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APPLICATION OF SLAG FROM THERMAL POWER PLANT FOR THE PRODUCTION OF POROUS FILLER

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Abstract. The article is devoted to obtaining a porous filler from the slag of the Thermal Power Plant and investigation of the filtration method for the drying of slag and clay as main raw materials for preparing the charge for porous filler production.
The possibility of using TPP slag as the raw material for the production of porous filler has been proved. The main benefits of using such wastes in the production process are environmental protection, conservation of raw resources for the production of finished products. According to the results of the research, insignificant values of the pressure drop confirm the application feasibility of the filtration drying as an energy-saving method of the drying of slag and clay for preparing the charge for porous filler production. The influence of the temperature of the drying agent in the range from 313 to 373K on kinetic during filtration drying of slag and clay has been established. Obtained results are useful for the organization and intensification of the filtration drying process of slag and clay as the preliminary stage at the porous fillers production line. The qualitative new porous filler with the bulk density of 230 kg/m^3, the specific heat of 0.82 kJ/kg·K, the thermal conductivity of 0.067 W/m·K and compressive strength of 27.7 MPa has been obtained which can be used for the production of lightweight concretes.

Key words: thermal power plant (TPP), coal combustion, ash and slag wastes, utilization, raw materials, additives, chemical composition, porous filler, drying methods, drying agent, porous filler, lightweight concrete.

1. Introduction

In recent years, the growing demand for electricity and heat has increased the number of worldwide thermal power plants (TPP). In Ukraine, the share of electricity production between the stations of different types is TPP – 65.57; NPP – 25.83; HPP – 2.37; other power plants – 0.03 (Pohrebennyk, 2016). The largest TPPs are located in Prydniprovye (Prydniprovska, Krivorozhska), Kharkiv (Zmiyivska), Kyiv (Tripilska), Ivano-Frankivsk (Burshtynska), Lviv (Dobrotvirska) regions, in Zaporizhya, Odessa and others.

The operation of power plants leads to air pollution and the accumulation of a significant amount of solid wastes such as slag and ash which are formed as a result of solid fuel combustion, especially coal, and are stored in ash slag dumps. Ukraine annually accumulates 8 million tons of ash and slag wastes, covering an area of over 22 thousand hectares. TPP, with a capacity of 1 million kilowatts, burns about 10.000 tons of coal with a yield of 1,000 tons of slag and ash disposition of which at the height of dump not more than 8 meters requires about 1 hectare (Yatsyshyn et al., 2018).

The chemical composition of the organic components of ash slag differs significantly from the carbonaceous substance of the source fuel and are coke and semi-coke containing aromatic hydrocarbons. The range of aromatic hydrocarbons that are part of the organic part of slag is quite broad and comprises toxic substances of different hazard classes. All these substances have mutagenic properties. The most significant slag contains substances belonging to hazard class IV are: naphthalene, acenaphthylene, phenanthrene and pyrene (Delitzin et al., 2012).

It should be noted that toxic trace elements that are part of ash slag can contaminate air, soil and groundwater, with further potential environmental and health impacts and risks. They can get into the air due to

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the high dispersion of ash and slag dust. During the ash and slag waste storage facilities of thermal power plants, environmental damage is caused by a dusting of dry ash on the landfill surface and filtration of water through a weakly shielded dump bed. Water-soluble microelements which are in mobile forms can pass into the water (Yatsyshyn, 2013). Contamination of water is hazardous in view of the quick inclusion of toxic components into the biosphere, for example, in the food chain: water → algae → invertebrates → fish → animals → humans. The content of dangerous trace elements in algae, invertebrates and fish can exceed their concentration in the source water by 10–100 times. When entering the biosphere, toxic components accumulate and their effect is enhanced (Miakaieva, 2018).

Most of the ash and slag dumps of Ukrainian thermal power plants are practically filled, and there is no possibility to expand them due to lack of territory. At the current rate of generation of these wastes, the opportunities for their storage can be exhausted in 5–7 years at most enterprises. Therefore, environmental management of ash slag is essential for individual thermal energy companies and Ukraine as a whole and finding the methods of waste utilization is an essential task.

