jntes
1
2022

Yurii SNIEZHKIN, Zhanna PETROVA, Vadim PAZIUK
Anton PETROV, Yuliia NOVIKOVA
Institute of Engineering Thermophysics National Academy of Sciences of Ukraine
Corresponding author: bergelzhanna@ukr.net

Doi: 10.53412/jntes-2022-1-6

THE LATEST TECHNOLOGY FOR OBTAINING COMPOSITE BIOFUEL AND FERTILIZERS

Abstract. *One of the main problems of the modern world is the search for and supply of renewable energy resources that could compete with oil and natural gas. In recent years, the world is entering the era of biotechnology, which uses renewable raw materials to produce energy and materials. One of the sources of alternative types of fuel is peat, which is the cheapest type of fuel for the population, raw material for nutritious soils and organic-mineral fertilizers.*

The purpose of the work is to create the latest technology for obtaining composite fuel and fertilizers.

The article examines the study of drying kinetics on a convective drying stand with an automatic system for collecting experimental data and their processing. The optimal modes of drying the composite mixture based on the solid residue of peat after the extraction of the humic component with crushed corn residues have been determined.

According to the methods, the kinetics of heat-moisture exchange during drying of the composite mixture was calculated and it was determined that the generalized drying curves of the composite mixture coincide with the obtained experimental curves.

The technology for obtaining humic substances and biofuel from peat and nutritious corn residues has been developed. Biofuel obtained by the technology on the basis of solid residue after extraction of humic substances from peat and nutritious residues of corn meets the standards of quality fuel and is 12.3 MJ/kg.

Keywords: *peat, nutritious corn residues, fuel, fertilizers, drying*

Introduction

One of the main problems of the modern world is the search for and supply of renewable energy resources that could compete with oil and natural gas. In recent years, the world is entering the era of biotechnology, which uses renewable raw materials to produce energy and materials. These technologies prevent environmental pollution; reduce emissions of gases, which causes the greenhouse effect, and other poisonous substances. In this regard, the active use of renewable energy sources from agricultural raw materials noted in the USA, Japan, Brazil, China, Canada, and EU countries.

Biofuel is an alternative type of fuel obtained because of the processing of animal or vegetable raw materials, as well as organic industrial waste and household products. Alternative energy considers biofuel as an option to replace traditional – coal, oil, natural gas, etc. Biofuel belongs to renewable types of energy, its main advantage is environmental friendliness, and modern production methods make it possible to obtain such samples of fuel, which in terms of their characteristics and cost are superior to traditional ones.

With the rise in gas prices today, the question of using it in municipal energy arises. The most common heat generator that is part of any heating system is a heating boiler. Depending on the type of energy resources, gas, solid and liquid fuel boilers are distinguished.

Gas boilers are technological and comfortable to use, but they also have their drawbacks, such as emissions of CO_2, NO_x, Benzo(*a*)pyrene, as well as the possibility of gas leakage and explosion. Compared to gas boilers, solid fuel boilers have the ability to use different solid fuels, are environmentally friendly, autonomous and safe to operate. There are classic solid fuels, which include hard coal, brown coal, oil shale, and others, as well as alternative biofuels – peat, biomass, agricultural products and waste, organic part of industrial and household waste.

Solid biofuel has a number of environmental advantages over traditional types of fuel. Energy consumption for production is about 3% of the energy content of the final product. When burning biofuel, the emission of carbon dioxide is 10-50 times lower than when burning traditional types of fuel, and the plant used exactly as much carbon dioxide released into the atmosphere as during growth.

Among the non-traditional types of solid fuels known in Ukraine, it is worth paying attention to peat – an organic rock formed because of incomplete biochemical decomposition of dead marsh plants in conditions of excess moisture with a lack of oxygen, which contains up to 50% of mineral components on a dry matter basis. Peat is the geologically youngest link in the chain of caustobiolites "peat – lignite – hard coal – anthracite", has the lowest level of carbonization and, accordingly, the lowest value of heat of combustion. The surface location of peat deposits and relatively small costs for the organization and management of mining operations make this useful mineral a potentially effective local type of fuel.

In Ukraine, peat reserves are of industrial importance. Geological reserves amount to 2.04 billion tons, which is equivalent to 660 billion m^3 of natural gas (Atlas of the energy potential, 2014).

Nowadays, peat, which contains a large number of humic substances, used as a fertilizer for agriculture. These substances are not water-soluble and become so only in an alkaline environment. Therefore, it is advisable to use peat as local fertilizers and fuel. If humic substances removed from it, and the rest burned, then this unique natural resource can be used more rationally. The main method of obtaining humic substances is an alkaline reaction with ammonia solutions or potassium and sodium hydroxides. Such processing turns them into water-soluble salts – potassium or sodium humates with high biological activity (Petrova et al., 2019).

Humic acids are the most important component of soil humus. The greater their content, the more fertile the soil. However, in their natural state, humic acids are insoluble in water and hardly available to plants. They become available only after indirect action – mineralization of the soil, when they transformed into simple mineral compounds. The use of humic substances in the agricultural sector ensures an increase in productivity by 25-40%, accelerates the recovery of the humus layer of soils three times.

