L. Kulakovskyi, Cand. Sc. (Eng.), **ORCID** 0000-0003-1273-6894
A. Bosak, Cand. Sc. (Eng.) **ORCID** 0000-0003-0545-9980
National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute»

CREATING FACTOR MODEL OF THE PEAT DRYING PROCESS IN PNEUMATIC STEAM-WATER DRYER

For countries with significant reserves of peat is an important issue of energy-efficient production of peat briquettes. The article states about the necessity of determining the optimal equipment's operation regimes of peat briquettes production. This especially due to the plants with a pneumatic steam-water peat dryer. These dryers are characterized by high productivity and low peat losses compared to factories with other types of dryers. This is achieved by the fact that the drying agent is used in a closed circuit and the heat of low-potential vapor is used. However, the drying process in this dryer has high energy consumption. That is why finding ways to reduce electricity consumption is a key task for implementing these dryers in production. The data and technology of operation the pneumatic steam-water dryer for creating a factor field of process was analyzed in article. In this paper, the basic parameters of peat that affect the peat drying regime, parameters of peat that are changed during the drying process and the parameters of the drying peat quality are determined. There were highlighted the disturbance effects and initial parameters of the model of peat drying process from them. The main controllable and uncontrollable effects and output parameters of the drying process also were chosen. Based on the analysis of the factors of the peat drying process and the developed functional model for the energy technology of the peat drying process, it was determined the interrelations of the output parameters from the input disturbances and control influences It was revealed that the main output parameter of the model is the parameter of electric consumption. The value of this parameter for the certain operating regimes should be minimized with the observance of qualitative indicators of the dried peat and the level of heat consumption by determining the necessary values of control effects.

***Keywords*:** peat, dried peat, pneumatic steam-water dryer, drying enclosures, cyclone.

1. Introduction

In many countries with a high level of agility, the Energy Strategies decelerate increasing the peat fuel production, in particular peat briquettes (Energy Strategy of Russia for the period up to 2030, Field Program for the Development of Peat Industry Organizations in Belarus, National Development Plan of Estonia, Concept of Development the peat industry of Ukraine until 2030, etc.). In order to achieve these goals, first, it is necessary to determine the optimal equipment's operation regimes. The peculiarities of the process of production of peat briquettes depend on the type of dryers installed at the plant. Determining the optimal operation regimes of dryers is not possible without the formation of an adequate factor field, describing the character of the drying process. Systematic analysis of the peat drying process for identifying the character and level of the relationship between the input parameters that objectively affect the process, and the output technical and economic parameters should be done.

An analysis of the drying process was carried out on the example of the Littleton peat briquetting plant (Republic of Ireland), where the pneumatic steam-water dryer (Peco dryer) is used. The choice of a plant with Peco dryer is that these plants are closed in recent decades. The reasons for closing were the depletion of peat deposits and high consumption of electric energy in the process of producing briquettes at these plants. In particular, in the 1990s, the Zamglay and Buchman peat briquettes plants (Ukraine) were close, in the 2000's Tuotsi (Estonia), Krokhan (Republic of Ireland) and there is a plan to stop else on in Derinlou (Republic of Ireland).As showed the results of the study of the operating regimes of steam tubular dryers, passing the operating regimes for optimal parameters allowed to reduce the electricity capacity of the drying process for more than 0,3 kWh/ t dried peat [1].

The purpose of the study is to find the necessary set of factors that influence to the process of drying peat in pneumatic steam-water dryers. It will allow to determine the main regime's parameters of the drying process for constructing a model of a dryer operation with optimal complexity.

2. Statement of the material

Drying of peat in pneumatic water-steam dryers occurs in five tube drying enclosures. In three of them, as a steam from the power plant is used as heat transfer agent. They are called enclosures of the first effect heat usage. Two enclosures (enclosures of the second effect) are heated with water. Water is heated due to the use of steam condensation. This steam is exuded from the peat during drying in the enclosures of the first effect [2].

Factory data provided by Littleton plant, Bord na Mona company (Republic of Ireland) indicates that in an hour this plant with pneumatic steam-water dryer produces only about 18 tons of briquettes from 45 tons of peat.

