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PROCESSING OF FLY ASH FROM THERMAL POWER PLANTS BY MEANS OF MECHANICAL CLASSIFICATION BY SIZE

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Abstract. The processing of ash and sludge waste from coal-fired thermal power plants (TPP) is an urgent problem. Solving this problem reduces the operating costs for the maintenance of ash storage facilities, allows to obtain new types of products, reduces the environmental impact. The purpose of the study is to establish the granulometric composition of the wet storage fly ash for several TPPs, to determine the possibility of obtaining a carbon-rich intermediate product (industrial product) by means of mechanical classification. This method involves combining rich and close-sized classes into industrial products and removing the remaining lean classes into waste. Two most common types of ash and sludge raw materials have been studied. The first one with low carbon content in the coarse and finest classes. The second type is high carbon content in all the size classes except the finest ones. It is established that the method applied leads to a twofold increase of the coal concentration in the industrial product. For the ash of the Prydniprovska and Kurakhivska TPPs, the industrial product has a carbon content of about 40% with a carbon content of 12-15% in the waste. An industrial product with a carbon content of 57% was obtained from the ash of Chernihivska TPP, the carbon content within waste is about 20%. The advantage of the obtained industrial product is that the absence of the finest classes alleviates its dressing by means flotation and gravity methods. The resultant waste, both in terms of carbon content and their size, meets the standards for fly ash of TPP for the manufacture of lightweight concrete and could be used in industry. The output of waste ranges from 45 to 80% of the initial raw material. The study also considers an option of selective extraction of high grade raw materials with a carbon content that exceeds 35% at the ash storage facility. For such raw materials, the method of isolation of the productive class allows to obtain a finished coal product with carbon content within the range of 70-72% for an output of 22-25% from the initial sample. The waste contains about 25% carbon. In this case, the industrial product is a ready-to-use pulverized fuel for secondary use at TPP. It is also possible to use it in the form of coal briquettes. Tentative assessment proves that this technology seems to be profitable, since the costs of raw materials lifting process as well as drying and vibratory screening process do not exceed the costs of coal mining, transportation and preparation processes for the coal combustion at TPP.

Keywords: ash, carbon, intermediate product, waste.

Introduction. There are 39 storages of ash and sludge waste materials from thermal power plants operate in the energy sector of Ukraine. To date, they have gained about 360 million tons of ash and sludge raw materials that cover an area of more than 31700000 square meters. According to previous studies the relevance of this raw material processing has been repeatedly pointed out, since the fly ash of TPP includes up to 20% of unburned carbon, i.e. underburning of coal [1]. Processing of operating ash storage facilities allows to extract some 70 million tons of coal. This raw material is a small-sized one and is suitable for reuse at thermal power plants.

Taking into account the high cost of coal as well as high cost of transportation process along with coal preparation for combustion [2], carbon extraction from the stale fly ash is an urgent problem.

In order to concentrate the product of coal underburning into a rich intermediate product the classification method is used since it is appropriate one. First of all determining of the close-sized classes as the most carbon-rich ones is necessary. Further, it is necessary to determine which classes should be included in the composition of the productive class, which will represent a rich intermediate product (industrial product). The remaining classes would be the waste ones.

This study work is based on the research of the Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine were effective technical support was developed and tested. This technical support is the following: vibratory screening machines with dynamically active rubber belt screens GNVS [3] and multi-frequency screens MVG [4].They allow to operate with a boundary separation size of 50 μm at a raw material humidity level up to 40-45% [3, 5], a device based on the fluidized bed drying process has been developed to ensure the dehydration and drying processes. This feature is the most effective for fine raw materials and products of the fly ash classification from TPP.

The purpose of work is to establish the granulometric composition for the fly ash of wet storage for several TPPs to determine the possibility of obtaining a carbon-rich intermediate product (industrial product) by means of mechanical classification, i.e. by means of combining rich and close-sized classes into industrial products and removing the remaining lean classes into waste.

Analysis of a large number of fly ash storage facilities of thermal power plants and sludge storage facilities of coal preparation plants has shown that raw materials (ash and coal sludge) could be classified into four main technological types, according to the size classes where carbon is predominantly concentrated.

The first type – the carbon-rich productive class is located in relatively coarse classes, their size range is usually within -3+0.15 mm. This is the most favorable, but also the rarest option.

The second type - the productive class, has an average size, for example, -0.15+0.05 mm. This type of raw material is the most widespread one.

The third type - the carbon–rich particles, too fine, dust-like, with a size greater than -0.07 mm and even -0.05 mm. Such a product is could be often found in the sludge storages of coal plants. This raw material is the most difficult to process. However, this type of raw material could be barely found within the ash storages of thermal power plants, since fine carbon classes have enough time to burn out in the flue gas.

