Methods of Increasing the Calorific Value of Fine Coal Waste

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Summary

The research and testing conducted so far on the application of fine coal waste as a fuel in power boilers and furnaces suggest the possibility of improving their quality and the chance to increase economic and ecological effects by their users.
Energy properties of fine-grained coal waste result from the contents and quality of the occurring coal maceral as well as water and mineral components' contents. The simplest way to increase the calorific value of coal sludge and floatation tailings is to lower their water and ash contents. The humidity of fine coal waste from current production is largely influenced by the applied dewatering installations, where the filtration presses proved the most effective. The degree of hydration of coal sludge and floatation tailings from settling ponds depends on the time of their deposition and the construction of settling ponds as well as the way of their breaking and storing of the broken material. The fine-grained coal waste delivered to power stations can be characterized by the humidity of 14 to 45%.
A significant quality improvement of fine coal waste materials was achieved through their granulation. The obtained granulated product can be characterized by its resistance to transport and storage conditions, it does not degrade in changing weather conditions and has better energy properties. By substituting sludge water pulp with sludge granulated product there can be obtained a unitary increase of combusted fuel net calorific value by about 2000 kJ/kg.
The essential quality improvement of fine coal waste can be achieved by lowering their mineral components' contents. The easiest solution is a selective separation of water-sludge flows that are richest in coal from water-sludge circuit, and in the case of waste from storage yards, it is a selective deposit mining.
The richest coal concentrates from coal sludge are obtained by separating a grain fraction over 30-50 μm. In the cases of application of dewatering vibration sieves with fabric diaphragms as well as arch sieves and centrifugal dewatering sieves, there were obtained coal concentrates of net calorific values in the range of 15 to 22 MJ/kg.
In the deposition methods of water-sludge suspensions in settling ponds applied so far, the possibility of gravitational enrichment of water-sludge suspensions with coal grains has not been used. Through water-sludge suspensions' flow channeling in settling ponds, there can be obtained rich and very rich-in-coal grains deposit areas, not to mention more effective supernatant water cleaning.
Floatation tailings' cleaning calls for different methods of separation, most often based on specific gravity differences and/or surface properties of coal grains and mineral components. Most frequently constructed cleaning installations are based on technologies using hydrocyclones, heavy water, and floatation processes. These technologies make it possible to obtain the richest coal concentrates.
The analysis of fine coal waste utilization leads to a conclusion that through cooperation of mining and power industries there can be created favorable conditions and possibilities for the improvement of both quantitative waste utilization and economic and ecological effects for the parties concerned.

Keywords: fine (fine-grained) coal waste, coal sludge, floatation tailings, granulated coal sludge, coal sludge and floatation tailings' combustion

Introduction

The use of low-calorie fuels is a natural phenomenon driven by the opportunity to achieve additional economic effects in power industry as well as to limit the quantity of waste generated by fuel producers and distributors. All these endeavors amount to rationalization of the application of the coal substance/maceral included in fuels and waste.

The main sources of low-calorie fine-grained fuels and fuel compositions are coal slurry and flotation tailings and their mixtures; besides, there are brown coal dust, graphite–coal-products' manufacture waste materials, soot from petro-chemistry and more and more frequent dust and sand fractions from biomass processing. In this group belong also low and medium calorie coal concentrates recovered from spoil as well as medium and coarse-grained waste from mechanical coal processing.

In conditions of coal mines and coal preparation plants, the fine-grained coal waste materials, differing not only in origin but also their physical and chemical properties, constitute the biggest mass fraction.

There can be distinguished the following fine-grained coal waste:

– coal slurry as a byproduct of water-slurry management;
– flotation tailings from coal preparation process by flotation;

– coal slurry, flotation tailings and their mixtures accumulated in settling ponds on the ground;
– coal slime from cleaning underground water-drainage galleries and ground settling ponds of mine waters.

Frequently, all of this waste or a part of it is stored together in settling ponds forming a new, heterogeneous kind of fine-grained coal waste – a fine-grained coal waste from settling ponds or, in the case of partially dehydrated flotation tailings deposited at storage sites – a fine-grained waste from storage sites.

Fine-grained coal waste, and particularly coal slurry and flotation tailings are used not only as low-calorie fuels (independently or as an additive to commercial fuels), but also as a technological fuel (e.g. an additive to ceramic bricks and clinker production), and a source of coal concentrates, not to mention insulating material for mine excavations, coal piles' surfaces, waste dumps, and as a light soil reclamation agent. [1, 2, 3, 4].

Implementation of fluidized-bed boilers and furnaces [5, 6, 7, 8], was a significant step forward in the development of mass application of low-calorie fuels; in these cases the low-calorie fuels are used as basic fuels and/or as a component of fuel mixtures and also as a complementary fuel. As regards the fluidized-bed boilers' operational practice, the combustion of coal slurries, flotation tailings, and fine-grained fractions extracted from spoil can be logged even at a calorific value of abt. 5.5 MJ/kg, although, for most of them, their calorific values exceed 8 MJ/kg.

Stricter and stricter requirements regarding environment gas pollution and the need to increase the economy of combustion processes suggest the purposefulness of a re-analysis of the so far employed solutions on preparation and use of low-calorie fuels as well as the necessity of developing new working directions to increase their effectiveness. The use of low-calorie fuels, similarly to commercial fuels, calls for defining and assessing a number of parameters, among other things, such as CO_2 emission index, mercuric and chlorine compounds contents and slagging index, a tendency towards fouling the heating surfaces (fouling index), and energy ash ballast per heat unit (g/MJ), etc.

The basic components of fine-grained coal waste are mineral components (rated as ash), and coal substances (maceral), as well as water whose quantity fluctuates considerably depending on the technology of fine-grained coal waste separation, the method and time of its deposition, etc. The fine-grained coal waste energy-generating properties are determined, first of all, by the type and quantity of maceral.

A measure of maceral energy properties is a gross calorific value, dry ashless basic, Q_s^{daf}, which varies depending on the degree of maceral carbonification. Based on the performed analyses of coal properties these differences fit between 29 and 36 MJ/kg, for long flame and gas coking coals respectively – Table 1.

The properties of fine-grained coal waste materials result from their origins, processing and preparation methods of broken material (mined coal and rock impurities), and, in the event of their disposal, on the methods of their storing, whereas the quantity of maceral in fine-grained coal waste depends not only on the forms of their occurrence but most of all on the employed technology of broken coal material preparation. All of these factors are crucial in regard of considerable differences in their chemical and physical contents as well as their physical-chemical properties.

Tab. 1. Gross calorific value of coal, ashless and dry, depending on the type of coal

Tab. 1. Wartość opałowa węgla bezpopiołowego i suchego w zależności od rodzaju węgla

Type of coal		Gross calorific values of the analyzed coal, ashless and dry Q_s^{daf}, MJ/kg	
Code	Name	Minimum - Maximum	Average
31.1.	Long flame coal	24,0 – 31,1	29.1
31.2.	Long flame coal	31,1 – 34,2	32,5
32.1.	Gas-flame coal	30,4 – 34,5	33,0
32.2.	Gas-flame coal	31,3 -35,2	33,3
33.	Gas coal	33,1 – 37,3	35,2
34.2	Gas-coking coal	36,2 – 36,3	36,2

From the standpoint of power industry, the most important requirements formulated for fuels are, among other things, their gross calorific value, net calorific value and sulfur content as well as water (humidity) and ash contents. These relations are aptly illustrated by the interrelation between gross and net calorific values and ballast content, namely:

$$Q_i^r = Q_s^{daf} - \alpha\,(A^r + W_t^r) \qquad (1–10)$$

Q_i^r – net calorific value received basic, kJ/kg
Q_s^{daf} – gross calorific value received dry, ashless, basic, kJ/kg
A^r – ash content, dry basic %
W_t^r – total moisture content %
α – factor of proportionality for a given kind of fine-grained coal waste, kJ/kg/%

In the case of coal slurries, accumulated from production of long flame coals type 32.2., in a specific mine, these interrelations can be illustrated by the following equation:

$$Q_i^r = 32.108 - 358,11\,(A^r + W_t^r)\text{kJ/kg} \qquad (1\text{-}2)$$

A significant conformity of the above equation (1-2) with the actual measurements of net calorific values of coal slurries is illustrated in Figure 1.

The size of energy effects is determined by exothermic oxidation reactions of carbon, hydrogen, sulfur compounds or similar, less endothermic reactions combined with the destruction of high-carbon hydrocarbons and the like, contained in the maceral of fine-grained coal fractions. The basic chemical reactions determining exothermic processes are the following:

$$C + O_2 \rightarrow CO_2$$
$$(C_nH_m) + (n+ 0,5m)O_2 \rightarrow nCO_2 + 0,5mH_2O$$
$$2\,H_2 + O_2 \rightarrow 2H_2O$$
$$S + O_2 \rightarrow SO_2$$

These effects increase with the degree of maceral carbonification and its content in fuel.

Mineral components (ash) and water, contained in fine-grained coal fractions, influence the decrease of maceral calorific value. As the temperature increases, the mineral components, among other things, lose their water of crystallization; they undergo decomposition, sintering, melting and sublimation absorbing a part of energy generated by maceral combustion. If there are pyrite compounds present, the maceral combustion energy effects are improved due to the exothermic reaction of sulfur oxidation into SO_2. A significant element of endothermic processes and physical properties of mineral components is their specific heat of 0.899 kJ/kg deg, on average.

Humidity has also influence on the reduction of fine-grained coal fractions' calorific value due to the temperature increase and water evaporation. Specific and water evaporation heats are c_w = 4.18 kJ/kg.deg and q_{pw} = 2,260 kJ/kg respectively, which means that each kilogram of water contained in the fuel will absorb about 2,600 kJ/kg.

Physical and chemical characteristics of the sample fine-grained coal waste delivered to power plants and being the subject of this study are presented in Table 2. The influence of ballast content on the calorific value of fine-grained waste is particularly severe during the excavation and preparation of the broken material (mined coal and rock impurities).

Frequently, there arises an additional problem for the users of fine-grained coal waste stemming

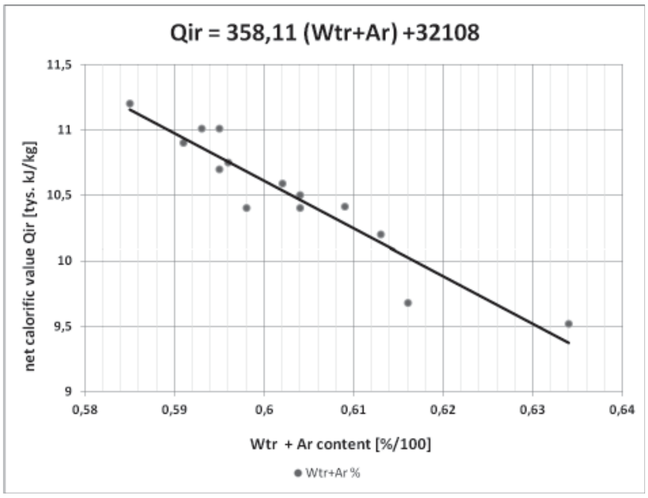


Fig. 1..Relation between coal sludge net calorific value and ballast content

Rys. 1. Relacja między wartością opałową odpadów węgla a zawartością balastu.

