



## BENEFICIATION AND PROCESSING OF NATURAL AND TECHNOGENIC RAW MATERIALS

Research article



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### Selection of Temperature regimes for conditioning and flotation of diamond-bearing kimberlite with compound collectors

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#### Abstract

The condition for stable fixation of a collector on the surface of diamonds and their flotation is the use of collectors of the optimal fractional composition and the choice of the optimum temperature regime of the process. To determine the parameters of the diamond flotation regime, the regularities of the phase transitions of asphaltene-tar fractions at increasing temperature and diluting F-5 with technical diesel fraction were established. It was demonstrated that increasing the collector temperature leads to the transfer of asphaltene-tar fractions to a dissolved and finely dispersed state. To an even greater extent, dissolving asphaltene-tar fractions is facilitated by the addition of medium- and low-molecular weight fractions of oil, for instance, a technical diesel fraction.

It was revealed that the KM-10, KM-14, and KM-18 reagents, being compounds of F-5 fuel oil with technical diesel fraction (10–18 % DF), were characterized by optimal viscosity and ability to displace aqueous phase from a diamond surface, thus ensuring stable hydrophobization and high floatability of diamonds. The optimal temperature regime has been selected, which involved maintaining the temperature at the stage of conditioning with the collector at +30–40 °C, at which the maximum selective fixation of compound collectors on the diamond surface, characterized by the value of the limiting wetting angle, was achieved.

The flotation tests have confirmed that the best results are achieved at a temperature of +30–40 °C at the conditioning stage and +14–24 °C at the flotation stage. At +24 °C, the best results were obtained for the relatively less diluted KM-10 and KM-14 fuel oils obtained by diluting F-5 fuel oil with a technical diesel fraction at the diluent volume fractions of 10 and 14 %. The diamond recovery achieved in the flotation tests was 3.8–4.5 % higher than when using the traditional collector, F-5 fuel oil. At +14 °C, the highly diluted fuel oil, KM-18 with a volume fraction of 18 % of the technical diesel fraction, demonstrated better collecting abilities.

The optimal compositions of the collector and the regimes of feed preparation and flotation were tested at a foam separation unit. The tests showed that it is possible to increase diamond recovery into concentrate by 2.3–4.5 %. The recommendations are provided on the use of thermal conditioning in the foam separation cycle and maintaining the conditioning medium temperature at +30–40 °C and the foam separation temperature at +14–24 °C.

#### Keywords

diamonds, kimberlite, collector, fractional composition, conditioning, wetting, foam separation, heat treatment

#### For citation

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## ОБОГАЩЕНИЕ, ПЕРЕРАБОТКА МИНЕРАЛЬНОГО И ТЕХНОГЕННОГО СЫРЬЯ

Научная статья

### Выбор температурных режимов кондиционирования и флотации алмазосодержащих кимберлитов компаундными собирателями

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#### Аннотация

Условием устойчивого закрепления собирателя на поверхности алмазов и их флотации являются применение собирателей оптимального фракционного состава и выбор необходимого температурного режима технологических операций. С целью определения параметров режима флотации алмазов установлены закономерности фазовых переходов асфальтено-смолистых фракций при повышении температуры и разбавлении мазута Ф-5 дизельной технической фракцией. Показано, что увеличение температуры собирателя приводит к переводу асфальтено-смолистых фракций в растворенное и тонкодисперсное состояние. В еще большей мере решению задачи растворения асфальтено-смолистых фракций способствует добавление средне- и низкомолекулярных фракций нефти, например, дизельной технической фракции.

Показано, что реагенты КМ-10, КМ-14 и КМ-18, представляющие собой компаунды мазута Ф-5 с дизельной технической фракцией (10–18 % ДФ), характеризуются оптимальной вязкостью и способностью вытеснять водную фазу с поверхности алмаза, что обеспечивает возможность устойчивой гидрофобизации и высокую флотируемость алмаза. Выбран оптимальный температурный режим, который предполагает поддержание температуры в операции кондиционирования с собирателем +30–40 °C, при котором достигается максимальная склонность компаундных собирателей к селективному закреплению на поверхности алмазов, характеризуемая величиной краевого угла смачивания.

Флотационными опытами подтверждено, что наилучшие результаты достигаются при температуре среды +30–40 °C в операции кондиционирования и +14–24 °C при флотации. При +24 °C наилучшие результаты получены для относительно менее разбавленных мазутов КМ-10 и КМ-14, полученных разбавлением мазута Ф-5 дизельной технической фракцией с объемной долей разбавителя 10 и 14 %. Достигнутое извлечение алмазов при флотации на 3,8–4,5 % выше, чем при использовании базового собирателя – мазута Ф-5. При +14 °C лучше проявляет собирательные свойства мазут с большим разбавлением – КМ-18 с объемной долей дизельной технической фракции 18 %.

Оптимальные составы собирателя и режим подготовки питания и флотации апробированы на установке пенной сепарации, где показали возможность повышения извлечения алмазов в концентрат на 2,3–4,5 %. Даны рекомендации по применению теплового кондиционирования в цикле пенной сепарации и поддержанию температуры среды в операции кондиционирования +30–40 °C и в операции пенной сепарации +14–24 °C.

