600), 11.28 g/t, with gold in the samples occurs in finely dispersed form (less than 100 µm) and impregnated in mineral, presumably in pyrite;

– the studies of the crushing process in DKD-300 in cyclic mode show quite a high result in terms of crushing degree in the initial ore sample: for sample No. 1 (trench 500) in the first cycle – 9.35, in the second cycle – 2.28, in the third cycle – 2.02; for sample No. 2 (trench 600) the crushing degrees were 9.23, 2.89, and 2.16 in the corresponding cycles;

– the studies of the grinding process of the crushing products passing 5 mm in the TsMVU-800 centrifugal mill showed that the grinding is generally effective for obtaining the bulk of the ore in fraction passing 1 mm in two cycles; the total yield of the control particle size class −0.071 mm for the size class −5 + 3 mm is 27.5%, for the size class −3 + 1 mm, 16.2%, which corresponds to the indicators of conventional coarse grinding;

– the release of gold (unlocking intergrowths) is confirmed by redistribution and selective concentration of gold into −3 mm particle size classes in the crushing processes with a degree of concentration of 1.51 for sample No. 2 (trench 600) and 1.52 for sample No. 1 (trench 500), as well as redistribution of gold into −0.071 mm class in the grinding processes and in the GRG test;

– the beneficiation of gold by pneumatic separation in the POS-2000 failed due to too coarse grinding at the TsMVU-800 centrifugal mill;

– the GRG test showed that for more efficient gravity separation of gold, up to 73.91%, the degree of grinding up to 80% passing 0.071 mm is required, allowing obtaining a gravity concentrate graded at 70.28 g/t gold;

– dry beneficiation as applied to the ores of Arkachan deposit is technologically inefficient. Additional laboratory studies of pneumatic separation processes at high degree of ore materials grinding are required.

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