Tab. 2. Physical-chemical properties of the selected fine coal waste combusted in power plants

Tab. 2. Fizykochemiczne właściwości wybranych odpadów węgla spalonych w elektrowniach

Fine coal waste	Analytical conditions					Working conditions				
	W^a	A^a	Q_s^d	S_t^a	C^a	W_t^r	A^r	Q_t^r	S_t^r	C_t^r
1. Coal sludge										
1.1. Sil.	3,32	43,6	15.173	-	-	22,8	35,1	11.487	-	-
1.2. Jan.	2,53	57,3	10.756	2,36	27,67	42,6	33,7	5.327	1,39	16,30
	4,35	57,1	9.846	0,66	-	45,0	28,3	6.323	0,50	-
- from band filter	4,13	56,7	10.047	0,76	-	40,9	35,1	5.313	0,43	-
- from chamber presses	4,13	56,7	10.047	0,76	-	29,2	42,2	6.686	0,49	-
1.3. Sob.	4,07	52,5	12.422	0,746	32,20	28,3	39,3	8.211	0,56	24,10
	-	-	-	-	-	25,7	37,6	9.277	1,06	-
1.4. Chw.	-	-	-	-	-	32,0	36,8	9.550	1,01	-
1.5. Mys.	-	-	-	-	-	26,1	24,8	14.450	0,63	-
1.6. Dzi.	-	27,4	-	-	-	32,0	18,6	15.033	0,75	-
1.7. Kuzbas (Ru)	0,7	73,6	-	0,11	22,8	44,7	-	3.200	-	-
2. Floatation tailings										
2.1. Gli. p.29	-	-	-	-	-	25,8	38,6	10.350	1,40	-
p.30	-	-	-	-	-	23,7	24,4	16.540	-	-
2.2. Pst.	3,32	47,8	13.751	0,46	-	21,3	37,9	10.398	0,37	-
2.3. Wał.	-	-	-	-	-	21,3	37,3	8.522	0,6	-
2.4. Sediment	0,5	13,6	30.136	0,46	75,7	21,9	10,7	23.132	0,36	59,4
3. Coal sludge/floatation tailings combusted in power plants										
3.1. P Concern: annual balance sheet:										
- average value	-	-	-	-	-	-	-	7.702	-	-
- minimum value	-	-	-	-	-	21,3	37,9	6.347	0,42	-
- maximum value	-	-	-	-	-	31,5	41,1	11.393	0,63	
3.2. Fluidized-bed boilers (FB)	-	-	-	-	-	26,8	41,9	7.633	0,55	-
3.3. FB pulp, annual average	-	-	-	-	-	40,9	34,4	5.573	-	-
3.4. FB sludge granulated product	-	-	-	-	-	27,0	41,6	7.702	-	-
	5,15	42,0	14.738	0,68	39,2	28,8	31,5	9.891	0,68	29,5

Fig. 2. Appearance/consistence of coal sludge extracted from a settling pond

Rys. 2. Wygląd/zawartość odpadów węgla wydobytych ze stawów osadowych from semi-fluid, pasty consistence of the waste (see Figure 2), which can be hazardous due to its washing out, dusting and environment pollution as well as the difficulties with outdoor storing during periods of droughty, rainy or frosty weather, and while mixing with other fuels.

Based on the analysis of the fine-grained coal fractions' properties and contents it follows that the rationalization of their management, as a source of thermal energy, requires some interference in their contents which results in the increase of organic coal mass participation and, at the same time, the decrease of water content and/or ash content. The process solutions in coal mines and preparation plants put forward so far, do not guarantee a significant growth of energy value of the produced fine-grained coal waste which is understandable considering the fact that the treatment processes aim at maximum recovery of maceral from broken coal material (mined coal and rock impurities).

To achieve a significant growth of energy value of previous coal slurries, flotation tailings etc., new organizational and technological solutions should be called for; such an opinion can be supported by numerous, dispersed test results and sparse implementations.

These endeavors deserve notice as considerable amounts of coal waste deposited in settling ponds remain under the management of coal mining and local administration. Depending on the particular data source the quantity of deposited coal slurries and flotation tailings in Poland is assessed at almost 11 MM t [8], 16,5 MM t [9] an over 20 MM t [10]; this quantity should be increased by current production of about 5 MM t. Significant differences in the balances are caused by the adopted rules of counting in the shutdown slurry storing sites, many a time handed over for management to a local government.

The deposited fine-grained coal waste materials differ considerably as regards their calorific value and the participation of particular calorific groups, namely [10]:

- slurry of net calorific value > 15 MJ/kg constitutes 9,3%;
- slurry of net calorific value from 12 to 15 MJ/kg constitutes 6,8%
- slurry of net calorific value from 10 to 12 MJ/kg constitutes 22,3%
- slurry of net calorific value < 10 MJ/kg constitutes 61,5%.

This means that the slurry of calorific value below 10 MJ/kg constitutes the largest amount of the waste.

The presented material encompasses the analysis of test results and implementations as well as the study on the possibilities of quality improvement of fine-grained coal waste materials and the rationalization of their energy management.

Issues related to the lowering of water content in fine-grained coal waste

The fine-grained coal waste materials delivered to power plants differ considerably as regards their water contents; the extreme water contents fluctuate from 14 to 48%. Most often, the lowest water content is characteristic of sludge and floatation tailings extracted from settling ponds being emptied, undergoing a periodic seasoning in weather conditions, and, obviously, the specially dried slurry and floatation tailings.

The fine-grained coal waste materials are most often obtained from water-slurry management cycles by their thickening in radial clarifiers or/and lamella clarification thickeners, wherefrom the thickened suspension is directed to filtration units for further dewatering or/and to settling ponds.

Filtration installations

An analysis performed in a coal mine revealed that the content of water in filter cakes and their consistence depends to a large extent on the type of applied filtration units. The averaged annual results showed that the cakes obtained from band filters contained 40.9% of water whereas the filter cakes from chamber filter presses contained 29.2% of water – Figure 3.

The use of the band filters, in comparison with the chamber presses, increased the amount of the slurry for management by about 12% and decreased the energy of the slurry by 1,375 kJ/kg, on average.

The research on the selection of filtration units revealed, that the use of fully automated chamber-membrane presses with air blast, depending on the kind of coal/waste, brings about the fact that the cakes are very resistant to penetration and have lower water contents, even by 8 moisture units (the lowest registered water content in a filter cake amounts to 17%).

Fine-grained material addition to the feed material for filtration

The research and tests dealing with the influence of grained-material addition to the feed on the effects of slurry dewatering were conducted on fly and bottom ashes from coal combustion in pulverized-fuel fired and fluidized bed furnaces. The research of water-slurry suspensions (362 mg/l), dewatered in the industrial band filter revealed the following:

- a 4 to 26% ash addition to a water-slurry suspension with a flocculent, lowers a sludge cake water content by 18 to 34%;
- a 15 to 26% ash addition to a water-slurry suspension with half a dose of flocculent, lowers a sludge cake water content by 34 to 40%;
- a 15 to 33% ash addition to a water-slurry suspension without the flocculent lowers a sludge cake water content by 32 to 40%;
- the obtained dewatering of cakes, while using the ash, showed the possibility of resigning from the flocculent addition for dewatering water-slurry suspensions;
- the kind of ash used for this purpose does not show fundamental differences in the effects of coal slurry dewatering.

The influence of the ash addition to water-slurry suspensions on the degree of sludge cakes dewatering in the band filter is illustrated in Figure 4.

However, the tests performed on a model of the chamber press indicated, that the addition of ash to the suspension is more effective here than in the band filter. These observations reveal the possibility of a more effective dewatering of sludge cakes with a smaller addition of grained material.

The trials aimed at estimating the possibilities of not only lowering sludge cakes' water contents through addition of ash but also its influence on the consistency of the obtained cakes. The ash addition not only increases water patency within the body structure of the dewatered slurry but

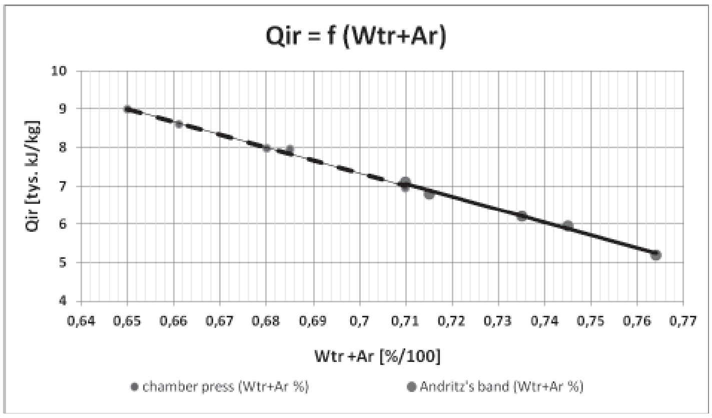


Fig. 3. Influence of filtration installation type on ballast content and coal sludge net calorific value

Rys. 3. Rodzaj instalacji filtrującej i jej wpływ na zawartość balastu oraz wartość opałową

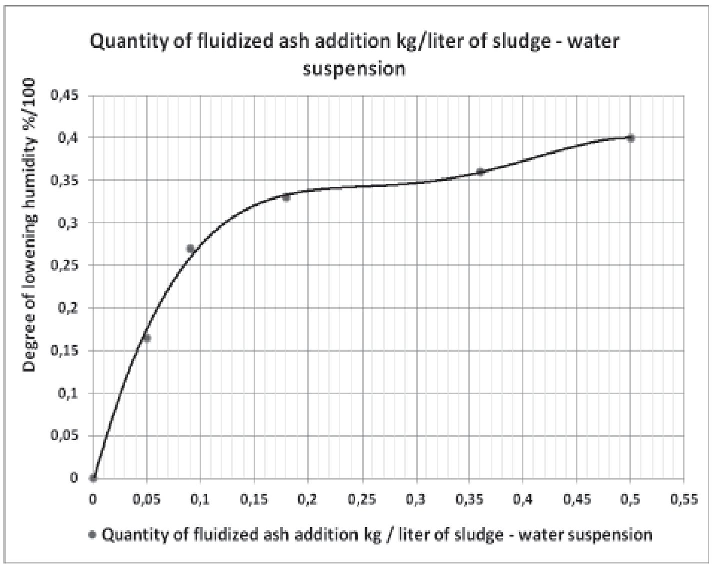


Fig. 4. Influence of fluidized ash addition on lowering coal sludge humidification

Rys. 4. Wpływ, jaki ma dodanie upłynnionego popiołu, na obniżenie zwilgotnienia odpadów węgla also changes the cake structure from pasty into thick-plastic, even solidified consistence.

These trials are of particular importance for the implementation of the technology for non-hazardous slurry deposition in the environment and the utilization of the slurry for land reclamation and revitalization of degraded areas as well as for shutting down municipal waste dumps [11, 12]. In the event of using fluidized ash for accelerating and making more effective the dewatering/filtration processes of water-slurry suspensions and also as an additive to the cakes from traditional processes, the obtained slurry with ash, with the passage of time, undergo natural petrifaction and become resistant to weather conditions no longer threatening to the environment [13].