Because of the growing demand for humic preparations, it is necessary to organize their industrial production on a large scale. This will allow faster introduction of humic acids and other preparations based on them into industry and agriculture (Sniezhkin et al., 2020).

Materials and methods

The creation of new compositions based on peat or its residues after extraction give a positive result when it burned (Novikova et al., 2022).

Suitable materials, such as milled peat and nutritious corn residues, used for research. Milled peat has an initial moisture content of 13.18% and an ash content of 27.23%. Corn feed residues have a moisture content of 8.45%, ash content of 9.8% and volatile matter of 9.55%.

According to the developed technology for extracting humic and humic substances, which consists in the preparation of a sample of peat, humic acids extracted from the sample with the appropriate concentration of alkali, followed by neutralization of the solution with acid. After neutralization, humic acids precipitated, the solution was filtered, dried, and the total amount of humic substances was determined (Petrova et al., 2021).

The humic component extracted from the peat and a solid residue with moisture content of 81.5%, ash content of 40% and volatile substances of 46.5% obtained. The created two-component composition has an ash content of 10%, volatile substances of 27% and moisture content of 44.3%, which is 4 times less than the solid residue of peat after extraction, respectively.

The resulting mixture of peat residues after extraction of fertilizers and nutritious corn residues dried on an experimental stand.

The study of drying kinetics carried out on a convective drying stand with an automatic system for collecting experimental data and processing it. The automated data acquisition system reads data at a rate of 7 values per minute. During the drying process, data on the time of the experiment, the temperature in the middle of the drying chamber and the mixture, and the change in the mass of the material read (O'Kelly et al., 2018).

Results

For peat and other organic soils, some researchers recommend drying temperatures in the range of 60-90°C in an attempt to prevent possible charring, oxidation, and/or volatilization of substances other than water vapor. However, not all of the relevant water completely evaporated at too low a temperature, and since the dry mass of the sample is a function of the drying temperature, the obtained water content values are lower as those determined for the temperature range of 100-110°C. Experimental data presented in this article show that drying peat and other organic soils in an oven at 100-110°C using gravity-convection or forced dryers is acceptable (O'Kelly et al., 2018).

At the beginning of the process, the influence of temperature on the kinetics of the drying process of solid peat residue after extraction in the embankment was determined (Fig. 1). Peat drying carried out at temperatures of 70°C and 100°C.

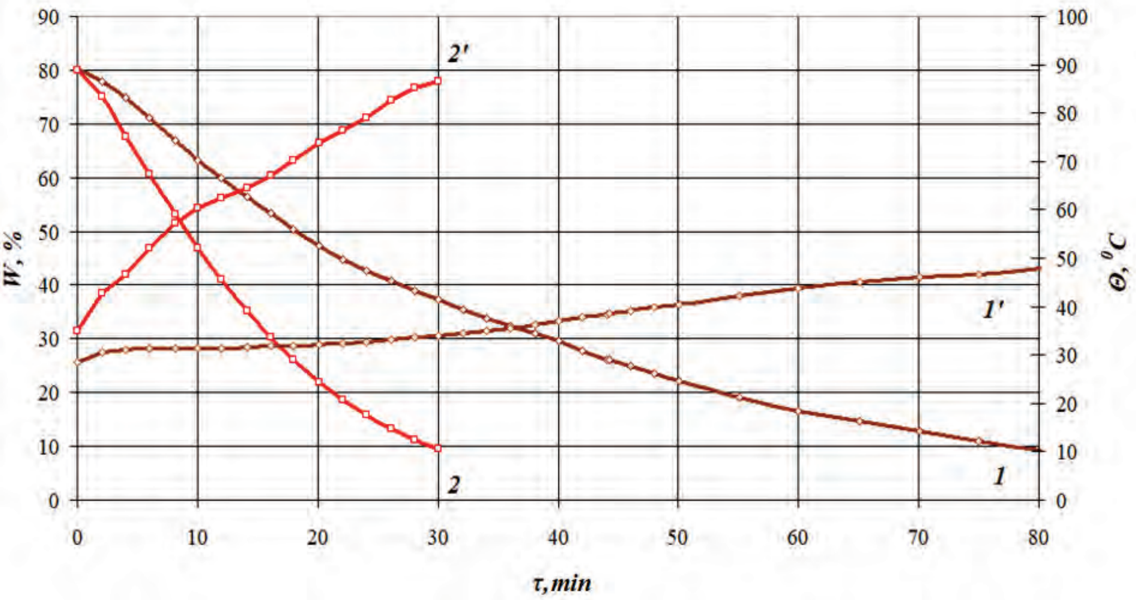

FIGURE 1. *Change in moisture content (1, 2) and temperature in the middle of the layer (1′, 2′) of solid peat residue after extraction versus time, V = 3 m/s, h = 10 mm, particle size ≥0.5 mm: 1, 1′ – 70°C; 2, 2' – 100°C*

Figure 1 shows the change in moisture and drying temperature of the solid peat residue after extraction of the humic component at temperatures of 70°C and 100°C. As can be seen, the increase in temperature to 100°C intensifies by 2.6 times.

