

Research on modeling the technology of processing anthropogenic old tailings of Primorsky Concentrating Factory

Elena Shepeta^{1*}, *Natalia Litvinova*¹, *Marina Bubnova*¹ and *Mehmet Bilen*²

¹Mining Institute FEB RAS, 51 Turgenev st., Khabarovsk, 680000, Russia;

²Zonguldak Bulent Ecevit Universiti, Turkey

Abstract. The possibility of processing old tailings of the Primorsky Concentrating Factory (PCF) has been assessed. The average mass fraction of WO_3 is 0.08%, Cu is 0.052%, the average content of Au is 0.38 ppm, Ag is 1.1 ppm. The grain size of scheelite and chalcopyrite is from 0.03 mm and below. Basically, intergrowths of scheelite are in quartz, less often is in pyroxene, chalcopyrite is in pyrrhotite, less often is in quartz. The results of experimental studies of the washability of secondary mineral material using flotation and gravity beneficiation methods are presented. The possibility of intensifying the flotation process of concentration using a Pneufлот® flotation machine was investigated. The recovery of scheelite at the same degree of concentration using a Pneufлот® flotation machine is 16.5% higher compared to the standard mechanical flotation machine, mainly due to the more efficient flotation (1.5 times) of sludge (-15+0 μ m). Flotation of the sand fraction of old tailings (SFOT) in a Pneufлот® flotation machine showed an opportunity of scheelite recovery into enriched concentrate of rough flotation from -44+15 microns material by 82%, and -15+0 microns (from sludge) by 75% of those classes, the case being for the mechanical machine (volume 3 l) – 77% and 49% of those classes, respectively. The content of the obtained flotation concentrate corresponds to the quality of the feed of rough scheelite flotation at PCF (at a concentration degree of 8.5 in the enriched product, the scheelite recovery was 69%), enabling to integrate it to the technological scheme of PFC. According to the combined gravity-flotation concentration scheme, a conditioned scheelite concentrate with a mass fraction of 70.9% WO_3 was obtained, throughout recovery being 57.3%.

Keywords: old tailings, scheelite, chalcopyrite, flotation, washability, gravity, mineral aggregates, sludge, testing.

* Corresponding author: elenashepeta56@mail.ru

1 Introduction

The decrease in the content of valuable minerals in ore at the final stages of the development of deposits necessitates an increase in the volume of processing of raw stock, an increase in the recovery of useful components while reducing the cost of obtaining commercial concentrates.

Possible directions of modernization of production facilities are the improvement of the technological scheme [1], including through the introduction of the preconcentration of the base ore [2–5], the regulation of the contrast of the flotation properties of the separated minerals [6–9], the use of new concentration devices [10, 11].

At Primorsky Concentrating Factory (PCF), the expansion of the mineral sources may be associated with the involvement of substandard mining dumps [12] and tailings stored in the tailings pond (old tailings) in the processing.

2 Materials and Methods

The tailings slurry of the flotation concentrating factory is discharged into the tailings pond. The distribution by size and content of the main elements in the tailings is presented in Table 1. The sample was taken from the tailings sump at PCF. Recovery of scheelite into the final standard concentrate was 86.5%, chalcopyrite into copper concentrate – 65%.

Table 1. Sieve characteristics of the sample of the current final tailings at PCF

Size classes, microns	Yield, %	Mass fraction, %			Content, g / t		Recovery, %				
		WO ₃	Cu	As	Ag	Au	WO ₃	Cu	Au	Ag	As
+250	4.69	0.05	0.037	0.03	0.96	0.22	2.66	3.05	4.62	2.53	2.15
–250+160	8.92	0.04	0.051	0.06	1.12	0.21	4.05	8.00	8.38	5.62	6.94
Total	13.61	0.04	0.046	0.048	1.06	0.21	6.72	11.05	13.00	8.15	9.08
–160+80	27.42	0.03	0.040	0.056	1.2	0.24	9.35	19.29	29.44	18.50	21.32
–80+15	37.55	0.037	0.037	0.09	1.65	0.24	15.79	24.44	40.32	34.83	46.40
–15+0	21.42	0.28	0.12	0.078	3.20	0.18	68.15	45.21	17.25	38.53	23.20
Total –80+0	58.97	0.13	0.067	0.085	2.21	0.22	83.93	69.65	57.56	73.36	69.60
Final tailings	100	0.088	0.057	0.072	1.78	0.22	100	100	100	100	100

The average content of valuable components in the tailings pond according to the commodity balance is as follows: WO₃ – 0.11%, Cu – 0.09%, Au – 0.76 g / t, Ag – 1.65 g / t; mass fraction of class –80+0 μm – 56–60%; pulp density – 2.5–3.0 g / cm³.

