Research of amber extraction technology by vibroclassifier

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Abstract. The article presents basic information about the method of hydromechanical extraction of amber from amber-containing rocks, water-sludge scheme and classification scheme. The constructive scheme of the vibroclassifier is also presented, which is based on the principle of using the influence – vibration and bubbling of the suspension by air bubbles. Studies of the separation process and distribution of fractions in multidisperse liquid on a vibroclassifier of complex action were performed. The obtained theoretical and graphical dependences allowed to establish changes in the parameters of the velocity of sand and amber particles in the bath of the vibroclassifier on the size of fractions and density of the suspension, focusing on the size of amber up to 5mm. At the same time, the problem of determining the dependence of the transition coefficient from the rate of free to the rate of compressed deposition on the density of the suspension and the size of the fractions was solved. Dependencies have been established that have a theoretical justification for the physical process and that describe the experimental data on the Rayleigh curve.

1. Investigation of the process of separation and distribution of fractions in a multidisperse liquid by a vibroclassifier of complex action

Developed devices based on mechanical spiral classifiers have been proposed for amber mining in Ukrainian Polissya deposits, which differ from known devices by the use of additional influences – vibration and bubbling of the suspension by air bubbles, for example, vibroclassifier, shown in figure 1 [1,2].

Perforated tubes for bubbling the suspension with small air bubbles are placed in the vibrating classifier inside the chute, a device for creating vibrations is installed under the bottom, additional water is supplied (1) [3]. Small particles of sand, clay and amber get into the lower part of the bath, where with the help of a device with paddle grips (2), through the drain threshold, are discharged into the receiving chute of the drain (3). The sands are picked up in a spiral and unloaded at the top of the classifier (4) [4].

To determine the size of the fractions carried into the drain, you must first determine the speed of free movement of the sand fractions and amber, then compressed air, and then determine
Figure 1. Vibroclassifier of complex action for amber extraction: 1 – additional (circulating) water; 2 – device with paddle grippers for moving floating fractions; 3 – unloading chute for floating amber fractions; 4 – unloading sands.

the degree of additional factors influence – vibration and bubbling [5,6].

To predict the course of this process in optimal conditions, it is important to have, if possible, a simple analytical apparatus to quantify its features [4,7].

The vibrating classifier is fed by amber-bearing rocks of the Klesiv deposit with host rocks, consisting of small and medium-sized sand fractions with a small amount of clay.

The rocks are mixed with water and fed into the bath of the vibrating classifier. According to the water-sludge scheme (figure 2), the density of the sand-clay suspension (pulp) in the bath is $1565 \text{g/l or } \approx 1.65 \text{g/cm}^3$.

Since the density of amber is less than the density of the suspension, then for amber we calculate not the deposition rate, but the rate of ascent [8,9]. In the calculations we take $\rho_a = 1.24 \text{g/cm}^3$, which will determine the lower limit of the rate of amber ascent, as fractions with lower density emerge faster.

The main host rock is sand, so for the solid phase of the suspension we take the density of sand $\rho_s = 2.65 \text{g/cm}^3$. The conditional size (diameter) of the fractions is the arithmetic mean diameter of two adjacent sieves.

The process of separation and distribution of fractions in the bath of the classifier is very complex (figure 3).

To perform a theoretical analysis, we assume that the pulp, which consists mainly of a mixture of sand different sizes with water, is a multidisperse, unstructured Newtonian fluid. To calculate the rate of free fractions deposition in such a suspension, we use the Rayleigh diagram (dependence of the fractions deposition coefficient on the Reynolds number), which we approximate and distinguish several areas: laminar, initial, middle, end of transition and turbulent. Each area is interpolated by its dependence and calculation formula [10,11].

The choice of the formula for calculating the rate of free deposition was performed not by the Reynolds criterion $R_e = (Vd)/\nu$, as it includes indeterminate values – velocity and diameter of parts, but by our dimensionless criterion $A$, which is converted by the first parameter P. Lyashchenko, only then adjust the results of the calculation in accordance with the Reynolds criterion ($R_e$):
Figure 2. Water-sludge scheme.

\[ A = \frac{\pi d^3 g \Delta}{6 \nu^2} \]  \hspace{1cm} (1)

where

\[ \Delta = \frac{\rho_1 - \rho_2}{\rho_2} \]  \hspace{1cm} (2)

where \( d \) – diameter of fractions, cm; \( g \) – acceleration of free fall, 981 cm/s\(^2\); \( \rho_1, \rho_2 \) – density of solid medium and pulp, respectively, g/cm\(^3\); \( \nu \) – kinematic viscosity of the pulp, cm\(^2\)/s.

According to the value of \( A \) in table 1 we choose the formula for calculating the rate of free fractions deposition in the liquid.
Table 1. Formulas for calculating the rate of free deposition of fractions in the liquid depending on criterion $A$.

| № | Criterion $A$ | Area on the Rayleigh curve / author of the formula | The rate of free precipitation of fractions |
|---|---------------|-----------------------------------------------|------------------------------------------|
| 1 | From 0 to 5.25 | Laminar / Stokes | $V = 54.48d^2\nu^{-1}\Delta$ |
| 2 | From 5.25 to 720 | The beginning of the transition area | $V = 23.6d^{3/2}\nu^{-2/3}\Delta^{5/6}$ |
| 3 | From 720 to 23000 | Middle / Alain | $V = 24.3d\nu^{-1/3}\Delta^{2/3}$ |
| 4 | From 23000 to $1.4 \cdot 10^6$ | The end of the transition area | $V = 37.2d^{2/3}\nu^{-1/9}\Delta^{5/9}$ |
| 5 | From $1.4 \cdot 10^6$ to $1.7 \cdot 10^9$ | Turbulent / Newton-Rittinger | $V = 57.5d^{1/2}\Delta^{1/2}$ |

$V$ – cm/s.