#### Ключевые слова

алмазы, кимберлиты, собиратель, фракционный состав, кондиционирование, смачивание, пенная сепарация, тепловая обработка

#### Для цитирования

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## Introduction

The foam separation process, which constitutes the main method of extracting small diamonds from kimberlite, involves the use of various oil products as collectors, including oil, F5 bunker fuel oil, and water-oil emulsions [1, 2]. Changes in the fractional composition of the oil products to be used as collectors as well as fluctuations in the temperature of the flotation pulp often lead to deterioration of the foam separation performance [3]. Insufficient fixation of the apolar collector on the diamond surface due to hydrophilisation of the diamond surface or inefficiency of the collectors is the main reason for the decrease in recovery [3, 4]. Increasing the stability of the collector fixation on the surface of diamonds and, as a result, increasing their floatability can be ensured by using methods for restoring the natural floatability of diamonds through selecting collectors of optimal fractional composition and maintaining the required temperature regime at conditioning and foam separation stages [5–7]. To improve the performance of diamond-bearing kimberlite foam separation, the physicochemical properties and optimum component composition of the collectors were studied in the course of this study, and the temperature regimes for the key stages of the technological process were selected.

### 1. Research techniques

The research of the structure of oil products used as a collector was carried out by the combined ultraviolet and visible light microscopy method [8]. Micrographs of a thin layer of the oil products were obtained by a Micromed-3-LUM microscope. Visiometric analysis and determining particle size distribution characteristics of asphaltene-tar fractions were carried out using the VideoTest 4.0 software package [9].

A SV-10 vibrating viscometer [10] was used to measure dynamic viscosity of the reagents. An important advantage of the method and device used is the possibility of obtaining continuous dependences of viscosity on temperature both in sample cooling and heating regimes.

To measure the limiting wetting angle of diamonds and kimberlite by a drop of collector in an aqueous phase, an OCA 15EC device with a USB-camera and a SD-DM direct dosage system for liquid was used in combination with ES electronic dosing module [11]. In the research, an improved measurement technique described in the relevant section of the paper was used.

Verification of collecting abilities of the studied petroleum products and their mixtures was carried

out using Hallimond tube, a non-frothing flotation unit with a porous glass aerator (Schott filter) [12]. The preparation of diamonds for testing involved chemical cleaning of their surfaces, which included washing in carbon tetrachloride, alcohol, distilled water, and treatment in concentrated hydrochloric acid solution. Individual mineral samples and mixtures of diamond and kimberlite grains of smaller size were used. The semi-industrial tests with the best collectors at selected temperature regimes were carried out at the LFM-001S foam separation unit of Yakutniproalmaz Institute with the use of industrial recycled water. Specific test conditions are outlined in the relevant sections of this paper.

### 2. Study of temperature and fractional composition effect on the structure and viscosity of petroleum products

The temperature of the medium at the stage of initial feed conditioning with flotation reagents and immediately in the flotation process is an important parameter of the foam separation process [7, 13]. Another important factor determining diamond flotation performance is the structure of a collector used, in particular, the form of adhesion-active high molecular weight fractions [14, 15]. The structure of petroleum products is largely determined by the ratio of low and high molecular weight fractions and the temperature of the medium. To substantiate the optimal temperature regime of the diamond-containing products conditioning and flotation processes, studies were carried out with a view to determining the effect of temperature on the structure of the used petroleum product on the example of the basic collector being used, F-5 bunker fuel oil. The research examined the temperature range from  $-10^{\circ}\text{C}$  to  $+50^{\circ}\text{C}$ , due to the specific storage and use regimes of the collectors.

For physical, chemical, and technological research, samples of F-5 bunker fuel oil and technical diesel fraction were taken. Bologoenefteprodukt LLC, according to the method developed by the IPCON RAS, prepared compound collectors consisting of F-5 fuel oil and technical diesel fraction from industrial products. The mass fraction of asphaltene-tar fractions in the initial F-5 fuel oil was determined using the standard procedure as per GOST 2177-99 (ISO 3405-88).

Analysis of the results of the collector structure studies showed that when F-5 fuel oil is cooled to a temperature of  $-10^{\circ}\text{C}$ , grains of the asphaltene-tar fraction and paraffin were crystallized, and droplets of low molecular weight petroleum fractions were condensed (Fig. 1, a). When bunker fuel oil was heated

to a temperature of +10 °C, droplets of low molecular weight fractions disappeared due to the mutual dissolution of the phases, while the asphaltene and paraffin crystals survived, however, in smaller quantities (Fig. 1, *b*). When heated to +24 °C (Fig. 1, *c*), optically distinct paraffin crystals practically disappeared. When further heated to +50 °C, paraffin crystals were not detected, and the amount of tars and asphaltenes decreased (Fig. 1, *d*).