The feed for testing the washability of old tailings at PFC is represented by a sample taken from a winter reclamation ditch (in 2017) at a depth of 2 m. There was no liquid phase in the sample, its weight was 100 kg. The average mass fraction was, %: WO₃ – 0.08 (variation limits for individual samples 0.046–0.10), Cu – 0.052 (0.017–0.078), S – 2.04, As – 0.054, P – 0.13, CaCO₃ – 5.8; the average Au content being 0.38 g / t, Ag – 1.1 g / t. The average mass fraction of the size class –80+0 μm in the sample was 23%.

Drainage of the liquid phase of the pulp through the sands (at a depth of 2 m) led to a decrease in the content of valuable components in the sample by 50–66% and an increase in the size of the material. Therefore, further the initial sample of old tailings will be referred to as the sand fraction of old tailings (SFOT).

Mineral composition of SFOT, expressed by mass fraction in % is as follows: pyroxene – 40, quartz – 35, biotite – 10, calcite – 5.5, sulfides – 4.5, feldspars – 3, other minerals (amphibole, epidote, muscovite, limonite, apatite, scheelite) – 2. Contents of scheelite and chalcopyrite, their associations with minerals by size classes are presented in Table 2.

In the class of –500+250 μm, open intergrowths of scheelite with quartz, less often with pyroxene, those of chalcopyrite with pyrrhotite, less often with quartz were observed; the

grain size of valuable minerals was 0.01–0.03 mm. With a decrease in the size of the tailings, closed intergrowths of a fine placer of scheelite appear in quartz, less often in sulfides; chalcopyrite is characterized by complex Po–Q–Cp intergrowths, rare Cp–Ars intergrowths occur, grain size being less than 0.01 mm.

Table 2. Contents and associations of scheelite and chalcopyrite in the average sample of the sand fraction of old tailings by size class

Size classes, microns	Yield, %	Mass fraction, %		Recovery, %		Mass share of intergrowths, %		Associations with minerals	
		Shl	Cp	Shl	Cp	Shl	Cp	Shl	Cp
–500+250*	17.76	0.060	0.13	11.72	16.61	95–90	100	Q, Px	Po, Q
–250+160	20.18	0.054	0.12	11.98	17.42	50–65	60–70	Q, Px,	Po, Q,
–160+80	39.04	0.104	0.17	44.65	47.75	5–10	25–30	Po	Ars
–80+0	23.02	0.125	0.11	31.65	18.22	—	—	—	—
Total	100	0.091	0.14	100	100				

* The percentage of grain size +500 microns in the sample is 0,15 %. Mass fraction of WO_3 — 0,073 %, Cu — 0,048 %. Abbreviations: Shl — scheelite, Cp — chalcopyrite, Q — quartz, Px — pyroxene, Po — pyrrhotite, Ars — arsenopyrite.

To assess flotation, a sample of the sand fraction of old tailings was ground in a laboratory ball mill at the ratio S:L:Me = 1 (kg):600 (ml):8 (kg), grinding time being 15 minutes. As a result, the proportion of grains of flotation size in the flotation feed increased, the distribution of target minerals in intergrowths decreased, and the mineral surface was activated due to the removal of surface films. After regrinding, the mass fraction of the flotation class –80+0 μm in the flotation feed was 58%. The distribution of tungsten trioxide and copper was 73% and 75%, respectively.

