PRE-CONTACT PNEUMATIC FLOTATION OF COPPER PORPHYRY ORE FROM ASSAREL DEPOSIT

Tsvetelina Ivanova, Marin Ranchev, Irena Grigorova, Ivan Nishkov

University of Mining and Geology "St. Ivan Rilski"; 1700 Sofia; irena_mt@abv.bg

ABSTRACT. The PNEUFLOT flotation machine is a representative of a new generation of pre-contact columns flotation machines combining the principle of pneumatic spraying with the column flotation cell design. The PNEUFLOT flotation machine does not have an impeller system. This means no wear and friction in the system stator - rotor. Another important feature is the ability to create finer air bubbles and lower air consumption than conventional pneumo-mechanical machines, resulting in flotation of fine products and obtaining high-quality concentrates. Porphyry-copper ores in the "Assarel" deposit is characterised by a variable and complex mineral composition and varying physical properties. In order to establish the possibilities for flotation with pre-contact on the ore, processed in the Assarel Flotation Plant, a series of flotation experiments with selected products from the technological circuit of the plant were carried out. The flotation tests were performed at the optimal technical parameters of the flotation machine and the experimental results obtained present the efficient flow of the selectivity of the flotation process, mainly due to the hydrodynamic conditions in the PNEUFLOT flotation machine, which creates a prerequisite for efficient separation of the copper minerals and molybdenite from the gangue.

Keywords: flotation, copper ores, Pneuflot, flotation machines

ФЛОТАЦИЯ С ПРЕДВАРИТЕЛЕН КОНТАКТ НА МЕДНОПОРФИРНА РУДА ОТ НАХОДИЩЕ АСАРЕЛ

Цветелина Иванова, Марин Ранчев, Ирена Григорова, Иван Нишков
Минно-геоложки университет "Св. Иван Рилски", 1700 София

РЕЗЮМЕ. Флотационната машина PNEUFLOT е представител на едно ново поколение колонни флотационни машини с предварителен контакт, комбиниращи принципа на пневматичното пулверизиране в съчетание с колонния дизайн на флотационната клетка. Флотационната машина PNEUFLOT не притежава импелерна система, което означава, че няма износване и триене в системата статор - ротор. Друга важна характеристика е възможността да се създават по-фини въздушни мехурчета и по-нисък разход на въздух в сравнение с класическите пневмомеханични машини, което води до флотация на фини продукти и получаване на висококачествени концентрати. Меднопорфирните руди в находище "Асарел" се характеризират с променлив и сложен минерален състав и вариращи физични свойства. С цел установяване възможностите за флотация с предварителен контакт на рудата, преработвана в ОФ „Асарел", са проведени серии от флотационни експерименти с избрани продукти от технологичната верига на обогатителния комплекс. Флотационните тестове са проведени при оптимални технически параметри на флотационната машина, като получените експериментални резултати ясно показват ефективното протичане на селективността на флотационния процес, дължащо се най-вече на хидродинамичните условия във флотационната машина PNEUFLOT, което създава предпоставка и за добро разделяне на медните минерали и молибденита от скалните примеси.

Ключови думи: флотация, медна руда, Pneuflot, флотационни машини

Introductıon

Flotation is an important and versatile mineral processing step used to achieve selective separation of minerals and gangue. It utilises the hydrophobic nature of mineral surfaces and their propensity to attach to rising air bubbles in water–ore pulp as the basis for separation (Biswas, A., Davenport, W., 1994).

Metal sulphide minerals, for which this process was originally developed, are generally weakly polar in nature and consequently, most have a hydrophilic surface (Wills, 1997).

The flotation reagent MINFIT is a unique complex of modified sulphites specifically developed for depressing iron sulphide minerals (pyrite, pyrrhotite, marmatite, etc.).

In the pneumatic pre-contact column flotation machines, such as PNEUFLOT® the contact between the solid phase (feed) and the air flow is performed in a mixing device at the top of a vertical pipe, or in a separate agitating tank (reactor) or in several aeration devices, disposed along the flotation cell feed slurry pipelines.

The main advantages of these devices are that the total height of the cell is reduced compared to conventional column machines, it can be self-induced with respect to air supply, there are no moving parts and flotation time is relatively fast. All this combined with the appropriate selection of flotation reagents will contribute to higher selectivity and production of high quality concentrates.

