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UP-TO-DATE METHODS AND TECHNOLOGIES FOR IMPROVING THE PERFORMANCE OF FOAM SEPARATION OF DIAMOND-BEARING KIMBERLITES

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ABSTRACT – The mechanism of stable hydrophobization of diamonds by asphaltene-resin cut fraction of fuel oils used as collectors for foam separation was considered. The use of special additives to collectors providing their active and strong fixation on a diamond surface was substantiated. It was proposed to use combined modes of ore and recycled water conditioning by acoustic, thermal, and reagent methods to restore the natural hydrophobicity of diamonds to increase their floatability. A technological mode of foam separation was developed, including thermal treatment of an initial diamond-containing product and maintenance of the required temperature in the conditioning with a collector, foam separation, and flotation. The developed reagents and modes were tested at a foam separation unit. The test results showed an increase in diamond recovery over a wide range of temperatures.

Keywords: Diamonds, Kimberlite, Foam separation, Conditioning, Reagents.

INTRODUCTION

One of the promising areas for increasing the output of fine diamond size classes is their recovery from kimberlites using the method of foam separation. The relevance of the foam separation and flotation process is due to the fact that it enables achieving extraction of -2 + 0.5 mm size class, in which more than 40% of the total quantity of diamonds contained in the ore is concentrated, which constitute up to 10% of the value of all the commercial products. At the same time, the recovery rate of small diamonds remains insufficiently high. Increasing the efficiency of a foam separation cycle can be achieved by optimizing the composition of collectors, using methods to restore the natural hydrophobicity of diamonds, selecting the temperature conditions of conditioning and flotation processes, and improving water recycling conditions [1,2]. The problem set is particularly relevant at low temperatures. For its solution the application

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of modified collectors with additives of diesel technological fraction (DTF) and aliphatic ketones was proposed. To restore natural floatability of diamonds it is advisable to use modifying agents of different composition. To achieve the required performance and stability of the foam separation production cycle, a reasonable choice of rational scheme and conditions of water recycling in the foam separation cycle, involving the maintenance of the optimal recycled water proportion and applying purification of water products from slurry, is required.

EXPERIMENTAL

A dynamic technique for evaluating the fixation of apolar collectors on minerals including the measurement of wetting angles (Θ) and wetting perimeter diameter (Dwet) was applied in the studies.

An extraction-spectrophotometric technique was used to measure the distribution of a collector (γc) between the products and phases of a flotation test. To investigate the fixation of the collector on diamonds, the method of optical microscopy on a Micromed-3-LUM microscope was used. The collector's viscosity was measured on an SV-10 vibrating viscometer.

The collecting properties of the studied collectors in relation to diamonds were tested using a Hallimond tube, a foamless flotation cell.

Ultrasonic treatment of pulp was performed using the IL100-6/1 unit. Thermal and reagent treatments were carried out in a thermostatic cell. The approbation of the modified collectors performance under the selected temperature conditions was carried out at the LFM-001S foam separation unit.

RESULTS AND DISCUSSION

The fuel oils used in diamond flotation are not optimal collectors by their composition, so it is advisable to modify their composition in order to improve the technological performance of the foam separation process. Based on the findings of historical studies, to increase the collecting ability of M-40 and F-5 fuel oils, it was proposed to change the asphaltene-resin cut fraction (ARCF) from the coarse-dispersed state into colloidal solution by adding light distillates [3] or by increasing the medium temperature [2, 4]. A promising approach to solving this problem is to modify the base collector by adding bisoluble organic compounds, for example, a number of ketones, which simultaneously ensure the autodispersing process [3].

In order to test the hypothesis of a decisive contribution of ARCF to improving diamond floatability, the studies of fixation of a collector of different composition on the diamond surface were carried out. M-40 fuel oil, diesel technical-grade fraction (DTF), and modified collectors based on M-40 fuel oil were selected as base collectors: M-40-20 (20% DTF)% , KSM-1 (20% DTF + 15% DEK); KSM-2 (20% DTF + 15% EMK); KSM-3 (20% DTF + 15% DMK) obtained by dilution of M-40 fuel oil with diesel technological fraction (DTF) and solvents of ketone group, diethyl ketone (DEK), ethyl methyl ketone (EMK), and dimethyl ketone (DMK). The additives to the base reagents were selected taking into account the historical research findings [3].

