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SPECIAL FEATURES OF A STRUCTURE OF TECHNICAL OPERATIONS FOR PEAT EXCAVATION WITH STAGE DEWATERING

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A method of development of a technology of peat extraction for intensifying of dewatering which involves drying of peat raw materials in thick layers with a layer-by-layer harvesting into large-sized roll with further delivery to the field storage unit of the enlarged sizes is presented in the paper. Throughout the year storage raw materials may be transported to the customer or to the shopfloor for further processing. Considering dimension and mass characteristics, a crumbed peat of various moisture capacity is a major type of products to be of high demand. On the basis of the results of scientific studies regarding gravity dewatering of peat and its drying in field environment, the ways of intensifying of field dewatering of peat for extraction at shallow-peat lands and fine-limit fields are proposed. The presented results of the experimental performance of a technology of peat drying in thick layers with a layer-by-layer harvesting indicate an increase of seasonal harvesting and a decrease of the influence of unfavorable meteorological factors on the stability of the extraction process. Performed investigations allowed to develop a structure of technical operations for peat excavation with the stage dewatering in spreading and intermediate storage units providing rational state of the extraction process regarding a complex of technical factors. A suggested scheme of a process area for a primary and secondary period of deposit exploitation by a technology of peat excavation is considered.

***Key words*:** peat, drying layer, excavation technology, peat deposit excavation, drying time, seasonal harvesting

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Introduction. For the moment the technologies of extraction of milled and sod peat are widely applied in development of peat lands in Russia and other countries. The technology of «milled peat» compounds up to 90-95 % of the peat industry. It is conditioned by large volumes of extraction and use of solar energy when dealing with the most power-consuming stage of the production cycle – peat drying on the surface of peat deposit. The expansion of milling technology of extraction and iteration procedure within the development of this technological scheme are conditioned by the utility of the end product which is a crumbed peat and it is considered to be suitable for the most types of further processing and direct use of field production.

Taking into account the variety of peat peculiar properties to be revealed in the process of peat deposits development, the evaluation of the potential use of peat and peat products of the projected peat enterprise should be performed with great attention. This issue will largely contribute to the process approaches and technological infrastructure of the production. Great variety of peat properties supposes a differentiated approach to the choice of a way of its extraction and use. Under modern conditions of the development of peat industry when evaluating the resource properties of peat, the following high-level classification is applicable [11, 19, 20, 22-24]:

• Raw materials for production of fertilizer organics (ash content $A^c \le 35$ %, degree of decomposition $R_T > 20$ % for terrestrial and transitional peat types and $R_T > 15$ % for lowland peat). More than 95 % of Russian peat reserves are suitable for fertilizers production [6]. The technologies of production of fertilizer organics on the peat basis allow to use the crumbed peat of various humidity as raw materials.

• Raw materials for production of fuel products ($A^c \le 23$ %; $R_T > 15$ % for terrestrial and transitional peat types and $R_T > 10$% for lowland peat). A raw materials base for production of fuel products on the basis of peat compounds 85 % of nation-wide peat reserves [6]. Raw materials and fuel products may be represented by the crumbed peat of normal amount of moisture or a sod peat formed in the field environment.

• Raw materials for production of peat litter, substrate slabs, feed bricks, peat pots, feeding hydrolyzed sugars and other products of chemical peat processing ($A^c \le 15$ % and $15 \le R_T > 25$ %). Raw material base here is limited by huge peat deposits of terrestrial type situated in the north, north-west of Russia and in the central part of Western Siberia. Raw material base compounds about 5 % of overall peat reserves. During the extraction of such raw materials the specific requirements for particle-size composition and conditions of peat structure may be imposed.

• Raw materials for production of activated carbons (terrestrial peat type $R_T \ge 35$ % and $A^c \le 6$ %). According to the State register of mineral reserves (SRMR) the nation-wide reserves of such raw materials are concentrated in the European part of the country and in total are equal to 430 mln t, and this figure may grow significantly by leading the detailed exploration of zones 1 and 2 (fig.1) which is confirmed by the data regarding the process of peat accumulation. Peat raw materials for shopfloor stage of production may be supplied as a crumbed peat of various level of moisture or as a peat formed at the field stage of production.