The study was conducted in the form of several laboratory flotation experiments in order to assess the effect of the reagent MINFIT®, the optimal concentration of residual CaO (mg/l) and the pros and cons of adding a conical froth crowder on the top of the flotation cell. The flotation tests were conducted in a PNEUFLOT pneumatic flotation machine – PNEUFLOT® (MBE Coal & Minerals Technology).

Materials and Methods

Table 1 presents the conditions of the flotation experiment performed with PNEUFLOT laboratory machine. The flotation experiment was carried out without using a conical froth crowder.

Table 1. *Flotation test conditions*

Parameters	Value
Solids concentration (%w/w)	32.00
pH of the pulp	11.76
Feed slurry flowrate (l/h)	350
Air flowrate (l/h)	300
Feed nozzles size (mm)	2.70
Froth height (mm)	70
Without using a conical froth crowder	√
Residual CaO concentration (mg/l)	588.00
MINFIT consumption (g/t)	200
Flotation time (min.)	Rougher flotation 2, 5, 7 and 9 min. Scavenger flotation 18 min.

Table 2 presents the conditions of the second flotation experiment performed with PNEUFLOT laboratory machine, when using a conical froth crowder.

Table 2. *Flotation test conditions*

Parameters	Value
Solids concentration (% w/w)	32.00
pH of the pulp	12.19
Feed slurry flowrate (l/h)	350
Air flowrate (l/h)	300
Feed nozzles size (mm)	2.70
Froth height (mm)	70
With using a conical froth crowder	√
Residual CaO concentration (mg/l)	590.18
Consumption of MINFIT (g/t)	200
Flotation time (min.)	Rougher flotation 2, 5, 7 and 9 min. Scavenger flotation 18 min.

Results and discussions

Tables 3-4 present the technological results from the flotation test without using a conical froth crowder.

Table 3. *Grade results of flotation test without using a central froth crowder*

Products	Mass pull, %	Grade, %					
		Cu	Mo, g/t	Fe	S	Al_2O_3	SiO_2
Ro Conc 1 (2`)	13.52	6.036	1121	27.97	31.54	4.97	23.53
Ro Conc 2 (5`)	13.18	4.172	1261	28.27	30.25	5.01	23.81
Ro Conc 3 (7`)	7.57	3.09	1205	29.07	30.85	4.82	23.34
Ro Conc 4 (9`)	5.29	2.376	1097	29.85	33.01	4.78	23.48
Ro Conc	39.55	4.36	1180.50	28.53	31.17	4.93	23.58
Scavenger Conc (18`)	7.99	2.151	1299	31.18	32.12	4.79	21.79
Tail	52.45	0.62	232	29.18	33.37	5.48	23.7
Feed	100	2.22	692.45	29.08	32.40	5.21	23.50

Table 4. *Recovery results of flotation test without using a central froth crowder*

Products	Mass pull, %	Recovery, %					
		Cu	Mo	Fe	S	Al_2O_3	SiO_2
Ro Conc 1 (2`)	13.52	36.71	21.88	13.00	13.16	12.90	13.53
Ro Conc 2 (5`)	13.18	24.74	24.00	12.81	12.30	12.68	13.35
Ro Conc 3 (7`)	7.57	10.52	13.17	7.57	7.21	7.01	7.52
Ro Conc 4 (9`)	5.29	5.66	8.38	5.43	5.39	4.86	5.29
Ro Conc	39.55	77.63	67.43	38.80	38.06	37.44	39.69
Scavenger Conc (18`)	7.99	7.74	14.99	8.57	7.92	7.35	7.41
Tail	52.45	14.63	17.57	52.63	54.02	55.20	52.90
Feed	100	100	100	100	100	100	100

Figure 1 presents the cumulative (%) recovery of the chemical components versus flotation time (flotation kinetics).

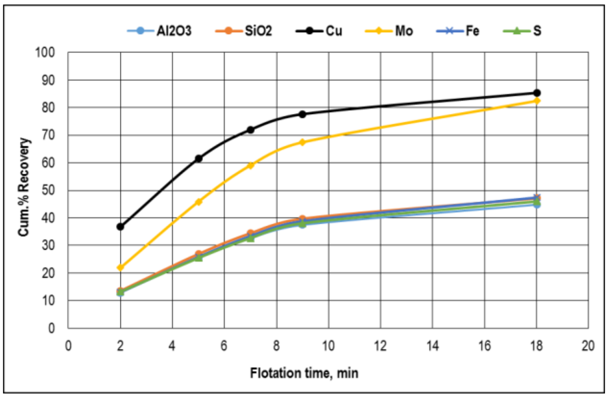

Fig. 1. Flotation time vs cumulative % recovery - flotation test without using a central froth crowder

Figure 2 presents the relation between the cumulative mass pull and the cumulative Cu recovery during the flotation experiment without using a central froth crowder.

