PEAT PROCESSING INTO COMPOSITE FUEL

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The paper presents a study of processing peat into fuel. The drying kinetics of composite raw materials based on peat, aged silt deposits, solid peat residues after extraction and corn crop residues were determined. The dependence of the drying optimization criterion on the moisture content of the material is investigated, which substantiates the effectiveness of the selected drying modes for composite raw materials. The heat of combustion of the composite raw material was determined, which is about 1.4 times higher than that of peat. Composite biofuel, as well as its components, were investigated using the methods of differential thermal analysis, which showed the temperature intervals and rate of dehydration, thermal decomposition of organic and mineral substances.

Key words: peat, obsolete sludge deposits, corn crop residues, drying, combustion heat

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1. Introduction

Every year the energy crisis is worsening in the world. Russia's attack on Ukraine has led to an unprecedented global energy crisis. Prices for gas and other traditional fuels have begun to rise rapidly [1].

According to Eurostat, as of 2021, the most common energy sources for the 27 EU countries were oil and oil products, followed by natural gas (Fig. 1). Renewable energy sources and biofuels were in third place [2].

The leaders in oil production in the world are the United States and Saudi Arabia. At the same time, Russia ranks third, and the percentage of Russian oil accounted for 34% of total imports by the EU countries. Most of the oil was supplied to Europe through the Druzhba pipeline system, which passes through Ukraine [3, 4].

In this way, “black gold” reached European countries, including Hungary, Slovakia, and the Czech Republic [3, 4].

According to the International Energy Agency, from 2009 to 2021, the share of Russia in the EU and the UK gas demand increased from 25% to 32% of total gas supply [3, 5]. Therefore, to protect consumers from rising energy prices, many countries are trying to reduce their dependence on Russian energy resources by implementing a policy of accelerated transition to carbon-free technologies and renewable energy sources.

Sources of alternative fuels include peat, biomass, slag, and waste from industry, agriculture, utilities, and other enterprises [6].

It is estimated that the world's peat reserves range from 250 to 500 billion tons, which in turn cover 176 million hectares [7]. On the territory of Ukraine, the largest geological peat reserves are concentrated in Polissia: in Volyn, Rivne, and Chernihiv regions [8]. Peat reserves in Ukraine are of industrial importance. Geological reserves amount to 2.04 billion tons, which is equivalent to 660 billion m^3 of natural gas [9].

