EAI Endorsed Transactions
on Digital Transformation of Industrial Processes Research Article EAI.EU

Study of the influence of increased productivity on the efficiency of separation and dewatering of polydispersed coal enrichment sludges in a modular installation with filtration and sedimentation centrifuges

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Abstract

Coal enrichment processes are accompanied by the formation of a significant amount of polydisperse sludges, the effective separation and dewatering of which is an important technological and environmental problem. The aim of this work was to study the influence of increasing the module productivity (increasing the solid phase flow rate by three times – up to 5.523 t/h on a dry basis) on the efficiency of separation and dewatering of polydisperse anthracite sludges of class 0–3 mm in the FGU-600 + OGS-469 modular installation. It was established that at increased load, the filtration centrifuge ensures the extraction of granular fraction with a moisture content of 8.8 % and ash content of 16 %, while the sedimentation centrifuge provides dewatering of fine fractions to a moisture content of 21.35–24 % at a solid phase concentration in the effluent of 2.5 g/L. Comparative analysis with previous results showed the preservation of high efficiency of the technological scheme, a slight improvement in the moisture content of the granular product and an acceptable increase in the loss of fine fractions. The obtained data confirm the possibility of scaling the proposed technology to industrial conditions.

Keywords: polydisperse sludges; coal enrichment; filtration centrifuge; sedimentation centrifuge; separation; dewatering; modular installation.

Received on 15 February 2026, accepted on 12 May 2026, published on 21 May 2026

doi: 10.4108/dtip.11959

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1. Introduction

One of the most critical contemporary challenges in the coal industry is achieving high efficiency in the separation and dewatering processes of polydisperse sludges, which are formed as by-products of coal enrichment. Coal enrichment sludges are polydisperse suspensions with a wide range of particle sizes – from granular (over 0.5 mm) to fine-dispersed (less than 0.05 mm) [1–3]. They are classified into primary and secondary, as well as unenriched and enriched fractions [1, 2]. According to research data, the content of size classes 1–3 mm in run-of-mine coal can reach 20–40 %, while additional formation of fine fractions occurs during transportation and enrichment [2]. Such products are characterized by high ash content (20–80 % and higher), which complicates their further utilization and leads to significant losses of valuable components [3].

The accumulation of sludges in external sludge ponds not only increases operational costs but also causes secondary environmental pollution [4, 5]. Global reserves of coking and thermal coal sludge waste represent a significant resource; their processing would reduce environmental impact and recover lost coal reserves [5, 6]. The fine-dispersed fraction (less than 40 μm) mainly consists of clay minerals with ash content up to 80 %, whereas particles larger than 40 μm contain coal grains suitable for reuse [7, 8].

Therefore, the development and implementation of efficient technologies for the separation and dewatering of polydisperse sludges is a decisive task. Such technologies would eliminate the discharge of liquid waste into sludge ponds, minimize losses of the granular coal fraction, and create opportunities for the further processing of accumulated waste [3, 9].

One of the promising solutions is modular installations that combine filtration and sedimentation centrifuges installed in series [9–12]. Previous studies by the authors [13] demonstrated the high efficiency of this scheme under baseline loads.

At the same time, the intensity and quality of dewatering are significantly influenced by particle dispersity, equipment power, and the specific features of the dewatering apparatus, which necessitates conducting studies on real sludges and verifying the results under operating industrial conditions [14, 15].

In this work, at the second stage of research, the possibility of increasing the module productivity by raising the solid phase flow rate was investigated in order to assess the scalability of the technology under industrial conditions.

2. Literature Review

The literature review indicates significant interest in optimizing the separation processes of polydisperse sludges. For example, studies [2, 15] examine the influence of clay minerals on the dewatering of coal suspensions, emphasizing the role of reagents in improving filtration. Research [16] focuses on dewatering fine coal to produce a marketable product, proposing combined methods. The theoretical foundations of filtration and centrifugation processes are thoroughly discussed in works [11, 12], with particular attention paid to evaluating the productivity of the filter cake and the structural characteristics of the filtration layer. Modeling of separation processes in centrifuges for polydisperse suspensions is presented in publications [17, 18], which analyze the influence of key parameters on separation efficiency. Experimental results on the application of decanter centrifuges for dewatering coal-water sludges are provided in [19, 20]. Special mention should be made of studies [1, 21, 22] dedicated to methods of intensifying the separation of suspensions and industrial sludges, in particular through aggregation (coagulation, flocculation) followed by gravitational separation. All of this highlights the feasibility and prospects of combining filtration and sedimentation centrifuges to improve overall process efficiency.