Flotation of scheelite and chalcopyrite from crushed SFOT samples was carried out in laboratory machines – mechanical flotation machine Mekhanobr (chamber volume 3 l, sample weight 1 kg) and Pneufлот® (contact tank volume 60 l, chamber volume 12.5 l, sample weight 15 kg) – using circulating water. Commercial Pneufлот® machines can beneficiate less than 0.3 mm ore material without regrinding. The content of rough matter in circulating water was 4.5 g/l, pH = 8.7. The flotation scheme included main sulphide flotation (10 min), rough scheelite flotation and two control flotations with a total time of 15 min. The pulp pH modifiers were not fed to the sulfide flotation; dialkyldithiophosphate IMA-I413p (25 g/t) was used as a collector, pine oil (20 g / t) was used as a foaming agent, and water glass (100 g/t) was introduced to reduce the loss of scheelite with sulfides. Scheelite cycle reagent mode: soda – 3.6 kg/t (pH = 10.4, pulp hardness – 0.96 mg-eq/l), water glass – 350 g/t, sodium oleate of technical acid B-115 – 250+50+25 g/t; pulp temperature during conditioning with reagents 28 °C.

Testing of the enrichment parameters according to the combined scheme was carried out on a laboratory gravity table and Mekhanobr V-3(1.0)-0.5 (0.3-0.1) l flotation machines.

The Pneufлот® laboratory unit was installed at the industrial site of PCF. Grinding of kilogram samples to a size of 58% of the class –80+0 μm and comparative experiments on a laboratory mechanical machine were carried out in a research laboratory using circulating water.

It was expedient to compare the washing capacity of the sand fraction of old tailings and the washing capacity of final tailings from the tailings sump. When testing in a Pneufлот® machine, a sample of the sand fraction was diluted with circulating water. In the contact tank, the slurry volume was 56 liters at 24.4% solids. Additionally (to eliminate the possibility of clogging of the power supply nozzles), circulating water was introduced into the chamber of the flotation machine with a volume of 4 liters. The tailings sample was transferred to the contact tank without dilution.

3 Results and Discussion

The results of flotation are presented in Table 3. Testing consisted of two runs in each batch. The best results are given.

Table 3. Parameters of concentration of final tailings of PCF and SFOT sample

Product	Pneufлот® flotation machine			Mekhanobr mechanical machine		
	Yield, %	Mass fraction of WO ₃ , %	Recovery of WO ₃ , %	Yield, %	Mass fraction of WO ₃ , %	Recovery of WO ₃ , %
Test 10, floatation feed being PCF final tailings (sampling point is tailings sump)						
WO ₃ rough floatation concentrate	4.70	0.20	10.42	1.89	0.22	4.70
Tailings	95.30	0.083	89.58	97.01	0.085	93.30
S-concentrate	—	—	—	1.10	0.16	1.99
Total	100	0.088	100	100	0.088	100
Test 11, floatation feed being SFOT						
WO ₃ rough floatation concentrate	8.17	0.60	69.43	5.93	0.62	52.45
Tailings	90.42	0.022	28.17	87.50	0.03	37.29
S-concentrate	1.41	0.12	2.40	6.57	0.11	10.26
Total	100	0.071	100	100	0.070	100

The absence of sulphide flotation and the extremely low recovery of scheelite from the tailing pulp is associated with a high residual concentration of water glass – 2.5–3 g / l, pH = 9.9 (in the process flow diagram of PCF enrichment, the upgrading of rough scheelite concentrates is performed using the Petrov method).

The best results in the flotation of scheelite from the sand fraction were obtained in the Pneufлот® flotation machine. With a concentration degree of 8.5 in the enriched product, the scheelite recovery was 69%. Table 4 shows that a rough concentrate with a mass fraction of WO₃ of 0.62% and an extraction of scheelite of 52.5% was separated in a laboratory mechanical machine. A significant proportion of scheelite losses (22% of total losses) are associated with sulfide concentrate. In a mechanical engine, sulfides floated more actively. The yield of sulfide concentrate was 6.6%, the mass fraction of Cu – 0.48%, S – 22.5%, As – 0.24%, copper recovery – 65.7%. Fine scheelite less than 44 microns in size is lost with sulfides. By introducing two cleaners (chamber volume 0.5–0.2 l) of sulfide concentrate, it is possible to reduce the loss of scheelite with sulfides to 2.11% while recovering 45% copper with a mass fraction of Cu 0.83%. With the introduction of sulfide middlings into the scheelite cycle, a rough concentrate was obtained with a mass fraction of WO₃ 0.47% and the recovery of 59.7%.