At the same time, at Manevitskyi peat-briquetting plant in Ukraine, for the production 1 ton of peat briquettes is spent 1,7-1,9 ton of peat [3]. At this plant, a pneumatic gas dryer is used. The loss of peat in a mass equivalent in the drying process consists of the moisture loss during the drying process, the loss of the peat with the removal of their particles by the drying agent through the cyclones, the loss with their penetration into the sludge water and the losses in pipes, as a result, of its clogging.

The loss of moisture in the drying process is characterized by such indicators as the productivity of evaporating moisture *W kg/h,* an amount of peat entering the installation G_1 and an amount of the dried peat [4]:

$$G_1 = G_2 + W,\ kg/h; \qquad G_2 = G_1 - W,\ kg/h \tag{1}$$

By the known values of productivity of evaporating moisture and moisture content of peat before and after drying, it is possible to determine the productivity by the input and dried peat using the following formulas:

$$G_1 = W\,\frac{100-w_2}{w_1-w_2},\ kg/h; \qquad G_2 = W\,\frac{100-w_1}{w_1-w_2},\ kg/h,$$

where w_1 and w_2– moisture content before and after drying,%.

Loss of peat with the removal of their particles by the drying agent depends on the efficiency of the cyclones, the concentration and aerosols' speed of movement. According to some estimates, the loss of dried peat is more than 10% [4].

The Peco dryer is equipped with three centrifugal fans designed to transport the peat mixture through the system (Fig. 1). Peat entering to the mixing chamber is picked up by airflow and is injected into the dryer's pipes. After exiting from the pipes, the peat-air mixture enters the guide chamber (helmet) and further into cyclone. In the cyclone, the deposition of the main mass of peat occurs. The air with small particles of peat is directed to the exhaust pipe of the cyclone. After that, it is sent to the second stage of purification (mechanical dry dust collectors or wet dust collectors, dry cyclones with additional fans at the end of the system). The speed of the peat movement in the pipes determines the time of peat passing through the dryer of the corresponding enclosure and directly affects on the drying process and the quality of dried peat. Therefore, the rotational speed of the engine of radial fans (two fans in water-driers IIA and IIB enclosure and one in steam enclosure of dryers), and consequently, their productivity should be included in the model. The first two enclosures are operated by open cycle with a single use of a drying agent. The air entering the drying enclosure absorbs moisture evaporated from peat and, after appropriate purification, is disposed of through the separation apparatus. Therefore, it is important to know the outside temperature, which is the initial temperature of the drying agent of the two water enclosures. In the enclosures of effect I, a drying agent is recycled. These enclosures are operated by a closed cycle. The air supplied by the fan to the fifth enclosure (IA) passes sequentially through all enclosures of I effect and absorbs moisture that is evaporated during the drying process. This air is not emitted into the atmosphere as in the enclosures of effect II. It is returned to the fan for re-use after partial drainage and heating in the heater (calorifier). Therefore, the additional regulating parameter for the enclosures of the I effect is the temperature of the air from the heater.