One of the rational methods of slag and fly ash utilization is to involve them in the production process, which corresponds to current trends in technology in industrialized countries (Cheng, Chen 2004; Work attachments, 2021).World experience to use ash and slag as concrete admixtures, road construction materials, raw materials and additives for cement production, concrete blocks, fillers and many other products is presented in the diagram (Fig. 1).

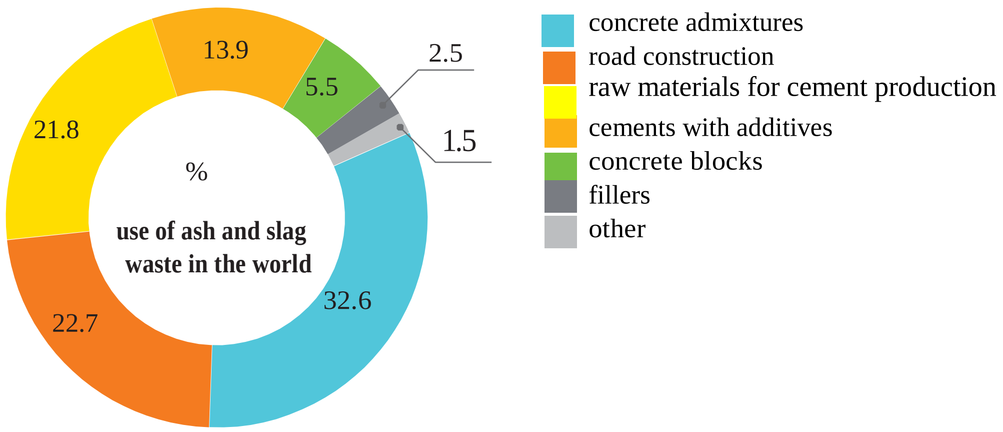

Fig. 1. World experience in the use of ash and slag materials

Developed countries have not only learned to dispose ash and slag safely but also benefit from it. Utilization of ash slag in the United States is 80 % of their formation; in Germany, ash slag is mainly used in unbound impurities for embankment or dam construction; in the UK, most ash slag is used as an impurity in pavement structures; in France and Poland, ash slag is mostly used for the road construction (Work attachments, 2021).

In order to develop cost-effective organizational and technical solutions for the management of the solid wastes of TPP, the experience of developed countries was taken into account and separate removal of ash and slag was introduced at some TPPs of Ukraine. This technical solution allows using dry ash as an additive for concrete, mortar, cement, as well as to using it for the production of silicate products, glass ceramics and road construction (Cheng, Chen 2004; Ciocinta et al., 2012)

One of the most efficient methods to reduce the slag volume is to transform it into potential resources. Slag which is formed in large quantities in coal-fired thermal power plants is considered an attractive material for developing cost-effective ceramics and fillers for light concretes creating new market opportunities. However, its humidity is very high caused by the hydraulic method of removal and transportation to the dumps. Therefore, only a small amount of slag is used for industrial purposes.

2. Statement of the problem and its solution

Currently, clay gravel is the most common artificial porous filler. At the same time, reserves of well-bloating clay rocks as the raw materials for its production are decreasing every year. Therefore, the use of slags of TPP in the production of artificial porous fillers becomes important (Mammadov, Gadirov, 2018).

Slag and clay, as the raw materials for industrial purposes, should be dried in view of their high moisture content. Belt, rotary and fluidized bed dryers are commonly used in the industry for the drying processes of dispersed materials and the large consumption of energy is the main disadvantage of such kind of equipment (Kindzera et al., 2020). Since the cost of drying is significant, finding alternative drying methods with designing new constructions of dryers is an urgent task.

Therefore, to implement the drying process of slag and clay, we propose the filtration drying method. Generally, during the operation of filtration dryers, the drying agent is blown down through the complex network of channels of different diameters and considerable length formed by voids between the particles of the material located on a perforated belt. The developed surface of the fixed bed facilitates good contact between the drying agent and material particles, so almost all heat energy remains in the material layer intensifying the heat and mass exchanging processes and as a result, reducing the drying time and energy loss with the out-coming drying agent.

