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GRANULOMETRICAL COMPOSITION OF THE WASTE OF THERMAL POWER PLANTS

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Abstract. The direct use of TPP waste is construction is constrained by existing norms and standards for concrete, bricks and other products. Ash and slag raw materials need to be further processed, primarily classified by size. Waste from Prydniprovska and Kurakhivska TPPs was studied: dry fly ash, slag and stacked ash from the wet storage ash pond, and was considered as three separate products. The purpose of this study is to determine the particle size distribution of these wastes on the example of Prydniprovska and Kurahivska TPPs. This is necessary to determine the prospects for the use of this waste and the development of appropriate processing technologies. As a result of the research, it was found that the current dry fly ash from electrostatic precipitators and cyclones at the two studied TPPs differs significantly in particle size distribution due to the different size and ash content of the combusted coal, different temperature conditions, blowing conditions, flue gas removal, etc. The physical and technical characteristics of the slag, its particle size and iron content were determined, which showed the possibility of its direct use as medium-strength crushed stone of the M600 grade in construction. Freshly poured ash into the ash pit has a significantly higher particle size than ash that has been stored for a long time. This is not due to the presence of slag in the fresh ash, as the content of the fine class of -0.16 mm in slag is 1.7%. This is confirmed by the higher particle size of dry fly ash compared to stale ash. It established that although dry ash of Kurahivska and Prydniprovska TPPs has different composition, over time, under the destructive influence of the environment, it becomes smaller in size and its composition becomes similar at both ash dumps. In the averaged samples, the number of large classes of +0.25 mm does not exceed 1%, the ratio of +74 µm and -74 µm classes is approximately estimated at 20 : 80. The reason for the waste size during long-term wet storage is annual temperature fluctuations, chemical reactions, mechanical stresses under the weight of the upper layers and during the movement of raw materials. Vibrating screening has an advantage over other methods for classifying dry and stacked ash due to its high efficiency and the ability to separate narrow size range with a high content of unburned coal.

Keywords: fly ash, slag, ash and slag waste.

1. Introduction

The processing of ash and slag waste from thermal power plants is attracting a lot of attention due to the fact that the raw material of ash pits is 75–95% fine, mostly silicate mass and is a valuable resource for use in construction, as well as for the extraction of coal stubs, production of ferrous, non-ferrous and liquid metals [1, 2].

Today, there are 39 TPP ash dumps in Ukraine. They contain about 360 million tons of ash and slag on an area of more than 3170 hectares. The existing ash dumps are continuously replenished. As of 2021, 12 TPPs in the territory controlled by Ukraine produced 9.56 million tons of waste, including 7.64 million tons of ash and 1.53 million tons of slag. The distribution of ash and slag was 84:16 (%).

Over the past 10 years, the level of ash and slag processing and utilization in Ukraine has been no higher than 10–12% of annual output, while in foreign countries it has been 80% (Portugal, France, Poland) and 100% (Germany, South Korea). The main reason for this situation is the lack of cost-effective processing technologies and insufficient study of raw materials. Today, the most promising is the use of ash for the production of concrete [2, 3].

TPP wastes can be stored in dry, wet, and semi-wet ways. In the West, the dry method is mostly practiced. For example, in Germany, dry ash is used 100%, and after a small amount of processing, it is stored in bunkers and sold to construction companies on a competitive basis.

In our country, from the first days of TPP construction, waste was subject to joint wet removal and storage of ash and slag, and since the 70s, separate removal and storage has been introduced. Keeping ash ponds wet, filling dams and other work requires constant operating costs. These costs account for up to 25–30% of the cost of electricity and heat produced on TPPs.

The development of cost-effective methods for processing TPP waste, both in the form of current dry products such as ash and slag and ash and slag waste, is an urgent task. Its solution will reduce the burden on existing ash storage facilities, reduce the severity of reconstruction and land allocation problems, produce new types of products, and improve the environmental condition.