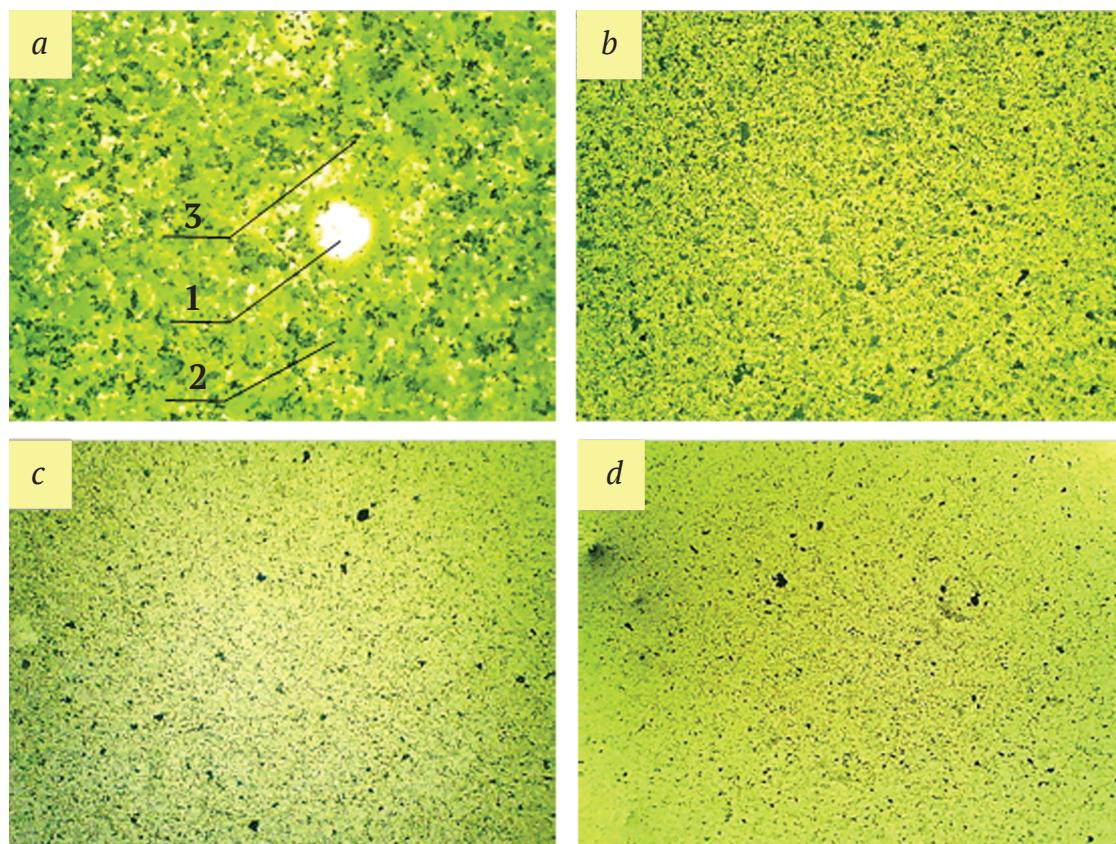
The results of optical-visiometric analysis of the particle size distribution of the asphaltene-tar fraction grains, represented as a mass fraction of the substance in solid and dissolved phase state as a function of temperature, revealed a pattern of their dispersion and dissolution with increasing temperature. As can be seen from Fig. 2, the mass fraction of asphaltene-tar fraction grains of optically discernible size (+0.1 microns) decreases from 28.1 % at a temperature of -10 °C to 20.2 % at a temperature of +50 °C.

Analysis of the particle size distribution characteristics of the asphaltene-tar fraction grains in the range of 0.1 to 10  $\mu\text{m}$  shows that heating the reagent leads to a proportional dissolution of both large and small grains, resulting in insignificant changing the particle size distribution.

Thus, the results obtained show that an increase in temperature contributes to the dissolution of the fraction of tars and asphaltenes. To maximize the dissolution of asphaltenes in low molecular weight fractions, heating up to +40–50 °C is required.

Changing the structure of petroleum products by the addition of low molecular weight hydrocarbon fractions, for instance, a technical diesel fraction, is a well-known way to regulate their physico-chemical properties [2, 16]. When using fuel oil as collectors, the use of additives of the technical diesel fraction or its analogues (diesel fuel, bunker fuel, domestic light fuel) provides not only the required properties, for instance, a decrease in the pour point, but also increases its collector capacity in relation to diamonds [17].

Dilution of fuel oils with low molecular weight petroleum refining fractions causes a significant decrease in viscosity, pour point, and flash point. The physicochemical properties of petroleum products vary with their phase composition changes due to changing the disperse structure of petroleum, including the phase state of high molecular weight components, primarily asphaltene-tar fraction [18].



