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DETERMINING THE POSSIBILITIES OF USING FLY ASH ON THE EXAMPLE OF THE DTEK PRYDNIPROVSKA TPP

Lapshyn Ye., Shevchenko O.

M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine

Abstract. The fuel and energy complex facilities of Ukraine are potentially dangerous sources of environmental pollution and pose risks to the health of the population living in adjacent territories. At the same time, ash and slag waste accumulated over many years has a unique mineral composition and often has a complex distribution of useful components that is not typical for natural deposits, representing, in fact, man-made deposits. Their processing allows solving environmental and economic problems. Based on developments in the field of using ash waste from thermal power plants operating on local types of fuel, it is possible to solve problems of resource and energy conservation, for example, in the energy sector and construction, which is a relevant area of research. In terms of chemical composition, ash waste is a complex mixture of various, mainly mineral substances, and their content depends on the composition of the fuel. With appropriate methods of use and available technologies, ash waste becomes a high-quality, cheap, wear-resistant, frost-resistant substitute for natural materials, with binding properties that are used in world practice in the production of concrete, bricks, construction, asphalt concrete mixtures, ceramic tiles, thermal insulation, etc. The conducted studies of the characteristics of fresh (dry) fly ash of DTEK Prydniprovska TPP showed the prospects of processing, the products of which are of industrial interest. Since the ash is a carbon-silicate mass, it is necessary to separate it into components (carbon - silicates). The results of the studies indicate the fundamental possibility of obtaining low-ash coal concentrate from fly ash by fine classification. It was found that the ashiest part is contained in the class +0–0.02 mm and varies from 44.97% to 81.47%. If the classification is carried out by the boundary size of 0.02 mm, it is possible to additionally extract from 5% to 16% of carbon with standard ash content. The carbon content in the undersize product (silicate part with a particle size of less than 0.02 mm) can be reduced to 8–12%, i.e. 3–3.5 times less than in the original product. The obtained carbon is suitable for obtaining coal-water fuel, and silicates are suitable for forming building mixtures and structures. The processing process is technologically possible, economically feasible and will allow: to reduce the need for additional allocation of useful land areas and construction of protective structures; to reduce operating costs affecting the cost of electricity generation; to implement the return of carbon extracted from ash; to reduce the volumes of purchased coal and transportation costs for its delivery from the station; to obtain additional products for the construction industry. Recycling of ash and slag waste (ASW) allows reducing the negative impact of existing ash dumps on the environment by reducing the volumes of their storage.

Keywords: coal, ash and slag waste from thermal power plants, coal combustion products, fly ash, processing experience, fly ash processing, classification.

1. Introduction

Every year, in the world, simultaneously with the generation of thermal and electrical energy as a result of the combustion of solid fuel at thermal power plants (TPPs) and combined heat and power plants (CHPs) [1–4], ash and slag waste is generated, which is produced in large quantities and poses a serious environmental hazard [5]. Fuel and energy complex facilities of TPPs and CHPPs are among the main sources of environmental pollution. The impact of toxic substances contained in ASW storage sites on the environment and the human body is analyzed in [5–18].

At the same time, ash and slag waste accumulated over many years has a unique mineral composition and often has a complex distribution of useful components that is not typical for natural deposits, representing, in essence, man-made deposits [19, 20].

In industrially developed countries of the world, such as the European Union, the USA and others, the utilization of ASW is an integral part of the technological process of coal thermal power plants, which involves the involvement of various types of waste in new technological cycles or their use for other useful purposes. This problem, which is the most important element in the overall chain of creating waste-free production systems, is given much attention both in our country and abroad [21–29].

In the process of utilization, ash and slag waste can be used as secondary raw materials. Based on the analysis of the review of world experience in processing ash and slag waste [18, 30], the main areas of their use are: filling of disused mines and quarries; construction (construction products); road works (fillers for road materials and asphalt fillers); agriculture; purification of wastewater from various industrial sources, etc. The world experience of ASW processing is useful and very relevant for Ukraine, given the huge volumes and low degree of their utilization in our country. The search for promising areas of using energy complex waste and new sales markets is an urgent need not only for Ukraine, but for any economically developed state.

