

## Techniques and Technology of Waste Disposal of Lignite Briquettes

Iryna Matsyuk<sup>1,a\*</sup>, Vyacheslav Krivoschokov<sup>2,b</sup>, Natalia Kushniruk<sup>3,c</sup>,  
Liudmyla Skliar<sup>3,d</sup>

<sup>1</sup>Department of Machinery Design Fundamentals, Dnipro University of Technology,  
19 Yavornytskoho Ave, Dnipro, 49005, Ukraine

<sup>2</sup>Department of Mineral Dressing, Dnipro University of Technology,  
19 Yavornytskoho Ave, Dnipro, 49005, Ukraine

<sup>3</sup>Department of Mineral Dressing and Chemistry, Kryvyi Rih National University,  
11 Vitalius Matusevich St., Kryvyi Rih, 50000, Ukraine

<sup>a</sup>matsyukin@ua.fm, <sup>b</sup>krivoschokov.v.i@nmu.one,  
<sup>c</sup>kushniruk-natalia@ukr.net, <sup>d</sup>lyuda.cuclina@gmail.com

**Keywords:** waste-free technology, lignite slurry and cinders, separate treatment of floating and sinking fraction, reagentless flotation separation, deposition

**Abstract.** Development of a waste-free technology for lignite slurry upgrading at briquetting factories, which provides for getting cleared water for closed-loop water supply and transportable product for burning or briquetting with sustainable equipment application.

Detection and study of peculiarities of lignite coal and slurry of briquetting factories, as well as research on slurry surface properties for substantiating a separation ratio. Determination of the separation ratio of lignite coal slurry taking into account its surface properties to estimate technological efficiency of reagentless flotation separation. Research on kinetics of settling and influence of different flocculants on efficiency of the slurry thickening process for sludge collection and getting circulating water. Development of waste-free technology for lignite slurry upgrading with the purpose of slurry recycling based on the substantiation of rational technological parameters and appropriate equipment.

Regularities of the process of reagentless flotation separation of lignite coal slurry, kinetics of settling are defined, which is the basis of technological solutions on separate briquetting waste treatment. A waste-free technology for upgrading lignite slurry and cinders with closed-cycle of water supply and transportable final product for burning and briquetting with moisture content of 26% ... 28 % is developed.

Floating and sinking fractions of lignite slurry are studied and necessity of separate treatment of these fractions is substantiated. Kinetic regularities of deposition of heat-treated lignite particles are determined; rational modes which provide for efficient deposition of particles of the sinking fraction with minimum flow of a flocculant are defined. A phenomenon of hydrophobic behaviour of mineral particle surface after heat treating and briquetting of lignite coal is revealed, which is taken as a separation ratio; this allowed substantiating the waste-free technology for lignite slurry upgrading through reagentless flotation separation.

The practical value of the results obtained involves development of a waste treatment technology at a briquetting factory (slurries and cinders) and its conversion into closed-loop water supply, which will allow obtaining 23 t/year of transportable final product additionally as well as decreasing consumption of pure water considerably and eliminating environment pollution.

### Introduction

Balance reserves in Ukraine make 45 billion tons including over 8 billion tons of lignite coal. When using the traditional technology of briquetting lignite coal, the wastes at briquetting factories – slurries (up to 3 %) and cinders (up to 15 %) are not recycled on account of lack of theoretical and experimental substantiation of their reclamation. Promising trends of improving the process of lignite briquetting include development and introduction of a waste-free technology of separate

treatment of slurries and cinders as well as a closed-loop cycle of reverse water supply at briquetting factories, which will eliminate slurry disposal outside the factories and, consequently, environmental pollution [1, 2].

### Unsolved Problem Identification

Analysis in the field of lignite coal conversion technology in the Dniprovskiy Basin was conducted and the quality of the coal was defined. Division of lignite coal into recent earth coal and mature tough coal is related to the influence of metamorphism and petrographic composition. Unlike bituminous coal, lignite coal contains bitumen, humic and carboxylic acids and features ductility.

The problem of lignite coal conversion consists in the lack of technologies of waste recycling (slurries and cinders) at a briquetting factory and its conversion into closed-loop water supply, which will allow obtaining transportable final product additionally, decreasing consumption of pure water considerably and eliminating environment pollution.