• Raw materials for mineral wax production containing not less then 4 % of gasoline bitumen. The raw materials base for such type of peat in Russia is represented by the Nizhegorodskaya, Tver and Vologda regions [19].

In the process of field water separation peat raw materials are subjected to significant alteration of water-physical properties which has impact to other characteristics (structural, chemical, etc.). For example, the same level of peat moisture for comparable-size composition may be reached in field environment by both hard and soft drying conditions and will be governed by the structure of technological process. Normally, the moisture capacity of the peat raw materials after hard drying will be lower in contrast to the soft drying regime, a loss of a part of fast bituminoid is possible, a crumbling ability of the field product will be higher, etc. Such peat will be less valuable for the production of sorbtion materials, advanced chemical processing, etc. The structure of technological process of peat extraction and manufacturing of field products on the peat basis should be governed by the requirements of the customer for conservation of useful properties peculiar to original peat.

Use of milled peat technologies is difficult and is often economically unsound for the regions of low quantities of solar radiation and high amount of precipitations [14, 15, 19]. The existing approaches for milled technology realization and developed in the preceding years methods of intensification of crumbed peat drying in the field environment deal with the main tasks of production concentration and its diversification not to the fullest extent, being a half-measure for small and medium-size enterprises, especially under the conditions of unfavorable meteorological factors. The

Fig.1. Zone distribution of the state of exploration of peat reserves on the territory of Russia

1 – a zone of almost unexplored peat reserves; 2 – a zone of understudied peat reserves; 3 – a thoroughly studied zone of peat reserves; 4 – a territory without peat reserves; 5 – a zone of identified peat reserves

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conducted analysis of data in public sources showed that the reserves for productivity improvement and lowering of production costs of peat extraction should be used within the means of optimization of the energy consumption costs at various stages of water separation, ensuring better use of meteorological conditions and intensification of a load per area unit of extraction field by the technological methods [1, 12, 13, 18, 19, 24, 25]; this will allow small and medium-size peat companies to become active players in the market of peat raw materials and products.

The result of analysis of state of exploration of peat deposits, peculiarities of the existing peat extraction technologies, structure of peat extraction industry, existence of potential customers of peat products determined that the peat raw materials in the form of crumbed peat of various levels of moisture capacity is a main type of peat resources demanded for further processing during manufacturing of products in different economic and investment directions of the region in the area of heat-power engineering, agricultural sector, construction, ecology, etc. Considering the small-area and small-thickness peat deposits, this type of raw materials may be obtained by the way of realization of technological processes, the foundation of which is represented as the excavator extraction of peat resources with the stage-by-stage dewatering.

Ways of intensifying peat extraction at shallow-peat lands and fine-limit fields. One of the alternatives for the development of peat extraction technologies regarding the intensifying of dewatering is drying of peat raw materials in thick layers with the layer-by-layer harvesting to the large-sized roll with further transportation to the field storage unit of oversized dimensions. The storage peat raw materials may be all year round delivered to the customer or to the shopfloor module for further processing.

The results of the conducted scientific studies regarding the gravity dewatering of peat and peat drying in the field environment to be generalized and published in the monograph [8] showed that the intensity of field drying of peat may be increased both during the season and out-off season.

Knowledge about form and energy bonding between moisture and solid phase of peat for various levels of moisture content allows in a more reliable way to approach to tackling with the vital task of peat industry regarding the optimization of energy consumption costs for different stages of peat dewatering. For drying of a thin layer of H_{opt} thickness within the limits of evaporation zone of h_{ez} the drying time is $\tau = \text{const}$ which does not reflect a possibility of a layer-by-layer declining of thick layers as far as thinner layers of $h_i \le h_{\text{ez}}$ are drying up (i.e. the radiation balance and heat flow rate which are composed of accumulation and deep outflow are not taken into account). To deal with this issue we may address to the value of the criterion of optimality by L.M.Malkov [1, 4]

$$K_{\text{opt}} = \frac{P_d(1+W_{\text{w}})}{\tau} = \frac{q_i}{\tau}, \qquad (1)$$

where q – harvesting of a moisture peat from the area unit of a drying field, $q = (m_{\text{d}} + m_{\text{m}})/F$; F – area of a drying field; P_{d} – load of a drying field by dry peat; W_{w} – harvesting wetness.