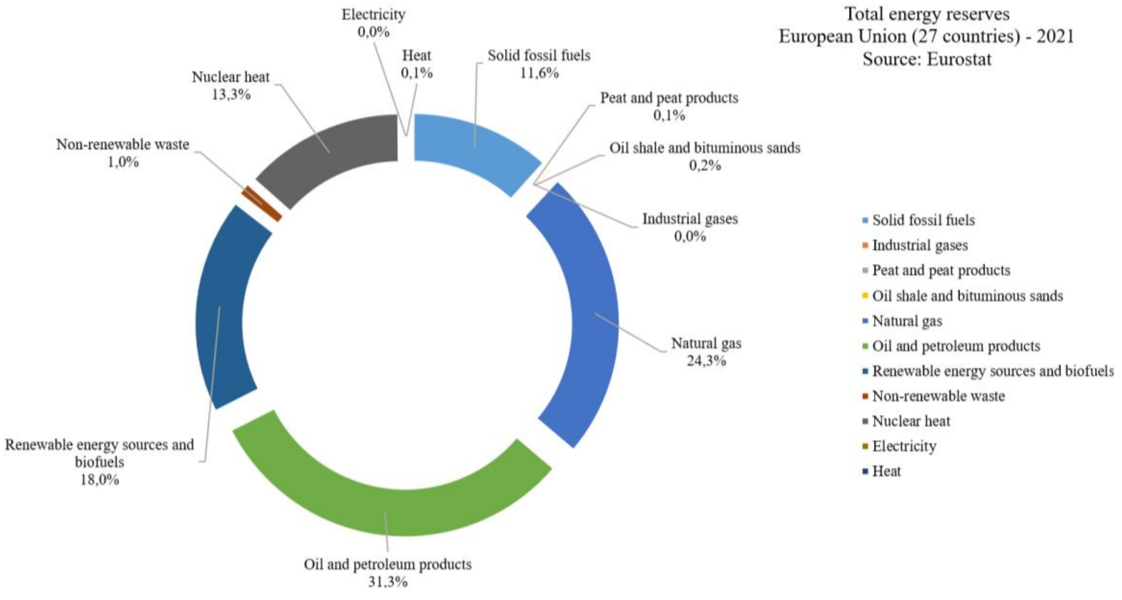

Fig. 1 Total energy reserves [2]

Peat also contains a large amount of humic substances. Because of this, peat has significant energy and agrochemical potential and is used as a local fuel, as well as a raw material for the production of greenhouse and consumer soils and organic fertilizers. Peat fuel is the cheapest and most efficient for short-distance transportation. The cost per unit of energy obtained from peat is 3 times cheaper than the cost of the same energy obtained from natural gas [6].

In Ukraine, there is also a problem of overcrowded sludge pits with outdated sludge deposits that have an excessive ash content. For example, in Lviv, sludge sites cover an area of 22 hectares, where more than 1.6 million tons of sediments have been accumulated and are currently overcrowded [10]. Similarly, the Bortynska station in Kyiv with sludge pits covering an area of 272 hectares is a great danger, as they are actually three times overcrowded - instead of the 3.5 provided, they contain 10 million tons of sludge mass [11, 12].

Paper [11] presents the technologies for processing sludge deposits, which shows that most of them are aimed at processing activated sludge. And since obsolete sludge sediments have almost lost most of their organic component, one of the ways to process them is to create composite raw materials based on them and burn them.

Ukraine is working to develop technologies for the production of fuel briquettes from sawdust, bark, logging residues, corn agrobiomass, agricultural raw materials, etc. The use of filler of plant or wood origin affects the ash content, strength and calorific value of the fuel, and the fractional composition of the filler affects the strength of the briquettes.

Biosmartex (Ukraine) has created a technological line for the production of fuel briquettes consisting of systems for preparing the coolant, drying in a drum dryer and forming fuel biobriquettes [13]. The resulting fuel briquettes are used for combustion in the heat generator of the drum dryer, which increases energy efficiency and creates a closed-loop production process.

Paper [14] presents a technological line for the production of granular composite biofuels based on peat and biomass, which consists in the thermal and humidity regime of the drying agent (250-300℃) and allows drying the material without thermal decomposition of natural substances that serve as a binder (lignin), which is necessary for the formation of granular products.

The most common method of extracting humic substances from peat for fertilizer production is an alkaline reaction with ammonia solutions or potassium or sodium hydroxides. This treatment turns them into water-soluble salts - potassium or sodium humates with high biological activity [15]. After extraction, not only humic fertilizers are formed, but also a solid residue that can be used to create composite fuels.

To use peat residue as an alternative fuel, it must be dried, as it has a high moisture content. At the same time, peat residue has a high ash content of 35-45%, which can be reduced by creating a composite based on it with biomass. The largest component of the theoretical energy potential of the country's biomass is the residues of corn crops after harvesting (stalks, cobs, leaves) and amounts to about 4.18 million tons of oil equivalent per year [16].

Utilisation of sludge deposits to prevent an environmental disaster will free up silt beds and create fuel for local needs.

In Ukraine, it is important to develop ways to process peat into fuel for use in municipal energy and industry.

The aim of the work is to study the processing of peat and the creation of a composite fuel based on it, with the addition of old silt deposits and corn residues, for waste disposal.

The following requirements were met when creating solid fuels:

- humidity 10-20%. High fuel moisture content causes a decrease in the heat of combustion, which in turn increases fuel consumption and the volume of combustion products;
- adding peat and biomass with lower ash content to reduce it in different types of waste.