### Analysis of the Recent Research

The share of coal in the world electrical power generation makes 4 %; however, in certain countries it is much larger, with 68% in Greece, 63% in the Czech Republic. In Germany, since 2000 lignite coal has become the cheapest source of electric-power generation taking into account the latest burning techniques and provision of ecological requirements. As shown by the developed countries' experience, lignite coal is not only a power fuel, but is also a valuable raw material for chemical and other industries [3, 4].

Works by A.A. Agroskin, A.T. Yelisevych, V.N. Krokhin, I.D. Remeslenikov, I.Yu. Sviatets are devoted to the development of theory and practice of coal briquetting, while M.H. Bedran, V.S. Bitetskiy, V.S. Butovetskiy, B.O. Bliuss, A.S. Kirnarskiy, V.I. Kryvoshchokov, O.I. Nazymko, P.I. Pilov, O.D. Poluliakh, T.H. Fomenko and others studied conversion of coal slurries and granular materials.

Currently, great emphasis is placed on the issue of waste disposal due to environmental protection and rational operation of briquetting factories, which will prevent discharging slime water into quarries-settling basins. That is why an efficient waste-free technology of treating lignite coal slurries with the purpose of their disposal based on the substantiation of rational technological parameters and relevant equipment is required [5-7].

### Unsolved Aspects of the Problem

A disadvantage of the traditional technology of lignite coal briquetting is loss of fuel material as slurry disposal outside factories due to the lack of closed-loop water-slurry cycle [9-10].

Slime water of a briquetting factory (after washing out working sites and the wet dedusting system) contains floating (46.96 %) and sinking (53.04 %) fractions. With the concentration of solid matter of 10–30 kg/m<sup>3</sup> the water becomes clear with difficulty, since the natural sedimentation velocity of particles of sinking fraction is small [11].

### Objectives of the Article

The objective of the work is to develop a waste-free technology for lignite slurry upgrading at briquetting factories which provides for getting cleared water for closed-loop water supply and transportable product for burning or briquetting with sustainable equipment application.

### Presentation of the Main Research

As it is known, at briquetting factories there occur wastes in the form of dust and slurries, which are discharged into a dust-settling tanks, as well as briquettes and cinders. It is found that in as little as 1.5 seconds in static conditions one can observe division of lignite slurries into floating and sinking fractions and after 4 minutes there is a clear boundary between them.

To conduct the analysis of surface properties of floating and sinking fractions, briquettes were produced and contact angles of wetting were measured following the well-known procedure.

To determine dependence of the contact angle of wetting  $\Theta$  on the heating temperature (Fig. 1) a sample of bank lignite coal was selected, dried, cooled, separated into floating and sinking fractions in the water, dried again and then briquetted with a hand-powered press at constant pressure ( $P = 120$  mPa) and different heating temperature in a muffle furnace with further cooling.

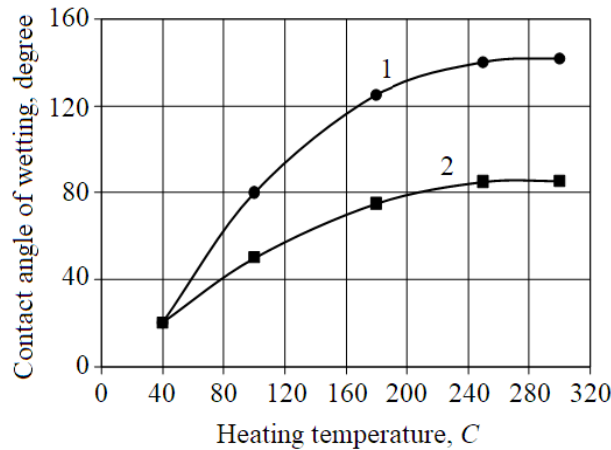


Fig. 1. Dependence of the contact angle of wetting on the heating temperature of floating (1) and sinking (2) fractions

As seen from Fig. 1, increase in the contact angle of wetting of both fractions is related to melting of bituminic resins, which increase hydrophobic behaviour, particularly that of floating fractions where their content is the highest. This allows taking hydrophobic behaviour of particle surface as the separation ratio for lignite slurries and performing separation of slurries into floating and sinking fractions.

