Study of classification processes of various bulk geomaterials in a hydrodynamic environment using laboratory models of counter-current drum separators

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Abstract. The paper presents the results of studying separation processes of various mineral particles of different density in a hydrodynamic (water) environment in three laboratory models of counter-current drum separators with cylindrical, conical and multifaceted drums. Research results have shown that compared to cylindrical and conical drum separators, the multifaceted separator is most effective in separating and refining in a hydrodynamic environment. The high recovery of heavy minerals in the concentrate proves this fact.

1. Introduction

Currently, developed counter-current separators for gravitational separation of geomaterials have obvious technological advantages. They include the creation of rational conditions of fractional separation when combining the dynamic processes of loosening the materials created by the working body of the drum type (providing conditions of porosity during gravitational separation in the water environment) on the one hand and the removal of light and small particles under the influence of hydrodynamic currents on the other hand [1]. An important part of the separator operation is maintaining the loosened state of the separated mineral mixture in the separation work area, which depends on the shape and rotation speed of the drum [2]. There are now many interesting installations and equipment which provide loosened conditions for the mineral mixture [3, 4]. Many authors argue for the need to study the processes in new devices for processing, enrichment of solid minerals, as well as the need for computer simulation [5, 6].

2. Research Methodology

The research of separating different mineral particles of different densities in a hydrodynamic (water) environment in counter-current drum separators used three laboratory models with cylindrical, conical and multifaceted drums.

Research of the separation efficiencies of the different minerals in the three separator models applied a water stream as the enrichment environment, where the separation proceeds in a downward flow. The geomaterial is separated in a continuous, counter-directional flow, unlike the Knelson separators where the process proceeds in a unidirectional flow [7, 8].

Figure 1 shows a schematic of the separation of minerals in counter-current drum separators in the
water environment.

![Diagram of drum separator operation in water flow](image)

**Figure 1.** Schematic of drum separator operation in water flow: 1 – drum separator; 2 – spiral riffles; 3 – water supply pipe for irrigation; 4 – pulp pipe; 5 – concentrate collector 6 – tailings collector

The separation of material in a hydrodynamic environment in a drum counter-current separator involves the following.

The mineral particles pre-mixed with water are conveyed as a homogeneous pulp through nozzle 4 to the working area of the rotating drum separator 1. There is a downward flow creating a gravitational separation of the minerals at the bottom of the drum. Heavy minerals are deposited and localized directly at the bottom of the drum. The rotation of the drum is continually stirring the material, thereby achieving a refinement of the settling heavy fraction from the mechanically entrained light particles. The downward flow of the pulp carries the light material to the tailings unit while the heavy settling material moves upwards and is constantly in the regrind mode, then discharged via riffles to the concentrate collector 5. Additionally, there is water supplied through spigot 3 for spraying over the entire length of the separator to effectively loosen the material deposited at the bottom of the drum.

3. **Research in the cylindrical counter-current drum separator**

Experimental studies of separation processes of minerals with different densities \(\rho=3.2–4\ \text{g/cm}^3\), \(\rho=4–6\ \text{g/cm}^3\), \(\rho=6.8–16\ \text{g/cm}^3\) from the waste rock with density up to \(\rho=2.5\ \text{g/cm}^3\) used crushed quartz ore with grain size \(-3+0.1\ \text{mm}\). Garnet served as a low density simulant, iron scrap as medium density, tungsten as heavy minerals and quartz sand as waste rock. We assessed separation efficiency based on the main parameter – the degree of recovery.

Each stage of the research into the separation of various minerals involved determining the most rational separator operation parameters based on summary reduction rates and separation efficiency: water flow rate, a number of drum revolutions, drum tilt angle determined in relation to the axis of rotation.

As a result of preliminary studies, we have found the most rational parameters. Laboratory tests on the separation of different minerals were carried out at an angle of inclination of the plant relative to the axis of rotation of the drum \(\alpha=4^\circ\), speed 20 rpm, process water flow rate 10–15 l/min.

Figure 2 shows the general view and a drawing of the cylindrical drum separator in operation.
Table 1 shows the results of the most characteristic experiments on the separation of different heavy materials (minerals) in a counter-current separator with a rotating cylindrical drum working body in a hydrodynamic environment.

| No. of experience | Composition | Size grade, (mm) | Weight, (g) | Output, (g) | Time of separation, (min) | Recovery, (%) |
|-------------------|-------------|-----------------|-------------|-------------|--------------------------|---------------|
| 1                 | quartz      | −3+0.1          | 1000        | 66          | 910                      | 5             | 65.1          |
|                   | garnet      |                 | 100         | 65          | 34                       |               |
| 2                 | quartz      | −3+0.1          | 1000        | 70          | 900                      | 5             | 81.2          |
|                   | cast iron   |                 | 100         | 82          | 18                       |               |
| 3                 | quartz      | −3+0.1          | 1000        | 69          | 890                      | 5             | 95.3          |
|                   | tungsten    |                 | 100         | 96          | 4                        |               |

The recovery of the relatively light garnet mineral with a density of 3.2–4 g/cm³ from the waste rock of quartz with a density of 2–2.5 g/cm³ in a hydrodynamic environment is 65.1 %. For minerals with a high density of 6–16 g/cm³ the recovery is 1.2–95.3 %.

When separating high density minerals from the background material by quartz, the maximum recovery rate with a process water flow rate of 10 l/min is 95.3 %, and for lower density materials (3.2–4 g/cm³) is 65.1 %.