Figure 2 shows the change in the drying speed of the solid peat residue after extraction of the humic component. As can be seen from Figure 2, the drying rate at a heat carrier temperature of 70°C is 2%/min, and at a heat carrier temperature of 100°C, it is 3.8%/min.

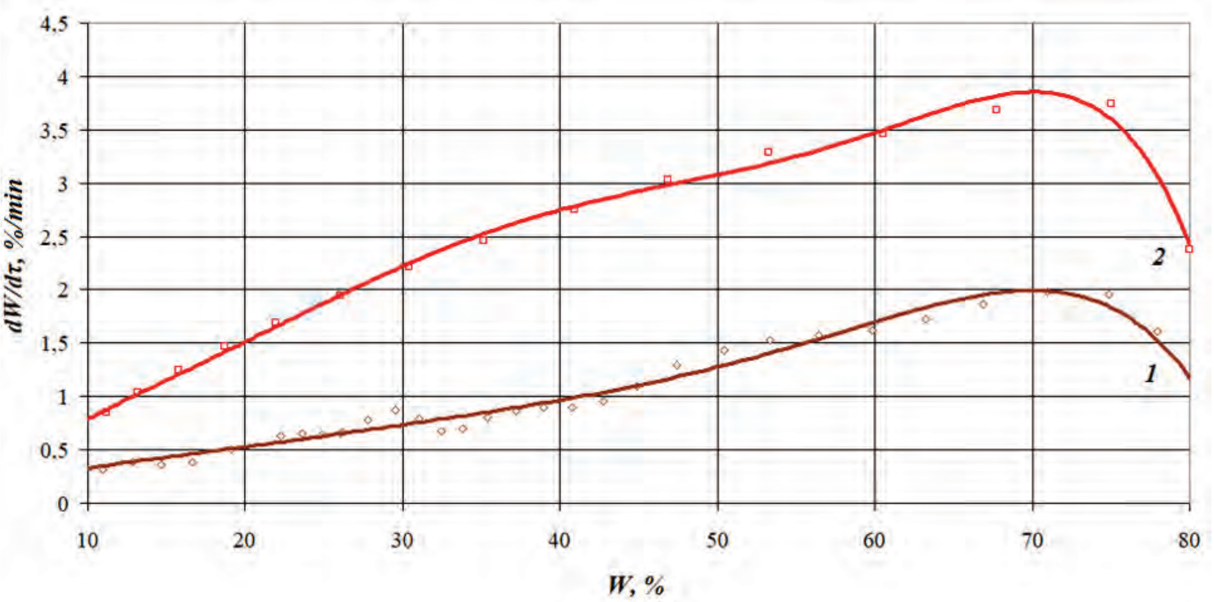

FIGURE 2. *Change in drying speed of solid peat residue after extraction, V = 3 m/s, h = 10 mm, particle size ≥0.5 mm: 1 – 70°C; 2 – 100°C*

Research is also being conducted on the drying of a mixture of solid peat residue after extraction of the humic component with nutritious corn residues crushed to 0.5 mm at temperatures of 70°C and 100°C.

Figure 3 shows the change in moisture content and drying temperature of the mixture based on solid peat residue after extraction of the humic component with crushed nutritious corn residues at temperatures of 70°C and 100°C. As can be seen from Figure 3, an increase in the temperature of the coolant from 70°C to 100°C intensifies the drying process by 1.8 times.

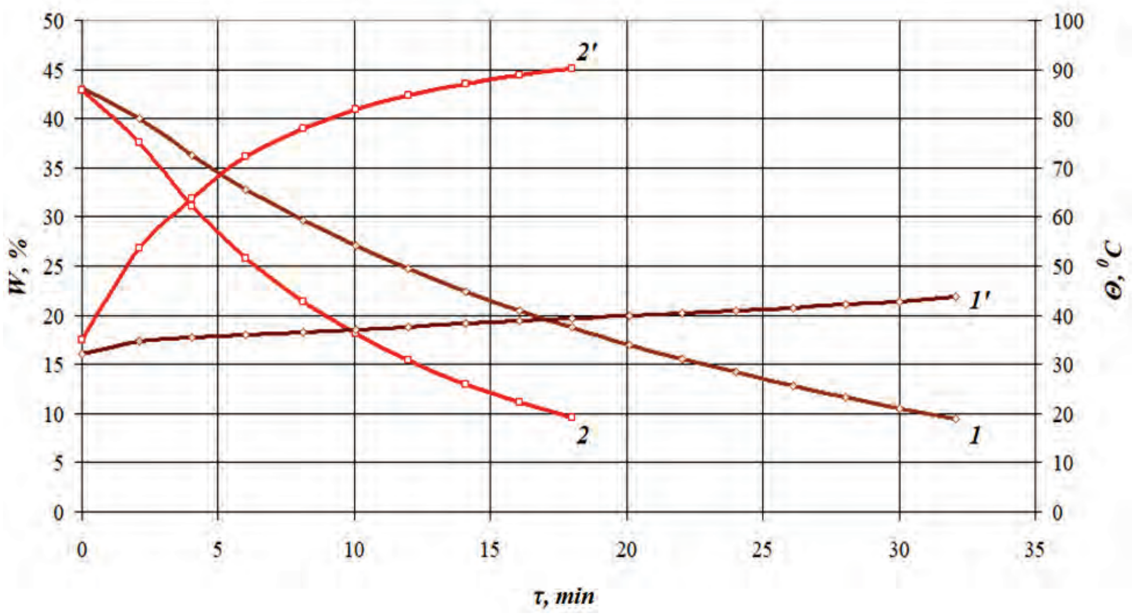

FIGURE 3. *Change in moisture content (1, 2) and temperature in the middle of the layer (1′, 2′) of the mixture based on the solid residue of peat after extraction and crushed corn residue ratio 1:1 over time, V = 3 m/s, h = 10 mm, particle size ≥0.5 mm: 1, 1′ – 70°C; 2, 2′ – 100°C*