The fourth type – ash content is quite uniformly distributed within all the classes of fineness, except the finestones, with a size greater than -0.05 mm.

For stale waste from wet storage of TPPs, the most widespread ash sludges are those ones of the second and fourth types. In particular, this could be confirmed by the results of experimental study shown below.

Research methods. Storage ash samples were selected using a special grid from different places of the aggradation map at the ash storage facilities of the Prydniprovska, Kurakhivska and Chernihivska thermal power plants. Averaging and reduction of samples were carried out by the quartering method. The yield of the size classes γ, and the ash content A within individual classes were determined experimentally by means of standard methods. For each i-th class, the carbon content $\beta_i = 100\text{-}A_i$ and carbon extraction $\varepsilon_i = \gamma_i \bullet \beta_i / a_i$ were calculated, where γ_i - output of the class, β_i - carbon content within the class, a_i - carbon content within the sample. In order to assess the efficiency, the degree of coal concentration in the productive class was used. $n=\beta_{prod.}/\beta_{initial.}$, where n - carbon content in the productive class to its content in the initial sample ratio.

Results and discussion. The results of experimental study for the ash sludge of the Prydniprovska and Kurakhivska TPPs are shown in Table 1.

Table 1 – Productive class extraction from stale ash

Size, mm	Output γ, %	Ash content A, %	Carbon content β_C, %	Carbon extraction ε_c, %
Prydniprovska TPP				
+0.1	6.5	58.50	41.5	10
-0.1 +0.063	14.3	59.66	40.34	21.5
-0.063+0.04	33.4	61.46	38.54	48
-0.04	45.8	87.96	12.04	20.5
Initial raw material	100	73.15	26.85	100
Productive class +0.1… +0.04	54.2	60.63	39.37	79.5
Waste -0.04	45.8	87.96	12.04	20.5
Kurakhivska TPP				
-0.63+0.25	0.83	5.3	94.7	3.8
-0.25+0.1	6.42	48.9	51.1	15.9
-0.1+0.05	18.17	68.0	32.0	28.1
-0.05	74.58	85.5	14.5	52.2
Initial raw material	100	79.3	20.7	100
Productive class -0.63… +0.05	25.42	61.2	38.8	47.6
Waste -0.05	74.58	85.5	14.5	52.4

Both samples from Table 1 belong to the fourth type of raw materials, when all classes are rich in carbon, except the finest ones. Table 1 shows, that there is a tendency to the carbon content decreasing with a decreasing of size for a minimum carbon content in the finest classes. It is obvious that fine classes need to be displaced into waste while the remaining classes should be combined into a rich industrial product, i.e. a productive class. Waste indicators will be equal to the indicators of the fine class derived. Note that the most effective process is a separation of the fine classes -0.04 or -0.05 mm in size by means of vibratory screening [3-5].

The results have shown that for fourth ash type with carbon content in the raw material within the range of 20.7-26.85%, extraction of the productive class gives industrial products with carbon content within the range of 38.8-39.37 % as well as waste product with carbon content within the range of 12 - 14.5%. Both industrial and waste products have pretty large yields. The coal concentration within the industrial product is the following: for the Prydniprovska TPP n=39.37/26.85 = 1.5 times, for the Kurakhivska TPP n=38.8/20.7 = 1.9 times.

The carbon content in the productive class is not enough to use it as fuel. In order to increase the carbon content this product needs to be refined. The favorable feature of the coal concentration process is an increasing of the product size subjected to the refinement process compared to the initial mass of raw materials. This enables to increase the efficiency of refinement by means of both flotation and gravity methods.

On the issue of carbon content in waste and the use of waste in construction, an explanation should be added.

A few decades ago for the use of TPP fly ash in construction carbon content should not exceed 5% [6]. Later, differentiated regularities were described in GOST 25592-83 and 25818-91 standards, 4 types of ash were distinguished for different coal types [7]. The loss of mass after ash annealing is taken as an indicator. In fact, this is a carbon mass, since sulfur and volatiles have time to evaporate during combustion in TPP boilers and flue gas [8].

According to [7], the acceptable mass loss after coal annealing of ash is within the range 5-7% for reinforced concrete, 10-15% for normalized concrete, 10-25% for anthracite ash. When using, Acceptable mass loss for fly ash of heavy concrete annealing is up to 10%.

Taking into account the above standards waste materials shown in Table 1 with a carbon content of 12 and 14.5% meet the existing standards of fly ash for lightweight concrete. Therefore they could be used in industry.

Let's consider the second common case when carbon concentration in the coarse and fine classes is low enough. The product is of the second type. Such raw materials are typical for the ash storage facility of the Chernihivska TPP (Table 2).

