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Technical Note

# Physical separation (gravity and shape) of small-sized mica ore

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ABSTRACT

To process small-sized mica contained in vein filling mined and in muscovite dumps a separation technology has been developed. The technology is based on gravity separation into shapes, with the behaviour of mica flakes, falling in a liquid under different hydrodynamic regimes, taken into account. The technology consists of separation into shapes, hydraulic separation and table separation. Being desintegrated in a rod mill, mica booklets get thinner and the sphericity coefficient decreases, resulting in separation indices upgrading. The technology enables to produce a concentrate with 95-100% mica content at recovery 60-66.7% from mica contained in small-sized ore. 

Keywords: Gravity separation; Mica; Phlogopite; Muscovite; Grinding

## 1. INTRODUCTION

Many years mica reserves in muscovite $KAl_2(Si_3AlO_{10})(OH)_2$ and phlogopite $K(Mg, Fe)_3(Si_3AlO_{10})(OH, F)_2$ deposits in Russia were calculated taking into account only 20-mm (surface area 4cm$^2$) mica crystals. In the early 1990s, for a number of objective reasons, the demand for sheet muscovite decreased. The enterprises mining muscovite, were faced to an acute problem connected with work reorientation. The demand for raw materials for mica paper and ground mica production exists. So mined and dumped mica ore of - 20mm in size, in which the muscovite content considerably exceeds that of sheet mica could be such a raw materials.

The problem of small-sized mica processing has being repeatedly discussed, beginning from the early days of muscovite ore deposits mining. However, all amount of the mica ore mined could not be processed because there was no adequate flowsheet of small-sized mica separation, the technologies available in other countries dealing with mica mining and processing being so far unknown for the authors of the paper. There is not any detailed explanation of the specific nature of mica ore separation in case the muscovite and accessory minerals density values are practically equal. Of particular concern is mica separation of the +10mm size class that can be used as an end use product. To upgrade this ore, the attempts were made to apply toothed-roll crushing followed by fine material screening on vibrating screens (Sedykh *et al.*, 1965). This technology was not widely used in practice due to over-grinding and low-grade concentrates production. Selective grinding was not considered to be effective due to high loss of fine fraction mica, which is difficult to be separated by known methods.

A number of works are known on application of air separation for small-sized mica ores (Kelina *et al.*, 1983; Plekhanov *et al.*, 1984). This technology, applied at one of the mines in Karelia, however, includes preliminary ore drying, which is energy-consumptive and needs complicated aspiration systems. A concentrate produced therewith is of low grade, the recovery is also low, and grade size of the material separated is also as low as 2mm.

Therefore the gravity and shape separation of small-sized mica ore is emphasized in the studies carried out by the Mining Institute, KSC RAN. The separation into shapes is applied to preserve mica crystals of larger than 10mm grade size (Gershencop and Khokhulya, 1996; 2001). Gravity separation of ore less than the 10mm grade size is based on the difference between .the sphericity coefficient of mica and that of ore minerals. The greater is the difference, the higher are the separation indices, in case the density values of minerals composing small-sized ores, are similar.

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## 2. EXPERIMENTAL

Mica booklets of larger than the 10mm grade size were separated from isometric ore minerals due to difference in shape. To separate mica of such a grade size, a special separator of 7-10t/h in capacity has been designed. A distinctive feature of the separator is that mica crystals go through slots easily without being jamed in slots. It is a cylindrical separator equipped with an automatic device to remove material caught by slots. The slot width is chosen due to total mica booklet thickness and ore minerals size characteristics, being equal to about 4-5mm. This separator has been industrially tested and introduced at one of the mica enterprises. This separator can be also used in separation of coarser ore fractions of, for example, as large as 70-100mm in size which are not considered to be small-sized.

Gravity separation of mica ore of below than the 10mm grade size is based on the difference between the mica flake and rock particle hindered fall velocities. This difference is due to their shapes at the comparable density values. So the higher the velocity is the better the separation results. A positive effect is achieved therewith by the material disintegration conducted in a rod mill at optimal, for mica crystals, conditions.