The chemical analysis of the components forming ashes and the accounting performed give evidence of predominant content of  $SiO_2$ ,  $Al_2O_3$ ,  $Fe_2O_3$ ,  $CaO$ ,  $SO_3$  and  $MgO$  in floating and sinking fractions compared to other oxides, while the spectral analysis proves that both fractions differ in quantitative content of such elements as  $Ba$ ,  $Ti$ ,  $Sr$ ,  $Mn$ ,  $Zn$  and  $Pb$ . This provides reasons to consider the difference of crystalline structure of these fractures, which influences their technological properties.

The float-and-sink analysis of floating fractions of lignite slurry (Tab. 1) was conducted by the following procedure. The sample was immersed in the water with the temperature of  $t = 100$  °C, stirred, cooled, and then the water, from which bitumen components were withdrawn, was removed. Then the sample was dried at room temperature and fractionated in solution of sodium chloride with salt content 1.5; 2.8; 5.0; 9.0 and 15 %. The float-and-sink analysis of sinking fractions (Tab. 2) was conducted in solution of zinc chloride by the standard procedure.

Table 1. The float-and-sink analysis of floating fractions of lignite slurry

Fraction density, $kg/m^3$	Output, $\gamma$ , %	Ash content, $A^d$ , %	$\gamma_i A_i^d$	Consolidated figures, %			
				Floating fraction		Sinking fraction	
				$\gamma$	$A^d$	$\gamma$	$A^d$
<1009	8.58	11.94	102.44	8.58	11.94	100.0	12.65
1009-1017	17.61	12.56	221.18	26.19	12.36	91.42	12.71
1017-1035	69.35	12.68	879.36	95.54	12.59	73.81	12.75
1035-1070	2.42	12.73	30.81	97.96	12.59	4.46	13.85
1070-1109	1.17	14.85	17.37	99.13	12.62	2.04	15.17
>1109	0.87	15.61	13.58	100.0	12.65	0.87	15.61
$\Sigma$	100.0	12.65	1264.74	-	-	-	-

Table 2. The float-and-sink analysis of sinking fractions of lignite slurry

Fraction density, kg/m <sup>3</sup>	Output, $\gamma$ , %	Ash content, $A^d$ , %	$\gamma_i A_i^d$	Consolidated figures, %			
				Floating fraction		Sinking fraction	
				$\gamma$	$A^d$	$\gamma$	$A^d$
<1100	0.27	12.61	3.40	0.27	12.61	100.0	22.18
1100-1200	1.03	14.35	14.78	1.30	13.98	99.73	22.21
1200-1300	15.05	16.52	248.63	16.35	16.32	98.70	22.29
1300-1400	72.53	23.07	1673.27	88.88	21.83	83.65	23.33
1400-1500	9.58	24.45	234.23	98.46	22.08	11.12	25.03
1500-1600	1.04	24.83	25.82	99.50	22.11	1.54	28.62
>1600	0.50	36.52	18.26	100.0	22.18	0.50	36.52
$\Sigma$	100.0	22.18	2218.39	-	-	-	-

The floating and sinking fractions of lignite slurries are slightly different in size (Fig. 2).

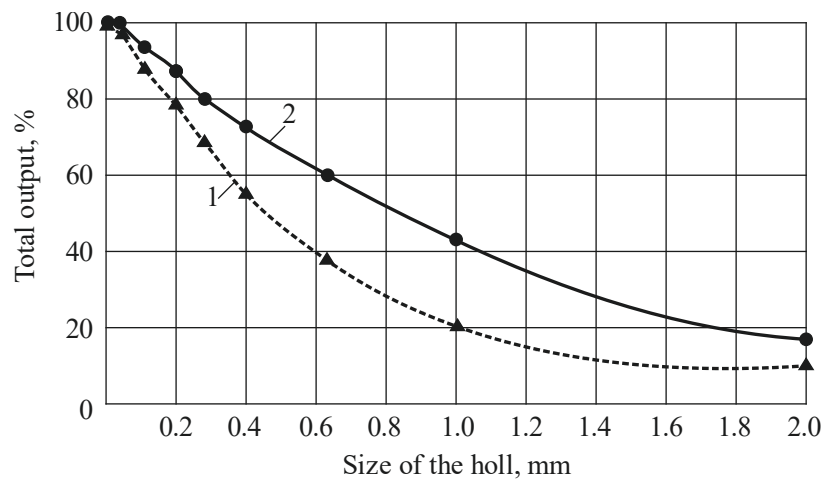


Fig. 2. Combined fineness properties of lignite slurries of floating (1) and sinking (2) fractions

Necessary equipment for clearing slime water and pulp thickening, which is based on definition of displacement rate of margin of separation between the cleared water and hydraulic fluid of solid matter in a measuring cylinder, is determined. Influence of different flocculants (PAA – polyacrylamide, KAT-FLOC 3840, KAT F 148, KAN 20 VHM and X 99 B1) on sedimentation of sinking fraction of lignite slurry at solid concentration of 50 kg/m<sup>3</sup> is defined. It was found that PAA or KAT-FLOC 38403 is the most efficient flocculant.