Knowing that the evaporation rate $i_r = -P_d(dW/d\tau)$, and applying to the formula (1), expression for τ is the following

$$\tau = \frac{P_d(W_1 - W_2)}{i}, \qquad (2)$$

we shall find

$$K_{\text{opt}} = \frac{(1+W_{\text{w}})i}{W_1 - W_2} \approx i_{\max} \qquad (3)$$

for $\Delta W = W_1 - W_2 = \text{const}$.

The value for drying intensity is determined from the relation

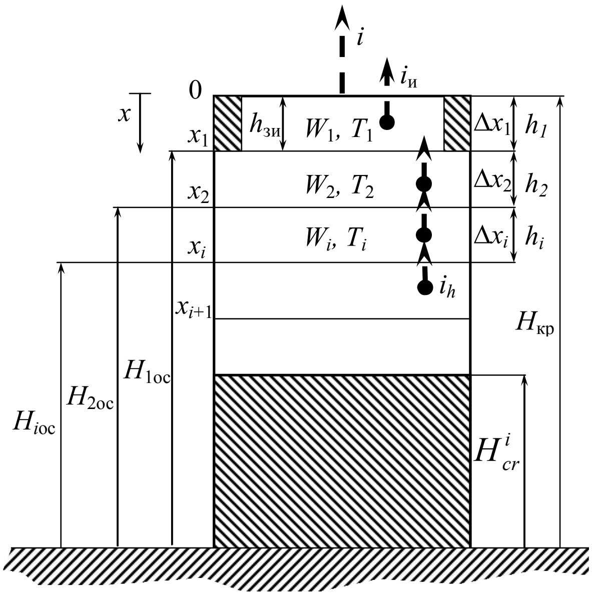

Fig.2. Scheme of layers location in the pile of peat of critical thickness during drying ($|i| = |i_g| + |i_u| + |i_h|$)

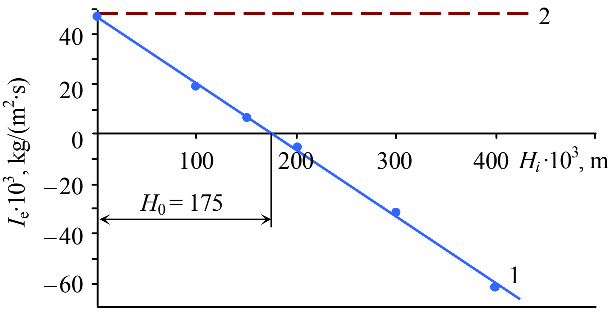

Fig.3. Pattern of evaporation rate, thickness of pile of terrestrial peat $R_т$ = 22-25 % (1) and maximum value $i_e = \alpha_R B$ (2)

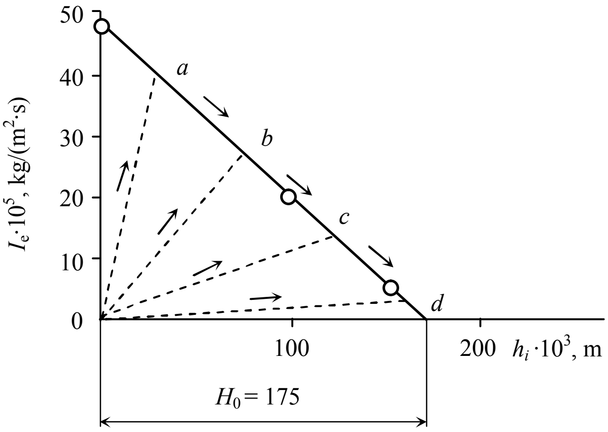

Fig.4. Scheme of smoothing the maximum (a, b, c, d) for patterns of evaporation rate and height of pile (layer) of peat materials (processing of data at fig.3)

$$i = -\gamma_d V \int_{W_1}^{W_2} dW , \qquad (4)$$

after integration

$$i = \gamma_d V (W_1 - W_2) , \qquad (5)$$

where $V = dx/d\tau$ – linear rate of evaporation, m/s.

Applying equation (5) to (3), we obtain

$$K_{\text{opt}} = \gamma_d V (1 + W_w) , \qquad (6)$$

where $V = i/\rho_l$.