**Fig. 1.** Micrographs of a thin layer of M-5 fuel oil at the combined lighting conditions at Micromed-3-LUM microscope after cooling to a temperature of -10 °C (*a*), heated to a temperature of +10 °C (*b*), +24 °C (*c*), and +50 °C (*d*):

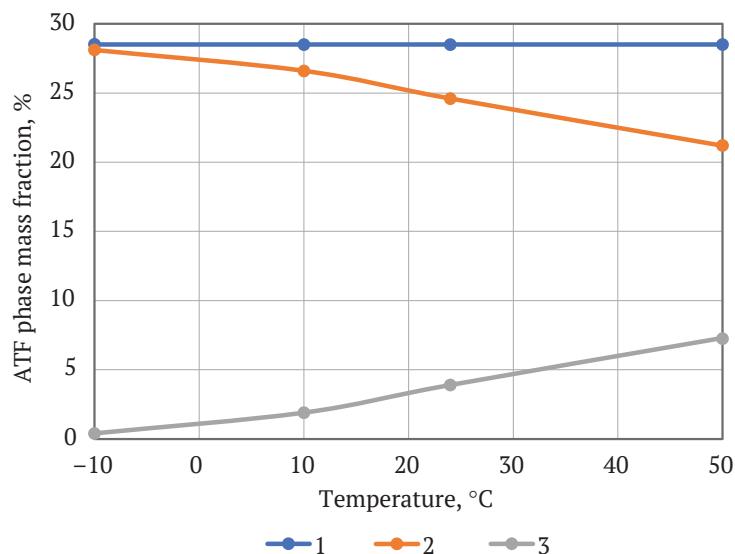
1 – drops of low molecular weight hydrocarbon fractions, 2 – crystals of saturated hydrocarbons (paraffins);  
3 – grains of asphaltene-tar fractions

The results of visiometric analysis of the phase composition of the asphaltene-tar fraction, represented in the form of dependences of the proportion of types of asphaltene-tar fractions on the degree of the dilution of F-5 fuel oil with diesel fraction, demonstrated a significant effect of low molecular weight hydrocarbon additives on the structure of the petroleum product. According to the results of optical-visiometric analysis, the proportion of asphaltene-tar fractions with a grain size of more than 0.1  $\mu\text{m}$  (detectable by the applied technique) decreases from 25 % to 4.5 % when diluted to 30 % with diesel fraction. Taking into account the natural decrease in the mass fraction of tars and asphaltenes when diluted, their proportion in finely dispersed,

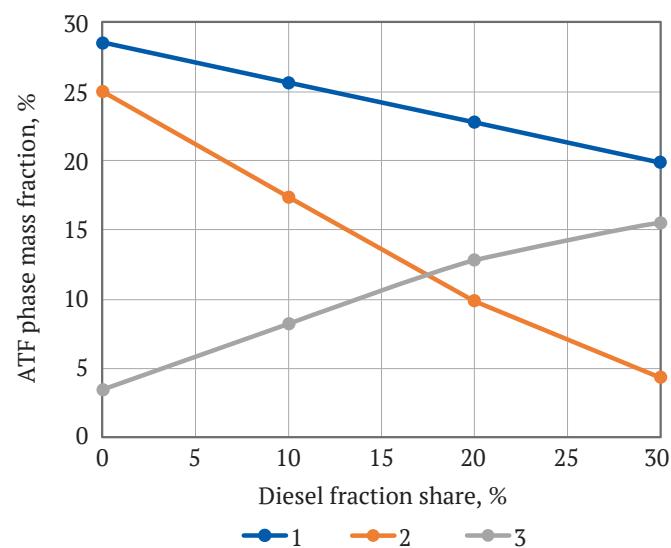
colloidal, and dissolved forms increases from 3.7 to 15.7 absolute percents or from 13.0 to 55.1 relative percents (Fig. 3).

Analysis of the results obtained shows that the dilution of fuel oils with low molecular weight fractions is the most effective factor in dissolving the tar and asphaltene fraction.

Viscosity is another characteristic of petroleum products that significantly affects the effective interaction of the collector with the diamond. As shown in study [2], the best results of foam separation of diamond-containing kimberlites are achieved using the compounds of fuel oil with diesel fuel or petroleum-water emulsions in the viscosity range of 12–19 MPa·s (for a standard temperature of +50 °C).



**Fig. 2.** Asphaltene-tar fractions (ATF) portion as a function of medium temperature:  
1 – total; 2 – in solid form based on the results of visiometric analysis;  
3 – in dissolved and emulsion form (as a difference between the first two values)



**Fig. 3.** Change in the asphaltene-tar fractions (ATF) phase proportions when F-5 fuel oil is diluted with a diesel fraction:  
1 – total; 2 – in solid form based on the results of visiometric analysis; 3 – in dissolved and emulsion form

The viscosity of fuel oils depends significantly on the temperature and their fractional composition. As shown in Table 1, a decrease in the fuel oil temperature from +50 to +14 °C leads to an increase in the viscosity several times. The studies using an SV-10 device showed that at a standard temperature of +50 °C the viscosity of petroleum products used as collectors varies in the range of 12.3 to 119 MPa·s. At the common foam separation process temperature of +14 °C, the viscosity increases several times and range 32.2 to 1,100 MPa·s. When the temperature decreases to +10 °C, straight-run fuel oil and M-40 fuel oil solidify. The viscosity of F-5 fuel oil reaches more than 1000 MPa·s.