2. Methods

Methods – experimental tests, particle size analysis. The particle size distribution (grain size distribution) of ash was determined by the mass content of particles of different sizes, expressed as a percentage of the mass of the dry sample taken for analysis. The particle size distribution was determined using DST 12536-2014, in which the statistical error is minimal, since the sieve analysis is performed until the end of sieving on certain sieves, the sieve residue was weighed on an electronic balance with an error of ±0.05 g.

3. Objects of research and problem statement

3.1. A thermal power plant (TTP) has several power units, each of which is an independent unit with full autonomy from coal supply to electricity generation. Coal in the boilers of power units is burned in the form of dust, which is prepared by tumbling mills [4, 5]. Fly ash is a finely dispersed material formed from the mineral part of coal and includes up to 20–25% of unburned carbon and is carried away in the form of dust with flue gases. Electrostatic precipitators are installed above each boiler to clean the flue gases; sometimes, an air cyclone is added to capture the coarse fraction. Each electrostatic precipitator field collects a certain fraction of ash, which differs in size, phase and chemical composition. The collected ash is poured into a hopper at the bottom of the filter, from where it is transported to the ash dump through a hydraulic seal. The granulometric composition of dry fly ash at domestic TPPs has not been studied sufficiently. Meanwhile, such studies, which are necessary to develop a technology for separate processing of dry fly ash, will show the possibility of using the same type of classifying equipment at different TPPs, the feasibility of selecting several raw material streams, for example, from separate sectors of electrostatic precipitators, etc.

3.2. Slag is a coarse material formed from the mineral part of coal, aggregates in the furnace space of boiler units and is removed from the bottom of the furnace. There is currently no separate removal of fly ash and slag. Hydraulic transportation in the boiler room is carried out in non-pressure channels and is delivered to the ash storage facility by dump truck. The slag content in the combined waste is usually no higher than 20%. The review of information sources did not reveal any studies of TPP slag as a separate valuable product.

3.3. Ash and slag waste is a polydispersed mixture of fly ash and fuel slag that is formed when they are removed and stored together . The content of ash and slag in the mixture is usually estimated at 80:20. Ash and slag waste after joint hydraulic removal of ash and slag is distributed unevenly in the ash pit in terms of area and volume. Filling of the ash pit can be one-sided or circular, the sequence of filling of the alluvium maps depends on the season and is specified in the project. The fuel properties and technological regimes also do not remain unchanged throughout the year, so the raw material has a heterogeneous particle size distribution over the ash storage area. When the ash dump is filled, the waste is fractionated along the beach depending on the point of pulp discharge, and the carbon-rich class of size is also unevenly distributed in the storage volume.

The selection of raw materials from the ash storage facility for further processing is most often offered from the pontoon by a hydraulic elevator. This involves a specially designed sludge lifting grid. It is also proposed to excavate ash and slag from the dam crest with an excavator or loader after preliminary drying. The averaging of all samples taken, or only a few selective samples after classification, is used.

For example, the Institute of Geotechnical Technology of the National Academy of Sciences of Ukraine has developed a method of sludge processing under patent 88246 UA, which involves sampling in a plane at points no more than 5–6 meters apart, and analyzing the samples for carbon content in narrow classes. Next, the samples are separated from the high ash classes using the fine classification method. Then the carbon part is dewatered on a high-frequency screen with vibration parameters: frequency ≥ 25 Hz, acceleration ≥ 6–8 m/s2. The results of sludge separation by size are combined into classes with high carbon content and classes with high ash content.

Insufficient attention has been paid to the study of the size of stacked ash in the ash storage facility. Meanwhile , the size of the selected products plays a significant role in determining the selection grid and processing technology. For example, the optimal size for the settling process is from 0.5 to 150–250 mm, for heavy media separation - 2.5–0.5 mm, for flotation - from 2.5 mm.

Purpose of the study. The objective of the research was to determine the particle size distribution of waste - dry fly ash, slag and fly ash from ash ponds - the example of Prydniprovska and Kurakhivska TPPs. This will help determine the characteristics of the raw materials, which is necessary for the development of processing technologies for these products.