2. Methods

The following methods were used in this study: analytical review of literary sources, comparative analysis; experimental studies; study of the composition of fly ash, as well as the possibilities and prospects of its use. Information resources of the Internet were used in the analysis of the state of the issue.

The aim of the work is to determine the possibilities of using fly ash as both energy and construction raw materials using the example of the DTEK Prydniprovska TPP.

Research object: fly ash of the DTEK Prydniprovska TPP.

To achieve the set goal, the following tasks were solved:

– an analysis of the properties, composition of ASW and the directions of their processing in international practice, as well as the results obtained, was performed;

– a study of the properties of fly ash (smoke filtrate) of the DTEK Prydniprovska TPP was conducted;

– the possibility of obtaining additional raw materials from ash was studied;

– promising areas of application of fly ash as additional raw materials were identified.

3. Theoretical and experimental parts

Analysis of the properties, composition of ASW and directions of their processing in international practice, as well as the results obtained.

During the combustion process of fuel, complex chemical and phase transformations of its mineral matter occur, resulting in the formation of substances with new properties [19, 20]. The main nomenclature of coal combustion waste products (in foreign publications – coal combustion products (CCW) or coal combustion by-products (CCPs)) include [31, 32]: bottom ash; boiler slag; phosphogypsum (FGD gypsum); fly ash; semi-dry absorption product (SDA Product). Fly ash (FA) (as synonyms, taking into account publications, also used are TPPs ash – TA, coal ash – CA, smoke filtrate – SF) is the largest type of waste (75–80% of ASW) [33]. The size of ash particles varies from 3-5 to 100–150 μm. The amount of larger particles usually does not exceed 10–15%. Ash is removed by hydro transportation into storage tanks, and slag is sent to dumps [18, 30].

The main components of ash and slag materials are oxides: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO. A small proportion is accounted for by sulfates $CaSO_4$, $MgSO_4$, $FeSO_4$; phosphates and alkali metal oxides are present in smaller quantities. Ash contains almost all the elements of the periodic table of D.I. Mendeleyev. The composition of ash varies greatly depending on the type of coal used, combustion technology and waste disposal. Ash from the same type of coal has different properties, especially from different types of coal. Almost all ashes contain organic inclusions (underburning) in the form of coke and semi-coke – either as independent particles or inclusions in large fractions of ash [19, 20].

From the review [18, 30] it was found that in countries such as the USA, EU, Japan, fuel combustion and waste disposal technologies allow obtaining ash with characteristics that meet local regulatory requirements, which after some processing can be shipped to the consumer. In recent years, in developed countries, due to the stimulation of ASW processing, the degree of ash utilization has been from 70 to 100%; in Western Europe and Japan, ash dumps have been virtually eliminated at thermal power plants. More and more attention is being paid to expanding the areas of their use as useful materials. Tightening environmental legislation in developed and developing countries forces the processing of ash and finding its rational use. In developed countries, the level of utilization is 5–7 times higher than in developing countries [27, 34–36].

In India, China, Kazakhstan, Kyrgyzstan, Uzbekistan, and Ukraine, as a result of fuel combustion, ash is obtained with a content of unburned coal higher than regulatory requirements. For example, in China, the widespread use of fly ash curbs the unburned carbon content, which traditionally ranges from 2–12%. According to the Chinese national standard GB/T 477-2008 (Fly ash used in cement and concrete), its amount should be less than 5%. This creates a major problem for the efficiency of enrichment and the selection of equipment [28, 37].

The output of ash from Ukrainian thermal power plants is about 8-10 million tons/year. During the operation of thermal power plants, millions of tons of ash have accumulated. Its existing dumps are overloaded, have large areas and require significant operating costs, affecting the cost of electricity production. The constant growth of ash dumps requires additional allocation of useful lands, building up protective structures. A comprehensive approach is required to solve this problem.