With the purpose of studying technological solutions of kinetics of settling of lignite slurries, multifactor experimental design techniques were performed and a mathematical (regression) model was obtained.

Based on the experiment design, an area was determined where the influence of rational parameters was studied, and replicate experiments were conducted, which were required for kinetic model identification.

The established regression equation takes the form:

$$Y = 88.5 + 2.5X_1 + 3.5X_3 - 1.5X_2X_3,$$

where  $Y$  is sediment yield, %;  $X_1$  is polyacrylamide reagent concentration (g), g/t;  $X_2$  is pulp density (p), %;  $X_3$  is deposition time (t), minutes.

On the basis of the experimental data for narrow grain-size classes, coefficients of kinetics of settling sinking lignite fraction were found, which were determined by the method of spline regression and recovery of empiric regression function from the equation of height of cleared liquid layer:

$$H = \Delta H \exp(-ktan),$$

where  $\Delta H = H_0 - H_t$ ;  $H_0$  is the original height of suspended mixture layer, mm;  $H_t$  is the height of the settled layer of suspended mixture, mm;  $k$ ,  $n$  are kinetics coefficients.

According to the analysis of studying the equation and dependences obtained, the solids content is inversely related to the height of the layer  $H_t$ , while the coefficients ( $k = 0.55-0.25$ ,  $n = 0.08-0.66$ ,  $q = 20-60$  g/t) define the shape and position of the kinetics curve.

With changes in conditions of the process, for example, technological factors, these coefficients change. The coefficient  $k$  is revealed through technological parameters – particle size, solid matter concentration in the suspended mixture, reagent concentration and others.

In the technological scheme suggested by the authors, slime water (from production sections, a factory's area, after ram press dedusting, wet dedusting) is fed for recycling; it is separated into floating and sinking fractions in thereagentless flotation separator [12]. The sinking fraction of the slime pulp is subject to separate conditioning and is directed to a lamellar thickener for thickening. To stimulate the processes of settling and thickening PAA or KAT-FLOC 3840 is applied, the consumption of which makes 40 g/t. The floating fraction is disposed to the device for its collection and mixing with the thickened slurry of the sinking fraction. The formed mixture of slurries is dewatered on a shaking sieve and then transported to a bunker of dewatered slurry. The broken briquettes and briquette cinders are subject to crushing up to 3 mm and delivered first to the bunker of the crushed cinders and then to a hermetically-sealed auger, to which slurries from the bunker of dewatered slurries are proportioned. Through the hermetically-sealed auger, the mixture of slurries and cinders is directed for intermixing to the state of transportable final product, which is delivered to the bunker for shipment to consumers (Fig. 3).