Furthermore, in the authors' previous work [23], the process of separating polydisperse anthracite sludges of class 0–3 mm was investigated in the FGU-600 + OGS-469 modular installation under nominal loads. At the second stage of research (the present work), the possibility of increasing the load on the installation by raising the solid phase flow rate by a factor of three (from 1.867 to 5.523 t/h on a dry basis) was studied, which made it possible to evaluate the stability of the technological scheme under conditions approaching industrial operation.

3. Objective

The aim of this work is to investigate the process of separation of polydisperse coal enrichment sludges in sequentially connected filtration and sedimentation centrifuges in order to optimize the parameters of solid phase retention and the degree of dewatering.

4. Experimental Methodology

The study utilized thickened sludge (fine coal fraction) from one of the coal preparation plants, which was fed into a modular installation consisting of sequentially connected centrifuges: a filtration centrifuge FGU-600 and a sedimentation centrifuge OGS-469. The layout of the centrifuges and their overall dimensions are shown in Figures 1 and 2.

The FGU-600 filtration centrifuge was set to a cone rotation speed of 1589 rpm (separation factor Fr = 400) and a rotor rotation speed of 1144 rpm (Fr = 436). The filtering surface of the centrifuge rotor had the following characteristics [23]:

– internal rotor surface area Srot = 3580 cm²;
– slot gap area – 346 cm²;
– slot shape – trapezoidal (height 3.7 mm, larger base of the trapezoid – 2.5 mm; inclination angle at the larger base 85°, slot length 190 mm oriented along the rotor axis);
– slot gaps were distributed as follows: gap size 0.25 mm – 146 pcs.; gap size 0.30 mm – 434 pcs.; gap size 0.35 mm – 80 pcs.; gap size 0.40 mm – 10 pcs.

The filtering surface of the cone was formed by 4 trapezoidal sector plates (sector dimensions 272 × 111 × 180 mm) with a total cone area of 1596 cm² (hole area 329.5 cm²) [23].

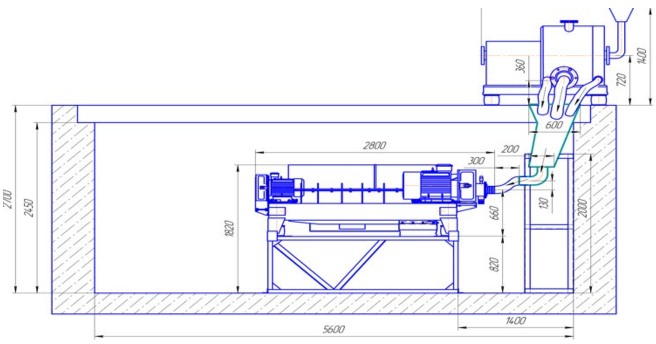

Figure 1. Layout diagram of the FGU-600 and OGS-469 centrifuges in the research process

The OGS-469 sedimentation centrifuge was operated at a rotor speed of 1800 rpm (separation factor Fr = 900), with relative screw (scroll) speed of 12.5 rpm.

The tests were conducted as follows. A constant water supply to the inlet of the FGU-600 filtration centrifuge was organized at a flow rate of 3.8 m³/h (1.25 L/s). Feeding of the FGU-600 centrifuge was performed by pouring coal sludge from buckets into a continuous stream of water flowing along a trough (Fig. 2). The sludge feed rate was 5.523 t/h (on a dry solids basis).