Ash from coal thermal power plants in Ukraine contains carbon in quantities from 5% to 30%, which does not allow the use of ash in the construction industry in large quantities (for concrete – prohibited by standards) [38, 39]. Therefore, technologies are needed that allow the use of ash with a high carbon content to obtain a useful product, or to improve the quality of ash to the indicators required by standards for widespread use in the construction industry.

In works [38, 39] it is proposed to use ash from thermal power plants as: fuel by gasification; sorbents for cleaning gases from power engineering, metallurgy, petro chemistry, cement and waste incineration plants and binders for stabilizing solid products of gas cleaning; binders for sand-lime and concrete bricks, autoclaved aerated concrete and others; asphalt concrete for road and repair work with low energy intensity, greater durability.

For the second option, it is necessary to reduce the carbon content to standard values, for example, by classifying and separating the size classes that contain the maximum amount of coal. To do this, it is necessary to study the characteristics of the ash and establish the required boundary size of separation.

Considering the diversity of rocks containing coal seams and their mineralogical composition, the development of technology for deep enrichment of fly ash in order to extract useful minerals and metals is of practical interest. For example, it is known that the host rocks contain aluminum, germanium, and iron in quantities of industrial interest. For their extraction as raw materials and industrial development of enrichment processes, additional research is needed to develop technologies and a feasibility study for each specific man-made ash dump [40].

This paper examines the issue of determining the possibilities of using fly ash as both an energy and construction raw material using the example of the DTEK Prydniprovska TPP, which is located on the banks of the Dnipro River and within the city of Dnipro. The waste accumulated in dumps in the area of the thermal power plant poses a serious danger to the natural environment. The volume of dust and filtration of ash dumps are a potential source of danger to public health and a threat to the flora and fauna of nearby areas, the waters of the Dnipro River and the Shyianka River flowing into it. The lands occupied by ash dumps are large (at the Prydniprovska hydroelectric power station more than 200 hectares) and require significant operating costs, which affect the increase in the cost of electricity production. As the amount of ash waste increases (more than 0.5 million tons of ash are generated annually), the area of territories allocated for ash dumps also increases, which leads to the withdrawal of useful land from industrial and agricultural production, requires the construction of protective dams on the side of the Dnipro River [40].

The chemical composition of ash waste depends on the deposit, section and seam from which the coal was mined, on the combustion mode, on the ash removal method, as well as on the duration of the ash waste's stay in the ash dump, which determines the main areas of its use. The operational (during combustion) and consumer (in building materials, etc.) properties of ash depend on the ratio of acidic and basic components [40].

Determination of the area of utilization of ash materials should be based on a detailed study of the fractional composition and properties of the ash.

Technological characteristics of the coal combustion scheme at the DTEK Prydniprovska TPP and the composition of fly ash (smoke filtrate).

Tables 1–4 show the technological characteristics of the coal combustion system at the DTEK Prydniprovska TPP and the results of studies of the properties of fly ash (smoke filtrate) (Dnipro city, Dnipropetrovsk region) (data obtained in the TPP laboratory).

As can be seen from Tables 1-4, in the mineral part of the ash from the DTEK Prydniprovska TPP, silicates make up, on average, 50-54%, there is a high content of aluminum (23–28%), iron (8–15%), as well as a relatively high content of unburned carbon (up to 25%).

Table 1 – Technological characteristics of the coal combustion circuit of the ASH at the DTEK Prydniprovska TPP

Coal consumption per year, tons	1 658 275
Number of bunkers, pieces	32
Specific density, kg/m³	2200
Productivity of one boiler feeder, t/h	5
Productivity of all boiler feeders, t/h	120
Ash yield, %	20

Table 2 – Main properties of ash from coal combustion at the DTEK Prydniprovska TPP

Density, kg/m^3	2200-2450
Bulk density, kg/m^3	760-1000
Specific surface, m^2/kg	200-700
Water absorption, %	20-40
Water demand (at normal density), %	24-33
Content of unburned residues, %	12-20
Residue on sieve with mesh No. 008, not more than, %	20
Content of silicon dioxide, not less than, %	40
Content of sulfur and sulfuric acid compounds in terms of SO_3, no more than,%	5
Average chemical composition of the mineral part of ash, %	
SiO_3	50-54
Al_2O_3	23-28
Fe_2O_3	8-15
FeO	0.5-2
CaO	2-5
MgO	1.0-3.0
SO_3	0.7-1.5
K_2O+Na_2O	2.0-4.5
TiO_2	0.7-1.0