The sphericity coefficient "Ω" was used as an objective criterion to evaluate the difference of particles shape. It was calculated by the ratio of the surface area of an equivalent-by-volume sphere to the particle surface area (Pettyjohn and Christiansen, 1948). As the sphericity coefficient decreases, so do the free and hindered fall velocities of mica flakes (Kizevalter *et al.*, 1982). It has been established that the sphericity coefficient of raw ore ranges from 0.5 to 0.65. It correlates with the sphericity coefficient of feldspar particles of the same grade size. The separation of this material is not efficient. The mica content in the concentrate is not higher than 60% and its recovery is low. If the sphericity coefficient is less than 0.4, the situation changes for the better, and the separation indices of the disintegrated ore are significantly higher.

The coefficient "Ω" for mica flakes is calculated by the formula:

$$\Omega = \frac{2.62 \cdot \sqrt[3]{\dfrac{\pi h^3}{4V}}}{1 + \dfrac{\mathrm{P} h^2}{2V}} \tag{1}$$

where h– the mica flake thickness, m; V– the flake volume, $m^3$; P– the perimeter of the mica flake, m. Mica discs of different geometrical dimensions with $\Omega = 0.30 \div 0.77$ were used to calculate the gravity process parameters. It enabled to follow their fall an aqueous medium under different hydrodynamic conditions that were governed by the Reynolds numbers ($Re_s$) change.

If the sphericity coefficient is constant, the inertial drag coefficient $\psi_s$ is the function of $Re_s$ numbers, with the function being one parameter-dependent. If the $Re_s$ numbers are constant, the inertial drag coefficient increases as the sphericity coefficient decreases (Fig. 1). Under the steady fall of discs, the revealed dependencies allowed to analytically determine the flake fall velocity in a liquid in three ranges of Reynolds numbers, which are the most characteristic of mica flakes fall in a liquid.

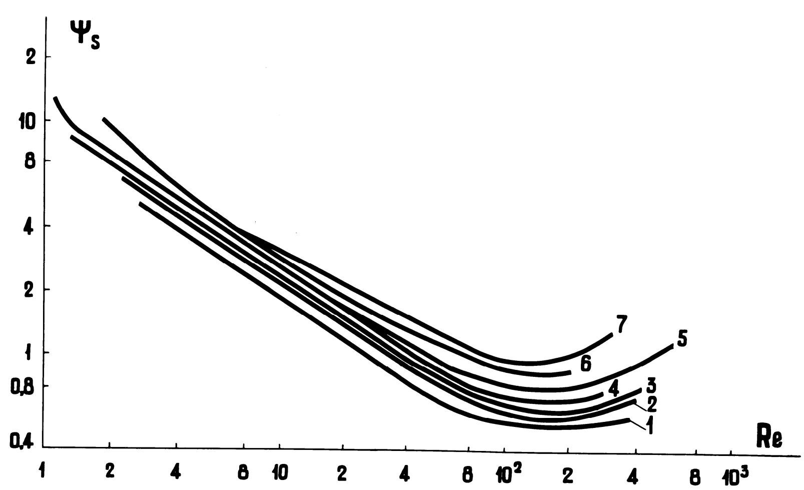


Figure 1. The inertial drag coefficient of freely oriented disks as a function of Reynolds numbers with various sphericity coefficients: 1– 0.79; 2– 0.70; 3– 0.64; 4 – 0.58; 5 – 0.53; 6 – 0.47; 7 – 0.32.

Experimental data processing, taking into account the dependence $\upsilon_o = \upsilon_{eqv.} f(\Omega)$, where $\upsilon_{eqv.}$ – the velocity of an equivalent in volume sphere, shows that, to determine the mica flake fall velocity ($\upsilon_o$), as a function $f(\Omega)$, the following expressions can be recommended, with the accuracy the velocity value determined being equal not more than 10 %.

for $1 \le Re_s \le 140$ $\quad f(\Omega) = f_1(\Omega)$ (2)

for $140 \le Re_s \le 160$ $\quad f(\Omega) = 0.05[(160-Re_s)f_1(\Omega)+(Re_s-140)f_2(\Omega)]$ (3)

for $Re_s \ge 160$ $\quad f(\Omega) = f_2(\Omega) = 1.245\sqrt{\frac{\Omega}{8.95-7.4^{\Omega}}}$ (4)

Kizevalter *et al.* (1982) the last dependence was given.