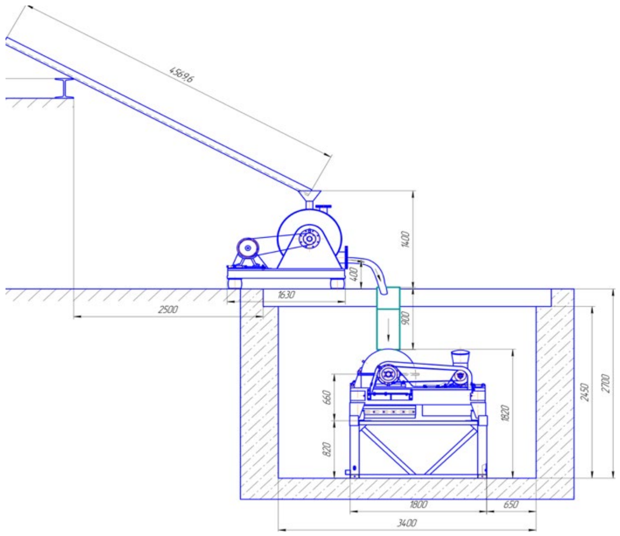

Figure. 2. Scheme of sludge supply to the FGU-600 and OGS-469 centrifuges in the experimental process

The filtrate from the FGU-600 centrifuge was mixed and fed to the OGS-469 centrifuge for dewatering.

The suspension flow rate from the rotor of the FGU-600 centrifuge was 1.920 m³/h (0.533 L/s).

During the study, samples of the process streams were collected (Fig. 3) and analyzed for solid phase content, particle size distribution, sludge moisture content, and ash content [23].

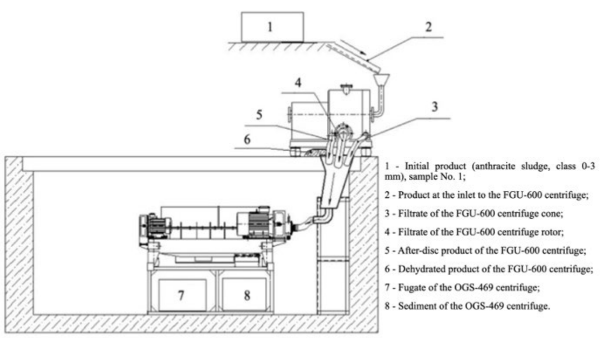

Figure. 3. Scheme of the studied process streams

The solid phase content in the samples was determined by drying a weighed portion of the sample to constant mass in a drying oven at 105 °C using an electric furnace with temperature sensor "Kharkiv 2M". Granulometric analysis was performed by wet sieving through a standard set of sieves (from 0.02 mm to 3 mm) on a vibrating sieve VA-V01. The ash content of the samples was determined according to standard procedures by high-temperature ashing in a muffle furnace until complete combustion of the organic matter, followed by weighing the residue to calculate the ash content as a percentage of the dry matter mass of the sample [23].

5. Research Tasks

The initial product fed to the centrifuges for separation (Fig. 3, sample No. 1) had an initial moisture content W = 18 % and ash content Ad = 18 %, as well as the following particle size distribution presented in Table 1.

Table 1. Results of sieve analysis of the initial sludge

Particle size, mm	Sample weight on sieves, g	Class share, %
3...1,25	17,25	20,99
1,25…1	5,65	6,87
1...0,8	9,85	11,98
0,8...0,63	12,4	15,09
0,63...0,5	6,3	7,66
0,5...0,3	15,3	18,61
0,3...0,2	10,05	12,23
0,2...0,1	2,6	3,16
0,1...0,063	0,7	0,85
0,063...0,04	0,3	0,36
0,04...0,02	0,25	0,30
0,02<	1,55	1,89
∑	82,2	100,00

Analysis of Table 1 shows that approximately 38% of the initial sludge has a particle size of less than 0.5 mm, and about 62% is represented by anthracite with a size of 0.5–3 mm. This fraction may be interesting for extraction and secondary use. The presence of particles larger than 1.25 mm at the level of 21% confirms the need for pre-extraction before settling centrifuges.