The aim of this work is the analysis of the chemical composition of TPP slag with purposes to use it for porous filler production; investigation of the hydrodynamics and kinetics of the filtration drying process of slag and clay as the raw materials for preparing the charge; preparation of porous filler samples and determination of three physical-mechanical properties.

3. Experimental part

3.1. Materials

Slag of the Thermal Power Plant. The chemical composition of Burshtyn TPP slag is given in Table 1. The initial humidity of slag is 28 %.

In landfills, there is a heterogeneity of slag properties in grain composition, bulk density, the number of unburned coal particles, and so on. The granulometric content of slag was determined by the sieve analysis according to which slag particles were divided into six grades. The particle size distribution of slag is presented in Fig. 2.

Table 1

The chemical composition of TPP slag*

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3	K_2O	Na_2O
50.7 %	21.3 %	20.6 %	0.8 %	2.9 %	1.2 %	0.3 %	0.7 %	1.5 %

*Results given by the laboratory of waste utilization of Burshtyn TPP (Ukraine).

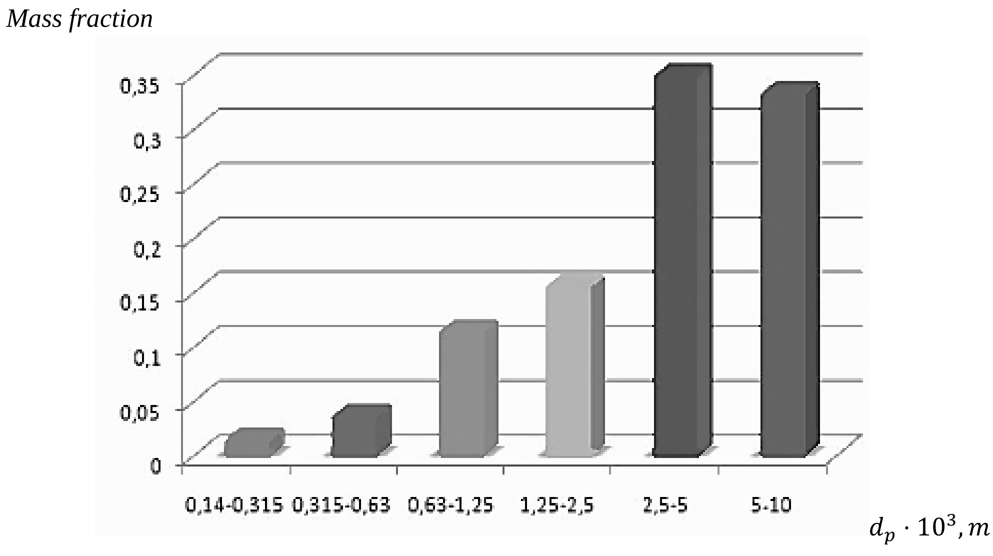

Fig. 2. Particle size distribution of slag

The fixed bed of the material was generated in a chamber with an internal diameter of 97 mm. The main characteristics of the fixed bed formed by TPP slag such as the bulk density ρ_(bulk.,) kg/m^3, the porosity ε, m^3/m^3, the specific surface area a, m^2/m^3 and the equivalent diameter of the channels de, m were determined according to standard methods and are presented in Table 2.

Clay. Clay of "Burshtyn" clay quarry was used for the experimental research. The initial humidity of clay is 36 %. The chemical composition of clay is presented in Table 3.

The granulometric content of clay determined by the sieve analysis is presented in Fig. 3.

The main characteristics of the fixed bed formed by clay were determined and are presented in Table 4.

Table 2

The main characteristics of the fixed bed formed by TPP slag

$d_p \cdot 10^3, m$	$d_e \cdot 10^4, m$	$\rho_{bulk.}, kg/m^3$	$\varepsilon, m^3/m^3$	a, m^2/m^3
2.08	7.47	1350	0.35	2250

Table 3

The chemical composition of clay *

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3	K_2O	Na_2O
64.5 %	11.3 %	6.5 %	0.4 %	10.0 %	2.9 %	0.5 %	1.0 %	2.9 %

*Results given by the laboratory of waste utilization of Burshtyn TPP (Ukraine).