4. Results and discussion

Dry fly ash from TPPs.

The current dry ash deposited on the electrostatic precipitator sectors has a fine composition, a special glassy structure, contains mainly silica, and about 20% of unburned carbon. The particle size distribution studies were performed for the dry fly ash collected at Prydniprovska and Kurakhivska TPPs.

At Prydniprovska TPP, dry ash samples were taken from 4 separate sectors of the electrostatic precipitator, with sectors numbered from 1 to 4, starting from the bottom, in the direction of flue outlet. Samples were taken throughout the day, then averaged for each sector separately. At Kurakhivska TPP, dry ash samples were taken from the bunker under the electrostatic precipitator, where dry ash is fed from the cyclones and the electrostatic precipitator. The sample was also taken during the day and averaged by guyarted. Table 1 shows the results of determining the particle size distribution of the current daily dry fly ash.

Table 1 – Dry fly ash from Prydniprovska and Kurakhivska TPPs

Size class, mm	Prydniprovska TPP					Ku-rakhovskaya TPP
	Electrostatic precipitator sectors				Average	
	1	2	3	4		
-5+1	-	-	-	-	-	14%
-1+0.315	0.8%	15.8%	3%	1%	5.2%	61.5%
-0.315+0.074	4%	42%	35.5%	4%	13.4%	21%
-0,074	95.2%	42.2%	93.5%	95%	81.4%	3.5%
Specific surface area, cm²/g	3560	1000	6590	5430	4145	-

Table 1 shows that the size distribution between the sectors of the ESP is uneven. Usually, the coarse classes falls on the first sector of the electrostatic precipitator, in our case - on the second. This unevenness is confirmed by the analysis of the specific surface area from different filter sectors. On average, the dry ash from the electrostatic precipitator contains both coarse classes of +0.074 mm and fine classes of -0.074 mm, the distribution between them is ~ 20 : 80.

The dry ash from Kurakhivska TPP is much coarser than at Prydniprovska TPP. At Kurakhivska TPP, the coarse classes are -5+1 mm, which account for 14% by weight, while at Prydniprovska TPP, the coarse class is -1+0.316, which accounts for 5.2%. The content of classes less than 0.074 microns is 3.5% at Kurakhivska TPP and 81.4% at Prydniprovska TPP.

Usually, the difference in the size of dry fly ash at different TPPs is explained by the different size and ash content of the combusted coal, temperature conditions, blowing conditions, and flue gas removal [4, 5]. But in our case, this difference is explained mainly by technical reasons, namely, insufficient performance of the electrostatic precipitator. According to the annual reports of DTEK, which is the management company at both TPPs, dust emissions at Kurakhivska TPP were 2–5 times higher than at other TPPs, so the reconstruction of electrostatic precipitators was gradually carried out by was not completed at the time of testing at the power units 6, 8, 9. The impact of the size and grade of coal burned should also be taken into account. During the year, Prydniprovska TPP mainly operated on Pavlohrad gas and lean coal of DGM13-25, G(G)M 13-25, T grades, and Kurakhivska TPP mainly on anthracite AS 6-13, AS 0-6.

The influence of coal grade on dry ash size was studied in the laboratory. Coal samples of the same size (2–3 mm) but of different grades were prepared: AS (anthracite, lignite, 0–6 mm, ash content 8–10%), T- lean, G-gas, B-brown coal. T, G, B grades had medium and high ash content of 14–28%. The averaged data on the particle size distribution of ash obtained after burning different samples in a muffle furnace under the same conditions are given in Table 2.

Table 2 – Determination of dry ash size in the laboratory for coal of different grades

Size class, mm	Coal grade			
	АШ	Т	Г	Б
2.0–0.63	3%	0.2%	2%	1%
-0.63+0.25	7%	18%	4%	2.5%
-0.25+0.05	54%	22.6%	49%	21%
-0.05	36%	59.2%	45%	75.5%
Weighted average size, mm	0.7	0,15	0,14	0.09

Table 2 shows that for all coal grades, the hight yield is obtained in the -0.25+0 mm size class. The finest ash is obtained by burning lignite. With the same feed coal size, the the coarse weighted average ash size is inherent in anthracite.

