

Perspective Trends in Fine Coal Slimes Flotation

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ABSTRACT: Fine coal slimes (less than 0-0.2 mm) present great difficulty in cleaning. Their flotation ability depends on their size and physico-chemical characteristics. In particular, the degree of metamorphism of the coal, and the proportion and ash content of super-fine coal particles (less than 50 μm) produces quite a strong effect on the selectivity of flotation. The flotation properties of ultrafine slimes also depend on their nature: whether they are primary slimes in feed coal, or whether they form in circulating and slime water as a result of coarse and fine fraction washing. A series of investigations on the flotation of coals at different stages of metamorphism and with various characteristics of fine slimes was carried out. The effect of aerohydrodynamic and design parameters of multisectional column apparatus on the selectivity of flotation separation of coal slimes and fly ash of power plants was studied.

1 INTRODUCTION

Preparation plants have to deal with the problem of "fine slimes" in respect of their circulation in the process flow sheets and the difficulty of selective separation.

Of traditional cleaning methods of slimes less than 0.5 mm material, flotation is the most efficient. As the fines (<0.5 mm) content in the feed run-of-mine coal increases to 20-35%, the proportion of ultrafine material (<50 μm) in flotation feed reaches 40-60%, and in most cases the ash content of fine slimes less than 50 μm is 5-10% higher than that of fractions over 50 μm .

The problem of efficient separation of fine coal slimes arises when solving a range of non-traditional tasks, which include:

- 1) the production of super-pure concentrates to prepare water-coal fuel;
- 2) deep cleaning so as to desulphurize power-generating coals;

In the performance of these tasks, coal grinding to less than 0.2 mm is required to obtain adequate liberation of coal, and the 0-0.05 mm fraction content can be as high as 50-85%.

- 3) the recovery of carbon-bearing particles from the fly ash of power-generating plants for their subsequent utilization in construction materials production.

When coal dust is burnt, 50-75% of the fly ash of power-generating plants comprises particles under

0.05 mm in size, while the average particle size is less than 0.2 mm.

The aim of this work was to evaluate the effect of fine particles (less than 50 μm) of coals of different degrees of metamorphism on the selectivity of slimes separation during flotation, and to develop efficient processes and conditions for fine slimes cleaning.

A series of studies was carried out on the flotation of coals of different degrees of metamorphism with various characteristics of fine slimes. The effect of aerohydrodynamic and design parameters of multi-section column flotation machines on the efficiency of the desulphurization of anthracite slimes and separation of the pure mineral part (>95% ash) from the fly ash of power-generating plants was investigated.

2 SUMMARY OF THE STATE OF THE ART

Ultrafine particles (<0.05 mm) are characterized by specific physical and physico-chemical properties. A small particle size signifies their significant specific surface and higher adsorption ability. As failure during grinding most often occurs along micro-defects of grains and those in the crystal lattice, fine particles possess higher structural homogeneity, lower significance of external defects and higher significance of surface layers.

The presence of fine slimes in the slurry results in the following technological effects:

- contamination of froth product with fine fractions of waste rock;
- worsening of coarse grain flotation and deterioration of waste grade;
- higher reagent consumption;
- decrease of flotation rate.

In order to enhance the efficiency of the separation of coals containing fine slimes, the following methods are used:

- regulating reagents;
- fractional reagent feeding;
- special conditioning regimes (time and rate of mixing, density of slurry during its treatment with reagents);
- corresponding flotation machines allowing to variation in aerohydrodynamic conditions;
- special technologies (for example, flocculation-flotation method, etc.)

The applicability of a given method can be established by investigating the behaviour of fine slimes during flotation. Applicability also depends on requirements to separation indices, i.e., to concentrate and waste quality. The content of slimes (including so-called secondary slimes) in coal coming for cleaning varies from 10 to 35 % with an ash content of about 20-40%. These slimes contain proportions of 20 to 70% fine particles of less than 50 (µm in size, with ash contents of 25-51%.