The selected sludge sample after mixing with water before entering the FGU-600 centrifuge (Fig. 3, sample No. 2) had a density (weight of 1 liter of suspension) of 1368.9 g and a solid phase concentration of C=738 g/L. During filtration, the sludge is separated into cone filtrates, rotor filtrates, and a dehydrated product, the particle size distribution of which is given in Tables 2–4.

Table 2. Results of sieve analysis of the filtrate from the cone of the FGU-600 centrifuge

Particle size, mm	Sample weight on sieves, g	Class share, %
3...1,25	0,3	0,24
1,25…1	0,6	0,47
1...0,8	1,65	1,29
0,8...0,63	6,05	4,74
0,63...0,5	5,5	4,31
0,5...0,3	30,4	23,82
0,3...0,2	38,2	29,93
0,2...0,1	20,1	15,75
0,1...0,063	4,75	3,72
0,063...0,04	3,65	2,86
0,04...0,02	3,1	2,43
0,02<	13,35	10,46
Σ	127,65	100,00

The analysis of the cone filtrate shows (Table 2) that 94.3% of the solid phase in the filtrate is fine particles less than 0.5 mm with an ash content of Ad=25%. The concentration of the solid phase in the filtrate was C=127.65 g/L, which indicates a fairly high efficiency of the FGU-600 filtration centrifuge at the stage of preliminary separation of polydisperse anthracite sludge.

Table 3. Results of sieve analysis of the filtrate of the FGU-600 centrifuge rotor

Particle size, mm	Sample weight on sieves, g	Class share, %
до 1,25	8,55	7,19
1,25-1,0	2,3	1,93
1,0-0,8	3,8	3,20
0,8-0,63	6,35	5,34
0,63-0,5	4,7	3,95
0,5-0,3	12,05	10,13
0,3-0,2	14,85	12,49
0,2-0,1	10	8,41
0,1-0,063	4,3	3,62
0,063-0,04	3,4	2,86
0,04-0,02	6,2	5,21
0,02 <	42,4	35,66
Σ	118,9	100,00

The centrifuge rotor filtrate (Table 3) had about 82.33% of particles smaller than 0.5 mm with a higher ash content Ad=45%. The concentration of the solid phase in the filtrate was C=118.9 g/L.

The dehydrated centrifuge product (Table 4) contained on average 32.92% of particles larger than 1 mm, 31.68 particles with a size of 0.5–1 mm and 35.4% of particles smaller than 0.5 mm, of which about 20% were smaller than 0.2 mm. This distribution indicates the effective extraction of the granular fraction of anthracite (mainly classes >0.5 mm) with a reduced ash content Ad = 16% and low humidity W = 8.8%, which creates good prerequisites for secondary use or return of this fraction to the main product stream of coal enrichment. Compared to previous tests (where the proportion of >1 mm was ~25%, and <0.5 mm was ~40-41%) [23], with increased productivity, a somewhat more uniform distribution by size is observed, with the preservation of high quality of the dehydrated product and even a slight improvement in moisture content.

Table 4. Results of sieve analysis of the dehydrated product of the FGU-600 centrifuge

Particle size, mm	Sample weight on sieves, g	Class share, %
3-1,25	24,3	27,40
1,25-1,0	4,9	5,52
1-0,8	8,85	9,98
0,8-0,63	12,4	13,98
0,63-0,5	6,85	7,72
0,5-0,3	13,1	14,77
0,3-0,2	9,7	10,94
0,2-0,1	3,95	4,45
0,1-0,063	1,05	1,18
0,063-0,04	0,6	0,68
0,04-0,02	0,45	0,51
0,02 <	2,55	2,87
Σ	88,7	100

Further separation of the filtrates in the OGS-469 sedimentation centrifuge resulted in the production of a sediment with a moisture content of W = 21.35–24% and an ash content of Ad = 26–27% and a fugate with a solid phase concentration of C = 2.16–2.8 g/L(average 2.5 g/L) and a content of high-ash fine particles of Ad = 74–75% with a size mainly less than 0.02 mm.

According to the results of the study, a generalized quantitative and qualitative scheme of the operation of the studied modular installation for the separation of polydisperse sludges was compiled (Fig. 4).