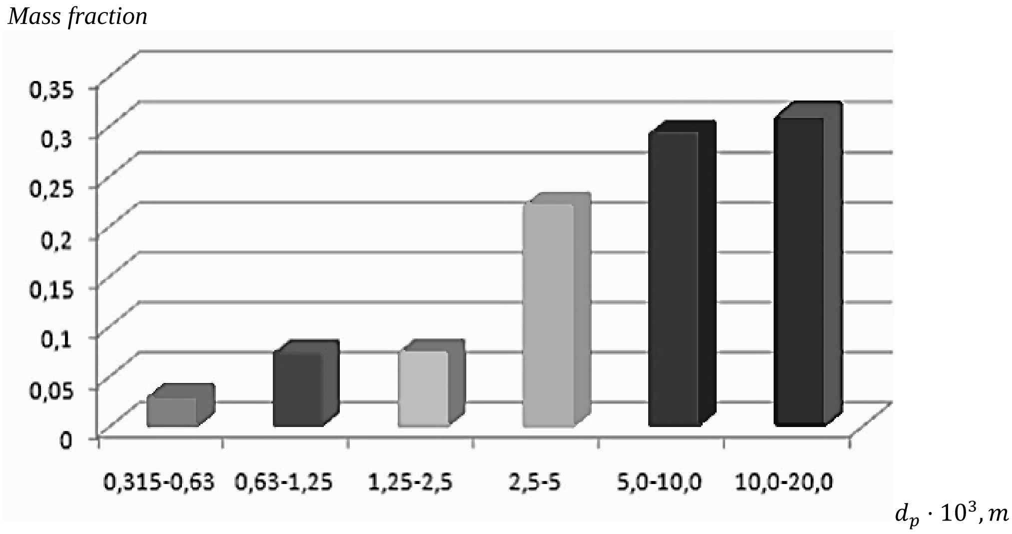

Fig. 3. Particle size distribution of clay

Table 4

Main characteristics of the fixed bed formed by clay

$d_p \cdot 10^3, m$	$d_e \cdot 10^4, m$	$\rho_{bulk.}, kg/m^3$	$\varepsilon, m^3/m^3$	a, m^2/m^3
3.35	12.03	1170	0.35	1180

3.2. Experimental procedure

The investigation of the hydrodynamics and kinetics of the drying process of slag and clay by the filtration method was performed using the experimental plant. For the experimental study of the hydrodynamics, the fixed bed of different heights made of slag as well as clay were formed in a cylindrical chamber and an airflow, as the drying agent, was supplied to it using an air pump. Different consumptions of drying agent through the fixed bed were set and were registered by the electronic flow-meter. The pressure drop was determined by the electronic vacuum gauge.

For the kinetics investigation, the air was heated by a heater and supplied to the chamber with the fixed bed of material. The drying agent velocity of 1.33 m/s and the fixed bed height of 0,12m were used as constant (were identified in previous studies as optimal). A set of experiments was performed for the temperatures of the drying agent from 313 up to 373 K. To determine the loss of weight during the drying process, analytical scales were used. The experiments were carried out till the material weight became constant.

4. Results and Discussions

Comparing the chemical composition of clay and slag of Burshtyn TPP, we can observe that they are close to the main chemical components. Thus, to preserve the formulary capacity of the filler samples, part of the raw clay material can be replaced with slag. Furthermore, there is a greater amount of Fe_2O_3 in the slag (20.6 %) than in the clay (6.5 %), as well as a sufficient amount of Na_2O + K_2O (1.5+0.7 %) in the slag that plays a big role in the formation of porosity under the influence of high temperatures. Thus, the possibility of using TPP slag as the raw material for the production of porous filler is proved.

The investigation of the hydrodynamics and kinetics of the filtration drying process of slag and clay was performed using the experimental plant according to the experimental procedure. The experimental results of hydrodynamics for the fixed bed of slag as well as clay are presented in Fig. 4 and in Fig. 5. In general, Fig. 4 and Fig. 5 demonstrate that the increase in the gas superficial velocity increases the pressure drop in fixed beds. The pressure drop in the fixed bed of slag (Fig. 4) is changing from 1250 Pa (the height H = $70 \cdot 10^{-3}$ m) up to 3200 Pa (height H = $190 \cdot 10^{-3}$m) and in the fixed bed of clay (Fig. 5) is changing from 430 Pa (the height H = $80 \cdot 10^{-3}$ m) up to 1280 Pa (height H = $240 \cdot 10^{-3}$m) at the superficial velocity of the drying agent of 0.8 m/s.