Let us suppose that the evaporation rate within the zone of evaporation is equal to the intensity of moisture transmission from the underlying layer to the upper one (fig.2),

$$i_e = -a_m \gamma_d \frac{dW}{dx} . \qquad (7)$$

Taking into account the linear rate of evaporation (7) and technological characteristics $\rho_l = \gamma_d W$, $i = \rho_l V_i$, $V_i = dx/d\tau$; $\gamma_d = \rho_p(1 - n)$, $P_d = \gamma_d H_{\text{opt}}$, $i = -P_c(dW/d\tau) = \gamma_d H_{\text{opt}}(dW/d\tau)$ we obtain a differential equation

$$K_{\text{opt}} = -a_m \gamma_d \frac{1}{dx} \left(\frac{dW}{W} \right) (1 + W_w) . \qquad (8)$$

After integrating over W under condition of $dx \to \Delta x = h$, $W_2 > W_1$ the final equation (6) will be the following:

$$K_{\text{opt}} = -a_m \gamma_d \frac{1}{h} \left(\ln \frac{W_1}{W_2} \right) (1 + W_w) . \qquad (9)$$

This implies that the thinner the drying layer is, the higher K_{opt} will be. During drying of thick layers the intensity falls down (fig.3, 4).

Equation (9) may be written with respect to main technological characteristics – a load of drying area over dry substance of peat $P_d = \gamma_d h$, then

$$K_{\text{opt}} = -a_m \frac{P_d}{h^2} \left(\ln \frac{W_1}{W_2} \right) (1 + W_w) . \qquad (10)$$

Consequently, for constant load of a drying field over dry peat substance, the criterion of optimality grows with the decrease of an area of layer height and growth of moisture content of the underlying layer W_2. Value of a diffusion coefficient of moisture may be calculated by the equation [5] $a_m = ih/(6\gamma_d \Delta W)$, where ΔW – alteration of moisture content over the time of fragmented peat drying, the layer thickness of which is less or equal to the value of the evaporation zone. Average values of the diffusion coefficient of moisture for the alteration of layer thickness from $4.0\cdot10^{-3}$ to $30.5\cdot10^{-3}$ m is respectively equal to $a_m = (1.68\text{-}6.38)\cdot10^{-6}$ m²/h for the fluctuation of the evaporation rate from 0.634 to 0.173 kg/(m²h).

For evaluation of a pattern of optimality criterion and a value of radiation balance B we modify the equation (10) taking into account the equation (5) and technological characteristics. Definitely, the equation is the following:

$$K_{\text{opt}} = \frac{\alpha_R (B-P)(1+W_{\text{w}})}{W} = \frac{q_i}{\tau}. \qquad (11)$$

Value of the optimality criterion grows following the growth of the value of radiation balance and the decrease of heat flow rate which also indicates the growth of peat harvesting with the reduction of moisture content in compliance with the equation (1).

Thus, from the point of view of the drying intensification, a layer-by-layer declining of thick layers is preferable in contrast to drying in single-layer spreading on the underlying wet peat pile. This circumstance is also confirmed in the papers [2, 4, 14, 16] where the intensity of peat drying in two-layers spreading was evaluated, i.e. drying on the dried out peat which was left after harvesting of the first layer ($W_2 < W_1$) [3].

Experimental studies. At the time of rapid development of peat industry in the USSR a range of researches performed a huge volume of the experiments, the main purpose of which was a search of ways for increase the peat harvesting. As the result, a considerable volume of empirical information was made but it was not theoretically interpreted. The analysis of the experimental data obtained over the years of field investigations, currently allows not only to confirm the correctness of the theoretical conclusions but also to determine new patterns which were unknown before.

A fundamental justification of the equation (11) follows from the analysis of the results of experimental studies of a pattern $iL/B = f(H_{\text{res}})$ in paper [4] (Fig.5). Here, L – a specific heat of evaporation out of peat, i – resultant value of drying intensity. The analysis of the presented data shows that iL/B is larger for thicker layer on which a drying of the upper, relatively thin layer, is performed, as iL/B grows up to 0.9 ($H_{\text{res}} \approx 100$ mm, a terrestrial pine-sedge peat, $R_{\text{т}} = 25$ %, $W_{\text{н}} = 2.5$ kg(w)/kg(d), and for the rest of peat types this value was 0.84 (lowland sedge peat, $R_{\text{т}} = 20\text{-}25$, $W_{\text{н}} = 4.2$ kg(w)/kg(d) and transitional peat, $R_{\text{т}} = 30$ %, $W_{\text{н}} = 5.1$ kg(w)/kg(d). With the reduction of H_{res} values of iL/B respectively go down to 0.68 and 0.50-0.40. For this value H_{res} a heat flow into the pile increases $P_{\text{acc}} \approx P_{\text{deep}}$. This thickness of a layer we call $H^i_{\text{cr}} = 20\text{-}30$, i.e. $h < H^i_{\text{cr}} < H_0$.