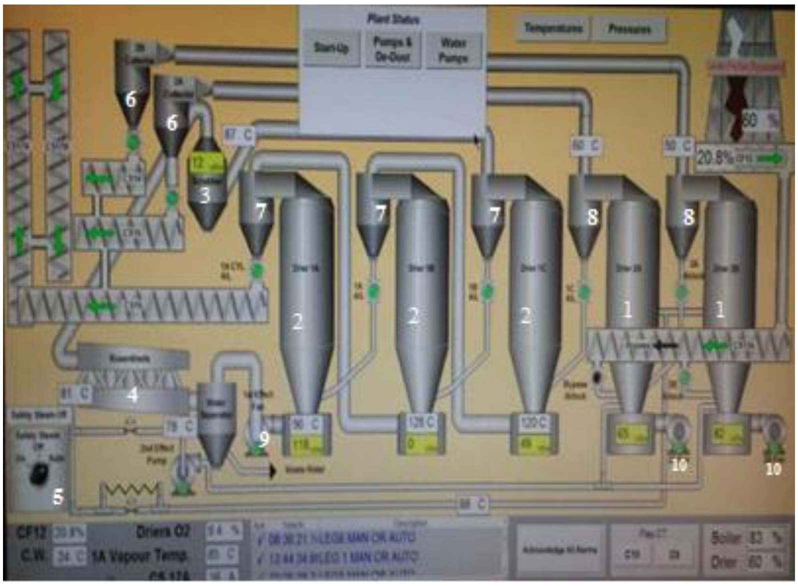

Figure 1 – Diagram for the operation of the Peco drying complex at the Littleton plant, where 1 – is the drying enclosure of the II effect, 2 – is the drying enclosure of the I effect, 3 – is a scrubber, 4 – is a heater, 5 – is a boiler, and 6 – are battery cyclones of the second stage of purification of IIA and IIB enclosures, 7 – drying cyclones of the II effect, 8 – cyclones of the I effect dryers, 9 – high pressure fan of the IA, IB, IC dryers, 10 – high pressure fan of IIA, IIB dryers

It is necessary include to the model of drying process such parameters of the heat transfer agent as the temperature of the waste steam from the turbine entering to the steam drying enclosures and the temperature of the hot water coming from the heat exchanger. The heat of moisture that evaporates from the peat in steam enclosures is used for drying peat in water enclosures. The utilization of the heat of a wet drying agent exiting the steam enclosures (I effect) is carried out in a scrubber. Saturated with damp and dusty mixture of air and peat particles in a scrubber is washed with water. This water contact with a utilized drying agent. It is heated, but is not used as a heat transfer agent for dryers due to purification and chemical aggressiveness. So, this water is fed to the heat exchanger. There heat exchange from sludge to pure water is proceed. Pure water is circulating between the heat exchanger and the IIB and IIA enclosures. Therefore, as a disturbing factor it can be taken into account the temperature of cold water. Although in the drying process, heat consumption by the Peco drying complex is not significant compared to other types of dryers (pneumatic gas), since low-potential heat carrier and steam extraction from a turbine are used. However, this parameter must be included in the drying process model.

One more regulative parameter is the load of peat driers. The supply peat to the dryer is regulated by changing the speed of the auger.

The peculiarity of drying peat in a pneumatic steam-water dryer is a significant consumption of electricity (40 kWh / ton of briquettes) [5]. This is due to the pneumatic transport of peat in the drying process through five enclosures (energy consumption for the operation of radial fans) and to ensure the circulation of water under the scheme of heat exchanger-scrubber and heat exchanger-drying enclosures by circulating pumps. Therefore, it is necessary to develop the operation regimes of the drying complex with a minimum of electric energy consumption to obtain a dried peat of the required quality. The bog piles of peat have widely different characteristics and blending help to achieve necessary results.

Output parameters of the drying process are also parameters of the quality of dried peat.

It should be noted, that the factory produces briquettes and granules of various sizes. This is for customers wishing to supply smaller briquettes for specially designed combustion devices for smaller fuels. Therefore, the dried peat moisture variation should be low – up to 2%.

The analysis of physical and mechanical properties of peat and dried peat is given in Table 1.

Table 1 – Physical and mechanical properties of peat and dried peat that determine the character of the peat drying process

The main parameters of quality of the dried peat	Parameters of peat, which vary considerably during the drying process	Parameters of peat affecting the peat drying regime
- fractional composition	- moisture	- moisture
- moisture	- moisture variation	- moisture variation
- moisture variation	- temperature	- temperature
- bulk density		- bulk density
- temperature		- fractional composition
- ash content		- flowability
		- ash content

A large difference in the quality of peat that supply to the plant are characterized for Ireland's plants. According to the Litellon plant data, the moisture varies from 40% to 60%, the ash content is from 3% to 10%, the bulk density is from 260 kg/m^3 to 360 kg/m^3, the level of impurities (wood, moss) is also different. So, there were installed a blending bunker and hammer mills at the plant for the averaging of these parameters and reduction fractional composition of peat particles. Some 200 wagons per day from 3 or more bog piles are blended in this way and a mean value for each of the peat physical characteristics is obtained.