3 RESULTS OF INVESTIGATIONS

In order to have the opportunity to compare the flotation ability of different coals, the concept of "maximum flotation ability" is used. This is derived from the release-analysis curve based on the maximum recovery of combustible mass into froth product, and the separation of froth products into fractions with different ash contents by means of many cleaning stages. In this case, the flotation ability of coal slime is virtually determined by slime properties.

Screenings of differently metamorphosed coals with different proportions and ash contents of finely dispersed fraction (under 50 µm) were considered, and the indices of the studied coal separation were compared with the release-analysis. As a criterion of flotation ability, it was assumed that the coefficient of relative efficiency of maximum separation can be found from the formula:

$$E_D = E_{CM}^C * E_{IM}^W / 100\% \quad (1)$$

where E_{CM}^C - recovery of combustible mass to concentrate, %; and E_{IM}^W - recovery of incombustible mass to wastes, %.

$$E_{CM} = Y_C * (100 - A_C) / (100 - A_F) \quad (2)$$

$$E_{IC}^W = Y_W * A_W / A_F \quad (3)$$

where Y_C - maximum yield of concentrate, %; A_C - ash content of concentrate, %; A_F - ash content of feed slime, %; Y_W - yield of wastes, %; and A_W - ash content of wastes, %.

The maximum concentrate yield was found using the curves of maximum flotation ability, including the middlings fractions yield.

The analysis of the data obtained demonstrated that it is not possible to draw a clear conclusion on the separate effect of ash content and fine slimes yield on the variation of efficiency index E_D . Assuming as a variable the weight content of ash in fine slimes equal to $Y_r * A_r / 100$, where Y_f - content of 0-50 µm fraction in slimes, and A_f - ash content in 0-50 µm fraction, we find the explicit effect of the degree of metamorphism on the results of maximum separation (Figure 1). Curve 1 characterizes coals of a moderate degree of metamorphism (coking, gas and gas-fat coals - C, G, GF), and curve 2 is characteristic of coals of a higher degree of metamorphism (weakly binding coal, anthracite - WB, A).

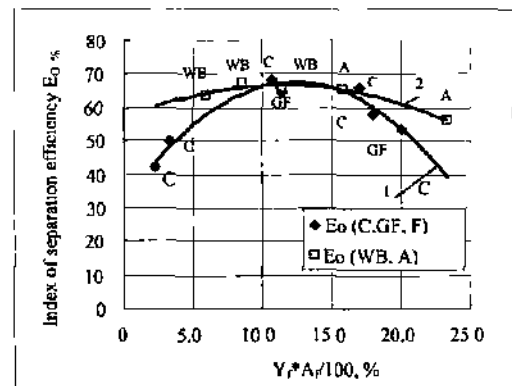


Figure 1 Index of separation efficiency (E_0) of maximum flotation ability as a function of weight content of ash in 0-50 µm fraction.

The efficiency of separation decreases both at low and high values of $Y_r * A_r / 100$, and the spread in relative efficiency figures at maximum flotation ability is higher for coal of a moderate degree of metamorphism. The maximum values of E_0 correspond to 10-12%.

In order to optimize the flotation of coals with high proportion and high ash content of fine slimes, a number of technological parameters for various ash and fine slimes contents were studied. The effect of feed characteristics when changing the reagent regimes, flotation kinetics, hydrodynamic parameters of flotation machines and when using a

floculation-flotation method was investigated, taking into account the combined effect of these factors on flotation figures.

A series of flocculation-flotation method investigations performed using latex flocculant BS-30F with coals of different degrees of metamorphism and particle size under 200 μm revealed positive results with this method application for coking, fat and weakly binding coals.

These factors were investigated in more detail in the context of the solution of a series of practical tasks in order to enhance the efficiency of fine coal slimes flotation.

3.1 Flotation of coking coal slimes

First of all, consider a specific example of the effect of primary and secondary slimes on the flotation of difficult-to-clean coking coals at the preparation plant of Nerungrinsky open cast mine (Yakutsky coal basin).