The test results show also the possibility of controlling the properties of sludge cakes used as fuel through replacing the ash with the additive of coal concentrates (grain fraction over 0,05mm, received from slurry). Moreover, the suspensions containing the additive of calcium ashes (fluidized and of the calcium type), in the form of sludge, make a good raw material for their granulation or direct fluidized bed combustion [14].

Using surface-active agents

The tests performed on the coal slurry dewatering in centrifuges revealed an interesting phenomenon, namely: despite an intensive dewatering of coal grains there can be also observed the presence of some water drops on the surface of the coal grains characteristic of the behavior of water drops on hydrophobic surfaces. The water drops which have not been torn off due to centrifugal force, subjected to a side air blast, easily fall off

Tab. 3. Influence of bottom ash addition on the strength of granulated product, produced to counteract the self-heating of pyrite compounds contained in coal sludge

Tab. 3. Wpływ, jaki ma dodanie popiołu z dna, na moc granulowanego produktu stworzonego, by przeciwdziałać samonagrzewaniu związków pirytu zawartych w odpadzie węglowym

Composition of granulated product, %		Shock strength, quantity of destroyed granules, % after days of seasoning				Compression strength, N/granule After 3,7,14,28 days of seasoning				Compression strength after 28 days, MPa
Coal sludge	Fluidized bottom ash	0	1	2	28	3	7	14	28	
50	50	90	30	40	10	11,2	25,6	72,0	90,4	0,58
34	66	70	50	40	0	13,7	27,1	87,3	106,3	0,67
0	100	40	10	10	0	18,5	55,2	133,5	167,7	1,06

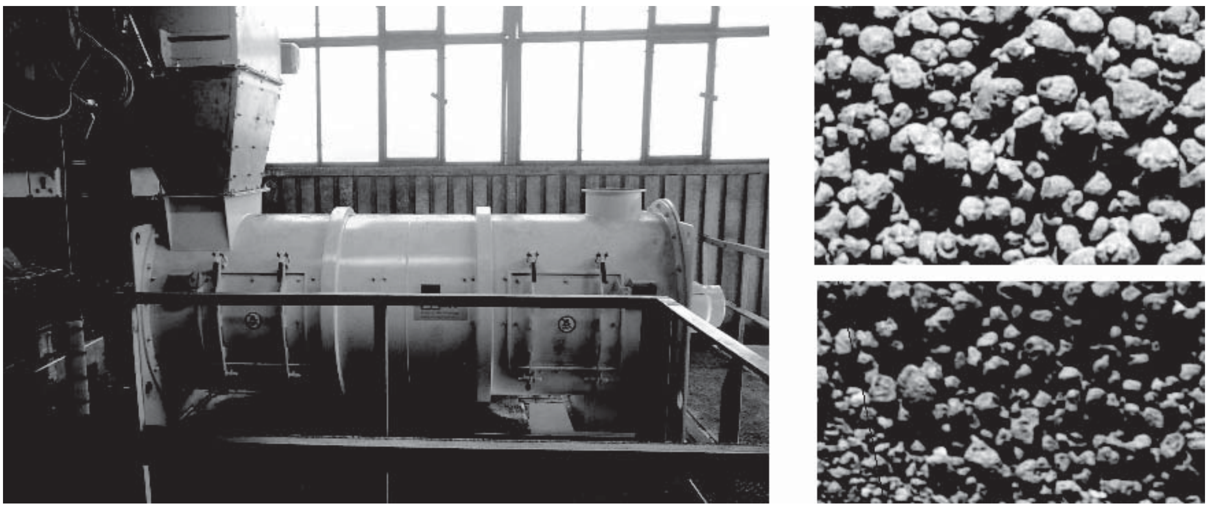


Fig. 5. Quick-performance mixer of WAH type for coal sludge granulation

Rys. 5. Szybko-wydajny mieszalnik typu WAH do granulatu osadu odpadów węglowych

Tab. 4. Comparison of coal sludge properties depending on the method of its preparation for combustion

Tab. 4. Porównanie własności osadów węglowych w zależności od sposobu przygotowania do spalania

Coal sludge combusted in fluidized-bed boilers	Analytical conditions					Working conditions				
	W^a	A^a	Q_s^d	S_t^a	C^a	W_t^r	A^r	Q_t^r	S_t^r	C_t^r
Jan.:										
- as delivered	3,22	56,71	11.129	0,60	29,08	27,5	42,5	7.311	0,45	21,8
- in the form of pulp	-	-	-	-	-	40,0	-	5.744	-	-
- in the form of granulated product						27,0	41,6	7.702	-	-
Sob.:										
- as delivered	4,07	52,54	12.422	0,76	32,20	28,3	39,3	8.211	0,56	24,1
- in the form of pulp	-	-	-	-	-	40.0	-	6.584	-	-
- in the form of granulated product	5,15	42,00	14.738	0,91	39,24	28,8	31,5	9.891	0,68	29,5
Sob. 5 % addition to steam coal	8,23	16,24	23.944	1,709	59,82	20,3	14,1	19.525	1,48	52,0

of the grain surface which means, that water/coal adhesion forces in the conditions under discussion are much stronger than the centrifugal forces in action. The easiness of their removing from the surface of grains by means of the air blast results from very low rolling friction forces of water drops. The above observations show the purposefulness of applying the air blast for coal dewatered in centrifuges to remove the remains of water, and using surface-active agents to reduce the difference of surface tensions on the boundary of coal/water phases.

In the event of dewatering low-silt slurries on a vibratory dewatering screen (in comparable conditions), the addition of 0.1 to 0.3% of a surface-active agent (fatty alcohols ethoxylate derivative), caused the decrease of water content in the sludge by the additional 15 to 20%. However, such a significant influence of the surface-active agent addition on highly silted slurries has not been noted.

Using elastic drainage bags

In recent years, the use of elastic drainage bags, made of water permeable material (known as Geotube, TenCate Geosynthetics etc.), is more and more popular for dewatering of coal slurry suspensions. The intensity of drainage increases with the participation of flocculants and subjecting the bags to additional pressure; that is one of the reasons why the elastic bags are placed in several layers, stacked upon one another. The filled elastic bags can be emptied and re-used or they can serve for shaping the degraded areas and hydro-technical structures.

Based on the described tests it follows, that while comparing the dewatering effectiveness of three different technical solutions, the highest density of water-slurry suspension was received in Geotube (85% of solid matter), next came filter belt press (65-70%), and the lowest density was obtained in deep cone thickener (48-50%) [15]. The costs for dewatering 180Mg/h during four and a half years, with the use of the above solutions, were the highest for Geotube (USD 47 MM), considerably lower for a filter band press (USD 20.3 MM), and the lowest for a cone thickener (USD16.8-19.5 MM). The data presented above can arouse objections as they do not cover the differences in quantity of the sludge for storage, and in the case of their utilization by power industry – the decrease of their calorific value due to higher water content.

The performed analyses show that the Geotube application is very useful for cleaning/emptying the settling ponds and sump galleries, not to mention the separation of coal concentrates. On the one hand, it will be possible to effectively dewater the suspensions and reduce their amount, and on the other hand, to put the elastic containers filled with thickened slurry to appropriate, planned use for the backfilling/insulating/isolating of mining excavations as well as for engineering operations related to shaping/strengthening of earthen structures [12].

The application of chemical dewatering agents – coal sludge granulation

The use of chemical agents for limiting water content in separated sludge is most often of practical significance when it is combined with obtaining of new, practical properties of the product, as, for example, the need of coal sludge solidification, neutralization of pyrite components in sludge, adaptation of sludge to its safe transportation and deposition [13].

In the way of appropriate use of coal slurries with characteristics accepted by the end-users (Q, A and S), stands usually their pasty consistence, high water content and vulnerability to transport and storage conditions. The granulation technology making use of active calcium compounds is an effective method of eliminating a number of the above mentioned disadvantages.

The reagents most often used for water binding in coal slurries are the following: quicklime (CaO), anhydrite/hemi hydrate gypsum ($CaSO_4/CaSO_4.0,5H_2O$), cement, fly and bottom ashes of the calcium and fluidized types, etc. A common feature of the reagents mentioned above is the presence of active calcium compounds (CaO and/or $CaSO_4/CaSO_4.0,5H_2O$).

A number of them reacts with the components present in coal slurry and the environment influencing significantly the granulation process, the properties of the received granulated product, and the process of its combustion, namely:

- Dewatering phase:

$CaO + H_2O = Ca(OH)_2$
$CaSO_4 + 2H_2O = CaSO_4.2H_2O$
$CaSO_4.0,5H_2O + 1,5\ H_2O = CaSO_4.2H_2O$

- Binding with water and aluminosilicates:

$Ca(OH)_2 + CO_2 = CaCO_3$
$CaSO_4 + 2H_2O = CaSO_4.2H_2O$
$CaSO_4.0,5H_2O + 1,5\ H_2O = CaSO_4.2H_2O$
$(SiO_2)_n.(Al2O3)_m + zCa(OH)_2 =$
$(SiO2)_n.(Al_2O_3)_m.(CaO)z + z\ H_2O$

- Desulfurization of combustion gas during granulated coal slurry combustion:

$Ca(OH)_2 + SO_2 = CaSO_3$
$CaCO_3 = CaO + CO_2$
$CaO + SO_2 = CaSO_3$
$CaSO_3 + 0,5\ O_2 = CaSO_4$

In this way, each mole of CaO (56 g), binds one mole of water (18 g), which indicates the possibility of binding water contained in the sludge in quantity adequate to the added CaO. Calcium sulfate binds water as well, for one mole (136 g) of anhydrous calcium sulfate there are two moles of water (36 g).

Dewatering reactions act at the same time as a binder for the created granules, whereas the produced calcium hydroxide, after "fulfilling the role of a binder" and undergoing the reaction of carbonization with carbon dioxide, creates calcite solidifying the internal granule structure. This is the reason why the process of their seasoning, which causes an increase in mechanical strength properties of the granules, is so important. A longer seasoning process of the sludge granulated in this way can also lead to pozzolanic reactions with aluminosilicates contained in ash which additionally harden the granulated material. The sludge granulated with binders containing CaO, during their combustion process induce a partial desulfurization of combustion gases.

The influence of the dose level of fluidized ash, containing free CaO and anhydrite, on the decrease of humidity in coal sludge granulated material corresponds to the one presented in figure 4., whereas the compression strength of the granulated material increases with the dose level of binders and, occasionally, their seasoning [13,14]. The influence of the fly ash additive on the strength of the granulated material, produced to counteract the self-heating of pyrite compounds contained in the coal sludge, is illustrated in Table 3.

The performed research and the determined conditions of use for the ash containing active calcium compounds instead of quicklime, became the basis for obtaining a patent [16]. Thereby, for coal sludge granulation there was confirmed the effectiveness of use of not only the typical calcium binders but also the fluidized ash and the ash type calcium.