2. Experimental part

2.1. Drying research

The drying kinetics was studied on an experimental convective stand with automatic data collection [17]. The experiment at a given temperature regime was repeated at least 3 times, and if the experimental data coincided, the experiment was switched to another regime.

The dependence of the drying optimization criterion (Rb) on the moisture content of the material as a drying optimization criterion equal to the ratio of the amount of heat consumed to heat the body to the amount of heat consumed to evaporate moisture in an infinitesimal period of time was investigated [18]:

$$Rb = \frac{c}{r} b, \quad (1)$$

where c is the specific heat capacity of the material, kJ/(kg ºC); r is the specific heat of phase transformation, kJ/kg; $b = \frac{d\bar{\theta}}{d\bar{u}}$ is the temperature coefficient of drying, which is an estimate of the derivative of the average temperature of the sample with respect to the humidity.

2.2. Thermal analysis of the composite

The calorific value was also determined using a methodology that complies with the standard methodology for solid fuels DSTU ISO 1928:2006 and the European standard ISO 18125:2017 "Solid biofuels - Determination of calorific value".

Thermal analysis was carried out in a Paulik-Paulik-Erdey Q-1000 derivatograph (IOM, Hungary) in the range of 21 to 1003 °C at a heating rate of 7.4 K/min. The samples were placed in an open conical platinum crucible without compression. The atmosphere was static air. Aluminum oxide was used as an inert substance in the comparison crucible. Data collection and processing was carried out using the Q-1500 mini computer program [19].

2.3. Fertilizer extraction

According to the technology developed at the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine, the extraction of humic and humus substances, which involves the preparation of a peat sample, extracts humic acids from the sample with an appropriate concentration of KOH or NaOH alkali. For extraction, containers made of materials that are resistant to aggressive acid and alkaline environments are used. After extraction, the resulting solution is centrifuged or filtered to obtain liquid humic substances and solid peat residue [20].

3. Results and discussion

This section summarizes the results of research into the drying of composite fuels, the determination of the heat of combustion, and the thermal analysis of composite fuels.

3.1. Technical analysis of a composite

The peat from the field of the Chernihivtorf State Enterprise (Chernihiv), outdated sludge deposits from sewage treatment plants (Fastiv, Kyiv region) and corn residues from (Sosonka village, Vinnytsia region) were used for the research.

Figure 2 shows that the ash content of silt deposits is 47.3%, which is not acceptable for combustion. Peat has a fairly low ash content of 14.1%. When creating a 1:1 composite based on sludge deposits and milled peat, we get a material with an ash content of 33.1% compared to the sludge deposits. Therefore, the development of a composite based on old silt deposits and milled peat makes it possible to eliminate silt from overflowing maps for land reclamation and environmental improvement.

During the creation of humic fertilisers using alkaline solution extraction, a large amount of solid residue is formed, which has an ash content of 40.1% (Fig. 2). The addition of corn residues with an ash content of 3.5% to the peat solid residue after extraction of humic substances resulted in a composite with an ash content of 10.1% (Fig. 2). This will make it possible to comprehensively process milled peat into fertilisers and fuel and reduce the environmental impact.

3.2. Research into the drying of composites

Fig. 3 shows the temperature curves and kinetics of drying peat-silt pellets on a convective drying bench at temperatures of 80 °C and 120 °C in the proportion of 50% silt/50% peat. The duration of drying peat-silt pellets with an increase in the temperature of the heat carrier from 80 to 120°C decreases by 1.4 times (Fig. 3). The heating of the pellets at a coolant temperature of 80°C is uniform and at a pellet moisture content of 10% is 72°C, at a temperature of 120°C the pellets are heated more intensively and at the corresponding moisture content is 115°C.

The drying of a composite based on peat residue after extraction of the humic component with corn residues crushed to 0.5 mm was also studied at 70°C and 100°C.

Figure 4 shows the change in moisture content and drying temperature of the mixture based on peat residue after extraction of the humic component with crushed corn residues at 70°C and 100°C. As can be seen from Fig. 4, when the temperature of the heat carrier increases to 100°C, the process intensifies, and the temperature of the material quickly increases 1.8 times to 90°C, and after 18 min the moisture content of the material is 10%. Drying at a temperature of 70 °C, as can be seen from the curves, slows down the process and the composite is heated to a temperature of 45 °C when the material moisture content reaches 10%.

