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ANALYSIS OF EFFICIENCY OF COLLECTIVE-SELECTIVE COPPER-LEAD ORE ENRICHMENT BY SODIUM OLEATE IN THE MAIN FLOTATION

Abstract: The problem of the polymetallic ores enrichment containing of copper, lead, zinc and other non-ferrous metals minerals' consists in the disclosure of splices, the separation of small-grained particles of one mineral from another mineral or waste rock. The purpose of this paper is studying the flotation reagents behavior in the suspension composition while ore enrichment according to the collectively selective scheme.

The elemental analysis of copper-lead ore samples is carried out. The flotation tests on the FML-1 flotation machine were carried out, the volume of the working chamber was 0.25 L, and the T-92 was used as the foaming agent. The decomposition with concentrated nitric and hydrochloric acids mixture's was applied to carry the ore samples and enrichment products to the solute state. The results of copper-lead ore enrichment the use of sodium oleate in the main flotation are presented. The material balance of copper-lead ore flotation process both for the main and control flotation and for the clean-up operations according to the collectively selective scheme (for the solid component) was calculated. It is shown that the addition of two clean-up operations to the scheme, with sodium dibutyl dithiothiophosphate as the main reagent, makes it possible to increase the lead and copper concentration in selective concentrates by 3 times. Based on the results of the material balance, the separation potentials and separation capacities of the main, reference and two clean-up flotations were calculated. The negative dynamics of the change in the separation potential from the initial stage of enrichment to the final one indicates the increase in the minerals separation complexity. The presence of the separation potential extremes relative to the metal concentration in the ore indicates a difference in the oxygen-containing and phosphorus-containing collectors reactivity. It has been established that the value of separating power serves as a quantitative measure of the applied flotation agents selectivity. Thus, the efficiency of the proposed enrichment scheme was evaluated based on separation criteria.

Key words: collectively-selective scheme, sodium oleate, sodium dibutyldithiophosphate, material balance, separation potential, separation power.

In contrast to past years, when some ores with a high content of lead, copper or zinc were sent after enrichment with potassium butyanthate in a collective or collectively selective scheme for metallurgical smelting, processing of ores of non-ferrous and rare metals mined in recent years is economically unprofitable without prior complex enrichment [1-5]. The problem of enrichment of sulfide copper-lead ores has not yet been fully resolved, since, on the one hand, ores are difficult to enrich in terms of dispersity and in terms of the identity of the flotation properties of the minerals that make up the ore. Therefore, finding more selectively active collectors [6-10] and more advanced modifiers will lead to further improvement of the flotation process [11-16]. In connection with this, the goal of the work is to evaluate the efficiency of copper-lead ore enrichment in a collectively selective scheme using sodium oleate in the main flotation.

Methods

Foam flotation was carried out on a laboratory flotation machine FML-1 with a chamber volume of 0.5 l by the following procedure: a sample of ore (75% of a fraction of 0.074 mm) with a mass of 10 g was loaded into the flotation chamber and mixed with water. Lime was added to maintain the desired pH. Then, a solution of the collector of a given concentration, a foaming agent, was added to the chamber, and stirring was continued for 9 minutes. As the flotation agent, collectors, sodium oleate and sodium dibutyl dithiophosphate (basic substance w 60%) were used. Foaming agent was T-92, consumption was 15 g/t. Decomposition of the samples of the initial ore and the resulting concentrates (0.1 g) was carried out with a mixture of concentrated hydrochloric and nitric acids (3: 1) [17]. Determination of the concentration of metal ions Cu^{2+}, Pb^{2+} was carried out using the Varian AA140 atomic absorption spectrometer. Elemental analysis was performed on an X-ray fluorescent analyzer of the Olimpus Delta XRF brand (Table 1).

