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M. R. Turko, PhD (Engineering), head of laboratory (open joint-stock company "Belgorkhimprom");
O. B. Dormeshkin, D.Sc. (Engineering), vice-rector for research (BSTU);
E. M. Miskov, PhD student (BGTU);
L. A. Solovyova, engineer (2 category) (open joint-stock company "Belgorkhimprom")

FLOTATION SYLVITE FROM POTASH ORES AT ELEVATED TEMPERATURES

In laboratory terms conducted research on the selection of factious composition amine and assortment components of collective mixture, optimal for flotation of sylvine at the temperature of fallopian solution 40°C; brands and charges of reagents are certain; are conducted the comparative tests of charts of joint and separate flotation of sylvine from ores 1–3 mine managements of JSC "Belaruskali" in the conditions of enhanceable temperatures.

Introduction. Production of potash fertilizers out of sylvinite ores from different deposits of post-Soviet and other foreign countries is carried out mainly from saturated solutions by the flotation method. Total mass fraction of soluble salts in the saturated solution varies with temperature changing; it brings to the variation of reagent properties used in the flotation suspension, which affects the physical-chemical interaction of the reactants in the volume and at the interface, as well as the technological process parameters.

Influence of temperature rise of saturated salt solution on potash ore flotation process in the range of 30–35°C is studied in detail [1–9].

At the same time, within the last 5–6 years it was actively invested into construction of new enterprises in different countries with significant potassium salt deposits. In particular, this concerns

the countries of south-eastern region (Uzbekistan, Turkmenistan, Kazakhstan). In Volgograd region (Russia) the Gremyatchinsk ore-dressing and processing enterprise is under intensive construction. In these regions during the period May – September, temperatures can significantly exceed 35°C. In recent years the record temperature during the summer months in the Republic of Belarus, according to the weather forecasters, has reached 36–39°C. That led to an evident deterioration in the flotation and increased loss of potassium with the tailings. Therefore the task of ensuring the effective operation of concentrating mills and the achievement of high flotation process performance at increased temperatures (above 35°C) remains topical and requires new types of reagents and the development of appropriate reagent modes.

Main part. The purpose of research, the results of which are presented in this paper was to establish the optimal technological parameters of sylvinite flotation out of ores from Starobin deposit at elevated temperatures of saturated salt mother solution. In research [10] a saturated salt mother solution SOF 1 RU of "Belaruskali" was used, whose composition was adjusted by the introduction of KCl and NaCl, while maintaining the desired temperature of the solution. The density of the saturated solution was 1241 kg/m^3, the content of soluble salts KCl – 12.9 wt. %, NaCl – 19.0 wt. %. The temperature in the climate chamber was 40°C. In all experiments on the new reagents effectiveness, the ore 1 RU of size – 1.25 mm with the KCl content – 26,7 wt. % and the insoluble residue (i. r.) – 6.4 wt. % were used. Ore preparation to flotation was carried out by its prior deshaling. With increasing of mother solution temperature from 20 to 40°C, the total salt content in saturated salt solution also increases from 31.1 to 32.9 wt. %, and, in general, by increasing the potassium chloride content. When sylvinite flotation processing at JSC "Belaruskali" alkylamines with apolar additives were used as gatherers, and – starchy feedings as a depressant. The most important indirect flotation characteristics of amine activity are the turbidity of its aqueous solution and the amine adsorption on the salt crystals of potassium chloride.

Establishing the optimal C_{20+22} fraction content in the amine hydrocarbon radical.

According to the literature [11], at increasing the mother solution temperature to 30–32°C the use of an amine with a C_{20+22} fraction content of hydrocarbon radical up to 25 wt. %. is favourable for the flotation process.