Our tests showed that the highest wetting angle (Θ) was measured for a DTF drop (Table 1, test 1). For the modified M-40 fuel oil, the wetting angle characterizing the adhesive ability of a collector, is 3.5 - 9.6 degrees less (tests 3-6).

Table 1 Parameters of collector fixation and foamless diamond flotation process

No.	Collector used	Θ, deg	η, mPa s (T °C)	D_{wet}, mm	γ_c, %	ε_{diam}, %
1	DTF	101.1	3.4-4.0 (25 °C)	2.5	34	48.3
2	M-40 fuel oil	84.5	59.1 -78.0 (80 °C)	4.4	45	68.4
3	M-40-20	91.5	18.6-22.3 (25 °C)	4.0	61	78.6
4	KSM-1	93.4	12.5-14 (25 °C)	3.9	82	92.2
5	KSM-2	97.9	10.5-12.5 (25 °C)	3.5	87	92.5
6	KSM-3	98.6	8.1-10.0 (25 °C)	2.9	80	88.7

The collector consisting of DTF, despite good wetting ability towards diamonds, does not demonstrate the best performance in terms of the parameters "Share of collector on diamonds" and "Diamond recovery ε_{diam}" (Table 1). However, for DTF, a significantly smaller diameter of the wetting perimeter of a droplet fixed on a diamond was established (Table 1). This result characterizes the tendency of low-viscosity DTF droplets to transition from the mineral-water interface to the air-water interface and decreasing the hydrophobicity of a diamond.

Comparison of the findings of these flotation tests and the data of physicochemical studies allows concluding that the best results are obtained when using collectors with a high wetting angle and a sufficiently high dynamic viscosity (η). It is these physicochemical characteristics of the collector that ensure its fast and stable fixation on diamonds.

To confirm the contribution of ARCF to an apolar collector fixation efficiency, the images of diamonds before and after the conditioning and flotation processes were obtained using combined optical microscopy (Fig. 1a, b). As a result of interaction with the collector, the floatated diamonds are covered with an almost continuous layer of the collector (Fig. 1b). After washing of medium molecular weight fuel oil fractions with carbon tetrachloride, the areas with color characteristics typical for ARCF were preserved on the diamond surface (Fig. 1c).

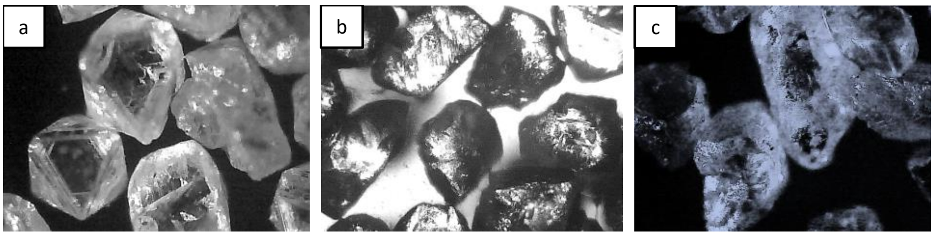

Figure 1 Images of diamond crystals at foam separation (a,b) with fixed asphaltene-resin cut fraction (c)

The ARCF fixation on diamonds is irreversible that increases the stability of the fixation of medium viscous fractions of fuel oil. The obtained research results confirmed increasing the stability of collector fixation on diamonds due to adhesion of ARCF as a crucial condition for effective flotation.

Increasing diamond recovery due to applying ultrasonic, thermal, and reagent treatment [4] was the basis for testing the effectiveness of the combined mode, involving the use of all three types of the treatment. The tests results showed that the combination of ultrasonic and thermal treatment with the addition of OEDP (oxy-ethylidene diphosphonic acid, a slurry dispersing agent) provides a noticeable increase in diamond recovery (Table 2).