Table 1 - Element composition of copper-lead ore

Element	Mass fraction, %	σ	**$Z_{a/2}$+σ/√(n)**	Element	Mass fraction, %	σ	**$Z_{a/2}$+σ/√(n)**
O	50.12	$2.14\cdot10^{-7}$	$2.96\cdot10^{-7}$	Mn	0.20	$2.50\cdot10^{-11}$	$3.46\cdot10^{-11}$
Na	2.91	$3.91\cdot10^{-9}$	$5.41\cdot10^{-9}$	Fe	8.83	$2.38\cdot10^{-7}$	$3.29\cdot10^{-7}$
Mg	5.64	$2.25\cdot10^{-8}$	$3.12\cdot10^{-8}$	Ni	0.04	$3.06\cdot10^{-10}$	$4.24\cdot10^{-10}$
Al	9.18	$5.63\cdot10^{-9}$	$7.80\cdot10^{-9}$	**Cu**	**0.99**	$\mathbf{2.40\cdot10^{-8}}$	$\mathbf{3.33\cdot10^{-8}}$
S	3.01	$3.18\cdot10^{-9}$	$5.38\cdot10^{-9}$	**Zn**	**0.08**	$\mathbf{1.41\cdot10^{-9}}$	$\mathbf{1.95\cdot10^{-9}}$
Si	17.00	$2.86\cdot10^{-7}$	$3.97\cdot10^{-7}$	Mo	0.39	$1.23\cdot10^{-9}$	$1.70\cdot10^{-9}$
K	0.02	$9.00\cdot10^{-10}$	$1.25\cdot10^{-9}$	Cd	0.01	$6.25\cdot10^{-12}$	$8.66\cdot10^{-12}$
Ca	1.03	$2.25\cdot10^{-10}$	$3.12\cdot10^{-10}$	**Pb**	**0.05**	$\mathbf{6.25\cdot10^{-10}}$	$\mathbf{8.66\cdot10^{-10}}$
Ti	0.48	$5.26\cdot10^{-9}$	$7.28\cdot10^{-9}$				

The results of elemental analysis show that the useful part of sulfide copper-lead ore (Table 1) is represented by metals Fe, Pb, Cu, Zn and nonmetals S, difficult to enrich the minerals Mn, Ti, the empty rock is composed of elements Ca, C, Si, Al, Mg, which allows to judge the presence of iron sulfides, iron oxides, lead sulfides, copper, zinc, and also silicates, carbonates, calcium and magnesium aluminates in the samples, the most common are quartz, calcite, orthoclase ($K[(Si,Al)_4O_8]$), anorthite ($CaAl_2Si_2O_8$), olivine $MgFeSiO_4$, kaolinite ($Al_4\,[Si_4O_{10}](OH)_8$).

Technological parameters of enrichment were calculated by formulas

$$\gamma\kappa = 100(\alpha-\theta)/(\beta-\theta)\gamma\kappa = 100(\alpha-\theta)/(\beta-\theta) \quad (1)$$

$$E_\kappa = \gamma\kappa\cdot\beta/\alpha\, E_\kappa = \gamma\kappa\cdot\beta/\alpha \quad (2)$$

where γk-concentrate yield,%, Ek-metal recovery in concentrate,%, β-metal content in concentrate,% [18].

The separation potential Ф (β) was calculated from the formula

$$\Phi(\beta) = (2x-1)\cdot ln\frac{x}{1-x} \quad (3)$$

The separation power was calculated from the formula

$$\Delta U = P\cdot\Phi(\alpha,\beta) \quad (4)$$

where: P is the amount of product obtained, g/h, Ф (α, β) is the separation potential, reckoned from the concentration of the initial product with the content of α.

The formula for calculating Ф (α, β) is given below

$$\Phi(\alpha,\beta) = (2\beta-1)\cdot ln\frac{\beta(1-\alpha)}{\alpha(1-\beta)} + \frac{(\beta-\alpha)\cdot(1-2\alpha)}{\alpha(1-\alpha)} \quad (5)$$

Results and Discussion

Based on the modified scheme of collectively-selective flotation of Cu-Pb ore using sodium oleate in the main flotation, a schematic diagram was drawn up (Fig. 1) and calculations of purification operations of enrichment were carried out (Tables 2, 3) [19].