As these coals are difficult to clean it is necessary to use a flow sheet including coarse fractions grinding to -30 mm, dense-media separation with recovery of middlings and fine slimes flotation also with recovery of middlings. The feed coal has a content of about 21% -0.5 mm slime, with an ash content of 17%. During cleaning using water recycling, the slimes proportion reaches 35%, and the finely dispersed slimes proportion is as high as 30-40% with a 30-39% ash content.

Figure 2 shows E_0 and concentrate ash content variation as a function of flotation time in kinetic tests with one-time (curves 1 and 3) and fractional (curves 2 and 4) reagent feeding.

The indices of the relative efficiency of flotation of slimes were found:

- from screenings (0-0.5 mm) of coking coal with 0-50 μm material content $Y_r = 18.1\%$ with ash content of this fraction $A_r = 18.8\%$ and with initial ash content of screenings $A_F = 15.3\%$ - $E_0(>);$
- from flotation feed with ash content $A_F = 20.5\%$ with 0-50 μm material share $Y_r = 40\%$ with ash content $A_f = 36.2\%$ - $E_0(F);$

Size grade distribution by products of flotation (yield and ash Y^h , $A_{f(i)}$ for screenings; Y^h , A_{IF} for flotation feed) was studied, including the recovery of concentrate and middlings at the first stage and recovery of middlings and wastes at the second stage. The analysis of the results obtained demonstrates that a high content and high ash content of fine slimes disturb the selectivity of coarser particle separation (Figure 3), though the overall efficiency of separation of slimes subjected to flotation remains practically the same.

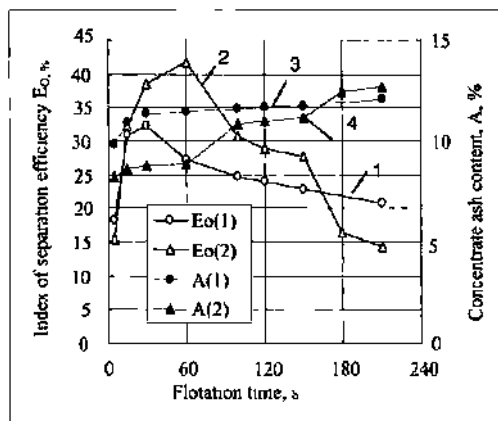


Figure 2 Variation of efficiency index E_0 with one-time and fractional feed of reagents

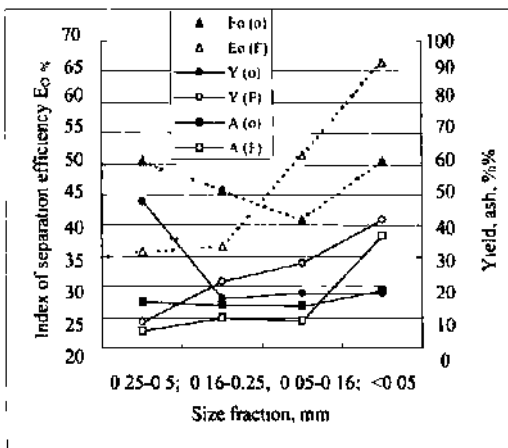


Figure 3. Index of separation efficiency in narrow particle sizes and distribution of yield and ash of feed material by size $E_0(i)$, $Y(i)$ and A_{i0} - screenings; $E_0(F)$, $Y_{<n}$ and A_{IF} - flotation feed.

Figure 4 shows the variation in the relative efficiency index of separation into three products with recovery of concentrate and middlings at the first stage and recovery of middlings and wastes at the second stage for coking coal screenings (0-0.5 mm) with different contents of 0-50 μm material (Y_f) and different ash contents of this material (A_f) as a function of the weight content of fine particles ($Y_f \cdot A_f / 100$) in slime.

The calculation of the indices of maximum flotation ability and flotation kinetics revealed the specificity of the flotation behaviour of slimes of the

studied coal. It was found that it is possible to enhance separation by fractional feed of the reagents. In this case, the efficiency of separation was 10% higher than when multiple cleaning stages were used.