Figure 4 shows the change in the presented change in the drying speed of the mixture based on the solid residue of peat after the extraction of the humic component with crushed nutritious corn residues at temperatures of 70°C and 100°C. As can be seen from Figure 4 drying speed at a temperature of 70°C – 1.9%/min, and at a temperature of 100°C – 3.3%/min.

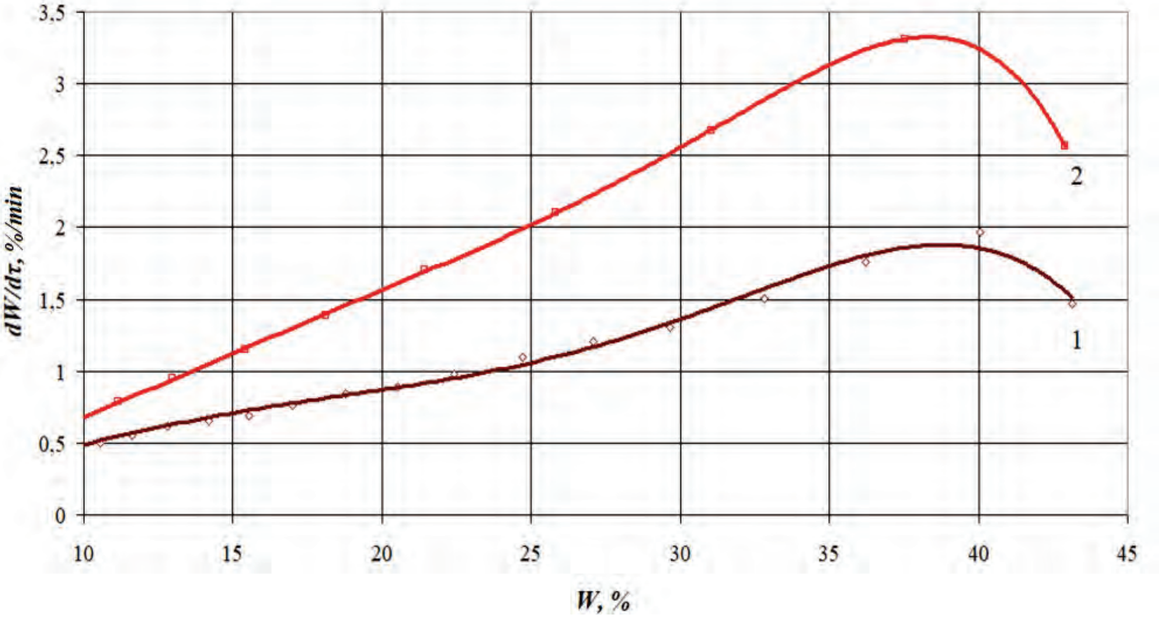

FIGURE 4. *Change in the speed of the mixture based on the solid residue of peat after extraction and crushed corn residue, V = 3 m/s, h = 10 mm, particle size ≥0.5 mm: 1 – 70°C; 2 – 100°C*

The nature of the drying process, which is depicted on the curves of drying kinetics, drying speed and temperature curves, is determined by the physico-chemical and structural-mechanical properties of the material. These properties affect the form of moisture connection with it, the diffusion nature of the phenomenon, as well as the method of heat transfer, in other words, the regularity of the body's interaction with the environment. A variety of factors and their interrelation makes it difficult to obtain analytical dependences of material drying kinetics. Therefore, when describing the drying process, empirical dependences are used. The most similar method for calculating the kinetics of drying is a method based on the study of the general regularities of the process, which brings the theory and practice of drying closer together (Sniezhkin, 2012).

According to the appropriate methods, the kinetics of heat-moisture exchange during drying of the composite mixture was calculated (Sniezhkin, 2012; Sniezhkin, 2018).

To study the kinetics of drying, composite mixtures were taken based on the solid residue after the extraction of humic substances from peat and nutritious residues of corn in a ratio of 1:1. After calculation according to the given method, generalized drying kinetic curves and drying speed curves were obtained.

We plot in the system of semi-logarithmic coordinate's *lg W* from the time of the experiment τ to determine the relative drying coefficients of the created composite mixtures (Fig. 5).

The drying curves of the mixture based on the solid residue of peat after extraction and crushed corn residues are presented in semi-logarithmic coordinates in Figure 5 indicate that the second period consists of three parts with critical points K_1 and K_2. The lower the temperature of the coolant, the later the value of critical points occurs and the process proceeds more slowly.