On the ground of the conducted research and pilot-scale tests, there were prepared the technical and economic guidelines followed by the practical application of an industrial installation for the continuous granulation of coal sludge, falling out of filtration presses in the form of cakes [12, 14]. The commonly used plate-type and drum-type granulators were substituted with a rapid-action mixer – Figure 5 [17], to lower investment expenditures and operating costs. The granulated material with grain size from 2 to 8-16 mm, received in the installation, is added to the produced steam coal or delivered directly to the heat and power generating plants /power plants as a low-calorie granulated fuel. The achieved economic effects allowed the investment expenditures to be recovered during the first year of operation.

A particular economic importance is attached to the use of granulated coal sludge in fluidized

Tab. 5. Characteristic of sludge separated from water-sludge circuit flows at a coal cleaning plant
Tab. 5. Cechy odpadów oddzielonych od obiegu ścieków odpadowych w fabryce oczyszczalni węgla

L.p.	Solid phase separated from technological center flow	Net calorific value, kJ/kg		Gross calorific value, kJ/kg		Ash content, %		Fraction content >32 [63] 45*,µm
		Solid phase (sludge)	Fraction >32, 63],45*µm	Solid phase (sludge)	Fraction >32 [63] 45*µm	Solid phase (sludge)	Fraction >32, [63], 45*µm	
1.	Underground sump gallery	6.925	-	11.890	-	30,4	-	-
2.	Screening plant +/- 20 mm	13.787	21.033	16.516	22.000	50,0	31,5	48,5
3.	Magnetite recuperators	10.4546	17.448	11.005	18.275	55,8	35,3	35,6*
4.	Jig	14.238	18.407	15.053	19.355	58,0	33,5	63,1
5.	Dewatering centrifuge	18.480		19.174		31,0		[53,7]
6.	Spiral separator	2.525	22.118	-	23.191	74,5	15,0	[15]
7.	Radial thickener	11.903	17.492	12.498	18.341	52,8	34,1	39,6*
8.	Filtration press sludge cake	9.863	-	10.471	21.243	57,5	24,3	23,3*
8.	Sludge settling pond	7.000-21.000 12.465	- 21.315	9.000-25.000 13.136	- 22.315	9,5-70,0 48,0	- 17,9	- [31,8]

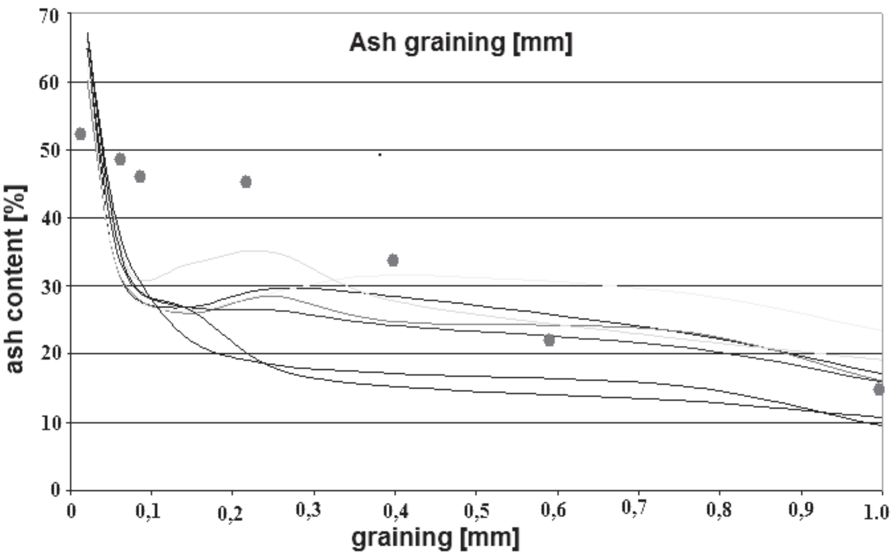


Fig. 6. Example of interrelations between ash content and grain size of coal sludge (lines) and floatation tailings (dots)
Rys. 6. Przykład korelacji między zawartością popiołu a rozmiarem ziarna odpadu węglowego (linie) oraz odpady flotacyjne

bed boilers. Currently, the boilers are equipped with an installation for water-slurry pulp generation, the pulp being injected to a fluidized bed. In this situation, the coal sludge cakes delivered from coal mines are hydrated and then changed to a pulp with an average water content of 40%. The obtained data records reveal that the combustion of granulated coal sludge, in comparison to pulp, brings about the increase of calorific value in the combusted slurries by about 2,000 kJ/kg and the decrease of their combustion costs – Table 4 [18].

Apart from the tests on granulation described above, there are used, albeit on a smaller scale, calcium, starch and lignosulfonate binders for briquetting coal sludge and flotation tailings [19, 20, 21].

Issues related to increasing the content of coal substance in fine-grained coal waste

The performed research work aimed at determining the possibilities and conditions of obtaining coal sludge with a higher maceral content within the existing range of water-sludge circulation systems in coal mines/processing plants. The current state of putting the fine coal waste in mining and power industries to appropriate use is based fundamentally on the acceptance of their poor quality. The operations performed so far had only a small influence on increasing energy effectiveness of their management.

Based on the conducted study and research work on the separation technologies for fine-grained raw materials and wastes aiming at the preparation of fine-grained coal waste, the following methods can be put to use [18, 22, 23]:

– selective separating coal-rich flows from water-sludge circuits;
– grain and densitometer classifications and the methods based on the differences of surface properties of their components;
– „deep" cleaning methods for fine mining waste;
– changes of previous storage methods of water-sludge suspensions in settling ponds.

The analyses of the obtained research and test results show high possibilities for implementing simple and effective methods for coal substance recovery and increasing economic effects for producers and users of fine coal waste.

Selective separation of fine coal waste from coal preparation plants' water-sludge circuit flows

Water-sludge management in coal mines can serve as an example of averaging various qualities and contents of flows from individual coal preparation plants' technological centers followed by dewatering of water-slurry suspensions which results in sludge with average properties and content. The analyses of solid phase contained in water-slurry circuits show a considerable differentiation of their contents and energy properties depending on the place of their being formed; and as it always happens to anything average, the good flows (coal-rich), are lost to usually useless, averaged sludge. The typical solutions for water-sludge management used so far call for economic and ecological verifications as well as a firm breaking away from tradition.

To assess the differences in contents and properties of the flows, there was examined the solid phase from suspensions separated at the following technological centers: underground water galleries, magnetite recuperators, sorting plants, jigs, radial thickeners, filtration presses, centrifuges, spiral separators and sludge settling ponds. The data in Table 5 illustrate the characteristics of sludge separated from the flows mentioned above.

The analysis of average results of examining solid phase separated from watercourses, for the mine under discussion, show the following differences in results (maximum – minimum):

- net calorific value – difference abt. 11 MJ/kg (dewatering centrifuge = 18,480; underground water gallery = 6,925 kJ/kg),
- gross calorific value – difference abt. 8 MJ/kg (dewatering centrifuge = 19,174; filtration press, mud cake = 11,471 kJ/kg),
- ash content – difference abt. 28% (jig = 58.0; underground water gallery = 30.4%),
- grain fraction content (of coal concentrate), difference abt. 40 (jig = 63.1; filtration press, sludge cake = 23.3%).

The above mentioned test results had been verified on the basis of water-sludge circuits in other coal mines. All these tests confirmed a significant differentiation in contents and properties of the solid phase segregated from individual flows. The differences applied only to the places of appearance of the richest and the poorest flows which results from the distinctness of coal properties and technological solutions for their preparation.

The illustrated differences in contents and properties of solid phase, segregated from flows of various energy coal technological centers are even more prominent in the event of floatation tailings. The replacement of thermal dryers with sediment filtration centrifuges for coal dewatering after floatation brought about significant economic effects but at the same time created a new problem regarding leakages from centrifuges. The separated flow creates foam abounding in very fine coal grains, difficult for sedimentation; this poses a number of problems with exploitation of water-slurry circuits in the coal mines. The separated mixture of sediment and floatation tailings was partially utilized as a component for coal briquette production [20]. In recent years, in one of the coal mines, there was put into operation a centrifuge leakage thickener and installation for the so called sediment separation in the form of filtration cakes [24]. The data in Table 2 illustrate the differences in contents and properties of filtration tailings and sediment.

The research performed on sediment shows that the leak generated at coal dewatering centrifuge after floatation, constitutes an unstable dispersion system prone to sedimentation under the influence of hydrophobic additions [25]. The segregated sediments were characterized by a gross calorific value over 30 MJ/kg and ash content below 8% and they can be added to floatation products or to the circulation of floatation feed material. Moreover, the suspension graining specifics and properties allowed using the sediment for making coal-water suspensions [26, 27].

Separation of coal-rich fractions from fine coal waste

Research on fine coal waste grain content reveals a certain regularity, namely, in coal slime there can be clearly distinguished grain fractions which are poor or rich in mineral components (marked as ash), illustrated in Figure 6. Most often the inflection point is marked by sludge graining on the level of 30 to 60 μm (micrometers). Grain fractions over inflection points include the lowest contents of ash, that is, they are characterized by higher caloricity – Table 5 and Figure 6. As for the floatation tailings, such a distinct interrelation between the ash content and their graining has not been observed.

Considering the fact that coal slime and floatation tailings are often stored together, one can speak about little defined deposit. In the event of storing fine coal waste water suspension mixtures in settling ponds they are subjected to gravitational segregation, adequately to their weight and grain contents.

The possibility and purposefulness of coal sludge grain classification has been confirmed for many years and by numerous centers, whereas their industrial implementation is very small indeed. Most frequently there are presented propositions for water-slurry suspensions in hydrocyclones and then on arch sieves or in spiral separators – Figure 7 [23, 28].

The choice of equipment for the research on grain classification is based on quality and quantity requirements for separating coal concentrates over 0.05 mm. From among many methods of coal slurry grain classification, the coal concentrate recovery trials were performed on the following units:

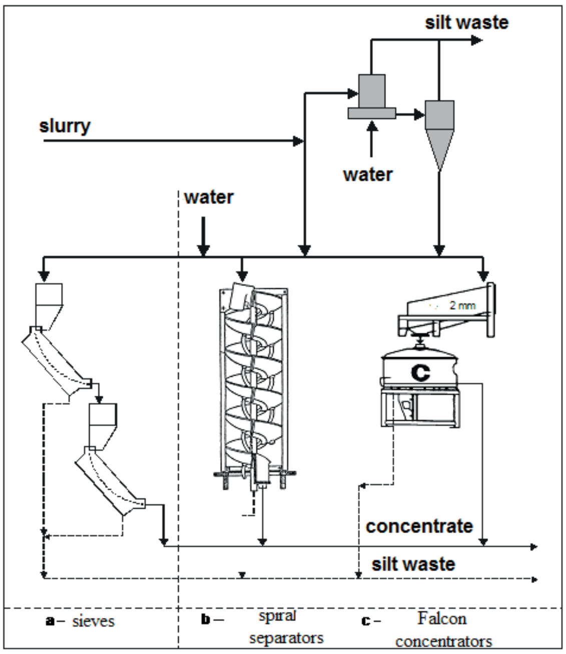


Fig. 7. Flow diagram/flow sheet for coal concentrates' separation from coal sludge and floatation tailings

Rys. 7. Schemat przepływu/arkusz przepływu separacji koncentratu węgla z odpadów węglowych i flotacyjnych

– screen unit type Stack Sizer of Derrick Corporation;
– arch sieves (VariSieve) designed by Progress Eco SA;
– quick-vibrating screens with textile filtration diaphragm.