Table 3 – Fractional analysis of ash from the DTEK Prydniprovska TPP (sample 1)

Size classes, mm	>1	+0.5–1.0	+0.25–0.5	+0.1–0.25	+0.08–0.1	+0.05–0.08	+0.02–0.05	<0.02
Output classes, %	0.07	0.2	2.3	11.6	10.3	18.4	53.4	3.8

Table 4 – Granulometric properties of ash from DTEK Prydniprovska TPP (sample 2) (source material with ash content of 80%)

Size classes, mm	+0.16–0.2	+0.125–0.16	+0.08–0.1	+0.063–0.08	+0.04–0.05	+0–0.04
Output classes, %	0.12	1.1	9.5	11	3	75
Ash content of classes, %	35.62	29.06	32.58	37.21	51.57	95

The work [40] presents the results of studies aimed at extracting iron, aluminum, and silicates. Considering that the products of ash processing have a finely dispersed fraction, convenient for further use, this eliminates expensive operations for preparing raw materials. For example, the resulting iron and aluminum powders are suitable for producing parts and units using the pressing method [41].

The high content of unburned carbon in the ash (underburning) indicates the feasibility of separating the carbon and silicate portion with subsequent sale of these products. The resulting carbon is suitable for producing coal-water fuel, and silicates for widespread use in the construction industry. The efficiency of such a solution is very high, since the return of carbon extracted from the ash, with daily consumption at thermal power plants of about a thousand tons, allows for a reduction in the amount of purchased coal and transportation costs for its delivery to stations [40].

Discussion of the results and prospects for the use of fly ash.

In order to establish the boundary size of separation for maximum extraction of coal, it is necessary to clarify its content in size classes, i.e., a detailing of its distribution is needed. For this purpose, specialists from the M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM of the NAS of Ukraine), in laboratory conditions, using the method described in [42], conducted studies of the properties of dry fresh ash obtained immediately after burning coal, i.e. before its storage. Table 5 shows the results of averaged (based on the results of 5 samples) characteristics of ash samples.

Table 5 – Properties of ash from DTEK Prydniprovska TPP
(source material with ash content of 71.93%)

Size classes, mm	Output class γ, %	Ash content of class A^d, %	Amount of ash C_a, %	Amount of coal C_c, %
+1.0-1.6	0.03	92,82	0.028	0.002
+0.63-1.0	0.05	89.23	0.045	0.005
+0.315-0.63	0.63	59.90	0.377	0.253
+0.2-0.315	4.21	55.07	2.318	1.892
+0.1-0.2	8.67	45.25	3.923	4.747
+0.05-0.1	8.42	52.94	4.458	3.962
+0.02-0.05	9.23	53.35	4.924	4.306
+0-0.02	68.76	81.24	55.86	12.9
Σ	100.0		71.93	28.07

Research (see Table 5) has established that the highest carbon content in ash is in the size classes from -0.315 mm to +0.02 mm inclusive. If the +0.02 mm classes are separated from fly ash, it is possible to obtain low-ash coal concentrate with a coal content of 15.17% with an ash content of 16.07% (meets regulatory requirements).

For this purpose, a new vibratory impact screen [43–45] has been developed at the IGTM of the NAS of Ukraine, which allows for the effective classification of fine-grained materials. Laboratory tests have shown that the use of such screens for fine classification allows for the extraction of the maximum amount of coal from ash and its use for power engineering. The remaining silicate mass can be used for the production of building mixtures and structures.

Figure 1 shows a classification scheme for fly ash.