Thus, it has been established that the size of ash from the electrostatic precipitator hopper at different TPPs can vary significantly. However, it is obvious that dry ash can be easily classified by mechanical means, compared to classification in centrifuges or hydrocyclones. Among mechanical classifiers, vibrating screens are considered the most effective [6, 7]. After classification, narrow size range is analyzed for carbon and iron content. Depending on its results, the raw material is divided into separate marketable products, or, if necessary, individual classes are further refined. For example, hydraulic methods and flotation are used to extract carbon, and magnetic separation is used to extract iron. Note that coarse grades may require grinding, for example, for hydraulic classification and flotation, a size of no more than 2.0 mm is desirable.

Fuel slag.

Separate extraction of slag may be feasible for direct use of the whole slag, or for certain narrow size range in construction, and probably for processing and extraction of heavy metals. To investigate this issue, an average sample of slag from Prydniprovska TPP was taken. It is a homogeneous material without foreign impurities, and the slag under study is classified as dense slag by grain density.

The following physical and mechanical properties of the dump slag were determined:

- initial moisture content - 3.8 %;
- bulk density in the air-dry state - 1410 kg/m3;
- average grain density - 2.3 g/cm3.

The strength of slag crushed stone was determined by the following parameters:

-weak grains content 38–42%;

-dry crushability - 24.1%;

-crushability in the wet state - 23.7%.

On this basis, it was established that the slag raw material corresponds to crushed stone with a strength grade of M600. This raw material is a universal building material that can be used in the construction of various facilities.

The frost resistance was assessed based on the following considerations. The content of dusty particles in the slag mixture under study is insignificant - less than 1.0% by weight. They mainly arise from particles that have collapsed under light pressure. It is known that if the raw material contains no more than 5% of dusty particles smaller than 50 microns, it is believed that the value of relative freeze-thaw does not exceed 3%. Thus, the slag is classified as weak in terms of frost heave.

The results of the slag particle size analysis are shown in Table 3.

Table 3 – Particle size distribution of slag at Prydniprovska TPP

Particle size, mm	Average particle size in the class, mm	Class yield, %.	Total yield, %.
-40+20	20	1.2	1.2
-20+10	15	10.6	11.8
-10+5	8	25.4	37.2
-5+2.5	3.75	27	64.2
-2.5+1.25	1.875	15.6	79.8
-1.25+0.63	0.94	10.9	90.7
-0.63+0.315	0.473	4.9	95.6
-0.315+0.16	0.238	2.7	98.3
-0.16	0.16	1.7	100.0
Weighted average size, mm		5.17	

In the total mass of crushed stone, large classes of -40+5 mm account for 37.2%. That is, more than 1/3 of the slag material is characterized by grains larger than 5 mm with maximum dimensions of up to 40 mm. The yield of small classes of -0.16 mm is very small - 1.7%. In the bulk, 95.6% of the slag is represented by particles larger than 0.315 mm. The weighted average slag size is 5.17 mm.

Thus, according to DST 25592-91, TPP slag can be classified into two marketable products: slag sand - grains with a size of 0.315 to 5 (3) mm and slag crushed stone - grains with a size of more than 5 (3) mm. Table 3 shows that these sand and crushed stone in TPP slag have a ratio of 58.4 37,2 (%)