Further temperature increase of the mother solution to 40°C requires verifying the optimum of C_{20+22} fraction content in an amine hydrocarbon radical used as a KCl collector [5]. In the experiments the amines from JSC "Belaruskali" were used, in particular brands Lyutamin VT 95, VT 95 Lyutamin summer and also new amine brands – Armin M and Armin 1622 manufactured by Akzo Nobel Surface Chemistry AB (Netherlands). The content of C_{20+22} fractions in the amine hydrocarbon radical varied from 2 to 47 wt. % by changing the ratio of amines Lyutamin VT 95, VT 95 Lyutamin summer, Armin M and Armin 1622 taking into account the C_{20+22} fraction content in them. The ratio of individual reactants in the model mixture of an amine collector: oil liquid paraffin (RV), polyethylene glycol (PEG), pine oil (PO) was (wt. %) 58: 7: 14: 21. The depressant consumption (potato starch) – 140 g/t feeding.

Sylvinite flotation of ores with particle size – 1.25 mm was carried out after deep deshaling at a flow collector 35 g/t feeding. As a result of studies of the flotation process at using winter amine brand Lyutamin TN 95 containing 2 wt. % of C_{20+22} fractions, the extraction degree of KCl in the rough concentrate was only 86.94%, while the transition to summer amine brand Lyutamin VT 95, containing 24.67 wt. % of C_{20+22} fractions, the extraction degree of KCl increased to 90.74%. A further increase in the proportion of C_{20+22} fractions in the amine, obtained when sharing summer amine brands Lyutamin VT 95 and Armin M from 30 to 47 wt. %, provided an increase of concentrate outcome from 29.20 to 33.49%, and of the extraction degree of KC1 – from 92.45 to 94.47%. In studies using a mixture of amine brands Lyutamin TN 95 and Armin 1622 with a total content of C_{20+22} fractions (wt. %) 25, 30, 35, 40 and collector consumption 35 g/t feeding, the concentrate output increased from 30.78 to 31 91%, and the extraction degree of KCl in the concentrate – from 91.05 to 93.09%. The results obtained are somewhat lower than when using a mixture of amines Lyutamin VT 95 summer and Armin M at similar values of the content of hydrocarbon radical C_{20+22} fractions, but with higher content of C18 fractions (Fig. 1).

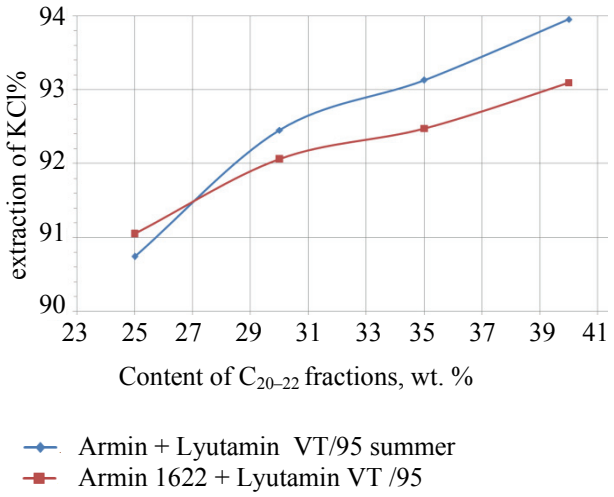

Fig. 1. Effect of C_{20-22} fractions in an amine hydrocarbon radical on the KCl extraction degree

Thus the performed studies confirmed significant influence of the C_{20+22} fraction t content in an amine on the sylvinite flotation values at elevated temperatures of a mother solution. It has been found that the optimum content of these fractions in the amine providing the maximum rough concentrate outcome and the extraction degree of KC1is 35–40%.

The optimum ratio of amines Lyutamin VT 95 summer: Armin M is (wt. %) 25:75, which corresponds to the following fractional composition of the collector (wt. %): C_{14} – 0,79; C_{16} – 11.01; C_{18} – 46.80; C_{20+22} – 41.40. When using amine brands Lyutamin VT 95 and Armin 1622 the optimum ratio of amines is (wt. %) is 53:47, and the total fraction composition in this case will have the following values (wt. %): C_{14} – 4.77; C_{16} – 16.78; C_{18} –37.91; C_{20+22} – 40.54.

Effect of the collector flow rate on the performance of sylvinite flotation.