The velocity $\upsilon_{eqv.}$ was calculated by the well-known Antonychev-Nagirnyak formula:

$$\upsilon_{eqv.} = \frac{\mu}{\rho_l \cdot d_{eqv.}}\left(\sqrt{20.4 + 2.95\sqrt{\mathrm{Re}^2\Psi}} - 4.52\right)^2 \tag{5}$$

where $\mu$- is the dynamic viscosity coefficient, Pa· s; $\rho_l$– is the liquid density, kg/m$^3$; $d_{eqv.}$ – is the diameter of sphere equivalent to a flake in volume, m; $Re^2\Psi = \pi d^3_{eqv.}(\rho_p - \rho_l)g/6\rho_l\mu^2$ - is Lyashchenko's parameter; $\rho_p$ – is the particle density, kg/m$^3$.

It is established that the free-falling discs velocity in a liquid depends on flow regimes determined by dynamic stability, being conditioned by the change of two factors, i.e. by the change of the equivalent diameter and sphericity coefficient. With numbers $Re_s>160$, the free-falling disc velocity decreases as the discs area increases, despite the substantial increase in the velocity of a sphere equivalent in volume (Table 1). As the disc diameter increases, the terminal velocity of its fall, according to formula (5), must increase but in reality the sphericity coefficient decreases, which increases the resistance coefficient and decreases the terminal fall velocity.

Table 1
Experimental values of the free-falling disc velocity in aqueous medium

| Disc dimensions | | $d_{eqv.}$ | $\Omega$ | $Re_s$ | $\psi_s$ | $\upsilon_{eqv.}$ | $\upsilon_o$ |
|---|---|---|---|---|---|---|---|
| d, $10^{-2}$m | h, $10^{-2}$m | $10^{-2}$m | | | | $10^{-2}$m/s | $10^{-2}$m/s |
| 0.3 | 0.08 | 0.22 | 0.71 | 429 | 0.51 | 30.4 | 16.3 |
| 0.4 | 0.08 | 0.27 | 0.64 | 463 | 0.76 | 34.8 | 14.0 |
| 0.6 | 0.08 | 0.33 | 0.54 | 655 | 0.88 | 41.7 | 13.7 |
| 0.3 | 0.05 | 0.19 | 0.59 | 265 | 0.84 | 27.1 | 10.8 |
| 0.4 | 0.05 | 0.23 | 0.53 | 322 | 1.01 | 31.2 | 10.2 |
| 0.6 | 0.05 | 0.30 | 0.43 | 444 | 1.19 | 37.7 | 9.7 |

The fall of discs under different flow regimes within the $Re_s$-numbers range from 1 to 1000 confirms the dependencies in Fig. 1 and dependencies deduced (2-4). The first zone is characteristic of the $Re_s$-values being less than 140 (Fig. 2).

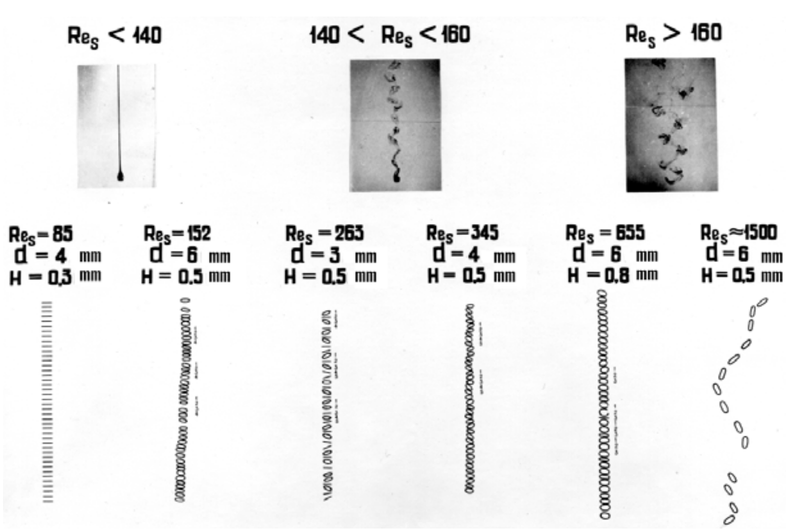


Figure 2. Vortexes generated by freely falling discs in various hydrodynamic regimes