When thermal power plant slag is used in construction, for example, to make concrete, cinder blocks, etc., it is analyzed for harmful impurities. No coal residues were found in the slag, but the slag, like the ash, should accumulate heavy metals that were in the original coal, in particular iron. It should be noted that iron in coal is present in the form of oxides, hydroxides, sulfides and sulfates, etc. During high-temperature combustion of coal with air, iron-containing minerals undergo transformations. For example, $Fe_2O_3 \cdot nH_2O$ limonite loses moisture when heated and turns into goethite FeO(OH), hematite Fe_2O_3, and magnetite F3O4. Coal combustion produces CO_2 and CO. CO oxide reduces iron oxides to pure iron according to the scheme $Fe_2O_3F \rightarrow {}_3O_4 \rightarrow FeO \rightarrow Fe$. Iron sulfides and sulfates also undergo oxidation by carbon dioxide and air oxygen. Such transformations are the reason why the content of iron oxides in the ash is about 20% when coal is burned with air [1, 6]. Obviously, some iron can also accumulate in the slag, so it is advisable to study the slag for the content of magnetic inclusions.

The magnetic properties of the slag were determined by magnetic separation of narrow size range It was found that the total amount of magnetic inclusions in the slag was low, with the majority of them falling on the two upper classes due to their highest yield (Table 4).

Table 4 – Content of magnetic inclusions in slag

Size, mm	Yield, %.	Magnetic fraction content in the class, %.	Yield of magnetic fraction, %.
-40+5	37.2	max 3	1.1
-5+2.5	27	6 – 9	2.4
-2.5+1.25	15.6	9	1.4
-1.25+0.63	10.9	min 11.8	1.3
-0.63	9.3	max 24	2.2
Total	100		8.5

Slag contains an average of up to 8.5% of magnetic inclusions by weight. These inclusions are mineral growths, mainly iron oxides and silicates. Let's assume that these growths are composed entirely of Fe2O3. Then, in terms of oxide to pure iron, the magnetic mass of the slag contains 8.5 × 0.7 = 5.95% pure iron. Taking into account that 8.5% of magnetic inclusions are not pure Fe_2O_3 oxide, but rather growths, the iron content in the slag will be lower than 5.95%.

Construction standards usually specify an iron content of no more than 5% in raw materials. For example, DST 25592-83 and DST 26644-85 "Crushed stone and sand from slag of thermal power plants for concrete" stipulate that "the mass loss in terms of resistance to silicate and ferrous decomposition should not exceed 8 and 5%, respectively." According to DSTU 9043:2020 (DSTU 3344-83, DSTU B V.2.7-39-95), crushed stone and slag sand for road construction should contain no more than 5% of metal impurities.

Thus, it has been established that slag from Prydniprovska TPP should be divided into slag sand and crushed stone, which, in terms of iron content, meet building codes and are suitable for the manufacture of concrete, cinder blocks, and use in road construction, load-bearing earthworks and structures, such as road fill, ash dams, etc.

Ash and slag waste from the ash pond.

An ash storage facility is a complex hydraulic structure equipped with a network of distributing pulp pipelines with pulp outlets. Spillways and drainage structures are arranged to drain the transport water clarified from the ash and slag from the ash pit. To collect water and return it to the TPP, pools (buffer ponds) and clarified water pumping stations are used. To drain surface runoff, ash dumps are equipped with interception and drainage structures, such as cut-off dams, upland ditches, etc. In particular, drainage wells are located on the surface of the storage facility, and excess water is removed to the nearest water body. This causes the layers of raw materials to shift in a certain way, which leads to mechanical stresses that affect the size of the ash and slag.

Since the ash dump receives fly ash and slag from different boiler units, it is not possible to determine the dynamics of changes in the size of these products during transportation and storage in the ash dump. In our case, at least a day passed between sampling of current dry ash, slag and fly ash, during which time the particle size distribution of these products most likely changes. In view of this, the particle size distribution of ash in the storage facility is not equal to the sum of the particle size distribution of current dry ash and slag, in fact, these are three different products. Our task was to identify the features and establish the general patterns of the size of each of them.

Sampling at the Prydniprovska TPP ash dump was performed from two sectors - one close to the waste discharge point and the other - at a distance. Accordingly, the two accumulated samples were labeled as fresh ash and stale ash. Also, these two samples differed in the time of hydraulic removal: ash from section 2 of the dump is classified as recently drained, i.e. "fresh", and from section 4 - ash that has been in the dump for at least 1 year (Table 5).