Table 1

**The viscosity of petroleum products at different temperatures**

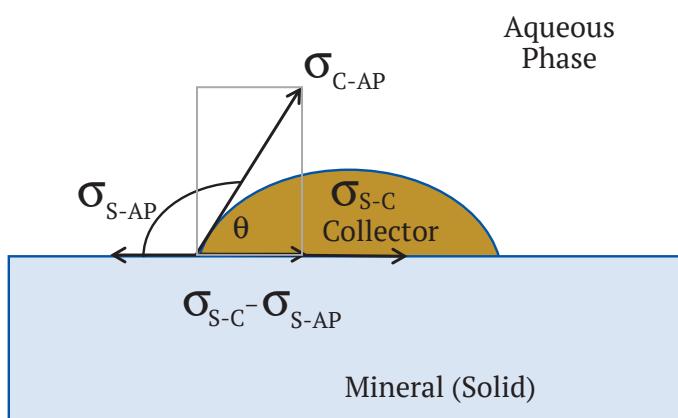
Product	Temperature, °C			
	+50	+25	+14	+10
Straight-run fuel oil	119.0	155.0	1100	Solidified
M-40 fuel oil	72.0	119.0	158.5	Solidified
F-5 fuel oil	32.5	64.5	119.6	1090
F-5 fuel oil + 10 % of Diesel fraction	12.3	17.5	32.2	45.2
Diesel fraction	0.98	1.64	3.6	5.8

Analysis of the data presented in Table 1 shows that industrial fuel oils exhibit higher viscosities (32.5–119 mPa·s) than those recommended in the research [14]. The compound of F-5 fuel oil with diesel fraction of 10 % (the viscosity of 12.3 MPa·s, Table 1) exhibits rather acceptable characteristics. Varying the degree of dilution of fuel oil with low molecular weight petroleum products makes it possible to achieve various viscosity values within the recommended range from 12.3 to 119 mPa·s.

Thus, the research findings demonstrated that temperature changes and dilution with low molecular weight fractions constitute effective factors in regulating the structure of asphaltene-tar fractions of fuel oil and its physicochemical properties.

### 3. Studies of the temperature effect on the interaction of diamonds and minerals with a collector

The most informative technique that assesses the ability of reagents to fix on the surface of minerals is the method of measuring three-phase limiting wetting angles. For the mineral – collector droplet – aqueous phase system (Fig. 4), the measured limiting (three-phase) wetting angle is determined by the relationship between oleophilicity (increase in the wetting angle) and hydrophilicity (decrease in the wetting angle) of the mineral surface [18].


**Fig. 4.** Schematic representation of a collector droplet on a mineral in a cuvette filled with an aqueous phase

To adequately simulate the actual conditions of the industrial process, an improved testing method was used, which included preliminary wetting of the mineral sample with a thin layer of water, applying a collector droplet to the wetted surface, and increasing the liquid level above the sample surface. Such conditions allow simulating both the process of fixing the collector on a mineral in the course of conditioning (Fig. 5, a) and its separation under the influence of external factors (the influence of the difference between the collector density and the aqueous phase density or hydrodynamic separation). The distribution of the collector between the sample surface and the surface of the aqueous phase (parts of the collector that have emerged due to the difference in the specific weights of water and the collector, Fig. 5, b) leads to preserving collector droplets on a hydrophobic sample with the formation of an equilibrium limiting wetting angle or completely separating the collector droplets from the hydrophilic mineral.

When processing a kimberlite, which is a polymineral rock, a collector is fragmentary fixed on naturally hydrophobic mineral-constituents of the kimberlite.

Before conducting measurements, the initial sample (diamond or kimberlite) was soaked in recycled water in contact with air for one hour and then the cuvette with the mineral sample was cooled or heated under thermostatic conditions in the range of +10–70 °C. This ensured maintaining the sample and performing the tests to measure the limiting wetting angles in the temperature range of +14–60 °C.

The composition of the recycled water corresponded to the recycled water of PP No. 3 of Mirny GOK. F-5 fuel oil was used as a collector. The research results showed a mild dependence of the limiting wetting angle on the temperature of the aqueous medi-