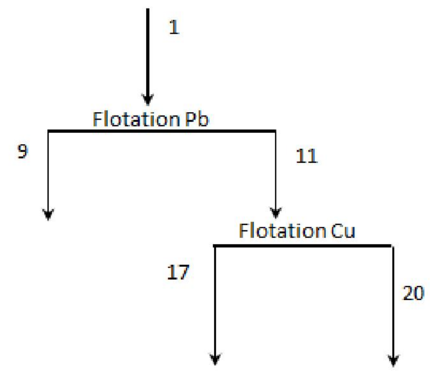

Figure 1 - Schematic diagram of flotation of copper-lead ore

Table 2 - Balance for final products of flotatio

Product Number	Product Name	Yield,%	Assay, %		Recovery, %	
			Pb	*Cu*	*Pb*	*Cu*
9	Concentrate Pb	13.79	0.25	0.01	68.95	0.14
17	Concentrate Cu	1.60	0.07	39.46	2.24	63.78
20	Tailings	84.61	0.02	0.42	28.81	36.08
1	Ore	100.00	0.05	0.99	100.00	100.00

Table 3 - Balance of Cu-Pb ore products enrichment

Product Number	Products and operations name	*Q*, g/h	*γ*, %	*β*, %	*ε*, %
I	Basic lead flotation				
	Come in:				
1	Classifier drain	375	100	0.05	100
12	Combined industrial product	146.57	39.09	0.02	14.95
2	Total:	521.57	139.09	0.04	114.95
	Go out:				
3	Concentrate of basic flotation	197.86	52.76	0.08	83.02
4	Main flotation tailings	323.71	86.32	0.02	31.93
	Total:	521.57	139.09	0.04	114.95
II	First cleansing flotation				
	Come in:				
3	Concentrate of basic flotation	197.86	52.76	0.08	83.02
8	Second cleansing flotation tailings	37.16	9.91	0.03	5.63
5	Total:	235.03	62.67	0.07	88.65
	Go out:				
6	Concentrate of first cleansing	88.88	23.70	0.16	74.58
7	First cleansing flotation tailings	146.15	38.97	0.02	14.07
	Total:	235.03	62.67	0.07	88.65
III	Second cleansing flotation				
	Come in:				
6	Concentrate of first cleansing	88.88	23.70	0.16	74.58
	Total:	88.88	23.70	0.16	74.58
	Go out:				
9	Concentrate	51.71	13.79	0.25	68.95
8	First cleansing flotation tailings	37.16	9.91	0.03	5.63
	Total:	88.88	23.70	0.16	74.58
IV	Control flotation				
	Come in:				
4	Basic flotation tailings	323.71	86.32	0.02	31.93
	Total:	323.71	86.32	0.02	31.93
	Go out:				
10	Foam product control flotation	0.42	0.11	0.39	0.88
11	Tails of the control flotation	323.29	86.21	0.02	31.05
	Total:	323.71	86.32	0.02	31.93

Calculation of the lead flotation cycle. The calculation of the first flotation cycle is carried out according to the following scheme (Figure 2) with the previously identified products. Calculation of the material balance of lead flotation was carried out using the Solver Excel software package. The results of calculating the qualitative-quantitative scheme of the lead flotation cycle are given in Table 2. Calculations were carried out according to the cycle of copper flotation (Figure 3).

Thus, to calculate the cycle of copper flotation, the initial indicators are: a) two indicators relating to the source data (Q_1 and α^{Cu}); b) four indicators of copper recovery in flotation products; (c) Four indicators of copper content in concentrate operations. The number of initial indicators is 4, the number of stages 4. The results are given in Table 4.