Despite the satisfactory preparation results, no trials were made on the application of concentration tables (too much space required), hydrocyclones (advantages and disadvantages are generally known), or gravitation jig (TBS Teeter bed separator; hydrosizer), due to the requirements for strict observing process parameters. Flotation tailings were separated in high force centrifuge separators to assess not only the possibilities of coking coal concentrate separation but also for economic evaluation of such implementation.

Tests on Stack Sizer screen unit

The tests on preparation of coal slurries were performed courtesy of Derrick Corp., who rendered available the Stack Sizer screen unit with polyurethane screens with a limiting slot of 0.075 mm [29].

The performed tests revealed an effective method of classification and silt removal from a stream of segregated coal concentrate with graining over 0.075 mm – Table 6. Keeping the feed supply and concentration on the same level is very important for classification results; the failure to ensure these parameters caused the deterioration in the quality of concentrates (Table 6, tests 4 and 5).

Tests on arch sieves

The choice of arch sieves for coal slurry classification was motivated by their specific properties. The contact feeding of coal slurry suspension film upon the slotted sieve surface curvature causes the decrease of active slot size and the increase of centrifugal forces effect on the dewatering and division into heavier and lighter grains. In many cases, on the arch sieves, there can be also observed the phenomenon of coal grains floatation.

The interrelation between the sieve slot size “s” and the limiting diameter of the separated grains “dgr” is illustrated by the following equation (product):

$$d_{gr} = 0,5 \div 0,6 \;.\; s$$

Considering the fact that the borders between the coal fraction and silt fraction run near the limiting grain diameter averaging at 0.05 mm, this means that an arch sieve with 0.1 mm slots is most suitable.

In the beginning, the tests on the division of fine-grained coal suspensions were performed on 1mm slot sieves which corresponded to 0,5 mm limiting grain with no guarantee for full separation of coal concentrates. The coal concentrates separation was improved by using 0.35 and 0.1 mm slotted sieves. A partial compilation of test results regarding the division on arch sieves is illustrated in Table 7.

The tests on coal slurry separation on the 1 mm slot sieve did not ensure the quantitative separation of coal concentrate but they allowed separating a concentrate fraction with an average ash content of 26% from the waste containing 44% of ash, on average. During preparation of water-slurry suspensions there appeared serious problems with the loosening of sludge cakes’ structure. There were performed trials on forming homogeneous water- slurry suspension by way of transporting it by car with a rotary mixer drum used for carriage of ready-mixed concrete. Unfortunately, the 30 kilometer ride did not result in achieving homogeneous suspension. A part of sludge and water formed a water-sludge suspension but at the same time there appeared some large-diameter sludge lumps, similar to balls and requiring mechanical break-up.

A considerable problem regarding fine-grained coal waste filtration cakes was presented by their liquefaction and producing water suspensions with high grain dispergation. A serious obstacle in these cases are the flocculants contained in the structure of filtration cakes added to suspensions to accelerate the coagulation of solid components before their dewatering in filtration presses.

The suspension of sludge and floatation tailings was sampled before a radial sedimentation tank (Dorr), and prepared on the arch sieve with 0.35 mm slots, which resulted in obtaining coal concentrates with average ash content of 26.7% and silt fraction with average ash content of 43,5% from waste mixture with ash content of 38.0% on average – Table 7.

The results of the analysis of grain fraction content +/- 0,063 mm prove that the coal concentrate separation from waste mixture (sludge + floatation tailings), on the arch sieve with 0.35 mm slot, is incomplete. It turns out that the bottom (silt) products contained, on average, 28.3% grain fraction over 0.063 mm, which results from the difference of contents of the fractions under discussion in the feeding material as well as the 0.35 mm sieve slot, which corresponds to the limiting diameter of 0.175 mm of the separated grain.

Tab. 6. Results of coal sludge grain classification on a Derrick Stack Sizer sieve

Tab. 6. Wyniki klasyfikacji ziarna węgla odpadowego na sicie Derrick Stack Sizer'a

Test number	Name of sample	W^a, %	A^a, %	Q_i^a, kJ/kg	S^a, %	Test number	Name of sample	W^a, %	A^a, %	Q_i^a, kJ/kg	S^a, %
1	Feed	1,5	51,2	12.807	0,82	4	Feed	8,8	40,6	13.473	0,79
	Mesh pass	1,7	54,0	12.092	1,16		Mesh pass	7,3	47,9	14.758	0,82
	Mesh on	2,5	28,3	20.228	1,05		Mesh on	6,5	38,1	14.864	0,79
2	Feed	8,0	39,6	14.188	0,83	5	Feed	2,6	44,4	14.622	0,90
	Mesh on	7,2	6,7	25.934	0,75						
3	Feed	5,1	45,3	13.743	0,95		Mesh pass	3,2	28,4	19.931	0,76
	Mesh pass	2,3	52,4	12.271	0,90		Mesh on	6,7	27,0	20.143	0,78
	Mesh on	4,9	35,7	16.973	0,86						

Tab. 7. Results of coal sludge grain classification on an arch sieve

Tab. 7. Wyniki klasyfikacji ziarna węgla odpadowego na sicie łukowym

Pos.	Description	Thickening g/l	A^a, %	S^a_t, %	Grain fraction + 0,063 Content %	Grain fraction + 0,063 A^a, %	Grain fraction - 0,063 Content %	Grain fraction - 0,063 A^a, %
1.	Arch sieve with 1,0 mm slots							
	Feed material:							
	- average	-	33,3	-	-	-	-	-
	minimum-maximum	-	29-33	-	-	-	-	-
	Mesh-on product							
	- average	-	26	-	-	-	-	-
	minimum-maximum	-	22-30	-	-	-	-	-
	Mesh-pass product:							
	- average	-	44	-	-	-	-	-
	minimum-maximum	-	37-63	-	-	-	-	-
2.	Arch sieve with 0,35 mm slots							
	Feed material:							
	- average		38,0	1,08	35,9	19,0	64,1	54,3
	minimum-maximum	26-92	32,5-42	0,95-1,2	25,9-58,6	16,2-23,8	41,3-74,4	52,4-56,4
	Mesh-on product							
	- average		27,6	0,95	57,9	19,9	42,1	50,8
	minimum-maximum	46-220	19-35,1	0,94-0,98	26,2-83,0	15,3-25,5	16,9-73,8	47,5-52,8
	Mesh-pass product:							
	- average		43,5	1,07	28,3	20,9	71,7	54,3
	minimum-maximum	19-87	41,4-45,1	1,02-1,17	21,7-41,5	18,6-25,7	58,5-78,3	52,5-55,8
3.	Arch sieve with 0,1 mm slots							
	Feed material							
	- average	80-120	43,9	0,74	27,6	12,1	75,4	-
	minimum-maximum		39-48					
	Mesh-on product							
	- average		20,1	0,73	78,6	15,4	21,4	-
	minimum-maximum		16,8-26,1					
	Mesh-pass product							
	-average	-	55,7	0,74	8,8	16,8	91,2	-

In all of these tests the upper product (concentrate), could be characterized by lower ash and sulfur contents in comparison to the feeding material. A relatively high diversity of test results has been caused first of all by the fact that the tests were performed on an industrial installation at the time of rendering coal floatation installation operational and the problems with smooth distribution of feeding material on the arch sieve.

The most complete separation of coal concentrates from water-slurry suspensions has been achieved on a 0.1 mm slot arch sieve – Table 7. There were tested three water-slurry suspensions made of sludge cakes and varying in grain fraction content +0,063 mm, which resulted in obtaining coal concentrates with high gross calorific values (18.6; 20.3 and 24.1 MJ/kg), and considerably lowered ash contents (26.1; 20.1 and 16.8%).

All the tests with arch sieves were used for developing guidelines for an industrial installation. To intensify the process of coal concentrates quantitative separation and increase sieves' capacity (counted as m^3/m^2), the traditional arch sieves were substituted with centrifugal dewatering screens (the so called OSO screens), the more so, that the producer, Progress Eco SA company, mastered the production of wear-resistant and 0,1 mm slot sieves – Figure 8. This solution was also supported by the experience with industrial use of the OSO screens for separation of bottom ash from fly ash from their water suspensions (pulp) [30].

Tests on the sieves with fabric filter medium

To separate coal concentrates from fine coal waste suspensions there was used a solution, developed at the Silesian Institute of Technology in Gliwice, Poland, based on desliming fine coal wastes by means of their screening through quick-vibrating screen with a fabric filter diaphragm (e.g. BS screen) [31]. According to the authors of this solution, depending on the used diaphragm the output of the coal concentrate from the delivered coal sludge fluctuated between 6,9 and 11,6% for a single-stage screening process and between 7.01 to 19.24% for a double-stage screening process.

The obtained test results were verified on the industrial installation at a coal mine. For that purpose, 28 tons of coal sludge were hydrated and, as a suspension with a density of 427 g/l, fed to hydrocyclones. From the hydrocyclones there was collected a silt suspension in the form of overflow and the outflow, constituting the feeding material for a BS screen in the quantity of 70 tons and a density of 627.9 g/l.

As a result of desliming on the BS screen there was collected a bleeding (silt suspension in water), in the quantity of 40 tons with a density of 212.2 g/l and 30 tons of a product containing 20 tons of concentrate and 10 tons of water. The trials to obtain a smooth spreading of the feed material upon the screen and de-silting of the material on the entire screen surface proved unsuccessful. A small quantity of the testing material made it impossible to optimize the process (spreading on the screen, the angle of the screen and vibrations, etc.). The analysis of the obtained results shows that the ash content in the tested sludge dropped from 43.9% to 20.1%, on the average (16.8 to 26.1%), as a result of sludge de-silting and at the same time there was an increase of concentrate calorific value up to 16,575 (15,033 to 18,009) kJ/kg, on the average.

The performed tests show the following:

- suitability of the installation with hydrocyclones and a BS screen for de-silting of low-calorie coal sludge suspensions;
- possibility of limiting coal loss in overflow and further decreasing concentrate ash content through optimization of de-silting process;
- effective increase of sludge energy properties through decreasing ash content even by 39% and increasing calorific value even by about 6,000kJ/kg.

Based on the performed tests and gathered work experience there were developed guidelines for building an installation for coal concentrate recovery from slime extracted from a lake where floatation tailings and slime from near-by coal mines had been accumulated for years.

The constructed installation with a capacity of 250 m^3/h was further extended due to a high sludge contamination and the need to achieve concentration stability of the feed material. Additionally, there were built grids and a twin-shaft mixer to ensure the homogeneity of the feed material. The working results of the installation allowed to lower the ash content from about 33% to about 22% and brought about the increase of net calorific value from 15.0 to 18.0 MJ/kg.

"Deep" cleaning methods of fine coal waste

Among many methods of "deep" fine coal waste cleaning the following was analyzed: floatation process, oil agglomeration, high acceleration gradient centrifuges and the technology for chemical coal desulfurization and demineralization.