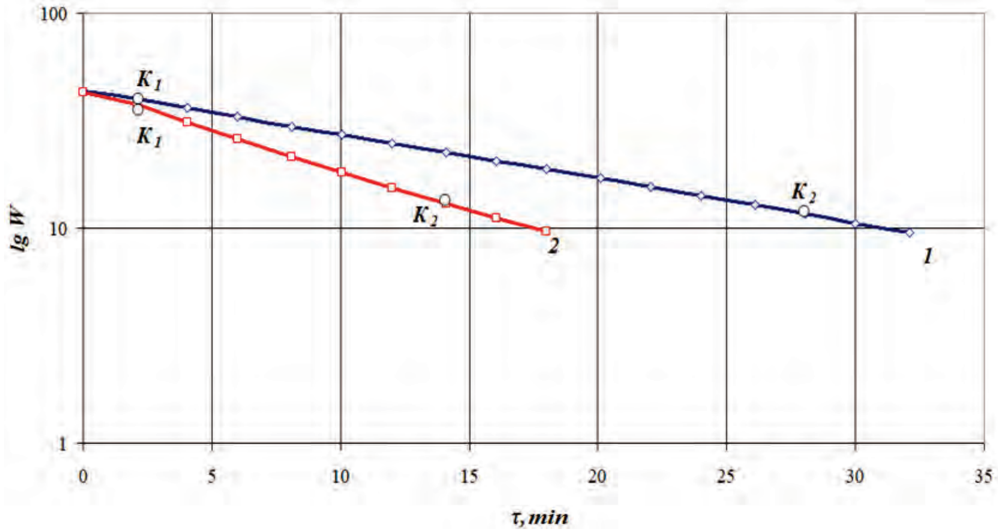

FIGURE 5. The influence of the temperature of the coolant on the duration and speed of drying of the bulk mixture based on the solid residue of peat after extraction and crushed corn residues in the semi-logarithmic coordinate system: 1 – 70°C; 2 – 100°C

In the mathematical description of the kinetics of moisture exchange during drying in the second period, values, or rather, empirical coefficients, which are determined by the properties of this material, should be taken into account. These coefficients should be determined directly from the experiment. The relative drying coefficient is determined only by the formula of moisture connection with the material, its structure, density and does not depend on the processing mode.

The values of the relative coefficients and kinetic drying coefficients calculated by the method for the specified regimes are summarized in the Table 1.

TABLE 1. Relative and kinetic coefficients of drying of the mixture based on the solid residue of peat after extraction and crushed corn residues in a ratio of 1:1

Regime	**Range of critical moisture, %**	**Relative drying coefficients**		**Kinetic coefficients of drying**	
		χ_1	χ_2	K_1	K_2
Regime 1 (t = 70°C, V = 3 m/s)	40-11.6	0.011		0.022	
	11.6-9.5		0.010		0.020
Regime 2 (t = 100°C, V = 3 m/s)	37.5-13	0.011		0.036	
	13-9.6		0.009		0.029

Depending on the range between the critical points, the relative and kinetic coefficients of drying change. In mode 2, which corresponds to a heat carrier temperature of 100°C, the kinetic coefficients are higher than in mode 1 at a heat carrier temperature of 70°C (Table 1).

Analyzing the generalized drying curves, we can say that all drying modes fit on one curve with an error of no more than 10% (Fig. 6).

Carrying out graphical differentiation of the generalized curve of drying kinetics, presented in Figure 6, obtained the generalized curve of the drying speed of the composite mixture, which is presented in Figures 7 and 8.

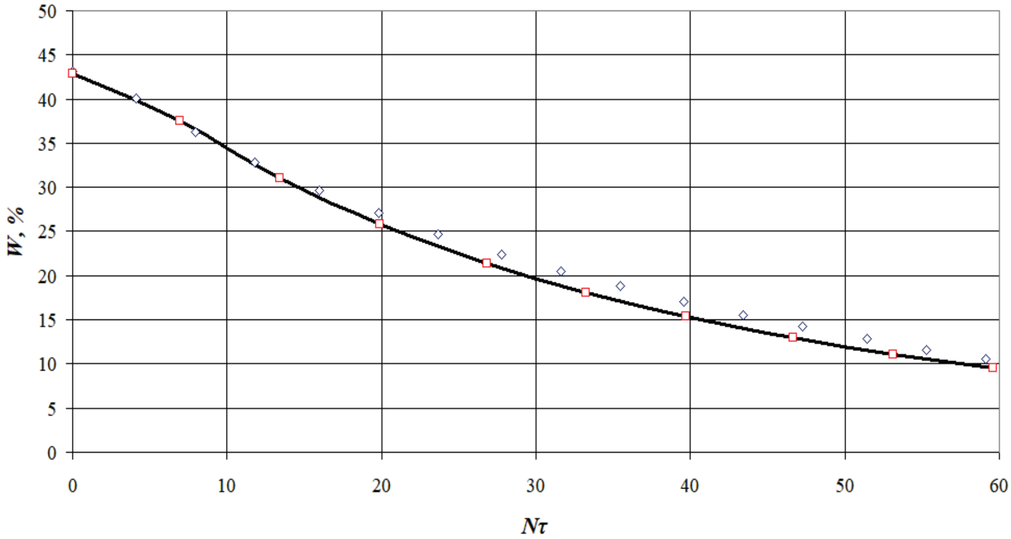

***FIGURE* 6.** *Generalized drying curves of the composite mixture based on the solid residue of peat after extraction and crushed corn residues in the W – N τ coordinate system*