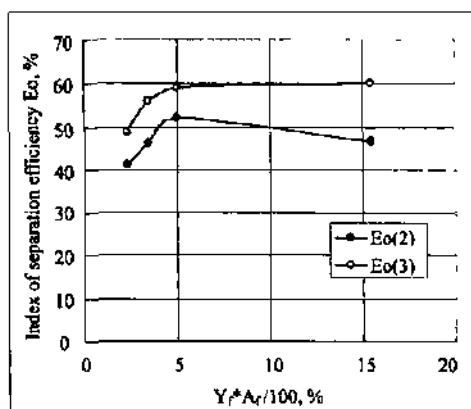


Figure 4. Indices of relative efficiency of separation into two EQ(2) and three EQ(3) products

3.2 Power-generating coals preparation

In Russia, thermal power stations are fueled with practically uncleaned coal, but in order to increase power plants' competitive ability and solve environmental problems, preliminary coal preparation is necessary. This problem is most urgent in the Rostov region, where thermal power plants are fueled with anthracites having a 30-35% ash content and 1.5-2.5% sulphur content.

The possibility of reducing ash and sulphur contents and increasing the calorific value of coal fuel by means of preparation was considered in a specific example of coals burnt at the "Novocherkasskaya" State Regional Power Station and coals being mined from the new deposit at Sadkinskaya mine (Rostov region).

The anthracite culm of 0-0.5 mm coming to the "Novocherkasskaya" State Regional Power Station for burning has an ash content of 31.7% and sulphur content of 1.9%.

The flotation ability of 0-0.5 mm feed slime and that of slime ground to 0-0.2 mm and 0-0.1 mm was determined. The efficiency of separation (E_o) at maximum flotation ability of the studied fractions is practically the same, while in kinetic tests at a fine slime flotation rate 2 times lower the efficiency of

separation $E_o(tm)$ sharply decreases. The application of the flocculation-flotation method makes it possible to increase the rate of fine slime flotation (0-0.1 mm) and obtain high separation results $E_o(FF)$ (Figure 5).

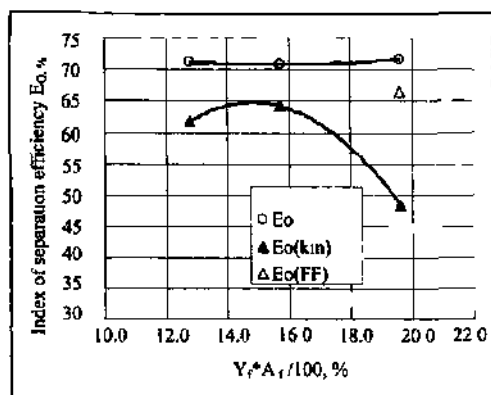


Figure 5. Indices of relative efficiency for different separation methods

The relative separation efficiency figure for 0-0.1 mm slimes when using the flocculation-flotation method is $E_o = 65.8\%$ at 72.3% concentrate yield with an ash content of 11%. Although the sulphur content in the concentrate remains high ($S_{otai} = 1.8\%$), the total annual sulphur emissions drop by 24% and ash and slag waste generation decreases by 3.6 times owing to reduced specific fuel consumption for the production of 1 MW-h of electric power.

The possibility of reducing ash and sulphur contents and increasing the calorific value of coal fuel by means of preparation was considered in a specific example of coals from the new deposit mined at Sadkinskaya mine (Rostov region). Studies of washability of slimes with a high content of high ash 0-50 μm material ($Y_r = 42.5\%$, $A_r = 40.6\%$) were performed for the purpose of desulphurization.

It was found that the most promising solution is the use of column multi-section machines in which separation efficiency is enhanced owing to the selection of optimum aerohydrodynamic conditions. The data obtained show that during flotation in column machines, sulphur recovery to concentrate is lower than in a mechanical flotation machine at equal levels of combustible mass recovery and concentrate ash content (Figure 6).