Since the peat passes through pipes of diameter 55 mm, it is necessary to control the physical and mechanical properties of peat, in order to reduce the probability of tube jamming (large size, bulk density) and to decrease erosion process from high ash content. Therefore, it is necessary at the entrance to the dryer control the moisture content, moisture variation, bulk density, ash content, fractional composition of peat. According to laboratory studies [6], the increasing of the peat temperature from 15 °C to 100 °C has increased the strength of briquettes by 40% by 25-times loaded. Therefore, such factors as temperature of peat and dried peat should also be included in the model. The bulk density, fractional composition and ash content are changed not too significantly during the drying process. So, these parameters of the dried peat are not included into the model of the drying process. Block diagram of the drying process in pneumatic steam-water dryers is presented in Fig. 2.

The analysis of the factor field, energy and technical indicators of the drying process in Peco dryer allowed to identify the main factors and parameters in mathematical model of drying process.

Parameters $Y_1, Y_2,..., Y_5$ – are the outputs of the system which should be optimized and controlled. The input variables that are manipulated to obtain the desired outputs are denoted by $X_1, X_2,..., X_5$. The disturbances that act on the system are represented by $Z_1, Z_2,..., Z_9$. When the values of $Z_1, Z_2,..., Z_9$, change, the outputs variables Y_1,

Y_2, Y_3 will also change. To adjust the outputs to the desired values, optimal values of inputs X_1, X_2,..., X_5. Based on the analysis of the factors of the peat drying process and the developed functional model for the energy technology of the peat drying process, it is necessary to determine the interrelations of the initial parameters Y_j from the input disturbances and control influences and obtain a model of the type:

$$Y_j^m = \sum_{k=1}^{N} \beta_{jk}\psi_k(X_1, \dots, X_5; Z_1, \dots, Z_9),$$

where β_{jk} – is an unknown parameter (constant) while $\psi_k(\cdot)$ ϵ is a chosen set of basis functions, *N=12*; and *k Є {1,...,5}*: $\psi_k = X_k$; or *k Є {6,...,15}*: $\psi_k = Z_k$.

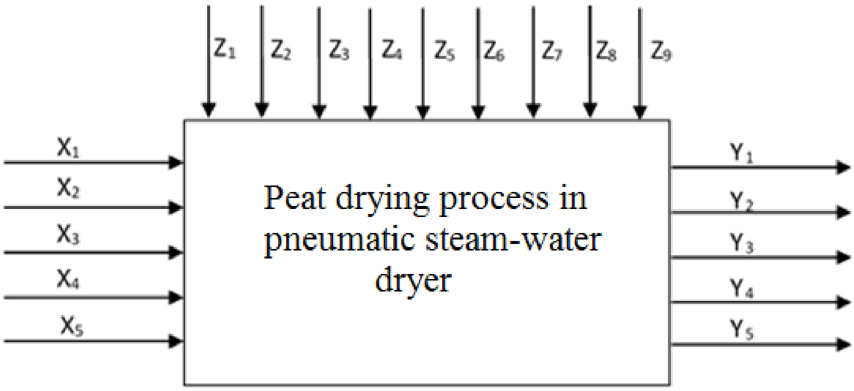

Figure 2 – Functional description of the model of the drying peat process in the pneumatic steam-water dryer, where Y_1 – dried peat moisture content, Y_2 – dried peat moisture variation, Y_3 – dried peat temperature, Y_4 – electrical energy consumption, Y_5 – thermal energy consumption, Z_1 – peat moisture, Z_2 – peat bulk density, Z_3 – peat moisture variation, Z_4 – peat ash content, Z_5 – peat temperature, Z_6 – peat flowability, Z_7 – peat fractional composition, Z_8 – air temperature, Z_9 – pure water temperature, X_1 – auger rotational speed, X_2 – air temperature from heater, X_3 – steam temperature, X_4 – fans flow rate of drying II enclosures, X_5 – fan flow rate of drying I enclosures

In order to get the optimal output parameters Y_1, Y_2, ..., Y_5, it is necessary to calculate and adjust the optimal values of the input control factors X_1, X_2, ..., X_5.