Calculation of the criterion for optimising the process of dehydration of composite raw materials.

Based on the data obtained on the drying kinetics of composite raw materials at the heat carrier operating parameters, the dependence of the change in the drying optimisation criterion (Rb) on the change in the average (integral) moisture content of the sample's during drying was calculated in accordance with the study. The graph of the dependence Rb = f(Wc) is shown in Figure 5.

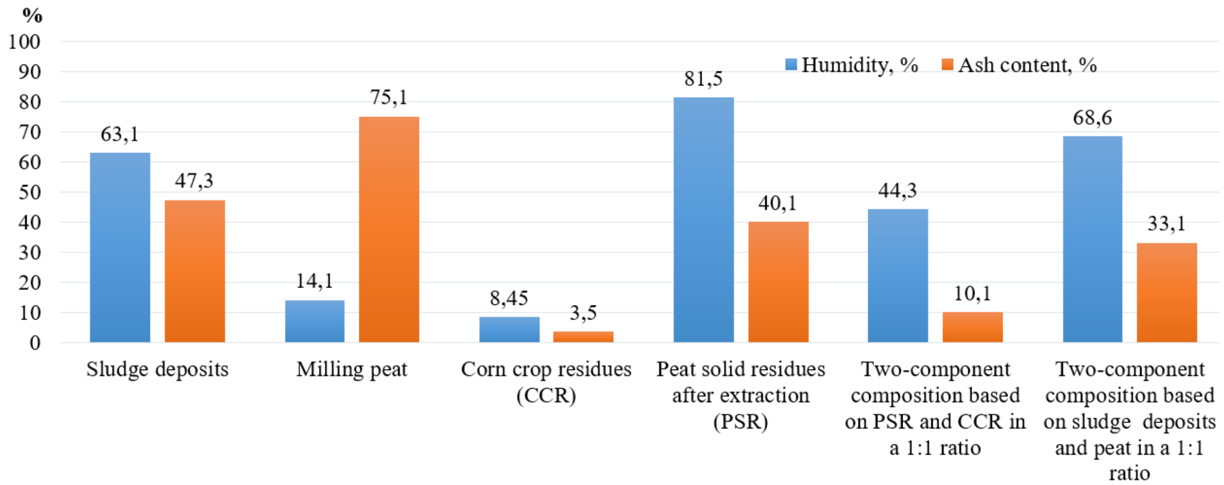

Fig. 2 Ash content and moisture content of raw materials

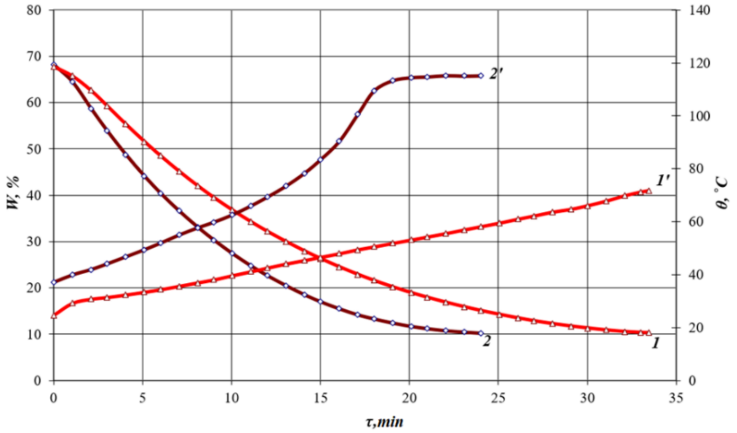

Fig. 3 Changes in humidity (W) (1, 2) and temperature in the middle of the layer (θ) (1′, 2′) of peat-based pellets and old sludge deposits of 1:1 ratio over time. Operating parameters: V = 2 m/s, d = 6 mm: 1, 1‘ - 80°C; 2, 2’ - 120°C