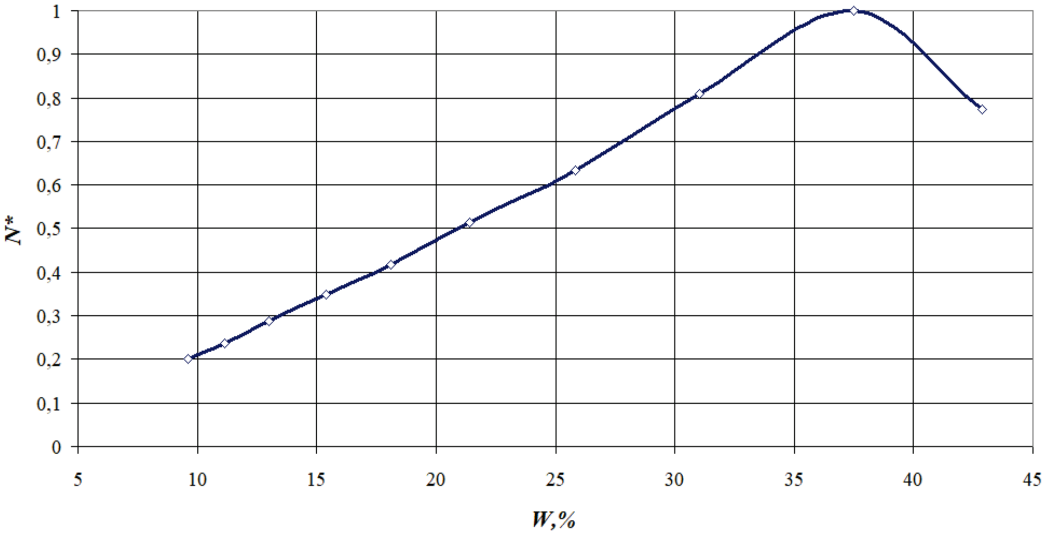

***FIGURE* 7.** *Generalized curves of the drying speed of the composite mixture based on the solid residue of peat after extraction and crushed corn residue*

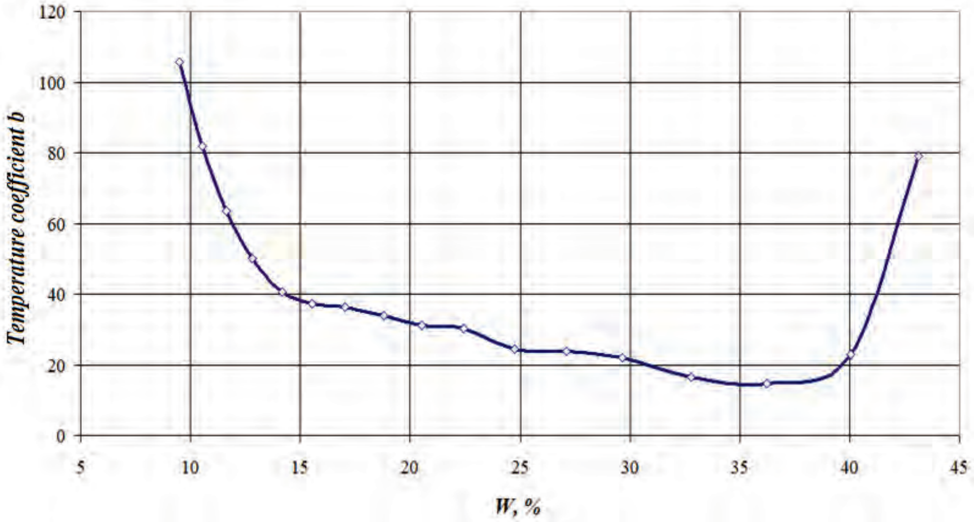

***FIGURE* 8.** *Change in the temperature coefficient of the moisture content of the peat-corn mixture at a coolant temperature of 70°C*

The total duration of the process in the absence of the first drying period:

$$\tau_T = \frac{1}{N}\left(\frac{1}{\chi_1}\lg\frac{W\kappa_1}{W\kappa_2} + \frac{1}{\chi_2}\lg\frac{W\kappa_2}{W\kappa}\right) = \frac{1}{N}\left(\frac{1}{0.011}\lg\frac{40}{11.6} + \frac{1}{0.010}\lg\frac{11.6}{9.5}\right) = \frac{1}{N}(48.89+8.2) = \frac{57.09}{N}$$

The kinetics of heat exchange during drying can be fully determined by calculations (Chmel and Novikova, 2019).

The heat flux density spent on evaporation is calculated by the intensity of moisture exchange $m(\tau)$ from the expression:

$$q_{evap} = rm(\tau) = rg\frac{d\overline{W}}{d\tau} \tag{1}$$

At the same time, the shrinkage of the material is not taken into account.

The heat flux density for heating the material is determined by the ratio:

$$q_h = \overline{c}g\frac{d\overline{t}}{d\tau} \tag{2}$$

where $\overline{c}$ is the heat capacity of the wet body.