4. Research in the conical counter-current drum separator

The organization of the counter-directional movement of the separated particles in the separator is similar to a separator with a cylindrical drum shape. When separating the geomaterial, the downward flow of water carries the light minerals to the tapering part of the conical drum shape and further into the tailings collector. Along the length of the separator, the hydrodynamic force increases according to the tapering trough principle. In these experiments, we selected the initial speed of the separator from its lowest value with successive increases to find a rational flow regime.

The mode parameters for the separation of the different minerals were similar to the experiments with the cylindrical drum shape separator (number of revolutions – 20, inclination angle – 4°, process water flow rate – 10 l/min).

Figure 3 shows the general view of the conical drum separator in operation.
Table 2 shows the results of the most characteristic experimental work on the possibility of enrichment of heavy minerals in a rotating conical counter-current drum separator in a hydrodynamic environment.

**Table 2.** Recovery of heavy materials (minerals) in a conical counter-current drum separator in a hydrodynamic flow

| No. of experience | composition | size grade, (mm) | weight, (g) | output, (g) concentrate | output, (g) tailing | time of delivery | Recovery, (%) |
|-------------------|-------------|-----------------|-------------|-------------------------|-------------------|-----------------|---------------|
| 1                 | quartz      | −3+0.1          | 1000        | 11                      | 878               | 5               | 71.1          |
|                   | garnet      |                 | 100         | 72                      | 28                |                 |               |
| 2                 | quartz      | −3+0.1          | 1000        | 123                     | 871               | 5               | 85.1          |
|                   | cast iron   |                 | 100         | 85                      | 15                |                 |               |
| 3                 | quartz      | −3+0.1          | 1000        | 118                     | 874               | 5               | 96.7          |
|                   | tungsten    |                 | 100         | 97                      | 3                 |                 |               |

The table shows that the recovery of minerals with a high density of 6–16 cm$^3$ is 96.7 % in a hydrodynamic environment. The recovery of minerals with a density of 3.2–4 cm$^3$ from waste quartz rock with a density of 2–2.5 cm$^3$ is 71.1 %.

5. **Research in the multifaceted counter-current drum separator**

Research of separation of various minerals in a hydrodynamic environment in a rotating multifaceted counter-current drum separator (in this case, in the heptahedral version [9]) used similar working parameters and minerals ($\rho=2.5$ g/cm$^3$, $\rho=3.2–4$ g/cm$^3$, $\rho=4–6$ g/cm$^3$, $\rho=6.8–16$ g/cm$^3$) as in cylindrical and conical separators (number of revolutions – 20, inclination angle – 4°, process water flow rate –10 l/min).

This shape of the multifaced drum creates special (phase) time-varying intensity conditions to maintain the loosened state of the separated mineral mixture during the operation of the rotating drum. Figure 4 shows the general view of the multifaceted (heptahedral) counter-current drum separator in operation.
Table 3 shows the results of experimental work on the efficiency of separation of different heavy minerals from the waste rock (quartz sand) in a rotating multifaceted counter-current drum separator.

Table 3. Recovery of heavy materials (minerals) in a multifaceted counter-current drum separator in a hydrodynamic flow

| No. of experience | composition | size grade, (mm) | weight, (g) | output, (g) | time of delivery | Recovery, (%) |
|-------------------|-------------|------------------|-------------|-------------|-----------------|---------------|
| 1                 | quartz      | –3+0.1           | 1000        | 257         | 735             | 5             | 89.6          |
|                   | garnet      |                  | 100         | 89          | 10              |               |
| 2                 | quartz      | –3+0.1           | 1000        | 233         | 752             | 5             | 95.8          |
|                   | cast iron   |                  | 100         | 95          | 5               |               |
| 3                 | quartz      | –3+0.1           | 1000        | 218         | 776             | 5             | 98.6          |
|                   | Tungsten    |                  | 100         | 98          | 2               |               |

Compared to cylindrical and conical drum separators, in the multifaceted separator is most effective in separating and refining in a hydrodynamic environment. The high recovery of heavy minerals of 89.6–98.6 % proves this fact.

6. Research findings
A general summary of the combined experimental results for the recovery of minerals with different densities in laboratory rotating counter-current drum separators is shown in Table 4 and Figure 5.

Table 4. Recovery of minerals with different densities in laboratory drum separators under the influence of hydrodynamic flows

| Parameters                        | Recovery of minerals in different media, (%) |
|-----------------------------------|---------------------------------------------|
|                                   | Minerals with a density of 3.2–4 (g/cm³) | Minerals with a density of 4–6 (g/cm³) | Minerals with a density of 6 (g/cm³) or more |
| 1. Cylindrical separator          | 65.1                                        | 81.2                                        | 95.3                                        |
| 2. Conical separator              | 71.1                                        | 85.1                                        | 96.7                                        |
| 3. Multifaceted separator         | 89.6                                        | 95.8                                        | 98.6                                        |
| Process water consumption, (l/min)| 10l/min                                     |                                             |                                             |
| Number of revolutions, (rpm)     | 20                                          |                                             |                                             |
| Inclination angle, deg.           | 4                                           |                                             |                                             |
Figure 5. Histogram of mineral recovery with different densities in laboratory counter-current drum separators of different designs: 1 – cylindrical drum separator; 2 – conical drum separator; 3 – multifaceted drum separator

Thus, the results of experimental research of separation efficiency of bulk geomaterials of -3+0.1 mm, but different fractions of the density in the hydrodynamic flow created in the counter-current drum separators of different separation design revealed that the most rational for separation in the hydrodynamic flow with a flow rate of technological water 10–15 l/min and number of drum revolutions 20 rpm is a multifaceted shape of operating drum with indicators to recovery heavy fractions (simulators $\rho = 6.8–16$ g/cm$^3$) in the range from 89.6 to 98.6 %.

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