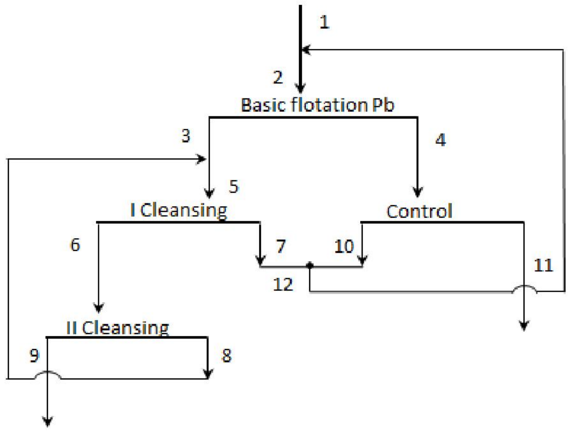

Figure 2 - The lead flotation cycle

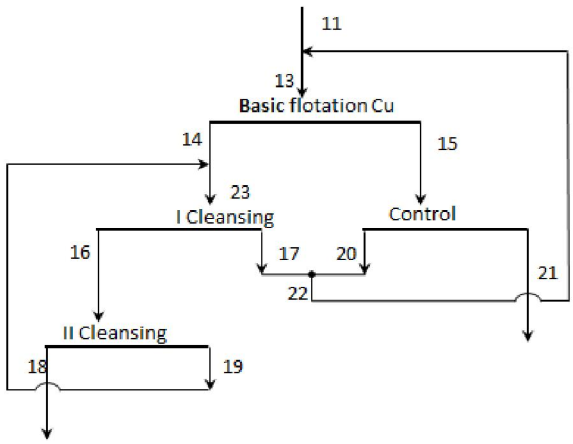

Figure 3 - The cycle of copper flotation

Table 4 - The balance of copper enrichment products

Stage No	Name of operations and products	*Q*, g/h	*γ*, %	*β*, %	*ε*, %
I	Basic copper flotation				
	Come in:				
11	Basic flotation tailings	323.29	86.21	1.15	99.86
22	Combined industrial product	36.54	9.74	4.00	33.96
13	Total:	359.83	95.95	1.60	133.82
	Go out:				
14	Concentrate of basic flotation	30.71	8.19	9.51	78.65
15	Basic flotation tailings	329.12	87.76	0.72	55.18
	Total:	359.83	95.95	1.60	133.82
II	First cleansing flotation				
	Come in:				
14	Concentrate of basic flotation	30.71	8.19	9.51	78.65
19	Second cleansing flotation tailings	7.34	1.96	2.67	4.56
23	Total:	38.06	10.15	9.40	83.21
	Go out:				
16	Concentrate of the first cleansing flotation	13.34	3.56	19.01	68.34
17	First clearing tailings	24.71	6.59	2.59	14.87
	Total:	38.06	10.15	9.40	83.21
III	Second cleansing flotation				
	Come in:				
16	Concentrate of the first cleansing flotation	13.34	3.56	19.01	68.34
	Total:	13.34	3.56	19.01	68.34
	Go out:				
18	Concentrate	6.00	1.60	39.46	63.78
19	Second cleansing flotation tailings	7.34	1.96	2.67	4.56
	Total:	13.34	3.56	19.01	68.34
IV	Control flotation				
	Come in:				
15	Basic flotation tailings	329.12	87.76	0.72	55.18
	Total:	329.12	87.76	0.72	55.18
	Go out:				
20	Foam product of control flotation	11.83	3.15	5.99	19.10
21	Basic flotation tailings	317.29	84.61	0.42	36.08
	Total:	329.12	87.76	0.72	55.18

The results of the circuit experiments confirm that the following concentrates can be obtained according to the developed technological scheme and the reagent regime: in the intercrack flotation lead concentrate with a lead content of 0.25%, extraction of 68.95%; in the copper flotation cycle, concentrate with a copper content of 39.46%, extraction of 63.78%; the use of purge operations makes it possible to increase the content of the valuable component of β_{Pb} from 0.08 to 0.25%, β_{Cu} from 9.51 to 39.46%. However, in both cases, the extraction of metal and the amount of concentrate are reduced.