Table 5 – Ash from the Zakhidna Balka ash dump at Prydniprovska TPP

Size, mm	Fresh ash, section 2	Stacked ash, section 4
+0.315	13.3%	1.6%
-0.315+0.074	39.0%	20.0%
-0.074	47.7%	78.4%
Total	100%	100%
Specific surface area, cm²/g	840	1680
Bulk density, kg/m3	1190	1100
Initial moisture content, %.	5.7	12.4

For Prydniprovska TPP, a comparison of dry ash (Table 1), fresh ash and stale ash (Table 5) shows that the content of large classes of +0.315 mm is the lowest in stale ash. In dry ash from electrostatic precipitators it is 5.2%, in fresh ash - 13.3%, in stale ash - 1.6%. The content of fine classes of -0.074 mm in dry ash and in stale ash is approximately the same, about 80% (81.4% in dry ash, 78.4% in stale ash).

Fresh ash, which has just poured into the ash storage facility, is coarser than stale ash: the content of fractions of +0.315 mm in fresh ash is 13.3% versus 1.6% in stale ash. Fresh ash has a significantly lower specific surface area - 840 vs. 1680 cm²/g. The large fractions of fresh ash are mainly represented by large grains and, partially, adherent particles of plate-shaped ash fractions.

It can be concluded that fresh, freshly poured ash becomes smaller in size over time in the ash storage facility. Obviously, fresh ash, as a larger product, is easier to classify, but it should be borne in mind that the moisture content of ash and slag can reach 45–50%.

At Prydniprovska TPP, a cumulative sample was taken for the stacked ash from section 4, and after drying and quarting , a more detailed analysis of its particle size distribution was performed (Table 6).

Table 6 – Indicators of fly ash in the ash dump of Prydniprovska TPP

Size class, mm	Yield, %
+0.2	0.5
-0.2+0.16	1.1
-0.16+0.1	4.9
-0.1+0.09	2.9
-0.09+0.074	9.1
-0.074+0.063	2.3
-0.063+0.05	32.4
Size class, mm	Yield, %
0.05+0.04	1.0
-0.04	45.8
Total	100

At the Kurakhivska TPP ash pond, fresh ash was sampled at two points near the pipeline mouth along the waste discharge fan. The stale ash samples were collected at three points located approximately in the middle of the ash pond, which has an elongated oval shape with a distance of 220 m between the most distant edges. These three sampling points are located on the cross-sectional line of the storage facility at a distance of 17–18 m to the sides of the storage facility and between the sampling points. These samples of fresh and stale ash were averaged by quarting and granulometric analysis was performed (Table 7).

Table 7 – Indicators of fly ash from the Kurakhivska TPP ash dump

Size,mm	Fresh ash	Stale ash
+0.25	2,5%	-
-0.25+0.1	14%	2.6%
-0.1+0.05	28.7%	12.9%
-0.05	54.8%	84.5%
Total	100%	100%

Table 7 shows that, compared to fresh ash, the fly ash from Kurakhivska TPP, as well as from Prydniprovska TPP, also has significantly fewer coarse classes and more fine ones. Field experiments at the Kurakhivska TPP ash pond showed that the lowest particle size of the stale ash is observed in the area of excess water discharge into the reservoir (Kazenyi Torets River). In this zone, the content of -0.05 mm classes was only 82% and the carbon content was also the lowest of all samples, 10.4–16%.

In general, for the two ash ponds, the data in Tables 5 and 7 clearly indicate that freshly poured ash is significantly coarser than the stale ash.

It is important that this cannot be explained by the presence of slag in the fresh ash, because the slag particle size is too high , and there are very few of its own small classes added to the fresh ash. Thus, Table 3 shows that the content of the smallest classes of -0.16 mm in slag is only 1.7%.

Thus, based on the comparison of fresh, freshly poured, and stacked ash, it should be concluded that the size of dry current ash is predominant compared to stacked ash.