In the Pneufлот® machine, sulphide flotation was practically absent; the recovery of copper into sulphide concentrate was 9.5% with its mass fraction of 0.32%.

The quality of the enriched scheelite product obtained from the sand fraction of old tailings corresponds to the quality of the feed for the rough scheelite flotation at PCF, which allows integrating it with the PCF's process flow diagram.

The sieve performance of the tailings of the Pneufлот® cell is shown in Table 4.

Table 4. Distribution of scheelite by size class in Pneufлот® tailings

Size classes, microns	Yield, %	Mass fraction of WO ₃ , %	Distribution in tailings, % of			Recovery to concentrate, % of size class
			product	primary flotation feed	class	
+160	2.61	0.015	2.00	0.55	42.0	58.0
-160+80	40.56	0.018	37.67	10.31	44.0	56.0
-80+44	19.84	0.016	17.11	4.68	22.4	77.6
-44+15	24.12	0.014	17.60	4.81	17.9	82.1
-15+0	12.87	0.038	25.62	7.01	25.5	74.5
Total	100	0.019	100	27.36	—	—

Flotation of SFOT in Pneufлот® showed the possibility of separating scheelite into a concentrated primary flotation concentrate from material with a size of -44+15 microns by 82%, and with a size of -15+0 microns (from sludge) by 75% of the class, for the mechanical machine (volume 3 l) – 77% and 49% of the class, respectively. The design of the Pneufлот® flotation machine made it possible to increase the efficiency of scheelite flotation from sludge by 1.5 times. These studies on flotation made it possible to assess the flotation capacity of the tailing dump materials; however, industrial enrichment of raw stock with such a low initial content of valuable minerals is economically inexpedient. The combined gravity-flotation scheme of SFOT processing has been studied. The results of enrichment of scheelite and chalcopyrite on a laboratory concentration table are presented in Table 5.

Table 5. Distribution of valuable components by SFOT gravity products

Products	Yield, %	Mass fraction, %		Recovery, %	
		WO ₃	Cu	WO ₃	Cu
Gravity concentrate	1.14	4.07	0.063	58.01	1.37
Middling of re-cleaning 2	2.87	0.17	0.12	6.12	6.60
<i>Total combined gravity product</i>	<i>4.01</i>	<i>1.28</i>	<i>0.10</i>	<i>64.13</i>	<i>7.97</i>
Middling of re-cleaning 1	37.07	0.039	0.074	18.13	52.54
Gravity tailings	58.92	0.024	0.035	17.74	39.49
<i>Total SFOT</i>	<i>100</i>	<i>0.080</i>	<i>0.052</i>	<i>100</i>	<i>100</i>

With the help of gravity concentration on the concentration table, it is possible to separate 4% of SFOT into a combined gravity product with a mass fraction of WO₃ – 1.28%, and scheelite recovery at 64%. Chalcopyrite is redistributed to the middling product of the first cleaning and tailings.

The results of enrichment for impurities on a laboratory concentration table are presented in Table 6.

Table 6. Distribution of impurities in SFOT gravity products

Products	Yield, %	Mass fraction, %				Recovery, %			
		P	Ca	S	As	P	Ca	S	As
Gravity concentrate	1.14	0.79	0.72	27.98	4.21	6.80	0.14	15.59	88.04
Middling of re-cleaning 2	2.87	0.17	3.77	17.22	0.18	3.69	1.86	24.23	9.51
<i>Total combined gravity product</i>	<i>4.01</i>	<i>0.35</i>	<i>2.90</i>	<i>20.27</i>	<i>1.32</i>	<i>10.49</i>	<i>2.00</i>	<i>39.82</i>	<i>97.55</i>
Middling of re-cleaning 1	37.07	0.16	7.79	2.31	0.002	44.90	49.51	41.98	1.36
Gravity tailings	58.92	0.10	4.8	0.63	0.001	44.61	48.49	18.20	1.08
<i>Total SFOT</i>	<i>100</i>	<i>0.13</i>	<i>5.83</i>	<i>2.04</i>	<i>0.054</i>	<i>100</i>	<i>100</i>	<i>100</i>	<i>100</i>

Mass share of P is 1.1%, As – 0.052%, S – 0.35 %, CaCO₃ – 4.3 %.