When falling, the disc is in its initial position. One can easily see what vortex is left by the coloured disc. This vortex takes a shape of an ellipsoid of rotation whose parameters depend the disc's geometric dimensions. The beginning of vibrations during disc fall corresponds to the second zone ($140 \le Re_s \le 160$). The angle of disc vibrations is negligible but the fortexes, originated from the back of the disc, force the disc to fall and change its initial position. Within the third zone ($Re_s > 160$), the effect of the inertial forces is more significant, and disc vibrations increase.

The dependencies deduced (2-4) made it possible to calculate the hydraulic size of mica ore that equals: -5+2, -2+0.63 and -0.63+0.2mm. To size the desintegrated material, special drum screens were designed. These are easy in fabrication and are of high efficiency in sizing (over 90%).

Based on the calculations by the free and hindered fall velocity, the two first size classes were transported to hydraulic separators where upward flows of separating medium flows were used. Depending on the given conditions, the hydraulic separator makes it possible to produce either three or two final products, i.e. a concentrate, middlings and tailings, or a concentrate and tailings. To simplify the technology, a two-product hydraulic separator has been used.

Finer ore of the –0.63+0.2mm grade size was separated on concentration tables with the concentrate and tailings production. Unlike mica flake falling in a liquid, when upward flows separate mica, the mica flakes, separated on concentration tables, move down with the highest velocity. It is favoured by a water flow running down along the inclined surface. As flakes move, their weight is distributed throughout the whole surface and, in accordance with the segregation conditions, these will be in the top layers of the flow, forming later a concentrate fraction. The main factors maintaining the mica–containing material separation on the concentrator deck, are the difference in shape, the presence of the flow velocity vertical components, and the effect of sluicing water. In case the size of the separated material increases and the difference of grains in size is substantial, the role of sluicing water and that of the segregation phenomenon increase significantly.

In mica material desintegrating, the amount of mica of the –0.2mm grade size increased, which, due to the absence of the flotation stage, increased the losses of mica of the fine grade size. The losses were compensated by higher technological indices.

## 3. RESULTS AND DISCUSSION

The major part of the mica deposits in Russia are stored in the tailing dumps and, thus, not involved in full-scale processing operations. As for their granulometric composition, the non-economic ores (-20mm) contain 10-30% as material of coarser than the 10mm grade size and 4-32% as material below the 0.2mm grade size. The main minerals of the deposits are muscovite, biotite, quartz, feldspar, and secondary minerals are pyroxene, garnet, sulfides and zircon.

According to the investigation results, the technological indices depend on many factors, for instance: the muscovite content in ore, the ratio of minerals, the muscovite distribution of machine classes and of grade size below 0.2mm, the muscovite crystal-to-rock mineral thickness relationship, and the others (Table 2).

Table 2
Muscovite ore separation indices (-20mm)

| Deposit | Content in ore % | Recovery into concentrate, % | Recovery into the -0.2mm grade size, % | Concentrate output, % |
|---|---|---|---|---|
| Malinovaya Varakka | 15.2 | 58.1 | 15.2 | 8.9 |
| Plotina | 13.3 | 65.4 | 8.0 | 8.8 |
| Tedino | 23.8 | 47.7 | 32.3 | 11.4 |
| Sosnovy Bor | 4.5 | 42.2 | 14.5 | 1.9 |
| Yona | 23.2 | 68.3 | 3.6 | 16.0 |
| Rikolatva | 10.7 | 66.4 | 5.8 | 7.2 |
| Neblogora | 20.3 | 72.9 | 3.0 | 14.9 |

The concentrate produced from ore delivered from different deposits, contains approximately the same amount of mica, exceeding 98%. For the material finer than the 0.2mm (0.16mm) grade size, a flotation technology has been designed to produce muscovite concentrate of about 100% mica content, with the recovery being equal to 80% of the flotation feed. From the ecological safety considerations, however, this technology cannot be used now.