3. Conclusions

It was found that the consumption of electricity of the peat drying process in Peco dryer is the highest among other dryers. Therefore, the output parameter of electricity consumption should be in the target function of the mathematical model of the drying process. Controlled (regulating) factors of the model are fan speed, steam temperature, air temperature at the outlet from the heater and the auger rotational speed. The factors that carry out uncontrolled (disturbing) influence on the drying process in pneumatic steam-water dryers are moisture, moisture content, bulk density, flowability, fractional composition, temperature, and ash content of peat, temperature of pure water and air temperature.

In further research, it is necessary to plan the experiment and carry out industrial experiments at the peat briquetting plant. According to the obtained data, it is necessary to construct a mathematical model of the drying process and to develop optimal regime parameters. This model will allow to achieve optimal values of the output parameters by optimizing the control effects for certain values of disturbing influences.

References

1. Kulakovskyi L. Ya. Pidvyshchennia enerhoefektyvnosti enerhotekhnolohichnoho kompleksu sushinnia na torfobryketnomu vyrobnytstvi [Increasing the energy efficiency of the energy technology complex of drying in the peat-briquetting industry]. / avtoref. dys. na zdobuttia nauk. stupenia kand. : spets. 05.14.01 "enerhetychni systemy ta kompleksy", Kyiv, 24 p, 2017.
2. J. Martin, Mechanical Section/ Irish Engineers Journal Supplement, pages 34-37, 1970.
3. V Gneushev and I. Kyrychyk Problemy roboty torfobryketnykh zavodiv za nestachi vyrobnychykh poliv [Problems of peat briquetting factories due to the lack of production fields]. / Uhol Ukrainy, February 2016, pages 43-47, 2016
4. V. Naumovych Iskusstvennaia sushka torfa [Artificial drying of peat] / Moskva, Nedra, 222p, 1984.
5. J. Martin Briquetting of peat fuel, Proc. Inst. Briquet. Agglom. Bien. Conf., 14, pages 153-171, 1975
6. D. Zverev Puty usovershenstvovanyia torfobryketnoho proyzvodstva [Ways to improve peat briquette production]. /Mekhanycheskaia pererabotka i transport torfa, pages 3-11, 1964.

УДК 622.331

Л.Я. Кулаковський, канд. техн. наук, **ORCID** 0000-0003-1273-6894
А.В. Босак, канд. техн. наук, **ORCID** 0000-0003-0545-9980
Національний технічний університет України
«Київський політехнічний інститут імені Ігоря Сікорського»

ФОРМУВАННЯ ФАКТОРНОЇ МОДЕЛІ ПРОЦЕСУ СУШІННЯ ТОРФУ В ПНЕВМОПАРОВОДЯНИХ СУШАРКАХ

Для держав із значними запасами торфу гостро стоїть питання енергоефективного виробництва торфобрикетів. В статті проведено аналіз даних та технології роботи пневмопароводяних сушарок, що застосовуються на торфобрикетних заводах. В роботі було виконано розробку факторного поля процесу сушіння в пневмопароводяній сушарці. Проаналізовано якісні характеристики торфу, що надходить на торфобрикетний завод, сушенки та характеристики торфу, що змінюються в процесі сушіння. Серед них були виділені характеристики, що були віднесені до збурюючих неконтрольованих впливів та вихідних параметрів системи. Аналіз і формування збурюючих впливів дозволив сформулювати достатню кількість неконтрольованих факторів моделі. Для компенсації їх впливу на процес сушіння було виділено контрольовані фактори. Встановлено, що основним вихідним параметром моделі є параметр електроспоживання, значення якого при певних режимах роботи повинно бути мінімізовано з дотриманням якісних показників сушенки і рівня теплоспоживання за рахунок встановлення необхідних значень керуючих впливів.

Ключові слова: *торф, сушенка, пневмопароводяна сушарка, сушарні корпуси, циклон.*

Надійшла 07.11.2019
Received 07.11.2019