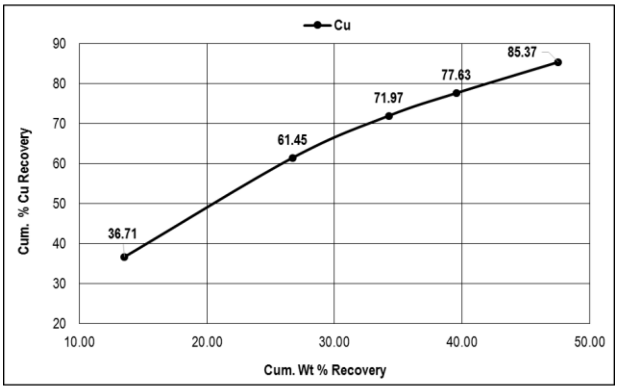

Fig. 2. Cumulative weight recovery vs cumulative Cu recovery - flotation test without using a central froth crowder

The technological results of the flotation test conducted with a conical froth crowder are presented in Tables 5-6.

Table 5. *Grade results of the flotation test with a conical froth crowder*

Products	Mass pull, %	Grade, %					
		Cu	Mo, g/t	Fe	S	Al_2O_3	SiO_2
Ro Conc 1 (2`)	9.98	6.186	1046	30.86	35.47	4.27	19.89
Ro Conc 2 (5`)	9.38	4.051	1131	28.87	33.38	4.92	23.62
Ro Conc 3 (7`)	5.68	3.452	1173	30.34	35.75	4.56	22.31
Ro Conc 4 (9`)	5.82	2.71	1018	29.8	35.5	4.79	23.37
Ro Conc	30.87	4.38	1089.93	29.96	34.89	4.62	22.13
Scavenger Conc (18`)	15.12	2.412	1050	30.45	33.28	4.7	22.35
Tail	54.02	0.816	227	30.09	35.42	5.03	22.4
Feed	100	2.16	617.77	30.10	34.93	4.85	22.31

Table 6. *Recovery results of the flotation test with a conical froth crowder*

Products	Mass pull, %	Recovery, %					
		Cu	Mo	Fe	S	Al_2O_3	SiO_2
Ro Conc 1 (2`)	9.98	28.63	16.90	10.23	10.13	8.78	8.90
Ro Conc 2 (5`)	9.38	17.62	17.17	9.00	8.96	9.51	9.93
Ro Conc 3 (7`)	5.68	9.10	10.79	5.73	5.82	5.34	5.68
Ro Conc 4 (9`)	5.82	7.32	9.59	5.76	5.92	5.75	6.10
Ro Conc	30.87	62.66	54.46	30.72	30.83	29.38	30.61
Scavenger Conc (18`)	15.12	16.91	25.70	15.29	14.40	14.64	15.15
Tail	54.02	20.44	19.85	53.99	54.77	55.98	54.24
Feed	100	100	100	100	100	100	100

Figures 3 and 4 present the results of rougher copper flotation (9 min) and scavenger copper flotation (9 min) whenusing a central froth crowder.

Figure 3 presents the cumulative (%) recovery of the chemical components versus flotation time (flotation kinetics).

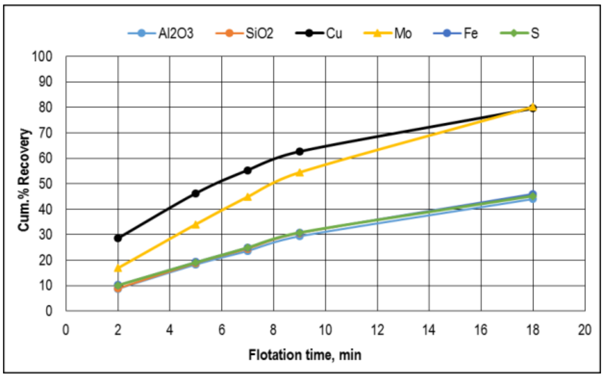

Fig. 3. Flotation time vs cumulative % recovery

Figure 4 presents the relation between the cumulative mass pull and the cumulative Cu recovery during the flotation experiment with a central froth crowder.