Investigations of the collector flow rate influence on sylvinite flotation performance at elevated temperatures of a mother solution (40°C) under conditions of ore deshaling quality variation (the content of insoluble residue in flotation feeding) were carried out using amine brands Lyutamin VT 95 summer and Armin M in a ratio of 1:1 in which the C_{20+22}mass fraction of the amine hydrocarbon radical was 35% [10].

The amine component ratio: RV: PEG: CM belonging to the collector, was kept constant and equal to (wt. %) 58: 7: 14: 21. The depressant consumption (potato starch) was constant at 140 g/t feeding. The content of i. r. in flotation feeding was 2.18 wt. %.

As for Fig. 2, at a change of collecting amine mixture consumption from 30 to 50 g/t feeding, the degree of KCL extraction into rough concentrate increases from 84.24 to 91.64%. However, even at the maximum flow rate of the collector, equal to 50 g/t of feeding the concentrate output is only 30.84%.

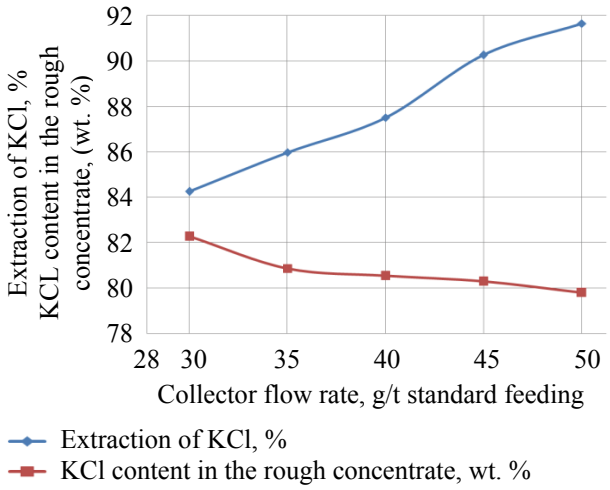

Fig. 2. Effect of flow collector on the extraction and quality of crude concentrate

The average content of KCl in the flotation tailings exceeded 3 wt. %, which is greater than the regulated value 1.35 wt. %.

In the next series of experiments the i. r. content of flotation feeding was 1.75 wt. %. Depramin 96 was used as depressant. Calculated C_{20+22} fraction content in amine hydrocarbon radical equal to 40 wt. % was provided by mixing amines brands Lyutamin VT summer 95 and Armin M in a ratio of 25: 75 by weight. %.

The ratio of the individual components in the composition of the amine collector: RV: PEG: CM was (wt. %): 54: 8: 15: 23.

When changing the flow rate of the collector on the amine from 35 to 55 g/t feeding much higher values wre obtained. Thus, at the amine flow of 35 g/t the average extraction rate of KCl into rough concentrate was 92.67% and at a rate of 55 g/t feeding – 95.0%. The average content of KC1 in rough concentrate thus increased from 78.22 to 75.70 wt. %.

However, there was a slight increase in the content of i. r. in the rough concentrate (Fig. 3), which indicates a deterioration of selectivity of the flotation process at high collector consumption due to the increase in the degree of amine adsorption on the NaCl and i. r. at elevated temperatures [5, 10].

The result analysis shows that the extraction rate of KCl into rough concentrate at collector consumption of 35 g/t feeding is higher than at the consumption of 50 g/t feeding, but at a higher i. r. content in flotation feeding. Thus, in determining the optimal conditions for the flotation process at elevated temperatures along with the composition and flow rate of the collector the quality of the preliminary deshaling, in particular the content of i. r. in the flotation feeding. must be taken into account.