Fine-grained coal waste floatation

Fine coal waste floatation was implemented in Poland on the basis of an imported technology and equipment in 1994. The decision on the building of a preparation plant was preceded by a thorough research of waste deposits in settling ponds and on dumping grounds. The size of the plant and its location resulted from the knowledge of material resources; the plant was built in the vicinity of a coal mine which accumulated considerable amount of post-floatation waste, rich in coal substance [32, 33]. The floatation cleaning plant operated until 2012, that is, till its economic material resources had been depleted. Some time earlier, a model floatation slime preparation plant, operating in Germany (Linen), could not stand up to competition and, consequently, was closed.

The ongoing research into the improvement of floatation technology and qualitative-quantitative inventory of fine coal waste resources do not justify any new investment projects in this area. The quality of post-floatation waste was undergoing considerable changes with dissemination and improvement of floatation processes which, in practical terms, meant that already in the eighties of the last century most of the produced waste was of little interest as a material for a secondary floatation.

Oil agglomeration

The interest in coal recovery from floatation tailings developed due to several reasons: on the one hand, the difficulties with acquiring the land for settling ponds' construction with growing quantity of waste and on the other hand, the intension to recover a high quality coking coal. Moreover, at that time, there were being developed coal-water fuel production technologies with a serious problem of coal micronization costs whereas in the case of floatation tailings the coal grain was very fine and of high quality.

In cooperation with OTISCA, an American company, there were performed tests on coal concentrates separation from three selected floatation tailing samples with the use of oil agglomeration technology. The waste samples were ground up to the grain size below 5 μm and then agglomerated with heptane. There were received coal concentrates with ash contents in the range of 2.51 to 3.69% (the waste before the process contained 47.8 to 69.8% of ash), coal contents of 74.4 to 75.5% (before 13.2-36.4%), and gross calorific value approximately 35 MJ/kg. From grain fraction of +100 Mesh (+150 μm), including 48.4% coal before obtaining finer grain, there were received coal concentrates with ash contents in the range of 61 to 63% [33, 34].

Unfortunately, the research results on sludge preparation from low carbonization coal in the oil agglomeration process were not satisfactory; perhaps the maceral structure is to a high degree hydrophilic (typical to young coals).

Coal recovery in the high acceleration gradient centrifuges

In specialized literature there are known examples of precious metals' recovery from the waste solids of ferrous and non-ferrous metal ores through their separation in the high acceleration gradient centrifuges. For the separation, there is used the acceleration exceeding gravity by 250 to 300 g.

Based on this information, the Falcon Company was ordered to make a suitability assessment for the centrifuges user for separating coal from floatation tailings [35]. The tests performed in an industrial centrifuge C-4000W resulted in the following conclusions:

– concentrate +150 μm, coal recovery ranged from 39.3 to 74.8% - on the average 65.9%;the

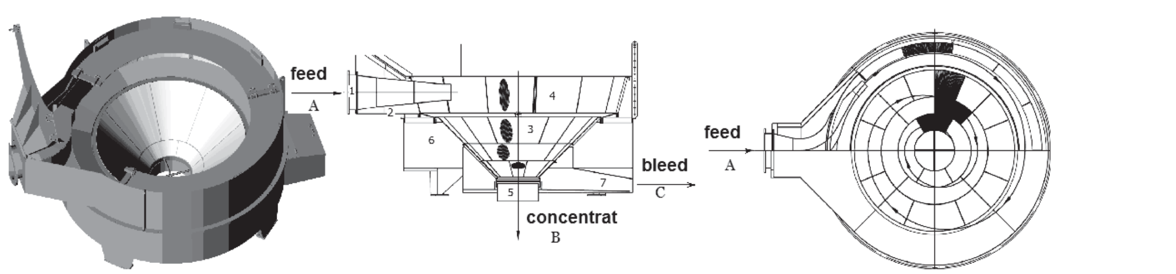


Fig. 8. OSO – centrifugal dewatering sieve

Rys. 8. OSO – odśrodkowy przesiewacz odwadniający

A – feed material; B – concentrate; C – bleed; 1 – feeding nozzle; 2 –guide ring body; 3 - tapered slotted sieve; 4 –guide ring; 5 –dewatered product outlet; 6 –bleed collecting tank; 7 – bleed outlet

A – materiał zasilający; B – koncentrat; C – spust; 1 – dysza nadawcza; 2 – obudowa kierownicy; 3 – sito szczelinowe stożkowe; 4 – kierownica; 5 – wylot produktu odwodnionego; 6 – wanna zbiorcza odsączu; 7 – wylot odsączu degree of pyritic sulfur removal ranged from 76.8 to 91.2% -on the average 85.5%;

– concentrate 40-150 µm, coal recovery ranged from 80,4 to 94,0% - on the average 87,6%; degree of pyritic sulfur removal ranged from 52,9 do 79,7% - on the average 66,6%.

For the conditions of the tested post-floatation waste, the Falcon company suggested pre-desliming of the suspension in hydrocyclones and screening the grain fraction +0.2 mm – Figure 7.

Technologies for chemical coal desulfurization and demineralization

The fullest coal desulfurization and ash removal can be guaranteed only by chemical processes belonging to most expensive methods of coal processing. Among many a described method, the one best qualified for implementation proved to be the Gravimelt technology, designed by TRW, an American concern [36].

The method involves melting the pulverized coal (coal waste), with sodium or potassium hydroxide. The process takes place in the temperature of 280 to 420°C and the inert gas atmosphere. The post-reaction product, after washing with water, neutralization with acid solution and re-washing with water, becomes a coal concentrate.

By the agreement of the Parties concerned, there were performed the trials on chemical cleaning of waste with the highest content of sulfur and ash delivered from two coal mines. From the waste with ash and sulfur contents of 70 and 5.75% respectively, there were obtained concentrates containing 2.5 to 3.7% ash and 0.48 to 0.50% sulfur and with a gross calorific value of about 35 MJ/kg (before 8.9 MJ/kg). The obtained coal concentrates could be characterized by a well developed specific surface area and ion-exchange properties [37, 42]. High ash content and a small degree of coal substance metamorphosis guarantee the production of active coal with a high sorption capacity.

The technology under discussion is justified for coal and coal slimes in the case of interest in active coal deliveries and the recovery of rare metals from chemical extraction by-products of the cleaned coals.

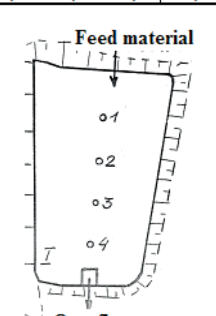
Issues related to the utilization of fine grained coal waste in and from settling ponds

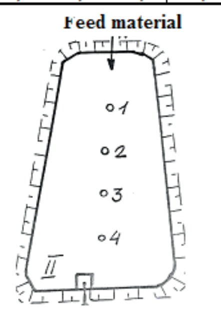
A significant amount of currently burnt coal sludge and floatation tailings comes from shut down settling ponds. Depending on the way of settling water-slurry suspensions and the time of their gravity drainage as well as the method of breaking and storing of deposits, the fine coal wastes can differ considerably not only as regards their nature (type of coal, preparation technology), but also their segregation index and hydration.

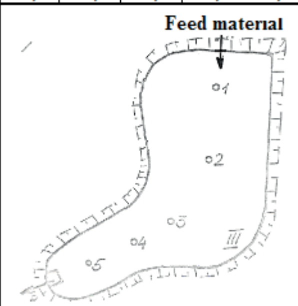
The research on fine coal waste deposits in 14 settling ponds and on one overlevel cone-shaped dump provided a rich pool of information on the

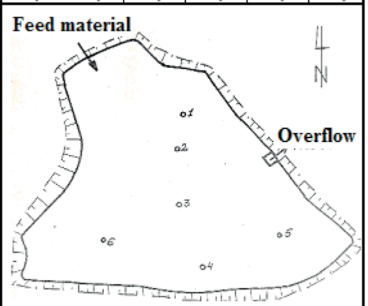
Sampling depth m	Ash content, %																		
	Settling pond I Sample no				Settling pond II Sample no				Settling pond III Sample no					Settling pond IV Sample no					
	01	02	03	04	01	02	03	04	01	02	03	04	05	01	02	03	04	05	06
1	45,6	41,8	25,6	34,0	42,7	22,4	29,8	30,3	28,5	29,0	33,2	46,3	43,6	37,8	38,0	17,2	38,6	41,4	38,7
2	59,9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37,2	-	-	-
3	-	24,3	17,3	22,4	57,5	42,1	37,5	36,3	29,4	32,6	41,9	28,9	37,4	28,8	40,5	38,1	46,0	31,6	38,7
4	63,9	-	-	-	-	-	46,0	-	39,9	-	-	-	-	-	-	40,0	-	37,8	-
5	-	18,2	-	17,6	32,3	37,6	-	42,5	-	-	-	45,4	41,7	30,1	36,8	16,8	-	42,2	-
6	23,5	-	25,3	-	31,4	40,2	41,8	29,3	-	-	-	-	-	43,4	35,9	-	-	-	-
7	13,3	32,7	-	40,6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average	41,2	29,2	22,7	28,6	41,0	35,6	38,8	34,6	32,6	30,8	37,5	40,2	40,9	35,0	37,8	29,9	42,3	38,2	38,7

Settling pond









Tab. 8. Ash content in coal sludge sampled from sludge settling ponds

Tab. 8. Zawartość popiołu w odpadzie węglowym pobranym ze stawów osadowych composition and properties of the deposited material. The flotation tailings' deposits in the settling ponds reveal a lower variability of composition and properties, which points towards deposit uniformity. In the case of coal sludge deposits, they are not uniform as regards their composition and physical-chemical properties.

The storage and dewatering processes of water-sludge suspensions in settling ponds are related to the solid phase sedimentation processes on the way of suspension flow from a dumping point to the point of excess water drainage (overflow well), concurrent with suspension water clarification. Depending on the construction of a settling pond its size and its flows, the deposited sludge suspensions are subjected to weight segregation creating a heterogeneous deposit which often changes as the pond is filling up; this can be illustrated by the example of deposit ash content variability in four settling ponds – Table 8.

The analysis of suspension sedimentation phenomena in systematic hydraulic systems indicates that significant solid phase segregation can be achieved by appropriate flow control. In this respect, there were achieved very good results in power stations due to trim (along the embankment), alternating discharge of slag-ash suspensions; in this way the existing embankments were fortified and there was accumulated material used for their upward extension and for hydrotechnical construction works [38]. In the case of the analyzed dumping grounds there can be observed a natural phenomenon of suspension flow by the shortest way, changing according to the degree of filling of a settling pond which does not mean that the conditions of sludge sedimentation and supernatant water cleaning are optimum.

By adequate shaping the discharges of water-sludge suspensions to settling ponds and forcing specified flows in settling ponds there can be obtained a selective sludge segregation and appropriate conditions for „coal concentrate deposit" formation as well as top purity discharge water.

Considerable amounts of fine coal waste accumulated in settling ponds encourage their management and preparation for securing coal concentrates production. Such activities in the coal mines are often hampered by the excess of domestic coal on the energy market and the additionally imported coal successfully competing with domestic fuel as well as relatively liberal soil protection requirements allowing for waste dumps exploitation.