In general, insignificant values of the pressure drop confirm the application feasibility of filtration drying as an energy-saving method of drying slag and clay.

The influence of the drying agent temperature on the kinetics during the filtration drying of slag and clay was investigated. The results in the form of graphs are presented in Fig. 6 and Fig. 7, respectively. In general, with the increase in temperature, the drying time decreases.

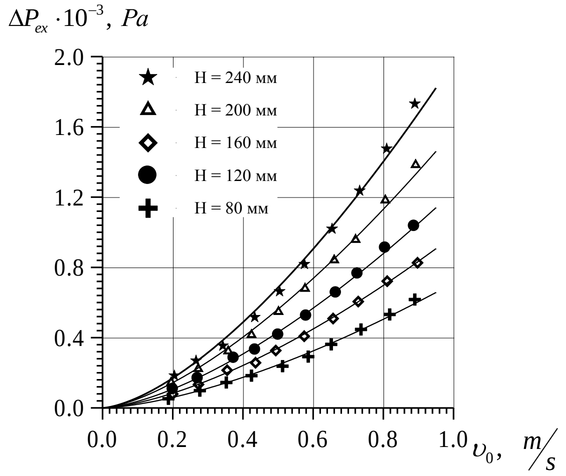

Fig. 5. Pressure drop in the fixed bed formed by clay of different heights versus superficial velocity of the drying agent

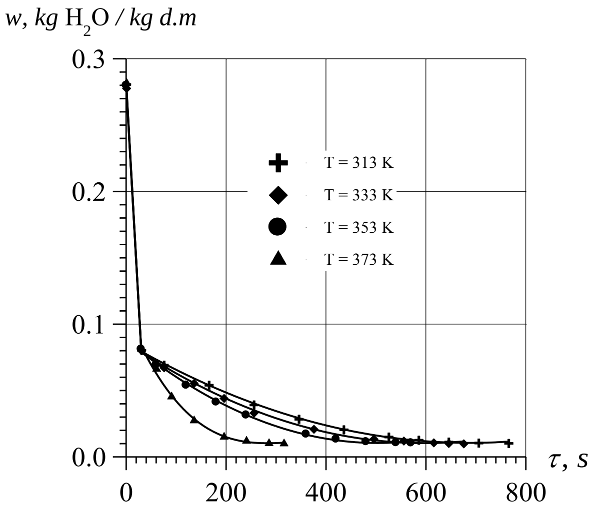

Fig. 6. Kinetics of the filtration drying of slag at different temperatures of the drying agent: $(\upsilon_0 = 1{,}33 m/s, H = 0{,}12 m)$.

As it is seen from the graphs, kinetic curves for slag (Fig. 6) have a period of mechanical displacement and removal of moisture. Surface moisture is on the surface of particles as well as in the channels between them, and in view of the low binding energy of the surface moisture with the material it is easily removed by the moving drying agent in a few seconds due to the pressure drop.

The kinetic curves for clay (Fig. 7) are characterized by the periods of complete and partial saturation of the heat agent by moisture. The long period of partial saturation of the heat agent by moisture indicates the proceeding of pore-diffusion processes in the material particles which define the time of filtration drying.