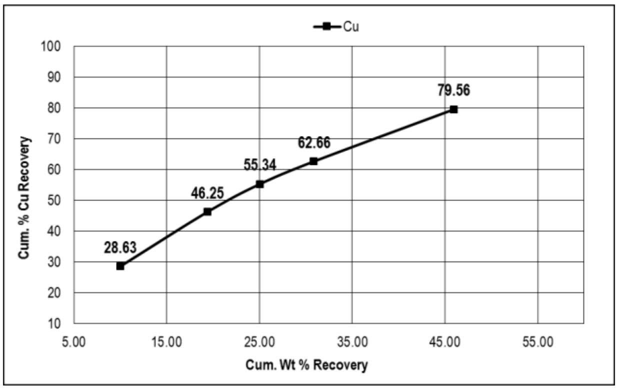

Fig. 4. Cumulative weight recovery vs. cumulative Cu recovery - flotation test with a central froth crowder

Figures 1 and 3 show the effect of MINFIT depressant. The consumption of 200 g/t and hydrodynamic conditions of the PNEUFLOT flotation machine results in higher selectivity against pyrite.

Investigation of the influence of residual calcium oxide (CaO) concentration on the flotation process efficiency

A series of laboratory flotation experiments were carried out during which the residual calcium oxide (CaO) concentration was maintained and controlled within certain limits, depending on the characteristic of the feed pulp entering the rougher and/or scavenger copper flotation circuit.

The experiments were carried out with a representative slurry sample from the mineral processing plant. The solids' concentration varies between 30-35%, pH of the pulp varies within the range of 12.30-12.66 pH, froth height varies between 60-80 mm and the grain size ranges within certain limits for the individual tests. It was determined that the residual calcium oxide concentration in flotation feed slurry is about 340 mg/l. An appropriate amount of calcium hydroxide [$Ca(OH)_2$] was added to the feed pulp, in order to achieve a concentration of residual calcium oxide in the range of 650-700 mg/l.

After rougher copper flotation (9 min), CaO content was around 175 mg/l. In the rougher flotation tail product, calcium hydroxide was added [$Ca(OH)_2$] in order to obtain a residual

CaO concentration within the range of 650-700 mg/l. Tables 7-8 present the technological results from the flotation test with residual CaO concentration 700 mg/l.

Table 7. *Grade results of the flotation test with residual CaO concentration of 700 mg/l*

Products	Mass pull, %	Grade, %					
		Cu	Mo, g/t	Fe	S	Al_2O_3	SiO_2
Ro Conc 1 (2`)	7.52	9.47	2867	34.82	41.51	2.38	10.7
Ro Conc 2 (5`)	10.14	7.75	4899	33.38	41.1	2.71	12.87
Ro Conc 3 (7`)	5.93	6.72	6308	35.05	39.85	2.47	12.74
Ro Conc 4 (9`)	5.23	5.55	6343	31.32	38.92	3.26	18.81
Ro Conc	28.82	7.59	4920.24	33.73	40.55	10.31	13.35
Scavenger Conc (18`)	19.04	2.96	5560	30.33	40.54	4.1	21.05
Tail	52.15	1.5	1024	29.6	38.77	4.83	23.54
Feed	100	3.53	3010.27	30.93	39.62	6.27	20.13

Table 8. *Recovery results of the flotation test with residual CaO concentration of 700 mg/l*

Products	Mass pull, %	Recovery, %					
		Cu	Mo	Fe	S	Al_2O_3	SiO_2
Ro Conc 1	7.52	20.17	7.17	8.47	7.88	4.40	4.00
Ro Conc 2	10.14	22.24	16.50	10.94	10.52	6.75	6.48
Ro Conc 3	5.93	11.28	12.42	6.72	5.96	3.60	3.75
Ro Conc 4	5.23	8.21	11.01	5.29	5.13	4.19	4.88
Ro Conc	28.82	61.90	47.10	31.42	29.49	18.93	19.11
Scavenger Conc (18`)	19.04	15.95	35.16	18.67	19.48	19.18	19.91
Tail	52.15	22.14	17.74	49.91	51.03	61.89	60.98
Feed	100	100	100	100	100	100	100

Figures 5 and 6 present the results of the flotation test - rougher (9 min.) and scavenger (9 min.) copper flotation with residual CaO concentration of 700 mg/l.

