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Functionality of Process Control in Moulded Goods Production

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Abstract. The article presents the findings of the research in the field of automatic control of peat mass quality in hollow peat pot production. The strength of the finished product determines its integrity and crumblability which affect the loss during drying and transportation. Therefore, knowing the strength characteristics we can use them for quality control. Besides, not strength but heterogeneity in the distribution of pores, moisture, and density is responsible for crumbling. Automatic regulation of effective peat mass water content is one of the main stages determining the quality. At this stage automatic control of the flow, dispersion and water content of peat mass entering the pulper tank as well as measurement and control of the amount of additional elements introduced, such as mineral components, wood pulp, and water to form the required consistency, are provided for. The models of automatic process control are built and analyzed with the methods of differential equation theory, numerical integration, and stability theory. The model is implemented with the custom-made proprietary software. The model adequacy is determined empirically by comparing the data obtained on the model with the actual technological process.

1 Introduction

The production [1, 2] of moulded peat goods should provide a strong and durable product since its strength indirectly determines its integrity and crumblability affecting the loss during drying and transportation. Hollow peat pots filled with nutrient-rich peat soil are widely used in the agrarian sector for growing seedlings of various vegetables and decorative flowers as well as those of berry and decorative shrubs, and other crops. Therefore, the knowledge of just strength parameters of the final product can be used to control its quality [3-5]. Moreover, crumblability is caused by not only strength but heterogeneity in the distribution of pores, moisture, and density.

Technological factors [3, 6-8] that influence the strength include dispersion and initial water content in moulding the prepared peat raw material. The substance fineness factor expressed as a percentage shows dispersion identified in the studies with a conditional specific surface area of particles S (m^2/kg). The fineness has to be determined to characterize peat as feedstock for industry, to study its physical-chemical and mechanical properties as well as to study various production processes [9-12].

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The process of moulding hollow peat pots can be divided into four interconnected stages:
• preparation of peat feedstock,
• preparation of peat wood mass,
• mixing,
• pressing and drying of finished products.

In mechanical processing the physical properties of peat raw materials and their macrostructure change and plant residues are partially destroyed.

2 Materials and Methods

When water content is suited for moulding, hollow peat pots are thin-walled products moulded from processed peat-wood mass with fertilizers and other minerals added. They are structured systems mostly with a coagulation contact type of and a wide spectrum of binding energy among particles. The drying process is one of the ways to increase the concentration of a solid phase occurring in a peat system. The dependence of strength on water content is a broken line consisting of two straight sections with a point of inflection in the domain of $W = W_c$ (Fig. 1).

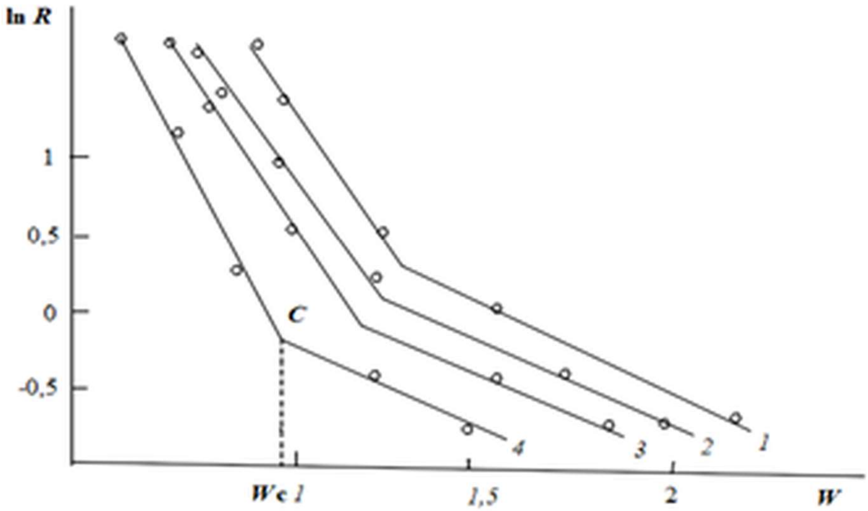

Fig. 1. Alteration of strength ln R (MPa) depending on water content W (kg/kg) of high-moor peat with decay degree of 25 % S = 570 (1), 445 (2), 380 (3), 309 (4) m^2/kg.

The first period determines the formation of a peat system structure which transfers from a liquid phase to a solid conditionally plastic one, with molecular bonds prevailing. The second section characterizes the temporal stabilization of a coagulation structure when the system changes from a viscoplastic state to a solid one, with hydrogen intermolecular bonds prevailing. For each of the structure formation periods the dependence of peat mass strength on its water content at a constant temperature is represented as an exponential equation:

$$R = R_{0W} \exp(-\lambda W) \tag{1}$$

where: $\lambda = (\rho \cdot k_V)/(c \cdot \gamma_0)$ is a structure strengthening coefficient determined by ρ as solid phase density, γ_0 as peat dry matter density, k_V as shrinkage factor and c as compaction factor determined by a compression curve. As follows from Fig. 1 the strength increase in the second period is higher than in the first one.

Peat mass effective moisture content is one of the main factors determining the final product quality. This stage provides the automatic control of peat flow rate in a pulper tank, the measurement and adjustment of the amount of additional elements introduced such as mineral components, wood pulp, as well as water to form the required consistency.