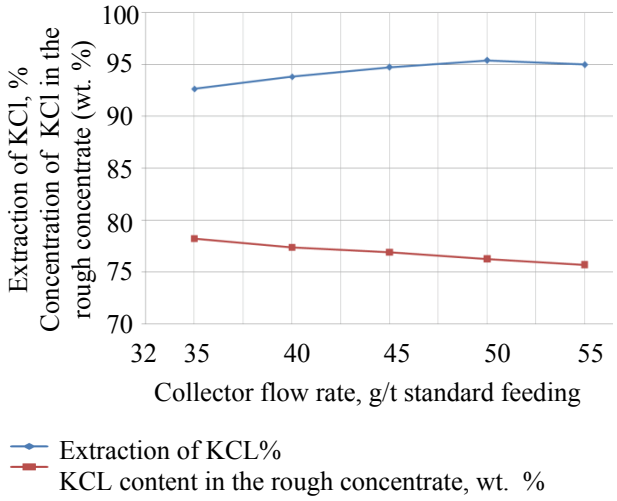

Fig. 3. Effect of flow collector on the extraction and quality of crude concentrate

Selection of amine modifiers for sylvinite flotation. To determine the effectiveness of the paraffinic base reagents as amine modifiers for sylvinite ore flotation at mother solution temperatures above 30°C, except for the reagents currently used at industrial factory "Belaruskali" such as liquid paraffin oil (RV), polyethylene glycol (PEG) and previously used gatch, other waxy reagents: vacuum gas oil, the oil swelling (production of "Mineral Wax Plant", the Republic of Belarus), reagents 1C, 2C, 5C (development BSTU) were investigated [8].

Studies were performed using amine brands Lyutamin VT 95 summer and Armin M in percentage ratio 50:50 [10]. It was maintained a constant collector flow rate – 40 g/t feeding, pine oil consumption – 12 g/t feeding. As depressant Depramin 96 was used (flow rate of 80 g/t feeding). The effectiveness of new reagents – modifiers was evaluated relative to the "basic" mode (RV: PEG with the same consumption).

The investigation results showed that the most effective amine modifier is gatch, for which the flotation values close to the "basic" were obtained (Tab. 1). Reagents 1C and 2C are poorly emulsified in a solution of the amine and the flotation figures are under "basic". The degree of KCl extraction into the rough concentrate was respectively 91.78 and 91.63% against 92.96% for the "basic" mode. Moreover, industrial production of these reagents still has not been organised.

The reagents: vacuum gas oil, oil swelling and reagent 5C produced on an industrial scale are of practical interest (Table 2). The introduction of vacuum gas oil to the aqueous amine solution is followed by poor emulsification and a film appearance on the amine surface, while mixing it in the amine melt provides a stable emulsion of an amine and a modifier.

Flotation test results at using vacuum gas oil emulsified in an amine melt exceed the performance of a "basic" mode. The average extraction of KCl into rough concentrate was 94.21% versus 93.78% for the "basic" mode. Similar flotation values were obtained at application of oil swelling reagent.

Key indicators of the 5c reagent flotation tests were somewhat lower as compared to gas oil and oil swelling, moreover, its flow rate increased to 25 g/t cord. Thus, results of studies allow recommending the usage of new apolar reactants – oil swelling and vacuum gas oil – as an amine modifier at KCl flotation from sylvinite ore at elevated temperature of the mother solution to 40°C.

Effect of collector component ratio on the sylvinite flotation performance. Investigation of the effect of reactant ratio, entering into the composition of the collector, on the sylvinite flotation performance at elevated temperature of the mother solution to 40°C. the following reagents were used: amine brands Lyutamin VT 95 and Armin 1622 in percentage 59: 41, and also the additives used at industrial flotation plants: paraffin oil liquid, polyethylene glycol, pine oil. Ccollector consumption by amine was maintained constant – 35 g/t feeding. The dosage of the amine reactant: RV: PEG: SM was varied in the following ratio (wt. %): 58: 7: 14: 21; 54: 8: 15: 23; 50: 8.5: 16.5: 25. The tests established that the decline in the amine proportion in a mixture from 58 to 50 wt. % improves values of flotation sylvinite ore concentration: increased rough concentrate yield from 31.78 to 32.52%, and the KCl extraction rate – from 92.23 to 93.63% [10].