Figure 5 presents the cumulative Cu recovery (%) versus cumulative recovery of other components (Mo, Fe, S, Al_2O_3, SiO_2).

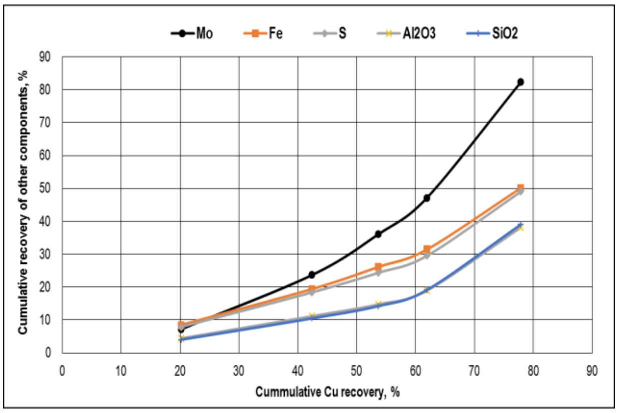

Fig. 5. Cu/Mo, Fe, S, Al_2O_3, SiO_2 selectivity as a function of flotation time

Figure 6 presents the Cu and Mo grade of the obtained flotation concentrates.

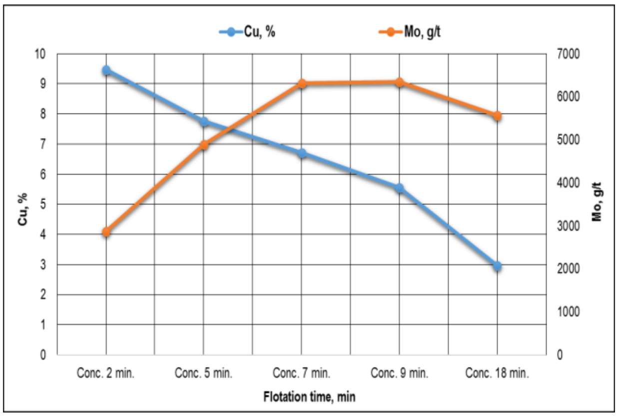

Fig. 6. Cu and Mo grade in the obtained flotation concentrates

It was determined that the residual concentration of calcium oxide in the flotation feed pulp was 436.66 mg/l. In order to increase the concentration, an appropriate amount of calcium hydroxide $Ca(OH)_2$ was added to the pulp, establishing a concentration of residual calcium oxide within the range of 650-700 mg/l.

After rougher copper flotation (9 min), CaO concentration was 244.24 mg/l. An additional amount of calcium hydroxide $Ca(OH)_2$ was added to scavenger flotation feed in order to maintain the concentration of residual calcium oxide in the scope of 650-700 mg/l.

Tables 9-10 present the technological results from the flotation test with maintained residual CaO concentration between 650-700 mg/l.

Table 9. *Grade results of the flotation test with residual CaO concentration of 677 mg/l*

Products	Mass pull, %	Grade, %					
		Cu	Mo, g/t	Fe	S	Al_2O_3	SiO_2
Ro Conc 1 (2`)	9.21	9.47	1692	30.78	38.52	3.09	15.23
Ro Conc 2 (5`)	11.88	7.98	2893	29.66	37.89	4.23	18.97
Ro Conc 3 (7`)	9.11	5.25	4658	29.69	38.65	4.37	20.74
Ro Conc 4 (9`)	11.30	3.20	4801	24.57	33.77	5.71	29.42
Ro Conc	41.50	6.41	3533.26	28.53	37.07	4.41	21.37
Scavenger Conc (18`)	22.94	2.56	3075	24.07	33.22	5.57	29.56
Tail	35.57	1.04	723	26.76	32.06	6.22	28.87
Feed	100	3.62	2428.61	26.88	34.41	5.32	25.92

Figures 7 and 8 present the results of the flotation test - rougher (9 min.) and scavenger (9 min.) copper flotation with residual CaO concentration of 677 mg/l.

Figure 7 presents the cumulative Cu recovery (%) versus the cumulative recovery of other components (Mo, Fe, S, Al_2O_3, SiO_2).