One of the drawn up technical-economical projects is the documentation for the installation of coal concentrate separation from fine coal waste water suspensions [39].

The recovery process involves the following technological centers:

1. Extracting the deposit from settling ponds and its transportation;
2. Preparing sludge suspensions in water at a specified concentration;
3. Coal concentrates' separation;
4. Coal concentrates' dewatering and storage;
5. Silt waste management;

A schematic linking of particular technological centers can be found in Figure 9.

In the case of flooded settling ponds it is best to use deposit hydraulic winning with a water jet and pumping unit, pumping the pulp to the suspension preparation center. The settling ponds with dewatered or solidified deposits require mechanical breaking followed by loosening of their structure and preparing water-sludge suspension in a slurrying drum or a rotary mixer.

The prepared suspension with a required solid phase content is subjected to primary de-silting in hydrocyclones followed by grain classification on a centrifugal dewatering sieve (OSO sieve), or on arch sieves or in spiral separators. There was also analyzed the use of Falcon centrifuges (very expensive). For the dewatering of the obtained concentrate there were considered dewatering sieves or a dewatering centrifuge with a basket with 0.05 mm slots. The dewatered coal concentrates need to be stored in closed or half-closed storage facilities.

All silt flows are being joined and, depending on local conditions, are subjected to thickening in settling ponds or in water-silt installations, or they are used for making mixtures (pulp), for mining excavations insulation.

The mine under analysis, with four neighboring settling ponds constituting the area of 20 hectares and volume of approximately 2.2 million m^3, deposited about 1.7 Mt of sludge and floatation tailings mixture. The quantity of coal concentrates to be recovered, at 85% work out of settling ponds, depends on the used classification devices and the assumed grain boundary, namely:

– 300 thousand ton coal concentrate containing 7.6% ash, with grain of +0.125 mm;
– 530 thousand ton coal concentrate containing 11.2% ash, with grain of +0.045 mm.

For a four-year work-out of the installation, eight months per year, the time of investment expenditure recovery was settled at 1.78 years.

In recent years however, there can be noted some progress as regards the use and cleaning of

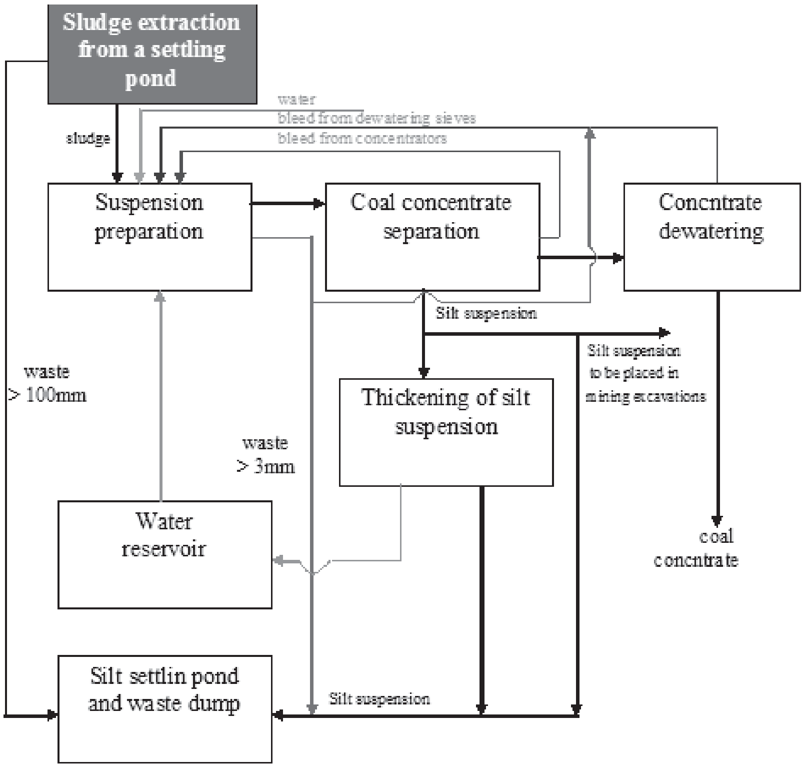


Fig. 9. Schematic diagram of relations between technological centers for coal concentrates' recovery from sludge accumulated in ground settling ponds

Rys. 9. Schematyczny diagram relacji między ośrodkami technologicznymi odzysku węgla z odpadów nagromadzonych w stawach osadowych

fine-grained coal waste from the shut-down sludge and flotation tailings settling ponds. The Eco Carbo-Julia Sp. company rendered operational a coal waste recycling unit, producing granular fuel for fluidized-bed boilers [40] and coal concentrate separated in a hydro-cyclone installation [41], intended for the power industry and also as a recyclable material component for floatation.

Summary

The research and testing conducted so far on the application of fine coal waste as a basic and additional fuel in power boilers and furnaces suggest the possibility and purposefulness of improving their quality as well as the chance to increase economic and ecological effects by their producers and end-users.

Energy properties of fine-grained coal waste as a fuel result from the contents and quality of the occurring coal maceral, deciding about their energy-generating properties. The presence of water and mineral components in fuel lowers the thermal effect as the thermal energy is absorbed in the wide temperature range into specific heat and the heat of vaporization. The simplest way to increase the calorific value of fine coal waste (coal sludge, floatation tailings), is to lower their water content (humidity) and/or ash content.

In the case of fine coal waste materials from current production, their humidity is considerably influenced by the used dewatering installations for water-sludge suspensions from radial and lamella thickeners. In the practice of our mining industry, filtration presses proved more effective than band and plate filters. The degree of hydration of coal sludge and floatation tailings recovered from the shut-down settling ponds depends on the degree of their gravitational dewatering (time of deposition and settling pond construction), and the method of winning and storing of the excavated material (aeration, atmospheric drying). That is why the water content range of the fine coal waste, finding its way to the power stations, is very wide, from 14 to 45%.

A significant improvement of fine coal waste quality has been achieved through the implementation of their granulation, especially with the use of a quicklime binder. The obtained granulated product is resistant to transport and storage conditions, it does not degrade in changing weather conditions and has better energy properties due to lower water content as well as the content of active calcium compounds, binding sulfur oxides during their combustion process. The granulated sludge can be used as an independent fuel and as a component of fuel mixtures made in mines, by wholesalers (in wholesale stores), and by the users of such fuels.

Particularly interesting economic effects can be obtained by substituting sludge-water pulp with sludge granulated product. In the case of the fluidized bed under analysis, there was achieved a unitary increase of combusted fuel net calorific value by approximately 2,000 kJ/kg. Moreover, the method of feeding the granulated product to the fluidized bed is much simpler and less energy-consuming.

The essential quality improvement of fine coal waste can be obtained first of all by lowering their mineral components' content. The simplest solution is a selective separation of flows that are richest in coal from water-sludge circuit; as for the storage yards, it is a selective deposit mining.

The richest coal concentrates from coal sludge, current production, and storage yards, are obtained by means of wet production technologies through grain classification and separating a grain fraction over 30-60 µm. In the events of applying dewatering vibration sieves with fabric filtration diaphragms as well as arch sieves and centrifugal dewatering sieves with properly selected slots, there were obtained the richest coal concentrates with net calorific values in the range of 16 to 22 MJ/kg. To increase the effectiveness of grain fractioning process on the sieves, the water-sludge suspension is de-silted and thickened in hydrocyclones before the process.

In the deposition methods of water-sludge suspensions in settling ponds used so far, the possibility of gravitational enrichment of water-sludge suspensions with coal grains have not been used. Through water-sludge suspensions' flow channeling in settling ponds, there can be obtained rich and very rich-in-coal deposit areas as well as more effective deposit water cleaning.

Flotation tailings' cleaning calls for different methods of coal concentrates' separation from mineral fraction than described, by way of example, for cleaning coal sludge. In this case, most methods are based on specific gravity differences of coal grains and mineral components and their differences in surface properties of particular grains contained in fine coal waste. Most often, the cleaning installations are constructed for processing floatation tailings from storage yards and partly from current production by using hydrocyclones, heavy liquid, and floatation process technologies. These technologies make it possible to obtain the richest coal concentrates.

Based on the conducted analysis of properties, composition and conditions of generating fine coal waste it is evident that fine-grained fractions rich in coal can be separated by means of specific, simple changes in technological flow charts used so far. By using simple methods of grain and densimetric classification, there can be cleaned and separated high calorific value fine-grained coal concentrates. Channeling water-sludge suspension flows in settling ponds can lead to zoning of ash-poorest fine-grained waste which means the location of the richest coal concentrates.

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Literatura - References

1. *Hycnar J.J.: Technologie przetwarzania odpadów kompleksu paliwowo-energetycznego. Inżynieria Mineralna 2002. Zeszyt Specjalny nr 1.*
2. *Alwaeli M., Czech Ł.: Możliwości gospodarczego wykorzystania odpadów poflotacyjnych. Archiwum Gospodarki Odpadami i Ochrony Środowiska 2009, vol. 11, nr 3.*
3. *Girczys J.: Odpadowe muły węglowe. Prace Naukowe GIG. No 815. Katowice 1996.*
4. *Yilmaz E.: Advances in reducing large volumes of environmentally harmful mine waste rocks and tailings. Gospodarka Surowcami Mineralnymi 2011. T. 27, z. 2.*
5. *Gibrat R., Chenin F.: The Transport, Preparation and Utilization of Colliery Tailings At the Emile Huchet Power Station. Paper No 1630. Digests of a paper published in August, 1954, in Part II of the Proceedings.*
6. *Fluidized bed boiler Beringen – Unit 2. CMI. Seraing Belgique 1997.*
7. *Hycnar J.J.: Paleniska fluidalne przykładem racjonalnego rozwiązywania problemów odpadów. Polityka Energetyczna 2006, Zeszyt Specjalny, t. 9 Pl ISSN 1429-6675 .*
8. *Grudziński Z.: Analiza porównawcza jakości mułow węgla kamiennego pochodzących z bieżącej produkcji i zdeponowanych w osadnikach ziemnych. VII Konferencja „Kompleksowe i szczegółowe problemy inżynierii środowiska" Koszalin – Ustronie Morskie 2005.*
9. *Sobko W., Baic I., Blaschke W.: Depozyty mułów węglowych – inwentaryzacja i identyfikacja ilościowa. Rocznik Ochrony Środowiska. 2011, t. 13, cz. 2, p. 1405–1415.*
10. *Hycnar J.: Aktualizacja bilansu jakościowego i ilościowego wybranych mułów węglowych. Ecocoal CC – Haldex. Katowice 2003.*
11. *Halat Z., Hycnar J.J.: Properties and utilization of drilling waste. 21 World Miting Congress & Expo 2008. Krakow. Poland.*
12. *Wróbel J., Fraś A., Przystaś R., Hycnar J.J., Tora B.: By-Products of Enrichment of Coal as a Source of Fuels And Aggregates. XVII International Coal Preparation Congress 1-6 October 2013. Istambul, Turkey.*
13. *Hycnar J.J.: Czynniki wpływające na właściwości fizykochemiczne i użytkowe stałych produktów spalania paliw w paleniskach fluidalnych. Wyd. Górnicze. Katowice 2006.*
14. *Szymkiewicz A., Hycnar J.J., Fraś A., Przystaś R., Józefiak T., Baic I., (2012): Application of fluidized bed combustion ashes for enhancement of mining waste management. Proceedings of the IV International Scientific and Practical Workshop Ashes from TPPS. April 19-20, Moscow.*
15. *P.389379. Patent z dnia 26.10.2009r. Szymkiewicz A, Fraś A., Borowski M., Jagiełło Z., Przystaś R., Hycnar J.J., Józefiak T.M., Szczygielski T.: Sposób otrzymywania stałej mieszanki paliwowej.*
16. *Murphy Ch., Benett Ch., Klinger G., Cousns B.: Alternatives to Coal Mine Tailing Impoundment – Evaluation of Three Dewatering Metods at Rockspring Coal Mine. Society for Miting, Metallurgy and Exploration. Seattle, Washington February 2012.*
17. *P.396624. Zgłoszenie patentowe z dnia 13.10.2011r. Szymkiewicz A., Fraś A., Przystaś R., Hycnar J.J., Józefiak T.M.., Baic I.: „Sposób otrzymywania granulatu opałowego z wykorzystaniem odpadów powydobywczych".*
18. *Hycnar J.J., Fraś A., Przystaś R, Foltyn R., (2013): Stan i perspektywy podwyższenia jakości mułów węglowych dla energetyki. XXVII Konferencja „Zagadnienia surowców energetycznych i energii w gospodarce krajowej". Zakopane, 13–16.10.2013.*
19. *Hycnar J.J., Józefiak T.: Brykietowanie odpadów drobnoziarnistych. VIII Śląskie Seminarium Ochrony Środowiska. Bytom 01.06.2007.*