Table 1

Impact of amine reagents – modifiers on sylvinite flotation technological parameters of ore with particle size –1.25 mm at the mother solution temperature of 40°C

Rreagents- modifier consumption g/t feeding				Product title	Outcome %	Concentration wt. %.		Extraction degree, %	
LP : PEG (basic)	gatch	2C	1C			KCl	н. о.	KCl	н. о.
5 : 10	–	–	–	Rough concentrator	32.21	79.44	1.44	92.87	30.62
				Tailings	67.79	2.90	1.56	7.13	69.38
				Initial feedings	100.0	27.55	1.52	100.0	100.0
–	15	–	–	Rough concentrator	31.98	79.69	1.42	92.84	30.94
				Tailings	68.02	2.89	1.49	7.16	69.06
				Initial feedings	100.0	27.45	1.47	100.0	100.0
–	–	15	–	Rough concentrator	32.04	78.51	1.32	91.61	29.74
				Tailings	67.96	3.39	1.47	8.39	70.26
				Initial feedings	100.0	27.46	1.42	100.0	100.0
–	–	–	15	Rough concentrator	31.74	79.61	1.19	91.75	26.43
				Tailings	68.26	3.33	1.54	8.25	73.57
				Initial feedings	100.0	27.54	1.43	100.0	100.0

Table 2

Impact of amine reagents -modifiers action on sylvinite flotation technological parameters of ore with particle size –1.25 mm at the mother solution temperature of 40°C

Rreagents- modifier consumption g/t feeding				Product title	Outcome, %	Concentration wt. %.		Extraction degree, %	
LP : PEG (basic)	Oil swelling	5C	vacuum gas oil			KCl	н. о.	KCl	н. о.
5:10	–	–	–	Rough concentrator	34.40	75.39	1.29	93.78	33.38
				Tailings	65.60	2.62	1.35	6.22	66.62
				Initial feedings	100.0	27.65	1.33	100.0	100.0
–	15	–	–	Rough concentrator	34.85	74.96	1.35	94.31	37.77
				Tailings	65.15	2.42	1.19	5.69	62.23
				Initial feedings	100.0	27.70	1.25	100.0	100.0
–	–	25	–	Rough concentrator	33.88	76.28	1.41	93.76	38.18
				Tailings	66.12	2.60	1.17	6.24	61.82
				Initial feedings	100.0	27.56	1.25	100.0	100.0
–	–	–	15	Rough concentrator	34.55	75.47	1.31	94.21	35.25
				Tailings	65.45	2.45	1.27	5.79	64.75
				Initial feedings	100.0	27.68	1.28	100.0	100.0

Thus, increasing of additive specific portion to the amine in the collector composition increases the efficiency of the collector and KCl flotation performance.

Features of sylvinite flotation process from ores 1, 2 and 3 at the JSC "Belaruskali" on the scheme of joint and separate flotation using a mother solution of elevated temperature. Joint sylvinite flotation was carried out at the separate conditioning of ore reagents with particle size from –1.25 to +0.2 mm and from –0.2 to +0.045 mm after their preliminary attritioning and deshaling by washing the class –0.045 mm and sieving to the class 0.2 mm.

The scheme of joint flotation and flotation of ore fractions of size 0.2 mm was carried out in the flotation machine PL-237, flotation of fine fraction of ore with particle size 0.2 mm was performed in flotation machine PL-240.

Comparative studies on the scheme of joint and separate ore flotation 1-3 RU of "Belaruskali" in

conditions of elevated temperatures of the mother solution was carried out using the following ore size: 1 RU for ores –1.25 mm with the KCl concentration – 26.68 wt. % and i. r. – 6.40 wt. %; 2 RU for ores –1.25 mm with the KCl concentration – 24,6 wt. %, and i. r. – 4.7 wt. %; 3 RU for ores – 1.0 mm with the KCl concentration – 26,0 wt. %, and i. r. – 10.1 wt. %. Amine brands Lyutamin VT 95 summer and Armin M in ratio (wt. %) 25: 75 were used at joint flotation. That provided the C_{20+22}fraction content – 40 wt. %, and the ratio (wt. %) 50: 50, and the fraction content – 35 wt. %. As the collector was used the amine mixture: RV: PEG: SM in the ratio (wt. %) 55: 8: 15: 22. The flow rate of the collector on the amine was 45 g/t cord. Depramin was used as depressant.