Pilot tests of the designed flowsheet (Fig. 3) have been carried out on small-sized mica ores from Malinovaya Varakka and Tedino deposits (Gershencop and Khokhulya, 1999; 2000). Unlike the laboratory tests, the muscovite content in ores to be tested, was equal to 10.5 and 16.1%, respectively; the material output of below than the 0.2mm grade size was 7.0 and 12.2%, respectively, with 10.0 and 15.2%

muscovite being recovered into this size class, respectively. According to the general sampling data the separation indices for muscovite ore -20mm have practically proved the results obtained in laboratory tests (Table 3).

The pilot tests have shown a possibility to separate these non-economic ores. The concentrates produced have been tested in ground mica, mica paper, electrical-insulating materials production, giving positive results. Ground mica from the concentrates produced was used in rubber industry as a plastic filler, in the pearlescent pigment production (Gershencop *et al.*, 1996). The latter were then used in paint-and-varnish, wall-paper and perfumery industries.

One of the main requirements placed by the industry to ground mica is a high ratio of the diameter of a circle whose area it equivalent to the area of on side of flake divided by the average thickness of that flake. This ratio is evaluated by the aspect ratio. Wet grinding of mica concentrate after these have been preliminary prepared, provides the aspect ratio said, increasing its demand in the home and foreign markets.