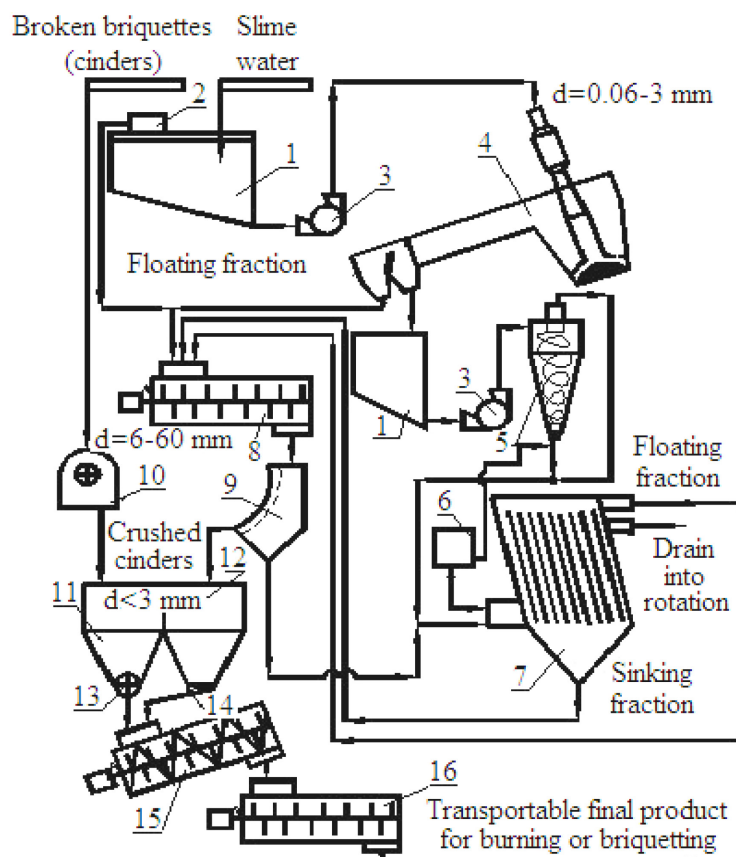


Fig. 3. Flow sheet for waste recycling machines at briquetting factories: 1 – bunker; 2 – reversible automated guided vehicle; 3 – pump; 4 – flotation separator; 5 – device for separate conditioning; 6 – PAA metering pump; 7 – flange thickener; 8 – mixing device; 9 – shaking sieve; 10 – crusher; 11, 12 – bunker; 13 – rotary valve; 14 – dosing pump; 15 – hermetically-sealed auger; 16 – mixing device

The peculiarity of the new reagentless flotation separator for recycling slurry (Fig. 4), which the authors suggest, is that a flotation cell with an aerator-ejector is contiguous to the converging slot [13].

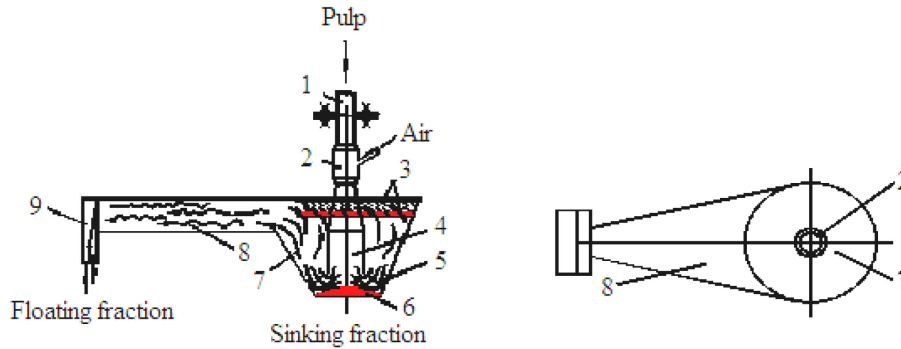


Fig. 4. Basic diagram of the reagentless flotation separation: 1 – pipework; 2 – aerator-ejector; 3, 5 – damping crate; 4 – piping of pulp-air mixture; 6 – impact plate-dispenser; 7 – flotation chamber; 8 – converging slot; 9 – receiving box for separation products with a chimney valve

As a criterion of estimation of separating capacity of reagentless flotation separation of lignite slurries, a complex factor  $K$  is taken which takes into account the influence of on hydrophobic behaviour of grain surface  $K_1$ , fraction composition of floating and sinking fractions  $K_2$ , grain-size composition of these fraction  $K_3$ :

$$\text{Of } K \geq K_1 K_2 K_3 \geq 1.25,$$

Where the coefficients  $K_1$ ,  $K_2$ ,  $K_3$  are calculated as:

$$K_1 = \frac{\Theta f}{\Theta};$$

$$K_2 = \frac{\rho f}{\rho s} \times \frac{\rho f}{\rho s};$$

$$K_3 = \frac{df}{ds},$$

where  $\Theta f$  is the contact angle of wetting of the floating fraction, degrees;  $\Theta$  is the contact angle of wetting which corresponds to the inversion point ( $\cos \Theta = 0$ ,  $\Theta = 90^\circ$ ), degrees;  $\rho f$ ,  $\rho s$  is the weighted average of density of floating and sinking fractions;  $\rho f = 1025 \text{ kg/m}^3$  is the density of suspended mixture with the slurry density of  $1350 \text{ kg/m}^3$  and solid matter concentration of  $100 \text{ kg/m}^3$ ;  $df$ ,  $ds$  is the average-weighted grain size of floating and sinking fractions, mm.