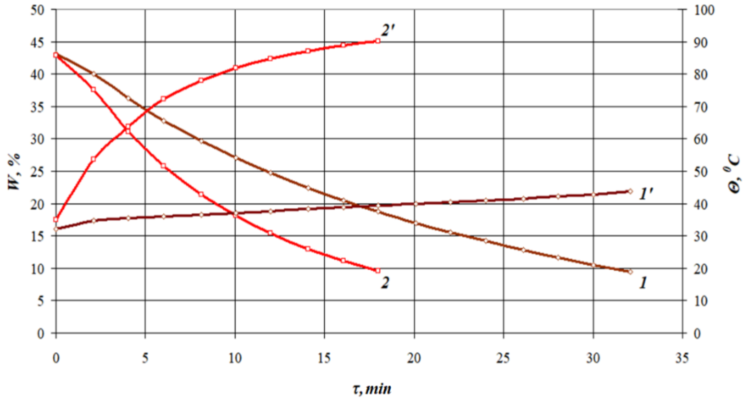

Fig. 4 Changes in humidity (W) (1, 2) and temperature in the middle of the layer (θ) (1′, 2′) of a composite based on peat residue after extraction and chopped corn residues in a 1:1 ratio over time. Operating parameters: V = 3 m/s, h = 10 mm, particle size ≥ 0.5 mm: 1, 1′ - 70°C; 2, 2′ - 100°C

As can be seen from Figure 5, a, at the beginning of the process, the material in the two-component pellets is actively heated to a moisture content of 68%, then the moisture is intensively removed to 20%, followed by further heating of the material.

Fig. 5, b shows that at the beginning of the process, the material is actively heated to a moisture content of 40%, then the moisture from 40 to 15% is intensively removed, followed by further heating of the material.

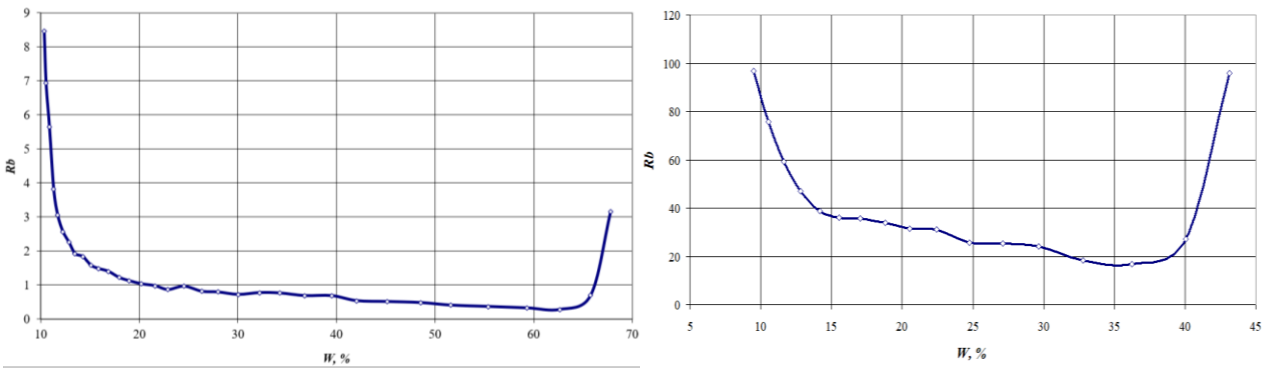

Fig. 5 Variation of the drying optimisation criterion (Rb) depending on the material humidity (W):
a - composite based on peat and old sludge deposits at t = 80 °C;
b - composite based on peat solid residue after extraction and crushed corn residues at t = 70 °C

3.3. Thermal analysis of the composite

Summarised results of measurements and calculations of the properties of the investigated comosites in the delivery state and in the dry state are given in Table 1.

The calorific value of aged silt deposits is in the range of 11.81-13.12 MJ/kg, and is close to the closest fuel - peat. The specific heating value of peat is on average 14.44 MJ/kg. Table 1 shows that two-component pellets based on sludge and peat have almost the same calorific value as peat.