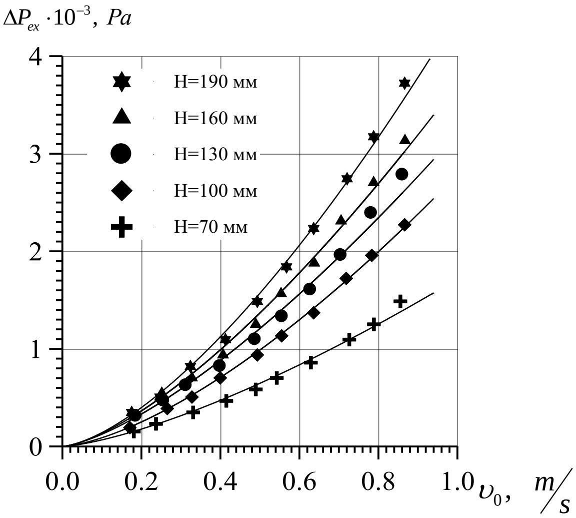

Fig. 4. Pressure drop in the fixed bed formed by slag of different heights versus superficial velocity of the drying agent

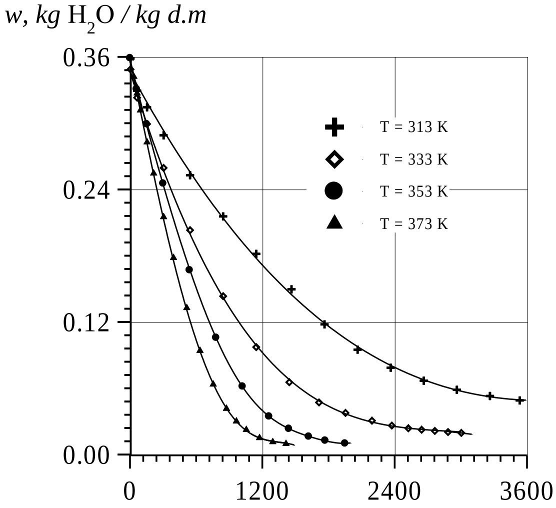

Fig. 7. Kinetics of the filtration drying of clay at different temperatures of the drying agent: $(\upsilon_0 = 1{,}33 m/s, H = 0{,}12 m)$.

Obtained results are usefull for the organization and intensification of the filtration drying process of slag and clay as the prelimilary stage at the porous fillers production line.

Raw granules (samples of porous filler) were prepared in the form of cubes with size 15×15×15 mm by using a dispersed charge which includes clay 55 %, slag TPP 35 %, burning additives (sawdust and coal) 5 %, binding and gas-forming additives 5 %. Primary porosity in raw granules occurs when the charge was granulated. Raw granules were placed to the muffle furnace and with an increase of temperature above 1000 K sawdust and coal additives were burned out as well as a gaseous phase was formed inside granulas which was created an excessive pressure in the internal cavity. The bloating process continued to a temperature of 1200°C and maximum porosity of the granules was fixed.

The obtained porous filler is characterized by a finely porous structure. The physical-mechanical properties of the filler prepared from TPP slag are shown in Table 5.

Table 5

Physical-mechanical parameters of the filler prepared on the basis of TPP slag*

Bulk density	230 kg/m^3
Specific heat	0.82 kJ/(kg·K)
Thermal conductivity	0.067 W/(m·K)
Compressive strength	27.7 MPa

*Results given by the laboratory of Ltd “EURO TECH EXPERT BUD”.

The physical-mechanical properties of the porous filler obtained from TPS slag correspond to the requirements of DSTU B B.2.6-189: 2013 “Methods of selection of thermal insulation material for building insulation” and obtained filler can be recommended for the production of lightweight concretes.

4. Conclussion

1. The possibility of using TPP slag as the raw material for the production of porous filler has been proved. The main benefits of using such waste in the production process are environmental protection, conservation of raw resources for the production of finished products.

2. The pressure drop in the fixed beds of slag and clay has been established by the experimental method. The insignificant values of the pressure drop confirm the application feasibility of the filtration drying as an energy-saving method of drying slag and clay for preparing the charge for porous filler production and results of the kinetics investigation are useful for the organization and intensification of the filtration drying process of slag and clay as the preliminary stage at the porous fillers production line.

3. The process of formation of the porous structure of filler from TPP slag includes the following stages: formation of the primary structure during granulation, sintering with the formation of closed and open pores and bloating under the pressure of the gases released inside the closed pores.

4. The qualitative new lightweight filler with a bulk density of 230 kg/m^3. the specific heat of 0.82 kJ/kg·K, the thermal conductivity of 0.067 W/m·K and compressive strength of 27.7 MPa has been obtained. It can be used for the production of lightweight concretes.

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