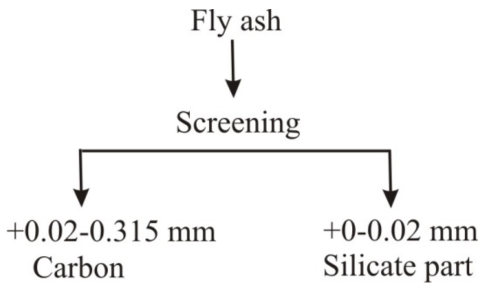

Figure 1 – Fly ash classification scheme

Considering the different grades of coal and the composition of the host rocks in ash storage facilities, the technology and equipment in each specific case must be adjusted for maximum screening efficiency.

It should be noted that at the TPP there is dry fresh ash obtained immediately after burning coal, i.e. before its storage, and ash from many-year-old (compacted) dumps. The technologies for processing fresh and dumps fly ash differ, since dump ash is a compacted rock that requires preliminary preparation for processing. Therefore, at this stage, the properties of dry fresh ash were studied, since it is a finished product for processing and subsequent disposal. Processing of this product is necessary to eliminate the replenishment of the ash dump, and the already accumulated dumps should be considered man-made and suitable for subsequent complex additional enrichment. During laboratory studies it was noted that there is a significant part of clay in the +0–0.02 mm classes. It was found that the most ash part is contained in the +0–0.02 mm class from 44.97% to 81.47%. If the classification is carried out according to the boundary size of 0.02 mm, it is possible to additionally extract from 5 to 16% of carbon with the standard ash content. As a result of separation, the carbon content in the undersize product (silicate part with a particle size of less than 0.02 mm) can be reduced to 8–12%, i.e. 3–3.5 times less than in the original product.

The conducted studies show that the products of dry fly ash processing are the silicate part and carbon. The carbon part is presented in the form of dust-like particles of coke, which after extraction from the ash can be returned for further combustion. This saves on the consumption of incoming coal.

The silicate part of the ash requires additional research, since its mineralogical composition, its value and the feasibility of including it in the technology of complex processing for subsequent utilization have not been determined. It should be noted that dry ash does not require dehydration and drying, additional transportation to the place of additional enrichment. When processing dry ash, an important factor is the cessation of the build-up of fly ash dumps.

4. Conclusion

Thus, the presented results show that the fuel and energy complex facilities of Ukraine are relate potentially dangerous sources of environmental pollution and create risks for the health of the population living in adjacent territories. At the same time, ash and slag waste accumulated over many years has a unique mineral composition and often has a complex distribution of useful components that is not typical for natural deposits, representing, in essence, man-made deposits. Their processing allows solving environmental and economic problems. Based on developments in the field of using waste ash from thermal power plants operating on local types of fuel, it is possible to solve problems of resource and energy conservation, for example, in the energy sector and construction, which is a relevant area of research.

In terms of chemical composition, ash waste is a complex mixture of various, primarily mineral, substances, and their content depends on the composition of the fuel. With appropriate methods of use and available technologies, ASW becomes a high-quality, inexpensive, wear-resistant, frost-resistant substitute for natural materials, having binding properties that are used in world practice in the production of concrete, bricks, construction, asphalt concrete mixtures, ceramic tiles, thermal insulation, etc.

The conducted studies of the characteristics of fresh (dry) fly ash from DTEK Prydniprovska TPP showed the prospects of its processing, the products of which are of industrial interest. Since ash is a carbon-silicate mass, it is necessary to separate it into its components (carbon – silicates). The results of the studies indicate the fundamental possibility of obtaining low-ash coal concentrate from fly ash by fine classification. It has been established that the largest ash content from 44.97% to 81.47% is contained in the +0–0.02 mm class. If the classification is carried out according to the boundary size of 0.02 mm, it is possible to additionally extract from 5 to 16% of carbon with the standard ash content. The carbon content in the undersize product (silicate part with particle size less than 0.02 mm) can be reduced to 8–12%, i.e. 3–3.5 times less than in the original product. The resulting carbon is suitable for producing coal-water fuel, and the silicates are suitable for forming building mixtures and structures. The recycling process is technologically feasible, economically feasible and will allow: to reduce the need for additional allocation of useful land areas and construction of protective structures; to reduce operating costs that affect the cost of electricity generation; to implement the return of carbon extracted from ash; to reduce the volumes of purchased coal and transportation costs for its delivery to stations; to obtain additional products for the construction industry. Recycling of ash dumps helps reduce the negative impact of existing ash dumps on the environment by reducing the volume of their storage.