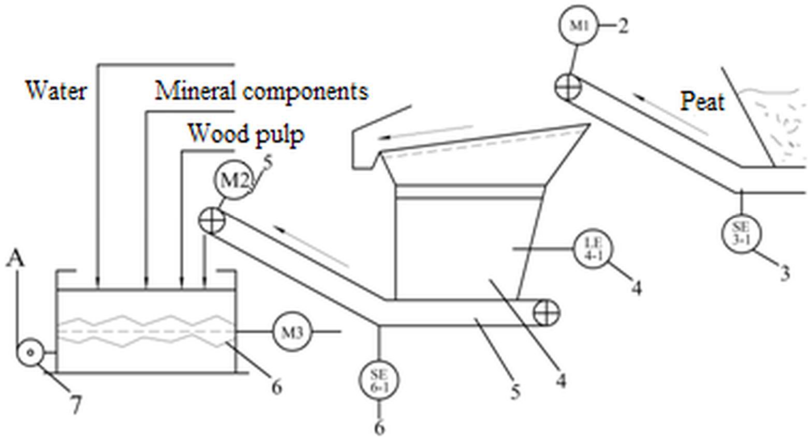

Fig. 2. Functional unit of peat mass preparation (explanations in the text).

Fig. 2 shows that peat feedstock is delivered and unloaded into Receiving Hopper 1. Belt Conveyor 2 sends the feedstock to Unbalanced-Throw Screen or Cascade Roller Disk Separator 3 where stumps and fractions larger than 25 mm are removed. The sifted material enters Measuring Hopper 4 is transported by Belt Conveyor 5 into Pulper Bath 6. The prepared peat-pulp mass is pumped over by Pump 7 from the pulper to the intermediate tank.

The batch-type pulper is used to saturate peat mass with water, to defibrate peat and wood pulp, to dissolve all the components and mix them intensively due to the intensive water vortex movement created by a rotating rotor with blades.

The main sensors of the unit automatic control are sensors feeling the level of bulk solids in hoppers and the feed conveyor speed. These automation tools help monitor the pulper feeding.

3 Results and Discussion

Each of the sections (Fig. 1) characterizes its own period of structure formation conditioned by the energy alterations of the intermolecular interactions of dispersed particles with each other and, therefore, with the dispersion medium. The nature of the energy level alterations allows individual structure formation periods to be fixed. Each of the periods corresponds to a certain interposition of solid and liquid phases as well as organic and mineral substances. The increment in peat strength is due to a change in the nature, the number of bonds between the structure elements during the transition from higher water content to smaller one, and structure imperfection [13-16].

High-moor peat R = 25% with initial dispersion S = 309 m^2/kg of peat feedstock has the inflection point C at the water content Wc = 0.9 kg/kg. The relatively low value of strength at W = 0.49 kg/kg is determined by the nature of shrinkage pressure distribution [3, 17]. This causes a change in the moulded peat strength. With an increase in dispersity up to

S = 445 m^2/kg, the shrinkage pressure distribution is more uniform which leads to a more uniform particle packing throughout the entire chunk volume and to the strength increase. The water content corresponding to the inflection point is 1.3 kg/kg by now. With the dispersion degree to S = 570 m^2/kg increasing further, the particle packing density increases and, therefore, the strength increases. The second period of structure formation does not begin simultaneously for the entire peat feedstock dispersion examined.

In the process of drying from moulding moisture to inflection point moisture the coagulation structure of peat chunks strengthens by the convergence and compaction of supramolecular formations which explains their intense shrinkage. In this water content range the moisture of physicochemical bonds is removed. Dehydration occurs due to the moisture flow out of large spaces. At the same time, the number of elementary interaction acts is growing which ensures the development of internal pressures being unequal in the upper and central layers. In the second period, the physicochemical bond of water with the material is generally removed.

Modeling the automatic control system of technological parameters (humidity, dispersity) in moulding hollow peat pots consists of several stages:

- constructing a conceptual model of the control system and its formalization,
- constructing the system model algorithms and their machine implementation,
- obtaining model results of control system parameters.

The model implementation is based on the custom-made proprietary software. The model adequacy is determined empirically by comparing the data obtained on the model with the actual technological process.

Conducting experiments on a model consists in identifying the dependence of the effects of variables *x (factor)* on *y (reaction)*. Each factor in the experiment x_i, $i = 1, k$; takes one of the valid values called a level. The whole range of factor levels determines the state in which the system exists.

The relationship between the factor levels and the system response can be represented as a ratio:

$$y_l = \Psi_l(x_1, x_2 \dots x_k)\ l = 1, m \tag{2}$$

Function Ψ_l linking a reaction with factors is called a reaction function. The initial form of dependence Ψ_l is not known, therefore, it is customary to use an approximate ratio:

$$\bar{y_l} = \varphi_l(x_1, x_2 \dots x_k)\ l = 1, m \tag{3}$$

Dependence φ_l is found experimentally.

The accuracy of steady-state modes and the quality of transient processes taken together determine the quality of an automatic system to control the moulding of hollow peat pots. The accuracy is assessed by the absence or presence of a mismatch in various steady-state modes and with the error ratio.

4 Conclusion

When conducting experiments with the model we took into account the sensitivity of the model to parameter changes and variations. The sensitivity analysis of the model made it possible to assess the degree of result alterations relative to the change in one or several input parameters and also determined the stability of the automatic control system.

To solve the tasks set we used the methods of system analysis and mathematical modeling of complex automatic control systems. The process of hollow peat pot production was decomposed into logical blocks. To construct and analyze the models we used the methods of the differential equation theory, numerical integration, and stability theory. The research into mathematical models and experimental data processing were based on the custom-made proprietary software.

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