In terms of the mass fraction of apatite and calcite, the combined gravity product corresponds to the current PCF's ore. An increased content of pyrrhotite and arsenopyrite is noted. In the flotation cycle in a closed experiment, the final conditioned scheelite concentrate with a mass fraction of WO_3 of 71%, recovery from feed at 89% was isolated from 6 kg weighed portions of the combined gravity product according to the PCF's technological scheme. The results are shown in Table 7.

Table 7. Results of flotation of valuable components of the gravity product

Products	Yield, %	Mass fraction, %		Recovery, %	
		WO_3	Cu	WO_3	Cu
WO_3 concentrate	1.56	70.88	0.010	89.29	0.15
Upgraded tailings	4.98	0.96	0.011	3.84	0.54
Drainage	0.09	9.1	0.055	0.67	0.05
Total rough concentrate	6.63	17.55	0.012	93.80	0.74
Cu concentrate	41.06	0.098	0.022	3.23	8.59
Copper tailings	0.60	0.11	8.30	0.05	47.85
Total S concentrate	51.71	0.07	0.086	2.92	42.82
Combined gravity product	52.31	0.07	0.18	2.97	90.67
	100	1.24	0.10	100	100

The performed volume of research allows calculating the indicators of the combined scheme of SFOT processing. Data are presented in the diagram (Fig. 1).

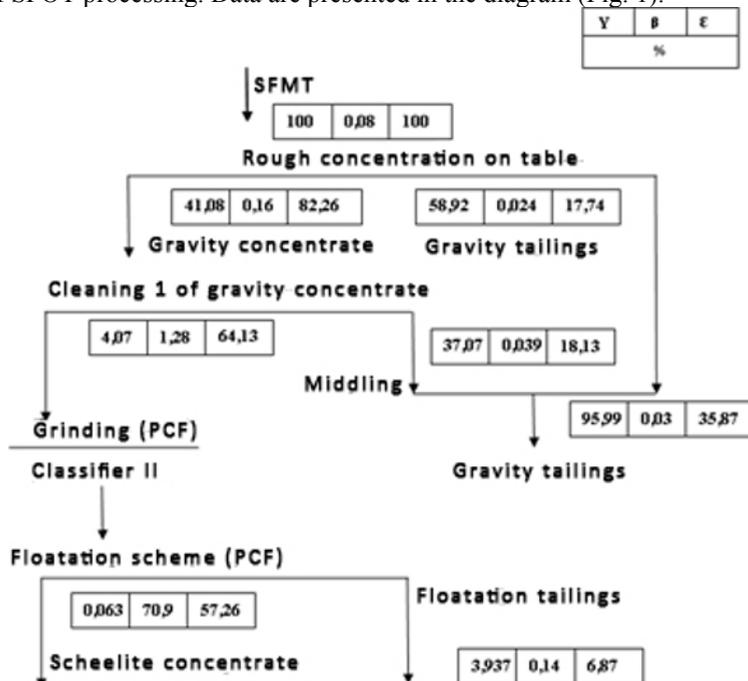


Fig. 1. Combined scheme of processing SFOT at PCF

4 Conclusions

The possibility of processing old tailings of Primorsky Concentrating Factory has been assessed. A comparison of flotation concentration of SFOT using a laboratory mechanical machine and a Pneuflot® flotation machine was made. The recovery of scheelite at the same degree of concentration in Pneuflot® machine is 16.5% higher, due to 1.5 times more efficient sludge flotation (-15+0 μ m). Flotation of SFOT using Pneuflot® showed the

possibility of separating scheelite into a concentrated primary flotation concentrate from materials with a size of -44+15 microns by 82%, and with a size of -15+0 microns (from sludge) by 75% of the class, for a mechanical machine (volume 3 l) – 77% and 49% of the class, respectively. The quality of the enriched scheelite product obtained from the sand fraction of old tailings meets the requirements for rough scheelite flotation at PCF, enabling to include it in the PCF's technological scheme.

According to the combined gravity-flotation enrichment scheme, a conditioned scheelite concentrate was obtained with a mass fraction of 70.9% WO₃, throughout recovery being 57.3%.

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