Tests have shown that the size of the feedstock does not remain constant over the area of the ash dump and over the depth. Therefore, the comparison of raw materials from different ash dumps should be made for averaged samples taken on the same grid. Such sampling was carried out from a boat at the ash ponds of Kurakhivska and Prydniprovska TPPs, and the results of the particle size distribution analysis are shown in Table 8.

Table 8 – Fly ash by averaged samples

Prydniprovska TPP		Kurakhivska TPP	
Size, мм	Output , %	Size, мм	Output, %
+0.2	0.5	-0.63+0.25	0.83
-0.2+0.1	6	-0.25+0.1	6.42
-0.1+0.074	12	-0.1+0.074	10.17
-0.074+0.05	34.7	-0.074+0.05	8.0
-0.05	46.8	-0.05	74.58

As can be seen from Table 8, in contrast to dry fly ash, the largest classes in the stacked ash of both ash ponds are 0.2–0.25 mm and are very few in number. The share of the smaller classes of 0.05 mm in both ash ponds differs - 46.8 and 74.58%. This can be explained by the specifics of the technology and equipment, different size and grade of the coal burned. Nevertheless, it is possible to compare the granulometric composition of the raw materials accumulated in the studied ash storage facilities. This comparison should be made by the ratio of classes plus 0.074 and minus 0.074 mm. The results of Table 7 show that the ratio of these classes in both ash storage facilities is approximately the same and can be estimated as 20:80. Tests at ash ponds of other TPPs also indicate this ratio.

Thus, it was found that despite a significant difference in the size of dry fly ash from electrostatic precipitators at Prydniprovska and Kurakhivska TPPs, over time, under the destructive influence of the environment, the composition of ash in the two ash dumps becomes smaller and becomes similar, the ratio of +74 μm and -74 μm classes in the raw materials of both ash dumps is approximately estimated at 20 : 80, and the content of large classes of 0.2–0.25 mm is up to 1%.

The reason for the decrease in the size of the current dry ash during wet storage in the ash storage facility is natural temperature changes, mechanical effects of movement and pressure of the upper layers, as well as chemical transformations.

This picture indicates certain advantages of separate processing of dry flowing ash from the electrostatic precipitator bunker and dry removal slag compared to processing of ash and slag raw materials from the ash pond, since the latter is a finer product that is difficult for both classification and beneficiation.

In conclusion, we note that the carbon content of the fly ash from the ash dump at Prydniprovska TPP was 12–20%, and at Kurakhivska TPP it was on average 19–20%, with individual samples ranging from 10.4 to 37.9%.

5. Conclusions

1. It was found that the current dry fly ash from the electrostatic precipitators at the two studied TPPs - Prydniprovska and Kurakhivska - differs significantly in size.

At Prydniprovska TPP, the content of large classes -1+0.315 mm is 5.2%, and the content of small classes -0.074 mm is 81.4%. At Kurakhivska TPP, the coarse class of -5+1 mm is 14%, and the -0.074 micron class is only 3.5%. The different size of dry ash from electrostatic precipitators is usually explained by a number of reasons, first of all, the size and ash content of the coal burned, as well as the different technology and equipment used, including the blowing mode, temperature, and aerodynamics of smoke removal. In our case, the significantly different size of dry ash at the two TPPs is explained by the increased removal of dust, especially fine fractions, with the flues of Kurakhivska TPP due to the incomplete reconstruction of electrostatic precipitators at power units 7, 8, 9.

2. It was found that the weighted average particle size of TPP slag is 5.17 mm. It is represented by particles larger than 0.315 mm by 95.6%, the content of small classes -0.16 mm is 1.7%. The largest classes of -40+5 mm account for about a third (37.2%) of the total weight. The slag has the same strength as crushed stone grade M600. The content of magnetic inclusions is 8.5%, which is less than 6% of total iron. TPP slag can be divided into slag sand and slag crushed stone with a particle size of 5 mm in the ratio of 58.4 : 37,2 (%). They comply with the construction standards DST 25592-91, DST 26644-85, DSTU 9043:2020 for the production of concrete, cinder blocks, road construction and are ready-made commercial products.