In accordance with the law of conservation of energy, the specific heat flow per unit surface of the body is equal to:

$$q(\tau) = rg\frac{d\overline{W}}{d\tau} + \overline{c}g\frac{d\overline{t}}{d\tau} = gr\frac{d\overline{W}}{d\tau}\left[1 + \frac{\overline{c}}{r}\frac{d\overline{t}}{d\overline{W}}\right] \tag{3}$$

The value of $\frac{d\overline{W}}{d\tau}$ determines the change in the average temperature of the material being dried per unit of change in the average humidity over an infinitesimally small period and is called the drying temperature coefficient.

$$b = \frac{d\overline{t}}{d\overline{W}} \tag{4}$$

The value *b* is a function of integral humidity $b = f(\overline{W})$.

The general variable $b\frac{\overline{c}}{r}$, as can be seen from equation (3), is an integral characteristic of the kinetics of the drying process. It determines the ratio of the amount of heat to the heating of the material during drying and to the evaporation of moisture in an infinitesimally small period. This basic drying criterion is called Rebinder's criterion:

$$Rb = b\frac{\overline{c}}{r} = \frac{\overline{c}}{r}\left(\frac{d\overline{t}}{d\overline{W}}\right) \tag{5}$$

The value of the number *Rb* depends on the temperature coefficient of drying, the specific heat capacity of the wet material and the specific heat of evaporation, and, accordingly, on the form of moisture connection with the material.

Figure 9, it can be seen that at the beginning of the process, the material is actively heated to a humidity of 40%, then moisture is intensively removed from 40% to 15%, followed by heating of the material.

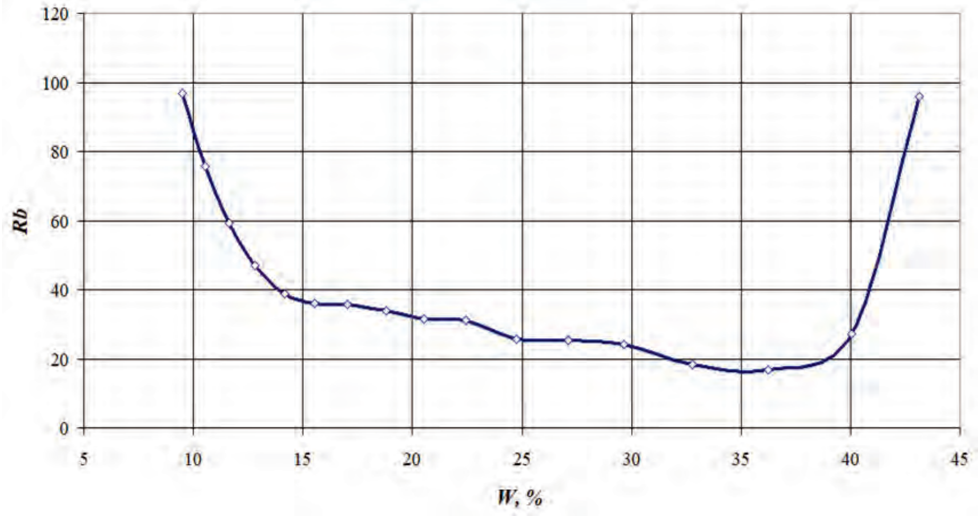

FIGURE 9. Change in Rebinder's criterion from the moisture content of the peat-corn mixture at a coolant temperature of 70°C

The analysis of the performed methods showed that they could be successfully applied to the study of the kinetics of heat and moisture exchange.

As a result, a technology was developed that simultaneously produces fertilizers and composite fuel. In Figure 10 presents a scheme of technology for obtaining humic substances and biofuel from peat and nutritious corn residues. The first step is the preparation of raw materials. The preparation of milled peat is carried out in several stages: grinding, treatment with an alkaline solution of a given concentration, mixing and centrifugation, after which we obtain humus substances and a solid residue after extraction, which is fed by a dispenser for mixing. The nutritious remains of corn, which are collected from the field, are crushed and dosed.