Table 2 – Productive class extraction from stale ash

Chernihivska TPP				
Size, mm	Output γ, %	Ash content A, %	Carbon content β_C, %	Carbon extraction ε_c, %
+0.8	0.13	99.3	0.7	0.003
-0.8+0.315	0.44	96.2	3.8	0.05
-0.315+0.2	0.48	51.5	48.5	0.9
-0.2+0.08	5.95	37.2	62.8	13.6
-0.08+0.05	12.15	45.8	54.2	24.5
-0.05	80.98	79.7	20.3	61
Initial raw material	100	73.02	26.88	100
Productive class -0.315… +0.05	18.58	43.2	56.8	39
Waste +0.315 and -0.05	81.42	79.82	20.2	61

Table 2 shows that coarse ash classes are lean in carbon, but there is a lack of these classes. Therefore, together with coarse classes, lean fine classes are the waste ones as well. Coal concentration in the productive class is the following n=56.8/26.88=2.1. The resultant industrial product’s size is within the range of -0.315 +0.05 mm. It is rich enough. Its carbon content is nearly 56.8% while its yield equals 18.58%. Taking into account its size, this industrial product is more easily enriched by means of flotation or gravity methods compared to the entire mass of the initial raw material.

The carbon content within the waste is 20.2%. Such waste, generally, meets the standards for ash which is used for the production of certain types of concrete [6, 7].

In case of their further processing, it should be taken into account that the waste's size, in fact, equals -0.05 mm. The number of such classes in waste is about 80.98% from the total mass number of 81.42%.

Raw materials testing of the numerous ash storage facilities shows that several sections, especially those ones rich in coal, could be distinguished within the storage area. Sampling at such sections and their processing is of significant interest.

Further, the selection and analysis of a rich sample for stale ash of the Prydniprovska TPP were carried out. The task was to classify the most carbon-rich productive class from this sample (Table 3).

Table 3 –Initial data for determining the productive class of a rich sample of stale ash of the Prydniprovska TPP

Size, mm	Output γ, %	Ash content A, %	Carbon content β_C, %	Carbon extraction ε_c, %
-0.2+0.16	0.1	28.5	71.5	0.2
-0.16+0.1	1.1	23.25	76.75	2.37
-0.1+0.08	9.5	26.06	73.94	19.71
-0.08+0.063	11.3	29.77	70.23	22.27
-0.05+0.04	3	41.26	58.74	4.94
-0.04	75	76	24	50.51
Initial raw material	100	64.36	35.64	100

Table 3 shows that the initial raw material has relatively high carbon content that equals 35.64%. For most ash storage facilities, the typical content of coal underburning is 20-25%. Also, rare case takes place when coarse classes of +0.1 mm in size are rich in coal, although there are lack of these classes. General tendency of the carbon content reducing with size the finest classes decreasing to their minimum values has been observed. At the same time, approximately half of the carbon is extracted from the fine classes -0.05 mm in size, ε_c = 4.94+50.51= 55.5%.

Raw materials are of the fourth type, when the carbon content is high enough in all classes except for the finest one -0.04 mm in size. Obviously, in this case, a rich industrial product is obtained by means of separating fine classes. Calculations were performed for two cases: in case of separation of classes -0.04 mm in size and in case of a wider class separation -0.05 mm in size. The results are shown in table 4.

The analysis shows that for both cases, high indicators are obtained, both in terms of the quality of the industrial product and in terms of its output. During separation of a wider class of -0.05 mm in size, compared with class of -0.04 mm in size, the concentrate yield has been decreased slightly from 25 to 22%. The concentrate quality in terms of carbon content has been increased from 70.55% up to 72.16%. Coal concentration for cases 1 and 2 are the following: n =70.55/35.64 =1.98 and n =72.16/35.64 =2.02, respectively.

In both cases, the industrial product is a finished coal raw material supplied for combustion in the boilers of thermal power plants. According to the standards, the ash content of such coal should not exceed 35% [2], in present study it equals 29.45 and 27.84%, respectively.

The resultant industrial product could be briquetted and sold as coal or used as pulverized coal fuel and fed (blown) into the furnace space of furnaces or boilers of TPP.

Table 4 – Extraction cases of a productive class according to Table 3

Size, mm	Output γ, %	Ash content A, %	Carbon content β_C,%
Case 1 – separation of classes -0.04 mm in size			
Productive class -0.2 +0.04	25.0	29.45	70.55
Waste -0.04	75.0	76.0	24.0
Case 2 – separation of classes -0.05 mm in size			
Productive class -0.2 +0.063	22.0	27.84	72.16
Waste -0.05	78.0	74.7	25.3

Besides, waste containing 24 and 25.3% of coal was obtained within the residue, and there is a lot of waste: 75% and 78% of the initial raw material mass respectively. The carbon content value 24-25% in the waste is comparable or even slightly higher than the average carbon content over the entire area of the ash storage. The waste does not have a tolerance to reliably match to the standards of fly ash for concrete [7] and most likely requires refinement. Taking into account their fine class, it is promising to refine them by means of flotation and gravitational sedimentation methods within a confined environment, for example, hydroseparation, desliming etc.