As a result of the study, it was found that preliminary filtration of concentrated polydisperse suspensions allows to remove a low-ash product and create prerequisites for enrichment of sludge waste, sedimentation tanks or coal sludge sludge accumulators. Modular installations consisting of filtering equipment (filtering centrifuges, drum screens, etc.) can be used to extract coal granular classes from waste with subsequent precipitation of the solid phase in centrifuges of the coal-slurry plant.

The obtained experimental results can be used to determine the optimal operating modes of modular installations for dewatering coal-slurry sludge and to develop industrial schemes for processing (re-enrichment) of sludge waste and sludge.

Comparing the results of this with the results of previous work [23], where the productivity was 1.867 t/h in terms of dry matter, we observe the following changes:

– the moisture content of the dehydrated product FGU-600 decreased from 10.1% to 8.8% – a positive effect;

– the concentration of the solid phase in the fugate of OGS-469 increased from 1.5 g/L to 2.5 g/L – a slight decrease in the efficiency of retaining fine fractions;

– the ash content of the sediment of OGS-469 significantly improved (from 42% to 26–27%);

– the ash content of the dehydrated product FGU-600 increased slightly (from 13–15% to 16%).

In general, the 3-fold increase in load showed satisfactory results. The technological scheme remains operational, and the obtained products meet the requirements for further use or disposal. The modular installation demonstrated stability and scalability.

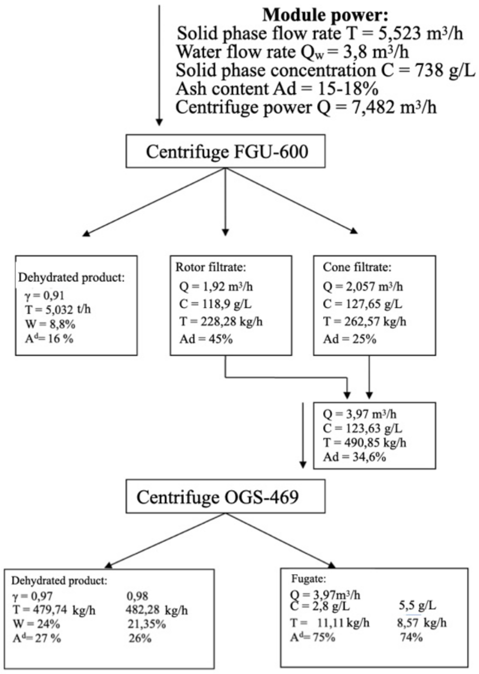

Figure. 4. Qualitative and quantitative scheme of separation of polydisperse sludge

6. Conclusions

It was established that polydisperse coal enrichment sludges of class 0–3 mm contain a significant proportion of granular low-ash fractions (over 60% of particles larger than 0.5 mm), the extraction of which is advisable both from a technological and an environmental point of view, since this allows to significantly reduce the volume of waste sent to sludge accumulators or dumps, and to return the valuable coal fraction to the product stream.

The effectiveness of preliminary filtration separation in the FGU-600 filtration centrifuge for selective extraction of granular coal fraction with low humidity W = 8.8% and ash content Ad = 16% has been proven, which creates real prerequisites for the reuse of this fraction and reduction of irreversible losses of coal with waste.

It is shown that further dehydration of finely dispersed high-ash fractions in the OGS-469 sedimentation centrifuge provides the production of sediment with a moisture content of W = 21.35–24% and an ash content of Ad = 26–27%, as well as a fugate with a very low solid phase concentration (C = 2.16–2.8 g/L, average ≈ 2.5 g/L) and a high ash content (Ad = 74–75%), which contributes to a significant reduction in pollution of water bodies and an increase in the efficiency of circulating water supply systems of coal enrichment plants.

It has been established that the sequential use of filtration and sedimentation centrifuges as part of a modular installation, even with increased productivity (solid phase consumption ≈ 5.523 t/h in dry matter), allows for a comprehensive solution to the problem of dewatering and separation of polydisperse sludge, minimizing the environmental load on the environment and increasing the level of resource conservation in the coal industry. The results obtained confirm the possibility of scaling the proposed technological scheme to industrial operating conditions.

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