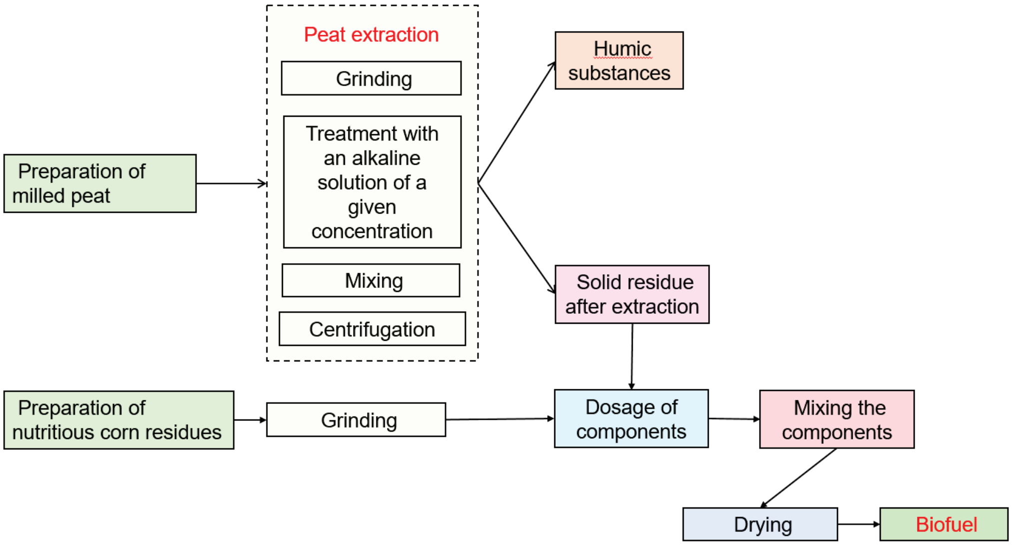

FIGURE 10. Developed technology for obtaining humic substances and biofuel from peat and nutritious corn residues

After dosing the components in a 1:1 ratio, the mixture is intensively stirred and sent to the drying unit. The resulting mixture is convectively dried on a drying unit at a coolant temperature of 100°C to a final moisture content of 10-15%.

The burner developed at the Institute of Technical Thermal Physics of the National Academy of Sciences of Ukraine allows burning of fine-fraction solid fuel, so this composition can be burned without prior granulation. In this burner, on the sidewall of the heat pipe, at an angle to its longitudinal axis, a nozzle for supplying combustion products of additional high-reaction fuel, which has a main fuel supply nozzle on the sidewall, is installed. In the additional fuel burner, highly reactive fuel is burned: liquid or gaseous, the high-temperature combustion products of which enter the heat pipe at an angle of 30-60° towards the blocked end of the heat pipe, creating a circulating eddy current. Solid, liquid or gaseous fuel is supplied to the combustion products of the additional fuel through the main fuel supply nozzle, which, being in a circulating vortex flow interacts with the combustion products: it is partially gasified, and its remains are heated to the spontaneous ignition temperature. The resulting fuel mixture has high reactivity, enters the outlet of the burner device, where upon contact with air in the register, it self-ignites, creating a highly stable torch. High reactivity of the fuel, in addition to a stable flame, ensures high combustion efficiency.

Conclusions

The technology for obtaining humic substances from peat was developed, the residue after extraction was used for composite biofuel.

The physicochemical characteristics of the components were determined, which made it possible to create an optimal ratio of the composition.

Conducted studies of the drying kinetics of the created composite mixture based on the solid residue of peat after extraction of the humic component with crushed nutritious corn residues made it possible to obtain optimal energy-efficient modes.

The technology for obtaining humic substances and biofuel from peat and nutritious corn residues has been developed. Biofuel obtained by the technology on the basis of solid residue after extraction of humic substances from peat and nutritious residues of corn meets the standards of quality fuel and is 12.3 MJ/kg.

References

Atlas of the energy potential of renewable and non-traditional energy sources of Ukraine. Institute of Renewable Energy NAS of Ukraine, Kyiv, 2012 (in Ukrainian).

Chmel V.M., Novikova I.P., *Burner device*. Patent of Ukraine No. 135494. Date of publication 10.07.2019.

Novikova Yu., Petrova Zh., Vorobiov L., Chmel V., Skliarenko Ye., Novikova I., 2022, *Investigation of the combustion process of the developed composite granules*. Paliva 14 (3), pp. 124-130. DOI: 10.35933/paliva.2022.03.03.

O'Kelly B.C., Sivakumar V., 2014, *Water content determinations for peat and other organic soils using the oven-drying method*. Drying Technology, Vol. 32 (6), pp. 631-643. https://doi.org/10.1080/07373937.2013.849728.

Petrova Zh., Vyshnevskyi V., Novikova Yu., 2019, *Nonwaste Technology of Receipt of Humic Fertilizers from Peat*. Materials of the 2nd International Scientific Conference «Chemical Technology and Engineering» (Proceedins), Ukraine, Lviv, June 24-28th, 2019. Lviv: Lviv Polytechnic National University, 2019, pp. 278-279. https://doi.org/10.23939/cte2019.01.278.

Petrova Zh.O., 2015, *Study of modes of extraction of humus and humic substances*. Scientific works of the Odessa National Academy of Food Technologies, 47(2), pp. 190-194 (in Ukrainian).

Petrova Z., Sniezhkin Y., Paziuk V., Novikova Y., Petrov A., 2021, *Investigation of the Kinetics of the Drying Process of Composite Pellets on a Convective Drying Stand*. Journal of Ecological Engineering, 22(6), pp. 159-166. https://doi.org/10.12911/22998993/137676.

Sniezhkin Yu., Petrova Zh., Novikova Yu., Petrov A., *2020, Technology of complex processing of peat*. Energy and automation, No. 5, pp. 32-41. http://dx.doi.org/10.31548/energiya2020.05.032.

Sniezhkin Y.F., Paziuk V.M., Petrova Z.O., Chalayev D.M., 2012, *Heat pump grain dryer for seed grain*. Kyiv: Polygraph Service LLC.

Sniezhkin Yu.F. Petrova Zh.O., 2018, *Energy-efficient thermal technologies of functional raw materials processing: monograph*. Kyiv: Naukova dumka.