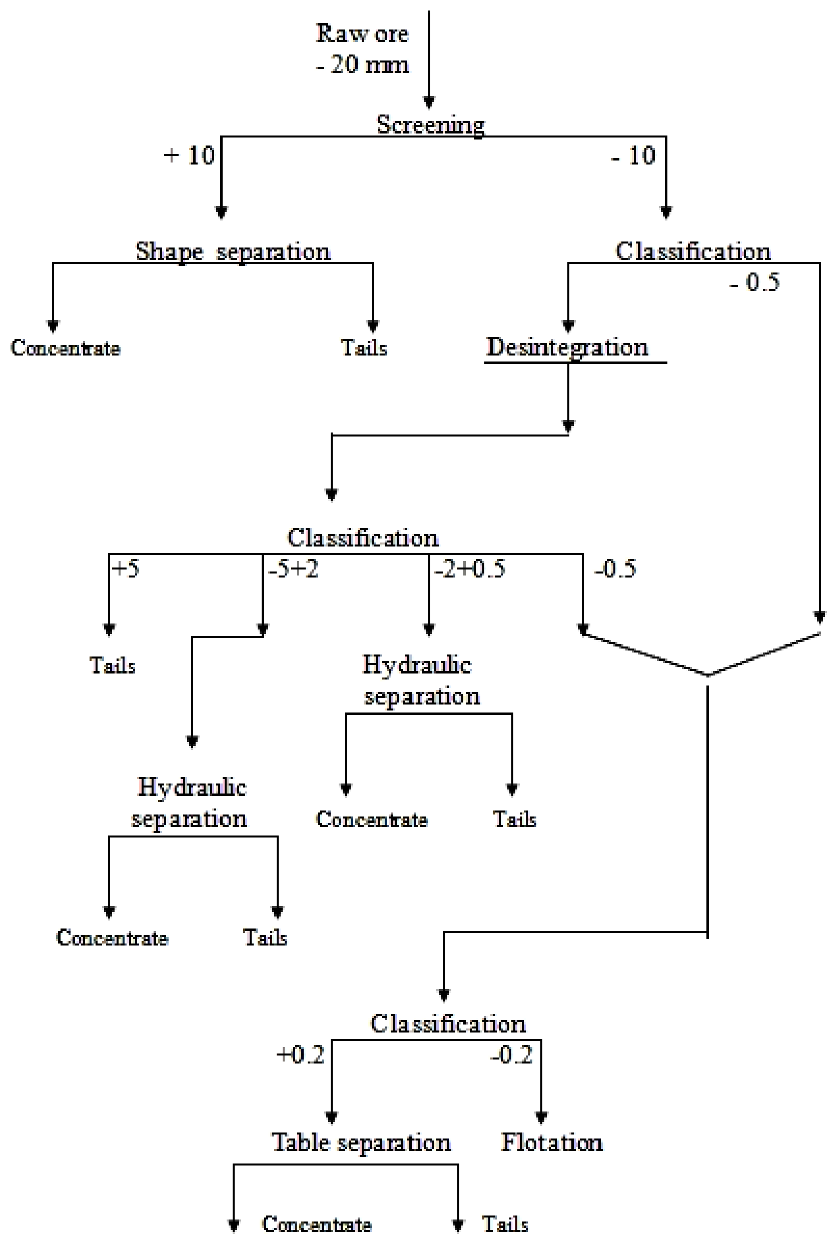


Figure 3. The flowsheet for small-sized mica ores

Table 3
Pilot separation indices for non-economic muscovite ores

| Deposit | Malinovaya Varakka | | | Tedino | | |
|---|---|---|---|---|---|---|
| | % | | | % | | |
| Operation | Output | Content | Recovery | Output | Content | Recovery |
| Shape separation | 1.3 | 97.4 | 11.3 | 1.0 | 95.8 | 5.5 |
| Hydraulic separation, -5+2 mm grade size | 1.6 | 97.3 | 13.9 | 1.4 | 98.4 | 7.9 |
| Hydraulic separation, -2+0.75mm grade size | 2.4 | 98.9 | 21.2 | 4.6 | 97.3 | 25.7 |
| Table separation, -0.75+0.2mm grade size | 2.4 | 95.0 | 20.3 | 3.6 | 96.2 | 19.9 |
| Ore -0.2mm | 11.6 | 10.8 | 11.2 | 28.4 | 11.6 | 18.9 |
| Total concentrate | 7.7 | 97.0 | 66.7 | 10.8 | 96.8 | 60.1 |

Three greatest dumps of Rikolatva mine have been also studied. The muscovite content there was, on average, 8%. This value differs from that calculated from investigations on laboratory samples taken in vein filling screening (larger than 20mm) during the operation of this mine. So does the output of the –0.2 mm grade size and muscovite distribution into this grade size class.

It should be noted that in spite of the fact that the dumps are staying in the open air, the mica quality has not been changed. The same cannot be said about the –0.2mm grade size whose output has decreased, so does the mica content due to its being taken out by the precipitations. Based on the mica content in these dumps, their granulometric composition, ore output (-20mm), and mica recovery into different classes, one can calculate the reserves of mica that can be recovered from these dumps. The calculations show that under the specified performance of the future plant, the muscovite reserves will be sufficient for a period of more than 25 years. According to the preliminary calculations, the pay-back is expected to be in 1.5-2 years.

Thus, in addition to the vein filling mined that contains small-sized mica, the mine dumps can be considered as a potential source of a raw materials from which ground mica can be produced.

## 4. CONCLUSIONS

A processing technology for small-sized muscovite ores contained in cut-off grade ore dumps has been developed. The technological flowsheet allowing to get from classes smaller than 20mm concentrates containing 95-98.9% of muscovite at recovery of 60-66.7% is offered. The technology is based on the use of the methods and apparatus for a wet gravity separation and ensures the production of conditioned concentrates that are, in the future, the source for ground mica production.

According to present technology the ore larger than 10mm is dressed in a special separator designed. Ore fines smaller than 10mm were ground to obtain form differentation on of mica and other minerals. For material larger than 0.5–0.8mm hydraulic separation was used, for ores 0.5–0.2mm (0.16mm) – separation on tables.

The results of semi-industrial tests have actually confirmed the laboratory results and have proved the viability of processing of rejected ores smaller than 20mm. The produced concentrate was successfully tested to manufacture powdered mica, mica paper, insulation products, etc.

The resources of muscovite will last for more than 25 years. The period of investments return is approximately at 1.5–2 years.

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