Table 10. *Recovery results of the flotation test with residual CaO concentration of 677 mg/l*

Products	Mass pull, %	Recovery, %					
		Cu	Mo	Fe	S	Al_2O_3	SiO_2
Ro Conc 1 (2`)	9.21	24.12	6.42	10.55	10.31	5.35	5.41
Ro Conc 2 (5`)	11.88	26.19	14.15	13.11	13.08	9.44	8.69
Ro Conc 3 (7`)	9.11	13.21	17.47	10.06	10.23	7.48	7.29
Ro Conc 4 (9`)	11.30	9.99	22.33	10.33	11.09	12.13	12.82
Ro Conc	41.50	73.50	60.37	44.05	44.71	34.40	34.22
Scavenger Conc (18`)	22.94	16.28	29.04	20.54	22.15	24.01	26.16
Tail	35.57	10.22	10.59	35.41	33.14	41.58	39.62
Feed	100	100	100	100	100	100	100

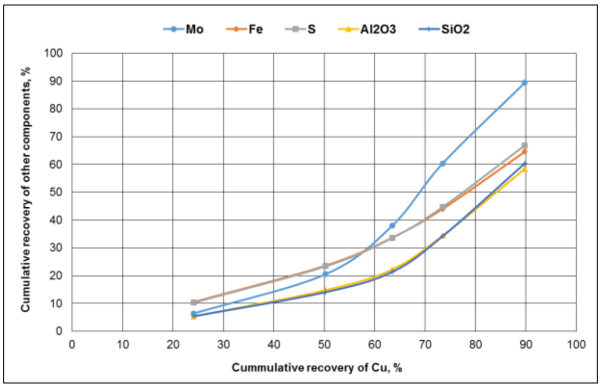

Fig. 7. Cu/Mo, Fe, S, Al_2O_3, SiO_2 selectivity as a function of flotation time

Figure 8 presents the Cu and Mo grade of the obtained flotation concentrates.

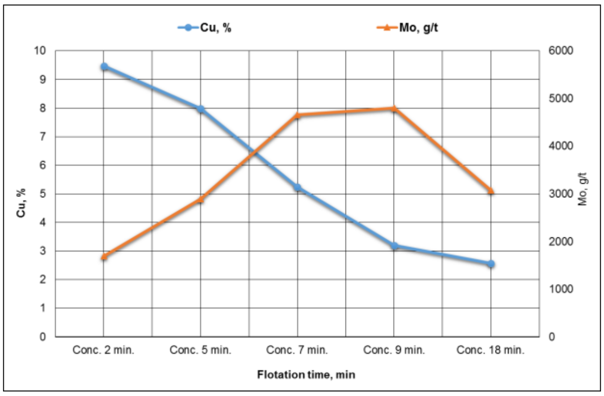

Fig. 8. Cu and Mo grade in the obtained flotation concentrates

Conclusions

The experimental results obtained during the flotation tests of copper–porphyry ore, showed that when using MINFIT® (200 g/t) depressant in the hydrodynamic conditions of the PNEUFLOT flotation machine, the flotation process proceeds with a higher pyrite selectivity. While, the Cu grade in the gangue is within the range of 0.6 and 0.82% and the Mo grade is about 230 g/t. The higher content of residual calcium oxide in the flotation pulp, results in low concentrate mass pull, but on the other hand, with an increased Cu grade in the final concentrate.

Maintaining an optimal residual concentration of CaO in the range of 650-700 mg/l in the rougher flotation circuit results in approximately 30% concentrate mass pull with 7.59 Cu grade. Maintaining an optimal residual concentration of calcium oxide in rougher and scavenger copper flotation leads to lower Cu content in the flotation tail and a total recovery of copper and molybdenum within the range of 90%. The selectivity curves clearly show the higher selectivity of the flotation process (depressed pyrite). Apparently, the hydrodynamic conditions in the PNEUFLOT flotation machine create a prerequisite for an effective separation (higher selectivity) of copper minerals and molybdenum from the gangue components (Al_2O_3 and SiO_2).

The kinetic curves showed that the copper minerals in rougher flotation circuit floated most rapidly during the first seven minutes, and Mo actively started to float after the fifth minute. It should be noted that the grade of Mo in some of the concentrates reached over 6000 g/t. Apparently, the hydrodynamic conditions in the PNEUFLOT flotation machine enable the flotation of fine molybdenum particles. It should be noted that the efficient flotation of Mo and the higher Mo grade (over 6000 g/t) in the obtained concentrates was possible due to the optimal hydrodynamic conditions created by the flotation cell. The laboratory flotation experiments were performed without using any molybdenum activating reagents, i.e. no suitable physicochemical conditions for Mo flotation were set up.

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