Among the formulas of table 1 only the first and fifth have a theoretical justification adequate to the physical process, others – describe the experimental data on the Rayleigh curve. All these formulas, as well as formula (1), includes the kinematic viscosity of the pulp $\nu$, the value of which must be determined.

2. Calculation of the sand fractions free deposition rate and amber ascent

The choice of formula for calculating the speed of free movement of individual fractions in dense pulps is determined according to criterion $A$, then specified according to criterion $Re$ (table 1).

The choice of formula depends on both the size of the fractions and the density of the pulp, as illustrated in table 2, 3 in which criterion $A$ is calculated at a pulp density $\rho_c = 1.4g/cm^3$, and $\rho_a = 1.6g/cm^3$, respectively $\nu = 0.021cm^2/s$ and $\nu = 0.036cm^2/s$, $\rho_a = 1.24g/cm^3$. In formula (1) for $A$, the value of $\Delta$ for amber is negative, so in the calculations we take the modulus $\Delta$ and determine not the deposition rate but the ascent rate [11].

According to the table 2, 3 Stokes’ formula describes the movement of small fractions, Alain – large, but in most cases it is necessary to use the formula (2) table 1, for the beginning of the transition region (from laminar to turbulent), for which $A = 5.25...720$, $Re = 0.5...30$. Each formula for velocity is applied to a certain range of fractional sizes, this is illustrated in figure 4. Modern computer capabilities allow for the dependencies of figure 4, as well as similar, with a different density of the suspension, to obtain simpler interpolation formulas than the formulas...
Table 2. Criterion $A$ for different pulp density and size of fractions, $\rho_c = 1.4 \text{g/cm}^3$.

| d, mm | $A$, sand   | $A$, amber |
|-------|-------------|------------|
| 2     | 8315*       | 1064*      |
| 1.5   | 3508*       | 449        |
| 1     | 1039*       | 133        |
| 0.5   | 130         | 16.6       |
| 0.3   | 28          | 5.25       |

* – Alain speed formula, ** – Stokes speed formula; others - the end of the transition area (table 1)

Table 3. Criterion $A$ for different pulp density and size of fractions, $\rho_c = 1.6 \text{g/cm}^3$.

| d, mm | $A$, sand   | $A$, amber |
|-------|-------------|------------|
| 2     | 2080*       | 720        |
| 1.5   | 877*        | 301        |
| 1     | 260         | 89         |
| 0.5   | 17          | 11         |
| 0.3   | 7.0         | 2.4**      |

* – Alain speed formula, ** – Stokes speed formula; others - the end of the transition area (table 1)

given in table 1.

According to figure 5, the dependence of the amber free ascent rate on the density of the suspension is extreme.

It increases with increasing density, reaches a maximum at $1.5 \ldots 1.6 \text{g/cm}^3$ and then tends to decrease, while the rate of deposition of sand decreases linearly throughout the studied density range. This feature is found for free deposition of fractions, but if this trend continues with limited deposition, it can be concluded about the rational density range, where the rate of amber ascent. Note the Newton-Rittinter formula (table 1), which is used in the turbulent region at $Re \geq 3000$ and $A \geq 1.4 \cdot 10^6$. In equation (1) we set $A=1.4 \cdot 10^6$, and in turn setting a different density of the suspension and its corresponding viscosity, for each density we determine the limiting size $d$. Then $d$ is adjusted to meet the condition $Re = 3000$.

3. Conclusions

In this work, the dependences of the velocity of sand and amber particles in the vibroclassifier bath on the size of fractions and the density of the suspension were established, emphasizing the size of amber up to 5 mm. Also solved the problem of determining the dependence of the transition coefficient from the rate of free to the rate of compressed deposition on the density of the suspension and the size of the fractions.

Therefore, it is seen that for sand of the same size with increasing pulp density, the deposition rate decreases, and vice versa. For amber, the rate of ascent is higher for a higher density of the
Figure 4. Dependences of the rate of free deposition of sand and amber ascent on the size of the fractions at a pulp density of 1600 g/l: (a) according to Stokes; (b) the beginning of the transition area; (c) according to Alain; (d) end of the transition area.
Figure 5. Dependences of the sand fractions free deposition rate (1) and the ascent of amber (2) with a size of 1 mm from the density of the pulp.

medium, but here the difference in density does not significantly affect the speed as for sand.

The calculation performed in the program Excel allowed to obtain a description of the large fractions motion by Newton-Rittinter: at a density of suspension $\rho_c = 1.5 \text{ g/cm}^3$ starting with amber size 23 mm and above, at $\rho_c = 1.6 \text{ g/cm}^3$ – starting from 25.7 mm, for $\rho_c = 1.7 \text{ g/cm}^3$ – starting from 30 mm.

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