The introduction to the circuit of a cycle for a combined industrial product in lead and copper flotations is caused by the need to reduce metal losses with tails. Thus, it has been shown that the use of sodium oleate as the main flotation agent in the lead flotation cycle and at the copper flotation stage of sodium dibutyldithiophosphate allows the development of selective and circuit regimes. Further, the efficiency of flotation enrichment was assessed (Table 5) [20].

Table 5 - Results of separation potentials and separation power calculation for a collectively selective scheme for copper-lead ore enrichment

Stage No	Name of the separation stage	Φ(β)		Φ(α,β)		ΔU, g/h	
		Pb	Cu	Pb	Cu	Pb	Cu
I	Basic flotation	7.12	1.82	0.13	6.62	25.75	203.15
II	First cleansing flotation	6.42	0.90	1.04	16.06	92.29	214.29
III	Second cleansing flotation	5.96	0.09	2.39	37.59	123.83	225.54
IV	Control flotation	5.50	2.42	4.76	3.37	1.99	39.87

Analysis of the data in Table 5 showed that more purification operations are needed to obtain cleaner products, namely lead concentrate with a high content of the useful component, than for copper concentrate. On the other hand, the maximum values of the separation potential Φ (α, β) for the second flocculation flotation for copper and lead control flotation serve as an indicator of the completeness of the ore minerals from the separation gangue, but which, according to the minima Φ (β), is complicated by the proximity of the flotation properties of the components of the mixture. The high value of the separation power for the second purification flotation, in both lead and copper, confirms the selectivity of the proposed reagents to the lead and copper minerals and indicates a sufficiently high efficiency of flotation enrichment in the proposed collective selective scheme.

Thus, as a result of the conducted studies, a qualitative-quantitative scheme for flotation of Cu-Pb ore was calculated using sodium oleate as the main reagent. It is shown that the scheme should include two clean-up operations at the Pb flotation stage, one control operation, at the copper flotation stage, two clean-ups of selective concentrate and closed-loop control flotation are also envisaged. An increase in the content of Cu and Pb in similar concentrates was established using the use of βPb purge operations from 0.08 to 0.25%, βCu from 9.51 to 39.46%. The results of calculations of the change in separation potentials and separation power indicate a rather high efficiency of the collectively-selective scheme for the enrichment of copper-lead ore.

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НЕГІЗГІ ФЛОТАЦИЯДА МЫС-ҚОРҒАСЫНДЫ КЕНДІ НАТРИЙ ОЛЕАТЫМЕН ҰЖЫМДЫ-ТАҢДАМАЛЫ БАЙЫТУ ТИІМДІЛІГІНІҢ АНАЛИЗІ