3. It has been established that fresh ash , which has just been poured into the ash storage facility has a significantly higher particle size than ash that has been stored for a long time. At Prydniprovska TPP, the content of -0.074 mm fractions in fresh ash is 47.7%, and in stale ash 78.4%. At Kurakhovskaya TPP, the content of -0.05 mm in fresh ash is 54.8% and 84.5% in stale ash. The distribution of ash and slag in fresh ash is approximately 80:20, but the slag contains almost no of these fine classes. The analysis of fresh and stale ash indicates a higher particle size of dry current ash compared to stale ash.

4. It was found that, despite the different size of the current dry ash, ash and slag in the ash ponds of Prydniprovska and Kurakhivska TPPs acquire a similar size over time. Thus, for both ash ponds, the number of large classes of +0.25 mm does not exceed 1%, and the ratio of +74 microns to -74 microns is estimated at 20:80. During wet storage, TPP waste becomes smaller due to the destructive effects of the environment, including mechanical stresses under the weight of raw material layers and during the movement of layers due to power supply and drainage flows, annual temperature changes, chemical reactions during long-term wet storage, etc. For the classification of stacked ash, vibrating screening with replaceable meshes of a special design [6, 7] has an advantage over hydraulic classification in hydrocyclones and centrifuges due to the possibility of separating separate narrow size range with high content of unburned coal.

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ГРАНУЛОМЕТРИЧНИЙ СКЛАД ВІДХОДІВ ТЕПЛОВИХ ЕЛЕКТРОСТАНЦІЙ

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Анотація. Безпосереднє використання відходів ТЕС в будівництві стримується існуючими нормами і стандартами на бетон, цеглу та інші вироби. Золошлакова сировина потребує доробки, в першу чергу класифікації за крупністю. Досліджувались відходи Придніпровської і Курахівської ТЕС: суха поточна зола виносу, шлак і лежала зола із золосховища мокрого зберігання, вони розглядалися як три окремих продукти. Мета даного дослідження полягає в встановленні особливостей гранулометричного складу зазначених відходів на прикладі Придніпровської та Курахівської ТЕС. Це необхідно для визначення перспективи використання цих відходів і розробки відповідних технологій переробки. В результаті досліджень було встановлено, що поточна суха зола виносу з електрофільтрів і циклонів на двох досліджуваних ТЕС суттєво різниться за гранулометричним складом завдяки різній крупності і зольності спалюваного вугілля, різному температурному режиму, режиму дуття, виносу димів тощо. Встановлені фізико-технічні характеристики шлаку, показники крупності і вмісту заліза, які показали можливість його безпосереднього використання в якості щебню середньої міцності марки М600 в будівництві. Свіжа, тільки що злита у золосховище зола має суттєво вищу крупність, ніж лежала протягом тривалого часу. Це не пов'язане з присутністю шлаку в свіжій золі, бо в шлаку вміст найдрібніших класів -0,16 мм становить 1,7%. Це підтверджує більш високу крупність сухої поточної золи порівняно з лежалою. Встановлено, що хоча суха зола Курахівської і Придніпровської ТЕС різна за складом, але з часом під руйнівним впливом середовища на обох золосховищах вона набуває меншої крупності і її склад стає подібним. В усереднених пробах кількість крупних класів +0,25 мм не перевищує 1%, співвідношення класів +74 мк і -74 мк приблизно оцінюється як 20 : 80. Причиною зниження крупності відходів при тривалому мокрому зберіганні є річні перепади температур, хімічні реакції, механічні напруження під вагою верхніх шарів і при пересуванні сировини. Для класифікації сухої і лежалої золи вібраційне грохочення має перевагу над іншими способами завдяки високій ефективності і можливості виділення окремих вузьких класів з високим вмістом недопалу вугілля.

Ключові слова: зола виносу, шлак, золошлакові відходи.