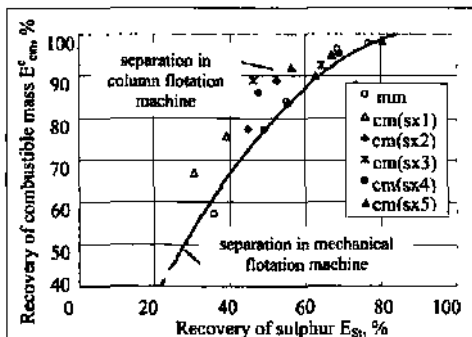


Figure 6. Sulphur and combustible mass recovery to concentrate under different separation conditions.

The optimum flow sheet and separation conditions for a multi-section column flotation machine are presented in Table 1.

From slimes containing 30.5% ash and 1.5% sulphur, concentrate containing 13.2% ash and 0.9% sulphur is produced at a yield of 68.7%. Slimes cleaning with the above-mentioned indices leads to an increase in low heat value from 4630 to 5890 kcal/kg. It makes it possible to decrease specific fuel consumption at thermal power stations and reduce total annual SO₂ emissions by 42%.

Table 1. Results of column desulphurization by flotation separation.

N	Concentrate			Tailings		E' _{cm} , %	E' _v , %	E _o , %
	Yield, %	Ash, %	Sulphur, %	Ash, %	Sulphur, %			
Coal slime (0-0.25 mm) of m. Sadkinskaya								
1*	68.7	13.2	0.9	64.87	2.64	84.42	42.80	57.42
2	78.4	17.3	1.0	72.63	3.31	91.64	52.30	49.15
3	68.2	14.6	0.8	62.96	2.53	83.18	40.41	55.54
4	69.2	14.2	0.9	63.52	2.57	84.08	44.03	55.35

*Optimal flotation results: slurry flow rate=1.3 cm/sec, air flow rate during rougher and scavenger flotation=1.6 l/min, air flow rate during cleanings=0.8 l/min.
Consumption of agents: Rougher flotation - kerosene 800 g/t, MIBK 200 g/t;
Scavenging - kerosene 400 g/t, MIBK 150 g/t;
Concentrate cleaning (1 and 2) - kerosene 150 g/t, MIBK 50 g/t.

3.3 Production of super-pure concentrates to prepare water-coal suspensions

The problem of enhancement of fine fraction flotation becomes more acute for the development of processes of super-pure concentrate production to prepare water-coal fuel.

Consider some results of coals flotation at "Cherkasovskaya" preparation plant (weakly binding coal, Kuznetsk basin).

For pure coal liberation, the degree of grinding was chosen so as to obtain the maximum recovery of combustible mass with minimum ash content of the concentrate. The indices of flotation separation of coal ground to different sizes show that coal grain opening takes place at fine grinding to - 50 Jim of 85% of the material and when the ash content of this material is close to that of the feed material- 17.1%.

The application of the flocculation-flotation method and concentrate recleaning at quite fine grinding makes it possible to optimize the separation process, increasing the relative efficiency index by 10% (Figure 7).

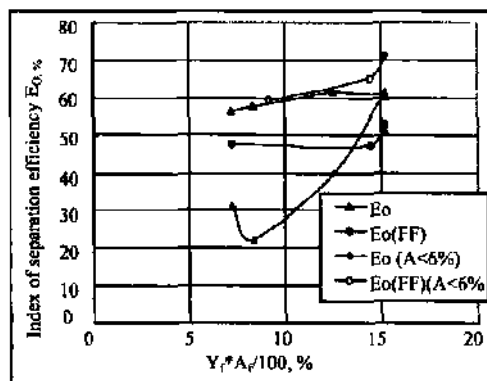


Figure 7. Variation of efficiency index E₀ when using flocculation-flotation separation method.