According to the scheme of joint ore flotation 1 RU crude concentrate with outcome 31.58% and KCl content 75.98 wt. % was obtained In Scheme 2 together ore flotation using a collector RC amine containing 40 wt. % C20 + fraction 22 obtained concentrate containing KCl 70.72 wt. % and the output of concentrate 30.93%, with recoveries in KCl roughing concentrate 88.96%.

According to the scheme of joint ore flotation 2 RU using a collector with amine containing 40 wt. % of C_{20+22} fractions the concentrate was obtained with KCl content 70.72 wt. % and the output of concentrate 30.93%, at KCL extraction degree into crude concentrate 88.96%.

Decreasing of C_{20+22} fraction proportion in the amine, from 40 to 35 wt. % did not affect the RCl extraction degree into rough concentrate, which suggests the possibility of using in flotation process amine with reduced content of hydrocarbon radical C_{20+22} fractions. According to the scheme of joint ore flotation 3 RU with coarseness –1.0 mm using amine containing 40 wt. % of C_{20+22} fractions the concentrate was obtained with KCl content – 77.85 wt. % and the output of concentrate 28.38% and the degree of extraction KCl 85.78% [10] .

Reduction of the amine hydrocarbon radical C_{20+22} fractions to 35 wt. % led to a decrease in crude concentrate outcome by 0.32%. The KCl extraction degree decreased by only 0.13%, which confirms the possibility of amine using with reduced C_{20+22} fractions also for ore 3 RU.

When studying the process of separate ore flotation 1 and 2 RU with particle size from –1.25 to +0.2 mm, and 3 RU with particle size from –1.0 to +0.2 mm collector reagent composition was used which is similar to the conditions of the joint flotation described above.

During sylvinite flotation out of finer ore fraction from –0.2 to +0.045 mm the amine brand Alkylamine C12 with foaming (pine oil) in a ratio (wt. %) 88:12 was used. The flow rate of the collector was 10 g/t cord. The ratio W: T in suspension at fine flotation was equal to 4.0.

With separate ore flotation 1 RU the crude concentrate with particle size from –1.25 to +0.2 mm with the KCl content – 81.77 wt. % and the particle size of –0.2 to +0.045 mm – with a KCl content – 66.06 wt. % was obtained The average KCl content in the concentrate was 78.17 wt%.

With separate ore flotation 2 RU out of ore fraction with particle size from –1.25 to +0.2 mm the rough concentrate was obtained with KCl content – 75,44 wt. % and with outcome 68%, and from the ore fraction the particle size from –0.2 to +0.045 mm – the rough concentrate containing KCl – 67.62 wt. % and the outcome 6.56%. The average KCl content in the rough concentrate was 73.65 wt. % and the outcome – 29.24%.

With separate ore flotation 3 RU out of fraction with particle size from –1.0 to +0.2 mm the rough concentrate was obtained with KCI content – 79.80 wt. % at using amines containing 40 wt. % of C_{20+22} fractions and 80.94 wt. % at using amines containing 35 wt. % of C_{20+22} fractions. At ore fraction flotation with particle size from –0.2 to +0.045 mm the rough concentrate was obtained with KCl content 65.67 wt. %. The average KCl content in the rough concentrate was 77.75 wt. %, and the KCl extraction rate – 85,33%.

Thus, the analysis of obtained results of the joint and separate sylvinite flotation from the ore 1–3 RU led to the following conclusions:

– separate sylvinite flotation out of ore 1 and 2 RU with particle size from –1.25 to +0.2 mm and from –0.2 to +0.045 mm provided a reduction in the overall flow of the collector as compared to the joint flotation by 6.5 and 6.3 g/t and the consumption of depressant Depramin 96 – by 48 and 47.3 g/t of ore, respectively; for ores 3 RU with particle size from –1.0 to +0.2 mm and from –0.2 to + 0.045 mm the reduction in the total flow of the collector was 5.9 g/t, of depressant consumption – 43.5 g/t of ore;

– A separate flotation simplifies the control of basic process parameters by allowing separate control of the two ore streams and the KCl content in general concentrate increases by 2.96 wt. %.