As can be seen from Table 1, extraction does not affect the calorific value of peat. As can be seen from the experimental data obtained, the calorific value of composite feedstock based on peat residue and corn residues is higher than peat in its native state.

Tab. 1 Results of calorimetric analysis of composite raw materials

Parameter	Milling peat	Sludge deposits	Peat solid residue after extraction	Composite (peat solid residue/corn residues)	Composite pellets (sludge/peat)
Higher calorific value as delivered, MJ/kg	13.50	12.79	14.31	16.57	14.70
Higher calorific value in dry state, MJ/kg	16.09	13.12	15.33	17.50	13.51
Lower calorific value as delivered, MJ/kg	12.33	11.96	13.27	15.32	13.39
Lower calorific value in dry state, MJ/kg	14.78	11.81	14.02	16.19	12.54

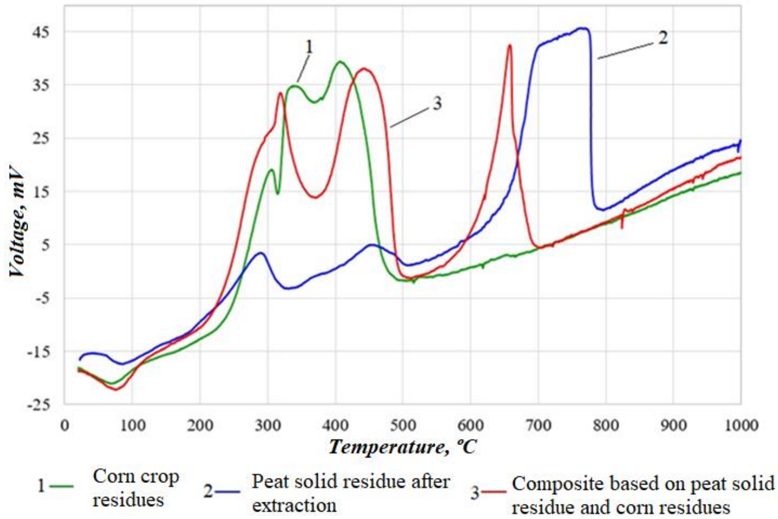

Fig. 6. Combined curves of differential thermal analysis

The energy performance of composite raw materials is quite high (Table 1), which allows them to be used as an alternative fuel in households and municipal energy.

The combined differential thermal analysis curves are shown in Figure 6. Mixing of peat solid residue and corn residues leads to a decrease in the decomposition interval of organic matter by 5 °C compared to the solid residue. The decomposition of organic matter in composite fuels takes place in 3 periods, as in the case of peat residue. However, the decomposition kinetics itself has a slightly different intensity. In the fuel, the decomposition intensity, compared to the solid peat residue, is 1.8 and 2.1 times higher in the first and second periods, respectively, and 3.5 times lower in the third period.

4. Conclusions

The kinetics of the drying process of composite raw materials was studied, which showed that an increase in temperature for the two composites reduces the duration of the process by 1.4 for peat-silt and 1.8 for solid peat residues and corn residues.

The calculation of the criterion for optimising the process of dehydration of composite raw materials confirmed the feasibility of the selected modes.

The resulting calorific value of composite raw materials based on peat residue with corn residues is high enough to allow their use as an alternative fuel in households, municipal energy and peat-silt for industry.

The differential thermal analysis study showed that the overall average decomposition rate of organic matter in the composite fuel is 20% higher than that of peat residue and 45% lower than that of corn residue.

The results show that it is possible to create fuels based on peat and old silt deposits for use in industry at the place of their production. And fuels based on solid peat residues and corn residues for use in municipal energy.

List of symbols and abbreviations

W	Humidity (%)
τ	Time (min)
θ	Heating temperature (°C)
V	Coolant velocity (m/s)
h	Layer height (mm)
d	Granule diameter (mm)
Rb	Drying optimisation criterion

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