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About the authors

Lapshyn Yevhen, Doctor of Technical Sciences (D.Sc.), Senior Researcher, Principal Researcher in Department Ecology of Natural Resources Development, M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, 19481948les@gmail.com ORCID ***0000-0002-5443-5566***

Shevchenko Oleksandr, Doctor of Technical Sciences (D.Sc.), Senior Researcher, Senior Researcher in Department of Geomechanical Basis of Open-Pit Technology, M.C. Poliakov Institute of Geotechnical Mechanics of the National Academy of Science of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, igtm.aishevchenko@gmail.com ORCID ***0000-0003-2630-0186***

ВИЗНАЧЕННЯ МОЖЛИВОСТЕЙ ВИКОРИСТАННЯ ЛЕТУЧОЇ ЗОЛИ НА ПРИКЛАДІ ДТЕК ПРИДНІПРОВСЬКОЇ ТЕС

Лапшин Є., Шевченко О.

Анотація. Об'єкти паливно-енергетичного комплексу України належать до потенційно небезпечних джерел забруднення природного середовища та створюють ризики для здоров'я населення, яке проживає на прилеглих територіях. Разом з тим накопичені на них за багато років золошлакові відходи мають унікальний мінеральний склад і найчастіше складний, нехарактерний для природних родовищ розподіл корисних компонентів, представляючи, по суті, техногенні родовища. Їхня переробка дозволяє вирішувати екологічні та економічні проблеми. На основі розробок у галузі використання золовідходів ТЕС, що працюють на місцевих видах палива, можливе вирішення проблем ресурсо- та енергозбереження, наприклад, в енергетичній сфері та будівництві, що є актуальним напрямом досліджень. За хімічним складом золовідходи є складною сумішшю різних, переважно мінеральних речовин, вміст яких залежить від складу палива. При відповідних методиках використання та доступних технологіях ЗШО стають якісними, дешевими, зносостійкими, морозостійкими замінниками природних матеріалів, що мають в'яжучі властивості, які у світовій практиці використовуються у виробництві бетонів, цегли, будівельних, асфальтобетонних сумішей, керамічної плитки, теплоізоляції, тощо. Проведені дослідження характеристик свіжої (сухої) летучої золи ДТЕК Придніпровської ТЕС показали перспективність її переробки, продукти якої становлять промисловий інтерес. Оскільки зола є вуглецево - силікатною масою, необхідно її розділити на складові (вуглець - силікати). Результати досліджень свідчать про принципову можливість отримання малозольного вугільного концентрату з летючої золи шляхом тонкої класифікації. Встановлено, що найбільш зольна частина міститься у класі +0–0,02 мм і змінюється від 44,97% до 81,47 %. Якщо класифікацію здійснювати за граничною крупністю 0,02 мм, можна додатково витягти від 5% до 16% вуглецю за нормативної зольності. Вміст вуглецю в підрешітному продукті (силікатна частина із крупністю частинок менше 0,02 мм) можна знизити до 8–12%, тобто у 3–3,5 разів менше ніж у вихідному продукті. Отриманий вуглець придатний для одержання водовугільного палива, а силікати – для формування будівельних сумішей та конструкцій. Процес переробки технологічно можливий, економічно доцільний і дозволить: скоротити потребу у додатковому відведенні корисних земельних площ та зведенні захисних споруд; знизити експлуатаційні витрати, що впливають на собівартість вироблення електроенергії; реалізувати повернення вуглецю, витягнутого із золи; скоротити обсяги вугілля, що закуповується, і транспортні витрати на його доставку зі станції; одержати додаткову продукцію для будівельної галузі. Вторинна переробка ЗШО дозволяє знизити негативний вплив існуючих золовідвалів на довкілля за рахунок зменшення обсягів їх складування.

Ключові слова: вугілля, золошлакові відходи теплових електростанцій, продукти згоряння вугілля, летюча зола, досвід переробки, переробка летючої золи, класифікація.