Table 2 Effect of ultrasonic (UST) and thermal treatment of the initial feed and that of additives of oxy-ethylidene diphosphonic acid (OEDP) on foam separation outcomes

No.	Treatment conditions			ε, %	
	UST duration, sec.	Temperature, ℃	C_{OEDP}, mg/l	diamonds	kimberlite
1	-	24	-	82.5	0.86
2	30	24	-	87.5	0.65
3	-	24	100	85.0	0.55
4	-	85	-	87.5	0.68
5	30	85	-	90.0	0.59
6	30	24	100	90.0	0.39
7	30	85	100	92.5	0.60
8	60	24	100	90.0	0.40
9	60	85	200	90.0	0.33

The analysis of the results of testing the developed process modes at a foam separation unit showed that when using the combined mode the diamond recovery (tests 5-9, Table 1) was higher than in the basic test or at separate application of the treatment types (tests 1-4, Table 1). The yield of kimberlite into the concentrate remained at the same level (0.47 - 0.68 %) when using the combined modes.

The reasonable temperature range before deslurring process stage is 80-85 ℃, in conditioning with collector, 30-35 ℃, and in foam separation, 20-24 ℃. At such temperature conditions the effective dispergating of the collector and its fixation on diamonds is achieved. However, the application of thermal conditioning is an energy-consuming process. Therefore, we conducted studies on the selection of collectors for different temperature conditions.

The experimental study showed that at lower temperatures (10 and 14 ℃) the best results were obtained for the KSM collectors obtained by diluting M-40 fuel oil with diesel process oil cut fraction and aliphatic ketones: diethyl ketone (DEK), ethyl methyl ketone (EMK) and dimethyl ketone (DMK) (Table 3).

Based on the results of the study of temperature effect on foam separation performance, the recommendations were given to apply the systems for heating recycled water and collector to maintain the temperature of the medium in conditioning and foam separation process stages up to 24 ℃. If there is no possibility of increasing temperature in conditioning, foam separation, and flotation process stages, it is reasonable to use KSM-1 and KSM-2 compound collectors.

Table 3 Recovery of diamonds in flotation with compound collectors based on M-40 fuel oil at different temperatures

Collector	Diamond recovery into concentrate, %		
	10 ℃	14 ℃	24 ℃
M-40 fuel oil	54.4	68.7	74.4
M-40-20	72.3	78.6	88.5
KSM-1	86.3	92.2	88.4
KSM-2	85.2	92.5	85.9
KSM-3	81.5	88.7	87.0

Increasing the foam separation performance is promoted by application and improvement of closed water recycling system [5]. However, the accumulation of slurry at increasing the proportion of recycled water causes an increase in diamond losses, the cost of which exceeds the savings from reduced reagent consumption. The required result from increasing the proportion of recycled water is achieved by removing slurry from the recycled water. The recommended increase in the proportion of recycled water used from 70 to 85 % was tested for the foam separation cycle at the Processing Plant. The selected scheme included a single-stage clarification of the feed thickening overflow and two-stage clarification of the aqueous phase of the foam separation products. The results of the tests confirmed the feasibility of reducing the collector consumption by 8% while maintaining diamond recovery and concentrate quality at the same level (Table 4).

Table 4 Foam separation cycle performance when changing recycled water proportion

Recycled water proportion, %	Collector consumption, g/t		ε_{diam}, %	Kimberlite yield into concentrate, %
	F-5 fuel oil	butyl aeroflot		
70	1,100	25	87.9	0.65
75	1,050	23.5	87.9	0.64
80	1,035	23.1	87.8	0.64
85	1,020	22.8	87.8	0.63
90	970	21.5	85.8	0.62

CONCLUSION

The important role of the optimal combination of adhesion activity and strength of fixation of a collector on diamonds was shown. The important role of asphaltene-resin cut fractions in stable fixation of an apolar fuel oil-based collector on diamonds was demonstrated.

Based on the results of laboratory and industrial studies, the effectiveness of combined modes of ore and recycled water conditioning by acoustic, thermal, and reagent methods to increase the floatability of diamonds was shown.

A technological mode of foam separation was developed and tested, including thermal treatment of an initial diamond-containing product and maintenance of the required temperature in the operations of conditioning and foam separation. It was shown that under the conditions of low pulp temperatures the highest performance was demonstrated by collectors with additives of diesel process oil cut fraction and aliphatic ketones.

The regime of water recycling in the foam separation cycle involving the recycled water proportion up to 85% with clarification of the overflow of the initial feed -2 - +1 mm thickening and clarification of the foam separation concentrates and tailings was selected.

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