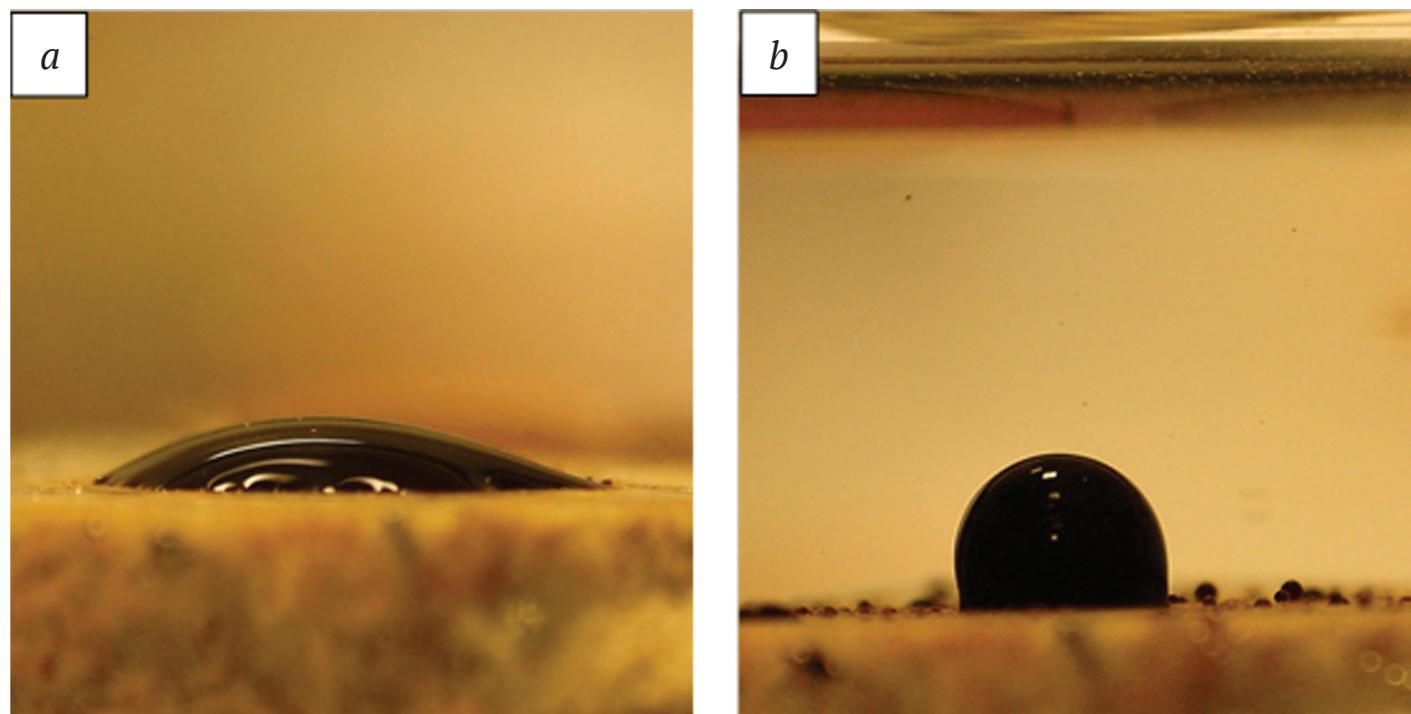


um. The limiting wetting angle, which characterizes the hydrophobicity of a diamond and its tendency to interact with the collector, gradually increases in the temperature range of +14–40 °C. The difference in limiting wetting angles at a temperature of +14 and +40 °C was 3–5 degrees (Table 2). A further increase in the temperature does not lead to an increase in the limiting wetting angle.

The hydrophobicity of hydrophobic kimberlite minerals (phlogopite, talc, etc.), similar to that of diamond, increases slightly with increasing temperature. The increase in temperature has a positive effect on hydrophilic kimberlite minerals (olivine, calcite), reducing their hydrophobicity until the cessation of the droplet fixing on the mineral surface at a temperature of +30 °C and above (Table 3). In most cases, a droplet

separates from the surface of the kimberlite section, and fuel oil is fixed only to certain areas of the surface, which are represented by inclusions of natural hydrophobic minerals, mainly layered aluminosilicates. The droplet is completely detached from the mineral surface at lower (+14–30 °C) and maximum (+60 °C) temperatures.

Analysis of the findings suggests that the optimum temperature regime for the conditioning stage with the collector involves maintaining the temperature at +30–40 °C, when the maximum collector's tendency towards fixing to the diamond surface (identified with the maximum limiting wetting angle) is achieved and there is no significant increase in the collector's tendency towards fixing to kimberlitic minerals.



**Fig. 5.** Images of F-5 fuel oil drop on phlogopite surface:  
a – on a moistened thin section; b – after the water level rises

**Changing the limiting wetting angles of a diamond and kimberlite minerals by a droplet of F-5 fuel oil as the temperature increases**

Ambient temperature, °C	Limiting wetting angle on minerals, degrees				
	Diamond	Phlogopite	Kimberlite	Calcite	Olivine
+14	91–95	52–67	Separation	42–53	45–55
+24	92–97	54–68	Separation	40–50	40–55
+30	94–101	55–65	Separation	Separation	Separation
+40	94–100	57–66	Fragmentary, 45–75	Separation	Separation
+50	91–96	58–68	Fragmentary, 40–75	Separation	Separation
+60	90–93	60–70	Separation	Separation	Separation

Table 2



#### 4. Study of the temperature effect in the process stages on the flotation of kimberlite diamonds

The change in the floatability of diamonds when the temperature of conditioning with collector varies was studied based on the results of flotation tests in the Hallimond tube at the conditioning and flotation temperatures of +10, +14, and +24 °C. The selected temperature interval corresponds to the foam separation conditions at industrial plants at different seasons. In the course of the tests, F-5 bunker fuel oil (produced by "Bologoenefteprodukt" LLC) and its compositions with industrial diesel fraction were used.

Taking into account the results of the studies carried out, a temperature of +30 °C was selected for the initial feed conditioning with the collector. The required flotation process temperature (+10–24 °C) was achieved by adding an aqueous phase with a temperature of +6–24 °C. Analysis of the tests results showed that the maximum recovery of diamonds into the concentrate was achieved at temperatures of +14 and +24 °C. At +14 °C, the best results were obtained for KM-10 and KM-14 (diluted fuel oils) obtained by diluting F-5 fuel oil with a diesel fraction at the diesel fraction volumetric proportion of 10 % and 14 % (the recovery of 78.4 and 77.9 %, respectively). This is 3.8–4.5 % higher than that of the best basic collector, F-5 fuel oil (Table 3).