3.4 Recovery of organic matter from fly ash of power-generating plants

The problem of coal particle recovery from the fly ash of power-generating stations is a separate issue as we deal here with a different coal material that passes

through the stage of burning. Nevertheless, it is a very interesting task related to the environmental and economical problems of recovering the pure mineral part of ash (with carbon content (LOI) of less than 5%) to use it for the production of construction materials and recycling recovered coal matter for burning.

Detailed investigations of fly ash separation were carried out at different power stations. Operating conditions of separation have been developed that include a conditioning regime at a high rate of dense slurry mixing (solid content

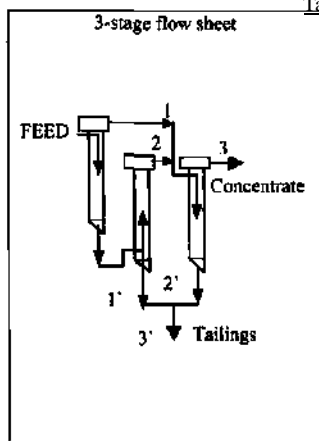
200g/l) with the addition of a collector, using a 3-section column flotation machine, making it possible to reproduce in one apparatus the flow sheets of rough, control and cleaner flotation, fractional reagent feeding, counter-current and straight-current slurry and air movement in different sections of the machine, with aeration conditions (consumption and dispersion of air bubbles).

The optimum results of fly ash flotation for a specific case at the "Novocherkasskaya" State Regional Power Station, which burns anthracites, (Rostov regions) are summarized in Table 2.

Table 2. Results of column flotation separation fly ash.

N	Concentrate		Tailings			E ^c _{cm} , %	E ^l _{usem} , %	E _o , %
	Yield, %	Ash, %	Ash, %	Ash, %	LOI %			
	Fly ash of Novocherkasskaya PS							
1*	20.4	40.3	79.6	96.6	3.4	81.76	90.34	73.86
2	17.2	37.3	82.8	95.3	4.7	73.57	92.48	68.04
3	21.39	48.6	78.61	95.6	4.4	76.04	87.85	66.80
4	20.50	41.50	79.5	96.3	3.7	80.20	90.00	72.18

*Optimal results. Slurry preparation prior to rougher flotation is carried out at a stirring speed of 2500 rpm and conditioning time of 3 min.
 Slurry density (solid matter content) - 200 g/l;
 Slurry flow rate in compartment - 1.3 cm/s;
 Air consumption - 0.5 l/min (at each flotation stage, in any compartment);
 Consumption of agents: Rougher flotation - kerosene 1400 g/t, MIBK 350 g/t;
 Scavenging - kerosene 1400 g/t, MIBK 250 g/t;
 Concentrate cleaning - kerosene 700 g/t, MIBK 250 g/t.



4 CONCLUSIONS

New flotation flow sheets and conditions have been developed that facilitate solutions to the problems below.

1. Desulphurization of fine fractions (0-0.25 mm) of anthracites in the Rostov region (specific case of Sadinskaya mine coals);
2. Intensification of finely dispersed slimes flotation with production of super-pure concentrates to prepare water-coal fuel (specific case of weakly binding coals from Kuznetsk);
3. Recovery for use of coal particles from the fly ash of electric power stations.

REFERENCES

Molchanov A.E., Chanturiya V.A., Rubinstein Yu.B. & Guzenko A.I. Possibilities of raising the rate of fine coal flotation. *Proceedings of the 1st International Symposium on Fundamentals of Mineral Processing, Vancouver. British Columbia.* 165-179.

Rubinstein Yu.B. & S.T. Hall. 1998. Improved utilization of Py ash through beneficiation. *XIII International Coal Preparation Congress, Brisbane, Australia:* 562-569.

Rubinstein Yu.B. 1994. Column Flotation Process. Designs and practices. *Gordon & Breach Science Publishers:* 312.

Rubinstein Yu.B., Deberdeev I. & Samoylova E.K. Progressive technologies of enrichment and processing of fine coals. 1998. *The mountain bulletin:* 52-60.