The maximum particle size of the floating fraction is:

$$d_{\max} = K_1 \sqrt{\frac{\sigma}{K_2 g}} K_4 \text{ mm},$$

where  $\sigma$  is the boundary surface tension for gas-liquid, mN/m;  $g$  is the gravitational acceleration,  $\text{m/s}^2$ ;  $K_4$  is the coefficient of proportionality which considers the impact of particles shape and conditions of their dampening ( $K_4 = 0.6-0.7$ ).

With  $K \geq 1.25$  the reagentless flotation separation is efficient, while with  $K < 1.25$  it is not.

The factors of floatation separation regarding the kinetics are defined in practice by the rate coefficient of the floatation separation of the mineral  $K_i$ , the separation selectivity coefficient  $c$ , floatation separation time  $t$ . In general, the coefficient  $K_i$  depends on hydro-aerating parameters of the floatation separator, properties of lignite slurry. If we consider the regularity of the process change within a certain period of time (from  $t_1$  to  $t_2$ ), conditions of the floating separation can definitely be taken as constant (Fig. 5), although the general kinetic characteristics of the process within the specified time range can vary with time.

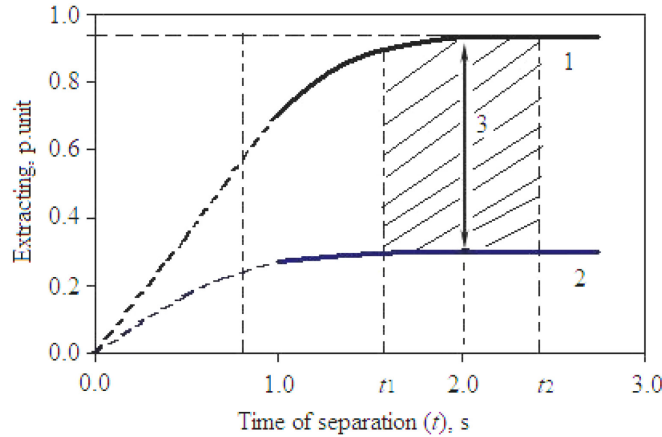


Fig. 5. Kinetics of reagentless floatation separation: 1, 2 – partial removal of floating and sinking fractions to the sinking product, p.unit; 3 – efficiency of floatation separation ( $\eta = E_f - E_s$ )

The change in  $E_i$  within the time range from  $t_1$  to  $t_2$  can be adequately approximated by the exponential curve segment with  $K_i = \text{const}$  and defined it as  $K_i = \ln(1 - E_i)/t$ . Then:

$$E_f = 1 - e^{-k_f t}; \quad E_s = 1 - e^{-k_s t},$$

where  $E_f, E_s$  are partial removal of floating and sinking fractions to the sinking product, p.unit;  $k_f, k_s$  are the rate coefficients of the floatation separation of floating and sinking fractions;  $t$  is the floatation separation time, s.

The contents and quality of the floating product are defined by removing both part of floating fraction and part of sinking fraction from it:

$$E_f = 1 - e^{-k_f t} = 1 - e^{-1.329 \cdot 2};$$

$$E_s = 1 - e^{-k_s t} = 1 - e^{-0.164 \cdot 2};$$

$$H = E_f - E_s = 0.93 - 0.28 = 0.65 \text{ p.unit},$$

while the selectivity coefficient of floatation separation of lignite slurry (relation of rate indicators of floatation separation into floating and sinking fraction product), is defined as

$$c = \ln[1 / (1 - E_f)] / \ln[1 / (1 - E_s)] = k_f t / (k_s t) = k_f / k_s.$$

Separate conditioning of the pulp by means of hydro cyclonage and sand reagentizing of hydrocyclone with their further mixing with the outflow allows decreasing consumption of reagents. That is why technical configuration of separate conditioning and floatation separation is a promising trend in the development of technology of treating coal slurries and other granular materials [14-16].

The device for separate conditioning of the pulp of a sinking fraction is made on the basis of the hydrocyclone and is different by spray lance of reagents and a drilled spiral aerator. The thickened (coarse grained) product and the outflow are combined in the mixing device, where the reagent is allocated from the surface of coarse particles to the surface of small particles for the further process of pulp thickening.

The advantage of the flange thickener with inclined platen frames includes high efficiency with a small area, no moving parts and drive as well as light wear and small maintenance costs. The efficiency of this thickener is twenty times as high as that of conventional thickener.