Table 3

**Recovery of diamonds in flotation with F-5 bunker fuel oil and its compositions with diesel fraction (DF) as collectors at different temperatures**

No.	Collector	Diamond recovery into concentrate, %, in flotation at temperature, °C		
		+10	+14	+24
1	F-5 bunker oil	70.6	74.6	80.5
2	KM-10 diluted fuel oil (10 % DF)	75.4	78.4	84.2
3	KM-14 diluted fuel oil (14 % DF)	74.3	77.9	83.2
4	KM-18 diluted fuel oil (18 % DF)	72.0	75.3	81.5

Further studies were carried out at a non-frothing flotation unit using mineral mixes. A sample of kimberlite (200 mg) was used, into which diamonds (50 mg) were loaded. The size classes used for kimberlite (0.5–0.75 mm) and diamonds (from 0.25 to 0.5 mm) made it possible to analyze the flotation products by sieving and calculate the balance of diamonds and kimberlite.

The test technique included conditioning a sample of kimberlite and diamonds at fixed temperatures (in the range of +24–40 °C). After conditioning, an aqueous phase with a temperature of +12–28 °C was added. After mixing, the medium temperature was set

at +14–28 °C, at which the flotation process was carried out. The results of flotation tests with diamond and kimberlite mixes when using heating at the conditioning stage indicated the following. When using F-5 fuel oil, the maximum increase in diamond recovery into the concentrate was achieved by heating the flotation feed at the conditioning stage with the collector up to +40 °C and performing flotation at +28 °C (test 3, Table 4). There was no noticeable change in the recovery of kimberlite into the concentrate when the flotation collector and the temperature regime varied.

For the KM-10 and KM-14 compound fuel oils, the dependence of diamond recovery on temperature is similar and characterized by maximum diamond recovery at the temperatures of +30/24 and +40/28 °C (the temperatures in the conditioning/floatation stages). It is characteristic that when using these compound collectors, diamond recovery is 2.5–3.35 higher than when using F-5 fuel oil. These results coincide with the research data indicating that in this temperature range the optimum reagent viscosity and the maximum limiting angle of wetting of the diamond surface by the collector droplet are achieved. At lower temperatures (+24/14 °C regime), the best performance (among the collectors considered) was demonstrated by the most diluted KM-18 collector (Table 5, tests 4, 7, 10).

The water recycling systems used at the processing plants of Alrosa AK are not designed for thermal conditioning of the recycled water. Therefore, the selected collectors were tested in the conditions of feed preparation close to the standard regime: at the feed conditioning temperature of +24 °C and the foam separation temperature of +16–18 °C.

Table 4

**The key process indicators of foam separation using the optimal heating regimes at the conditioning stage**

No.	Collector used	Air conditioning/floatation temperature, °C	Diamond recovery into concentrate, %	Kimberlite yield to concentrate, %
1	F-5 fuel oil	24/14	74.5	1.5
2	F-5 fuel oil	30/24	77.8	1.5
3	F-5 fuel oil	40/28	80.3	1.7
4	KM-10	24/14	77.0	1.9
5	KM-10	30/24	81.2	1.6
6	KM-10	40/28	83.2	1.5
7	KM-14	24/14	77.8	1.7
8	KM-14	30/24	82.2	1.5
9	KM-14	40/28	83.6	1.8
10	KM-18	24/14	80.5	1.3
11	KM-18	30/24	81.2	1.4
12	KM-18	40/28	81.2	1.5



The tests were carried out at a LFM-001S automated foam separation unit of Yakutniproalmaz Institute, equipped with a recycled water system and an automatic air dosing apparatus (Fig. 6).

The LFM-001S foam separation unit (see Fig. 6) operated in practically industrial conditions (collector consumption of 1000 g/t, butyl aerofloat consumption of 50 g/t, a foamer consumption of 150 g/t). The unit used recycled mineralized water from the TSF of No. 3 of Mirny GOK at a rate of the water supply into the under-foam layer of 50 ml/min and an air flow rate of 100 ml/min. Prior to the test, the foamer was added directly to the recycled water of the foam separation unit.

During the tests, the temperature of the mix of kimberlite and diamonds and recycled water was regulated. At the unit, the treatment with the collectors was performed at +24–30 °C, while the foam separation was carried out at +16–24 °C.