20. Borkowski G., Hycnar J.J.: *Utilization of Fine Coal Waste as a Fuel Briquettes. International Journal of Coal Preparation and Utilization, 33; p. 194–204, 2013.*
21. Giemza H., Gruszka G., Hycnar J.J., Józefiak T., Kiermaszek K.: *Technologie odzysku drobnoziarnistych materiałów i odpadów węglowych na potrzeby produkcji paliw i energetyki. XXIII Konferencja z cyklu: Zagadnienia Surowców Energetycznych i Energii w Gospodarce Krajowej "Dylematy polskiej polityki energetycznej" Zakopane 11–14 październik 2009.*
22. Hycnar J.J., Foltyn R., Olkuski T., Blaschke A.S., (2005): *Kierunki energetycznego wykorzystania drobnoziarnistych odpadów z wydobycia i wzbogacania węgla kamiennego. VII Konferencja Naukowa „Kompleksowe i szczegółowe problemy inżynierii środowiska" Koszalin – Ustronie Morskie 2005.*
23. Lutyński A., Lutyński A., Szpyrka J.: *Badania podatności na wzbogacania mułów węglowych zdeponowanych w osadnikach ziemnych. Czasopismo Techniczne, nr 150–153. 2012.*
24. Kot J.: *Doświadczenia z użytkowania „instalacji odzysku części z zawiesiny wodno-mułowej zawierającej ziarna o wymiarach wyłącznie <25 μm" w KWK „Jas-Mos". Szkoła Eksploatacji Podziemnej. Kraków 20–24 lutego 2012.*
25. Hycnar J.J.: *Technologia zagospodarowania odcieku z wirówek odwadniających flotokoncentrat. Ecocoal CC. Katowice 2008.*
26. P. 402768. *Sposób otrzymywania suspensji węglowo-wodnej. Zgłoszenia w UP 2013*
27. Michalik A., A Hycnar J.J., Kula H., Fraś A., Sikora L.: *Zakres i warunki stosowania suspensji węglowo-wodnych. XXVII Konferencja „Zagadnienia surowców energetycznych i energii w gospodarce krajowej". Zakopane, 13–16.10.2013.*
28. Hycnar J., Bugajczyk M.: *Kierunki racjonalnego zagospodarowania drobnoziar¬nistych odpadów węglowych. Polityka Energetyczna t. 7, Zeszyt Specjalny, 2004.*
29. Rolnik R.: *Zastosowanie wysoko wydajnych przesiewaczy w technologii klasyfikacji oraz wzbogacaniu ziare drobnych i bardzo drobnych. Maszyny Górnicze 2009, nr 2.*
30. Hycnar J., Pasiowiec P., Brożyna J.: *Segregation, classification and dewatering of fly ash and bottom ash. Proceedings of the III International Scientific and Practical Workshop ASHES FROM TPPS. April 22-23, 2010 Moscow, Russia.*
31. Białas M., Białas J., Lutyński A., Kasztan A., Narloch G.: *Wydzielanie ziaren węglowych z zawiesin odpadowych. Gospodarka Surowcami Mineralnymi, t. 17, Z. Spec. 2001.*
32. Hölter H., Weber A.:*Modern Ecological Techniques in the Coal Preparation. 12th International Coal Preparation Congress. May 23-27, 1994, Cracow Poland.*
33. Meyer R.A. a th.: *Gravimelt Process for Coal Desulfurization and Demineralization IEA. 2nd International Conference on the Clean Coal and Efficient Use of Coal and Lignite. Its Role in Energy, Enviornment and Life. Hong Kong. December 3, 1993.*
34. Hycnar J., Pinko L., Dziwok M.: *Wzrost cen energii elektrycznej powodowany kosztem ochrony środowiska. Karbo-Energochemia-Ekologia 1998, nr 8.*
35. Keller D.V.: *A preliminary rapport on the application of the Otisca T-process. Otisca Industries Ltd. USA.Siracusi. 1991.*
36. Hycnar J.: *Zastosowanie wirówek do separacji minerałów. Inżynieria Mineralna. 2002, Zeszyt Specjalny nr 1.*
37. Hycnar J.J, Mokrzycki E. i in.: *Technologie czystego węgla – odsiarczanie i demineralizacja za pomocą silnych zasad. Studia, Rozprawy, Monografie 40 PAN CPPGSMiE. Kraków 1995.*
38. Hycnar j.; *Składowanie odpadów z elektrowni. Gaz, Woda i Technika Sanitarna 1985, nr 4.*

39. *Założenia techniczno-ekonomiczne produkcji koncentratów węglowych z mułow zgromadzonych w osadnikach kopalni węgla kamiennego Chwałowice. Ecocoal CC. Katowice 2001.*

40. *Kral O., Ciołeszyńska U.: Innowacyjne paliwo energetyczne z odpadów poflotacyjnych węgla kamiennego. Czasopismo Techniczne 2012, nr 150–153.*

41. *Repka V., Kral O., Repkova M., Pavlik R.: Możliwość wykorzystania mułu węglowego ze stawów osadowych należących do firmy EKO CARBO – Julia Sp. z o.o. w Wałbrzychu, Polska. Czasopismo Techniczne 2012, nr 150–153.*

42. *Hycnar J.J., Rondio K., Ścieżko M.: Test on Demineralization of High Sulphur Steam Coal Fines in TRW Gravimelt Process. The XII International Coal Preparation Congress. 23–27 May, 1994. Cracow - Poland.*

Metody podwyższenia kaloryczności drobnoziarnistych odpadów węglowych

Dotychczasowe badania i doświadczenia stosowania drobnoziarnistych odpadów węglowych, jako paliwa w kotłach i piecach energetycznych, wskazują na możliwość podwyższenia ich jakości oraz zwiększenia efektów ekonomicznych i ekologicznych u ich użytkowników.

Właściwości energetyczne drobnoziarnistych odpadów węglowych wynikają z zawartości i jakości występujących macerałów węglowych oraz zawartości wody i składników mineralnych. Najprostszą drogą podwyższenia kaloryczności mułów węglowych i odpadów poflotacyjnych jest obniżenie w nich zawartości wody i popiołu.

Na wilgotność drobnoziarnistych odpadów węglowych z bieżącej produkcji duży wpływ mają zastosowane urządzenia odwadniające, najbardziej skutecznymi okazały się prasy filtracyjne. Stopień zawodnienia mułow węglowych i odpadów poflotacyjnych eksploatowanych z osadników zależy od czasu ich deponowania i budowy osadników oraz sposobu urabiania i magazynowania urobku. Dostarczane do energetyki drobnoziarniste odpady węglowe charakteryzują się wilgotnością od 14 do 45%.

Znaczącą poprawę jakości drobnoziarnistych odpadów węglowych uzyskano poprzez ich granulowanie. Otrzymywany granulat charakteryzuje się odpornością transportową i magazynową, nie ulega degradacji w zmiennych warunkach pogodowych oraz charakteryzuje się lepszymi właściwościami energetycznymi. Zastępując pulpę mułowo-wodną granulatem mułowym można uzyskać przyrost jednostkowy wartości opałowej spalanego paliwa o ok. 2.000 kJ/kg.

Zasadniczą poprawę, jakości drobnoziarnistych odpadów węglowych można uzyskać przez obniżenie w nich zawartości składników mineralnych. Najprostszym rozwiązaniem jest selektywne wydzielanie najbogatszych w węgiel cieków wodno-mułowych z obiegu wodno-mułowego. A w przypadku ich uzyskiwania ze składowisk, selektywne wybieranie depozytu.

Najbogatsze koncentraty węglowe z mułów węglowych, uzyskuje się poprzez wydzielanie frakcji ziarnowej powyżej 30-50 μm. W przypadkach zastosowania odwadniających przesiewaczy wibracyjnych z tkaninowymi przeponami oraz przesiewaczy łukowych i odśrodkowych sit odwadniających uzyskiwano koncentraty węglowe o wartości opałowej w granicach 16 do 22 MJ/kg.

W dotychczasowych metodach deponowania zawiesin wodno-mułowych w osadnikach nie wykorzystuje się możliwości grawitacyjnego wzbogacania zawiesin wodno-mułowych w ziarna węgla. Poprzez ukierunkowanie przepływu zawiesin wodno-mułowych w osadnikach można uzyskać obszary bogatych i najbogatszych depozytów w ziarna węgla oraz uzyskać bardziej efektywne oczyszczenie wody nadosadowe.

Wzbogacanie odpadów poflotacyjnych wymaga stosowania innych metod rozdziału, najczęściej opartych o różnice ciężarów właściwych lub/i właściwości powierzchniowych ziaren węgla i składników mineralnych. Najczęściej budowane instalacje oparte są o technologie stosujące hydrocyklony, ciecz ciężką i procesy flotacyjne. Wymienione technologie umożliwiają uzyskiwanie najbogatszych koncentratów węglowych.

Z dokonanej analizy zagospodarowania drobnoziarnistych odpadów węglowych wynika, że poprzez współdziałanie górnictwa i energetyki istnieją warunki i możliwości nie tylko zwiększenie ich ilościowego zagospodarowania, ale także zwiększenia efektów ekonomicznych i ekologicznych dla zainteresowanych stron.

Słowa kluczowe: drobnoziarniste odpady węglowe, muły węglowe, odpady poflotacyjne, granulowane muły węglowe, spalanie mułów węglowych i odpadów poflotacyjnych