To implement the scheme of waste recycling at briquetting factories, core process equipment, which can be manufactured within the factory, is chosen and substantiated.

## Summary

It has been established that after heat treatment and briquetting of lignite coal, hydrophobic behaviour properties of its surface are in evidence. For the floating fraction of lignite slurry, the contact angle of wetting made  $122^{\circ}$ ... $136^{\circ}$ , while for the sinking fraction it was  $85^{\circ}$ ... $90^{\circ}$ , which is indicative of pronounced hydrophobic behaviour of the floating fraction surface and allows conducting reagentless floating separation of these fractions with an efficiency factor up to 65 % and maximum size (2.25 mm) of the floating fraction.

Separate treatment of floating and sinking fractions of lignite slurry with their further mixing with broken briquettes (cinders) of 3 mm is conditioned by surface properties of slurries. Moreover, separate conditioning and thickening of the sinking fraction should be preceded by reagentless floating separation before mixing.

A waste-free technology for upgrading lignite slurry and cinders with closed-cycle of water supply and transportable final product for burning and briquetting with moisture content of 26% ... 28 % is developed.

## References

- [1] BP Statistical Review of World Energy: <https://www.bp.com>
- [2] Solid combustible minerals. State Research and Production Enterprise "State Information Geological Fund of Ukraine": <http://geoinf.kiev.ua>
- [3] Mineral Commodity Summaries: <http://minerals.er.usgs.gov/minerals/>
- [4] Svetets, I.E. (1985). *Technological use of brown coal*. Moskva: Nedra.
- [5] Aleksandrova, T.N., Rasskazova, A.V., & Prohorov, K.V. (2011). Substantiation of the innovative technology of fuel briquettes production from the brown coal raw material in the Far East of the Russian Federation. *VI International Brown Coal Mining Congress "Role and position of Brown Coal in the Global Power Industry of the 21-st Century" (Poland, Belchatow, 11-13 April 2011)*, (1), 21-24.
- [6] Murko, V.I., Fedyaev, V.I., Aynetdinov, H.L., & Baranova, M.P., (2013). Environmentally clean technology of fine waste coal utilization. *The 8th International Symposium on Coal Combustion (The 8th ISCC), Turkey*, 679-682.
- [7] Jasienko, S., & Gryglewich, G. (1995). *Chemistry and physics of coal*. Wroclaw: Oficyna Wydawnicza Politechniki Wroclawskiej.
- [8] Baranova, M.P., & Kulagin, V.A. (2011). Energy and Ecological Aspects of Coal-water Slurry Utilization. *The 7th ISCC, Harbin*.
- [9] Shpirt, M.Ya., Ruban, V.A., & Itkin, Yu.V. (1990). *Rational utilization of waste from extraction and enrichment of coal*. Moskva: Nedra.

- [10] Tamko, V.A., Shevkoplyas, V.N., & Saranchuk V.I. (1996). Non-waste processing of brown coal of the Alexandrian deposit. *Coal of Ukraine*, (6), 16-20.
- [11] Krivoshchokov, V.I., & Matsyuk, I.N. (2003). Resource efficient waste recycling at lignite briquetting factories. *Mineral Processing: Collection of research papers*, 18(59), 171-176.
- [12] Krivoshchokov, V.I., & Matsyuk, I.N. (2004). Technological properties and waste disposal at lignite briquetting factories. *Coal of Ukraine*, (20), 43-47.
- [13] Krivoshchokov, V.I., & Matsyuk, I.N. (2006). Reagentless floatation separation: methods and arrangement. *Mineral Processing: Collection of research papers*, 25(66)-26(67), 84-92.
- [14] Krivoshchokov, V.I., & Matsyuk, I.N. (2010). *Lignite slurry treatment process: monograph*. Dnipropetrovsk: National Mining University.
- [15] Falshtynskyi, V. (2016). Obosnovanie parametrov formirovaniya polostey rassloeniy v porodakh krovli pri gazifikatsii ugol'nogo plasta. *Razrabotka Mestorozhdeniy*, 10, (1), 16-24.
- [16] Kushniruk, N.V., Harkusha, M.S., & Matsyuk, I.M. (2017). Developing a new technology of recycling lignite slurries at briquetting factories. *Proceedings of the International Science and Technology Conference "Development of Industry and Society"*, Kryvyi Rih, SHEI "KNU", 396.