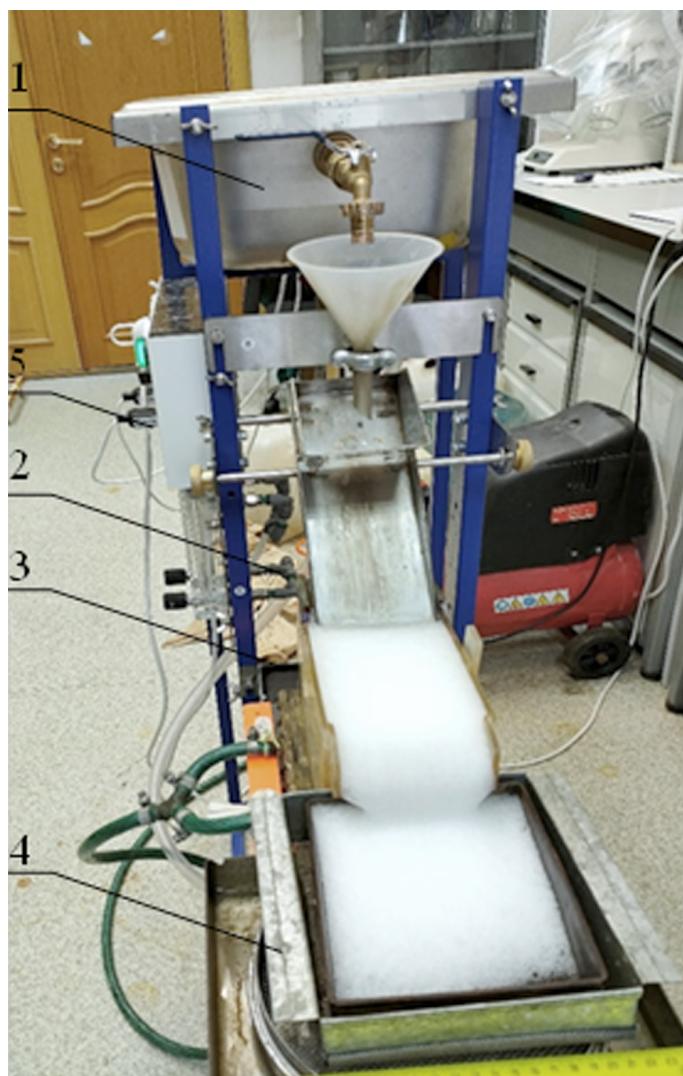


Fig. 6. Automated foam separation unit:

1 – recycled water tank; 2 – supply tray; 3 – working chamber;  
4 – concentrate receiver; 5 – unit air flow control

After the foam separation, the products were picked and the extracted diamonds were weighed. As the performance criterion, the selectivity index calculated as a function of diamond recovery ( $\varepsilon$ ) and kimberlite yield into the concentrate ( $\gamma$ ) was used:

$$S = \varepsilon - 1,3\gamma. \quad (1)$$

The value of 1.3 in equation (1) reflects the ratio between the cost of additionally recoverable diamonds and refinement costs at increased kimberlite yield.

The results of tests on the bench unit (Table 5) indicated the possibility of increasing the recovery of diamonds into concentrate by a maximum of 2.3–4.5 % when using the KM-10 and KM-14 collectors at a temperature regime of +30/18 °C.

Table 5  
The performance of the foam separation process  
at the bench unit

No.	Reagent	Diamond recovery into concentrate, %	Kimberlite yield in concentrate, %	Selectivity, %
1	F-5 fuel oil	79.4	1.7	77.19
2	KM-10	81.7	1.9	79.23
3	KM-14	83.9	2.9	80.13
4	KM-18	80.0	2.4	76.80

When the temperature during the foam separation stage exceeds +24 °C, the diamond recovery increases by 1.0–1.3 %. However, at the same time, the yield of kimberlite into the concentrate also increases, by 1.5–1.8 %, and the selectivity decreases. Therefore, increasing the intensity of thermal conditioning requires adjusting the foam separation reagent regime to prevent an increase in the yield of kimberlite in the diamond concentrate.

Based on the findings of the studies on the effect of temperature on foam separation performance, the recommendations for the use of thermal conditioning in the foam separation cycle and maintaining the conditioning temperature at +30–40 °C and the foam separation temperature at +14–24 °C are provided.

### Conclusions

The regularities of dispersion and dissolution of asphaltene-tar fractions when the process temperature increases and F-5 fuel oil is diluted with a diesel fraction, leading to changes in the collector phase composition.

It was shown that the compounds of F-5 fuel oil with a diesel fraction (10–18 % DF) exhibit the required physicochemical characteristics (viscosity and diamond surface wettability), which provide stable fixation of the collector to the diamond surface.



Measurements of the limiting wetting angle revealed that when maintaining the conditioning stage temperature at +30–40 °C, the collector's maximum adhesion to the diamond surface is achieved, while the studied collectors are not markedly fixed to kimberlite minerals.

Flotation tests have shown that the best results are achieved at temperatures of +14 °C and +24 °C. At +14 °C, the highest dilution fuel oil, KM-18 with a volume fraction of 18 % of the diesel fraction, demonstrated better collecting abilities. At +24 °C, the best results were obtained for the relatively less diluted

KM-10 and KM-14 fuel oils obtained by diluting F-5 fuel oil with a diesel fraction with the diluent volume fractions of 10 and 14 %, respectively. The diamond recovery achieved (78.4 and 77.9 %, respectively) was 3.8–4.5 % higher than when using fuel oil F-5, the traditional basic collector.

The optimal compositions of the collector and the regimes of feed preparation and flotation were tested at a foam separation unit. They showed the capability of increasing the recovery of diamonds into concentrate by 2.3–4.5 %. These parameters were recommended for the use on an industrial scale.

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