Аннотация: Мыс, қорғасын, мырыш және басқа түсті металдардың минералдарынан тұратын полиметалды кендерді байыту мәселесі жабысқан өсінділерді ашудан, бір минералдың майда сеппе бөлшектерін басқа минералдан немесе бос жыныс бөлуден тұрады. Жұмыстың мақсаты байытудың ұжымды-таңдамалы сұлбасы бойынша суспензияның құрамындағы флотореагентті зерттеу болып табылады. Мыс-қорғасынды кен үлгісінің элементтік талдауы жүргізілді. Флотациялық зерттеулер ФМЛ-1 флотомашинасында жүргізілді, жұмыс камерасының көлемі 0,25 л, көбіктендіргіш агент ретінде Т-92 қолданылды. Кенінің үлгілері және байытудың өнімдері еріген күйге қоспаны концентрленген азот және тұз қышқылдарында еріту арқылы ауыстырылды. Жұмыста негізгі флотацияда натрий олеатын қолдануымен жүретін мыс-қорғасынды кенді байыту нәтижелері келтірілген. Ұжымды-таңдамалы сұлба бойынша (қатты компонент бойынша) негізгі және бақылау флотациясы, қайта тазалау операциялары үшін материалдық баланс есептелген. Сұлбаға натрийдің дибутилдитиофосфатымен жүретін екі қайта тазалау операцияларын қосу селективті концентраттардағы қорғасын және мыс мөлшерін 3 есе арттыратынын көрсетеді. Материалдық баланс нәтижелері бойынша негізгі, бақылау және екі қайта тазалау флотацияларының бөлу потенциалдары және бөлу уақыты есептелді. Байытудың бастапқы стадиясынан соңғы стадиясына дейін бөлу потенциалының теріс динамикасы минералдарды бөлу процесінің күрделілігінің артуы туралы мәліметтейді. Бөлу потенциалдарының кендегі металл мөлшеріне қатысты экстремумдары оттек- және фосфорқұрамды жинағыштардың реакциялық қабілеттіліктерінің айырмашылығын көрсетеді. Бөлу қуатының шамасы қолданылған флотореагенттердің селективтілік көрсеткіші болып табылады. Осылайша, бөлу критерийлерінің негізінде ұсынылған байыту сұлбасының тиімділігін бағалау жүргізілді.

Кілт сөздер: ұжымды-таңдамалы сұлба, натрий олеаты, натрий дибутилдитиофосфаты, материалдық баланс, бөлу потенциал, бөлу қуаты

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АНАЛИЗ ЭФФЕКТИВНОСТИ КОЛЛЕКТИВНО-СЕЛЕКТИВНОГО ОБОГАЩЕНИЯ МЕДНО-СВИНЦОВОЙ РУДЫ ОЛЕАТОМ НАТРИЯ В ОСНОВНОЙ ФЛОТАЦИИ

Аннотация: Проблема обогащения полиметаллических руд, содержащих минералы меди, свинца, цинка и других цветных металлов состоит в раскрытии сростков, отделении мелковкрапленых частиц одного минерала от другого минерала или пустой породы. Целью работы является изучение поведения флотореагентов в составе суспензии при обогащении по коллективно-селективной схеме. Проведен элементный анализ образцов медно-свинцовой руды. Флотационные испытания выполнены на флотомашине ФМЛ-1, объем рабочей камеры 0,25 л, в качестве пенообразователя использован Т-92. Образцы руды и продукты обогащения переводились в растворенное состояние путем разложения смесью концентрированных азотной и соляной кислот. В работе приведены результаты обогащения медно-свинцовой руды с использованием олеата натрия в основной флотации. Рассчитан материальный баланс процесса флотации медно-свинцовой руды по коллективно-селективной схеме (по твердому компоненту), как для основной и контрольной флотации, так и для перечистных операций. Показано, что добавление в схему двух перечистных операций, с основным реагентом дибутилдитиофосфатом натрия, позволяет повысить содержание свинца и меди в селективных концентратах в 3 раза. По результатам материального баланса рассчитаны разделительные потенциалы и разделительная мощность основной, контрольной и двух перечистных флотаций. Отрицательная динамика изменения разделительного потенциала от начальной стадии обогащения к завершающей свидетельствует о возрастании сложности разделения минералов, наличие экстремумов разделительного потенциала относительно содержания металла в руде указывает на различие в реакционной способности кислородсодержащего и фосфорсодержащего собирателей. Установлено, что величина разделительной мощности служит количественной мерой селективности используемых флотореагентов. Таким образом, на основании критериев разделения проведена оценка эффективности предложенной схемы обогащения.

Ключевые слова: коллективно-селективная схема, олеат натрия, дибутилдитиофосфат натрия, материальный баланс, разделительный потенциал, разделительная мощность

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