Conclusion. On the basis of flotation process studies of the sylvinite out of ores 1–3 RU JSC "Belaruskali" on schemes of joint and separate flotation of coarse and fine fractions under conditions of elevated temperatures of the mother solution the following was established.

1. To increase the collector effectiveness the optimal content of C_{20+22} fractions in amine hydrocarbon radical is 35–40 wt. %.

2. For the industrial tests are recommended amine brands Lyutamin VT 95 summer and Armin M, sharing which provides obtaining of collector necessary fractional composition– amine.

3. The optimal collector flow rate is 45 g/t feeding, and further increasing of the collector flow rate leads to a deterioration of the flotation process selectivity.

4. As an amine modifier (collector) at the sylvinite ore flotation under conditions of elevated temperatures of the mother solution the following reagents are recommended: vacuum gas oil, oil swelling, and reagent 5C.

5. Comparative tests of reagent-depressants have shown that at elevated temperatures the depressant Depramin 96 effectiveness considerably exceeds the standard depressant efficiency – potato starch.

6. The results of comparative tests of joint and separate sylvinite flotation out of ore 1–3 RU JSC "Belaruskali" showed a significant reduction in the reagent consumption at separate flotation of ore classes with particle size +0.2 and –0.2 mm, which allows reagent saving and significant reduction of residual amine content in the feeding compression, increasing its effectiveness. And for the flotation of ore fine fraction amine brands Alkylamine C12 or Lilaflot FAB 53 are recommended.

7. In general, the use of separate flotation at mother solution elevated temperatures is advantageous both for reduction of reagent consumption, and for the basic technological characteristics as compared to the joint flotation.

References

1. Титков С. Н. Обогащение калийных руд. М.: Недра, 1982. 216 с.

2. Титков С. Н. Разработка новых реагентных режимов флотации сильвинитовых руд / Т. М. Гуркова, Л. М. Пимкина; под ред. С. Н. Титкова. М.: Недра, 1982. 180 с.

3. Дуденков С. В. Основы теории и практика применения флотационных реагентов. М.: Недра, 1969. 390 с.

4. Глембоцкий В. А. Взаимодействие минералов с реагентами при флотации. М.: Недра, 1967. 302 с.

5. Александрович Х. М. Основы применения реагентов при флотации калийных руд. М.: Наука и техника, 1973. 412 с.

6. Алиферова С. Н. Активация процессов флотации шламов и сильвина при обогащении калийных руд: автореф. дис. … канд. техн. наук: 25.00.13. Екатеринбург, 2007. 198 л.

7. Абрамов А. А. Обогащение руд // Труды науч.-техн. конф. ин-та Механобр. Ленинград, 1969. С. 304.

8. Подлесная З. С. Исследование закономерностей флотационного обогащения сильвина из глинисто-солевых суспензий с использованием аполярных собирателей: дис. … канд. техн. наук: 05.15.08 Ленинград, 1979. 167 л.

9. Провести исследования, осуществить поиск и подбор реагентов, отработать реагентные режимы флотации сильвина при температуре суспензии выше 30°С на СОФ 1 – 3 РУ ОАО «Беларуськалий». Разработка оптимальных составов реагентов для флотации и рекомендаций для проведения опытных и опытно-промышленных испытаний: отчет о НИР (промежуточ.) / БГТУ; рук. темы Е. И. Грушова. Минск, 2012. 46 с. № ГР 20113942.

10. Проведение лабораторных исследований по выбору реагентов и отработка реагентов-собирателей и реагентных режимов при флотации сильвина из руды СОФ 1 – 3 РУ при температуре суспензии 40°С. Разработка рекомендаций для опытно-промышленных испытаний: отчет о НИР (промежуточ.) / ОАО «Белгорхимпром»; рук. темы М. Р. Турко. Минск, 2012. 80 с. № ГР 20111695.

11. Подбор фракционного состава аминов, состава реагента-собирателя в соответствии с разработанной методологией: отчет о НИР (промежуточ.) / ОАО «Белгорхимпром»; рук. темы М. Р. Турко. Минск, 2011. 40 с.

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