Thus, when rich areas at the ash storage facility are distinguished and industrial product is extracted from stale ash with a carbon content that exceeds 35%, a ready-to-use rich coal concentrate could be obtained. For the separation of fine classes -0.05 mm and -0.04 mm in size into waste, the most appropriate vibratory screens are those ones designed by IGTM [3-5].

Conclusions. Two most common types of raw materials have been studied for ash and sludge waste of thermal power plants: low carbon content in the coarse and finest classes (type 2), all classes are rich in carbon except the finest one (type 4).

It was established that the method of a rich intermediate product obtaining by means of combining rich close-sized classes is efficient enough and allows to double the coal concentration. It was found that for the stale ash of the Prydniprovska and Kurakhivska TPPs, the industrial product has a carbon content nearly 40% with a waste content of 12-15%. For the stale ash of Chernihivska TPP, the carbon content within the industrial product is about 57%, the carbon content in waste isabout 20%. The advantage of the resultant industrial product in the absence of fine classes is an alleviated dressing process. The waste is of a fine size. In terms of carbon content they meet the standards for fly ash of TPP for the lightweight concrete manufacturing. Thus, they could be used in industry. The output of waste ranges from 45 to 80% of the initial raw material.

Selective extraction of rich raw materials with a carbon content that exceeds 35% at the ash storage is a promising technology. For such raw materials, the method of the productive class separation allows to obtain a finished coal product with a yield of 22-25% and a carbon content of 70-72%. The waste contains about 25% of carbon. In this case, the industrial product is a ready-to-use pulverized fuel for combustion at TPP. It is also possible to use it as coal briquettes. Initial assessment shows that such technology seems to be profitable, since the costs of raw materials lifting process as well as drying and vibratory screening process do not exceed the costs of coal mining, transportation and preparation processes for the coal combustion at TPP. Processing of technogenic raw materials of existing ash storage facilities, in particular, allows to extend their service life and increase environmental safety.

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ПЕРЕРОБКА ЗОЛИ ВИНОСУ ТЕПЛОВИХ ЕЛЕКТРОСТАНЦІЙ МЕХАНІЧНОЮ КЛАСИФІКАЦІЄЮ ЗА КРУПНІСТЮ

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Анотація. Переробка золошлакових відходів вугільних електростанцій (ТЕС) є актуальною задачею. Її вирішення зменшить експлуатаційні витрати на утримання золосховищ, дозволить отримувати нові види продукції, покращить екологічний стан довкілля. Метою роботи було встановити гранулометричний склад золи виносу мокрого зберігання на кількох ТЕС та визначити можливість отримання багатого вуглецем проміжного продукту (промпродукту) методом механічної класифікації. Цей метод передбачає об'єднання багатих вузьких класів крупності в промпродукт і виведення бідних класів, що залишилися, у відходи. Досліджено два найбільш поширені типи золошлакової сировини. Перший - з малим вмістом вуглецю в найбільш крупних і в найтонших класах. Другий - коли всі класи крупності багаті на вуглець, крім найтонших. Встановлено, що використовуваний метод дозволяє підвищити концентрацію вугілля в промпродукті в 2 рази. Для золи Придніпровської та Курахівської ТЕС промпродукт має вміст вуглецю приблизно 40% при вмісті вуглецю у відходах 12-15%. Для золи Чернігівської ТЕС отримано промпродукт із вмістом вуглецю 57%, у відходах міститься близько 20%. Перевагою отриманого промпродукту є те, що без тонких класів він легше збагачується флотацією і гравітаційними методами. Отримані відходи, як за вмістом вуглецю, так і за крупністю задовольняють стандартам на золу виносу ТЕС для виготовлення легких бетонів і можуть використовуватися в промисловості. Вихід відходів становить від 45 до 80% вихідної сировини. Також у роботі розглянуто варіант виборчого вилучення на золосховищі багатої сировини із вмістом вуглецю від 35%. Для такої сировини метод виділення продуктивного класу дозволяє отримати готовий вугільний продукт із вмістом вуглецю 70-72% при виході 22-25% від вихідної проби. Відходи містять близько 25% вуглецю. В цьому випадку промпродукт є готовим пилоподібним паливом для повторного використання на ТЕС. Також можливе його використання у вигляді вугільних брикетів. В первинній оцінці така технологія видається рентабельною, оскільки витрати на підйом сировини, сушіння та вібраційне грохочення менше витрат на видобуток вугілля, транспортування та підготовку до спалювання на ТЕС.

Ключові слова: зола, вуглець, проміжний продукт, відходи.

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