If $H_{\text{res}} < H^i_{cr}$ peat drying in the thick layers with the layer-by-layer harvesting, and peat drying up are not reasonable due to the losses of heat energy into the pile (an underlying layer – peat, mineral soil). Values of H^i_{cr} should be specified for a certain type and class of peat, its moisture capacity, particles dimensions, level of decomposition and other internal and external characteristics affecting heat-and-mass transfer.

Verification of a possibility of increase peat harvesting when it is dried in the multilayer thick spreading was performed on the basis of the experimental data for $q = f(H_{\text{res}})$, obtained in 2013 in the field environment, OJSC «Peat plant «Usiazh» (Republic of Belorussia) [9, 10, 17, 21] and retrospective data obtained in 1981 in Tver region [2, 4, 7] (Fig.6).

The analysis of the data shows a steady trend of increasing cyclic harvesting of peat with the growth of a layer thickness H_{res}.

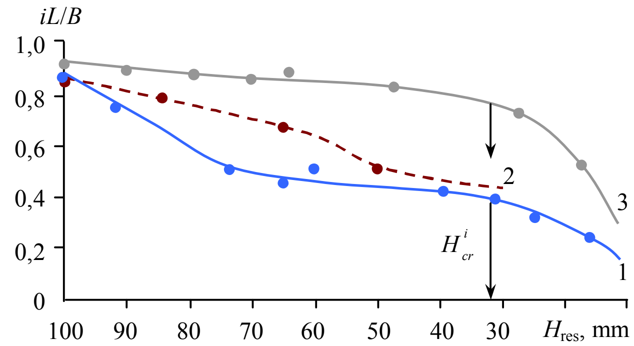

Fig.5. Relative heat costs for moisture evaporation iL/B for peat drying in thick layers

1 – lowdown sedge peat; 2 – transitional peat; 3 – terrestrial pine-sedge peat [15, 20]

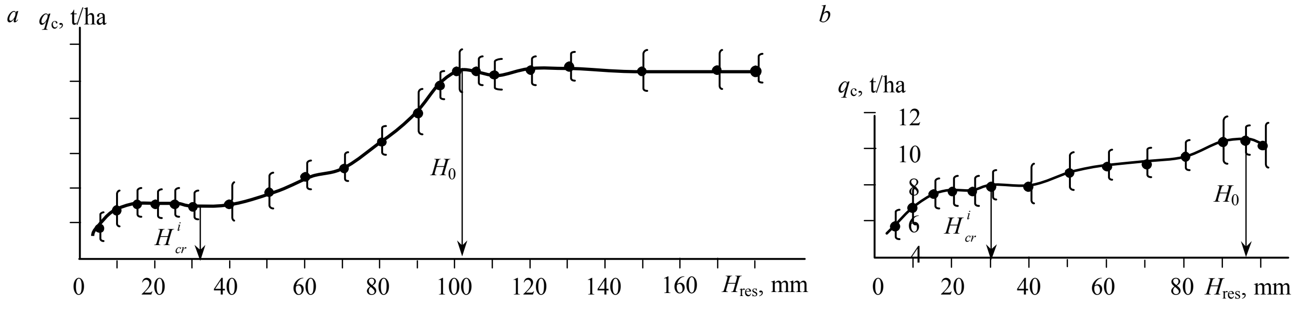

Fig.6. Cyclic harvesting of peat and thickness of aeration layer (without turning): *a* – data of 2013; *b* – data of 1981

A verification was obtained for various seasons of peat harvesting and the characteristics of original peat raw materials differed. For small values of $H_{res} = H^i_{cr} \le$ 20-30 mm harvesting increases from 6 to 8 t/ha (Fig.6, *b*) and from 15 to 18.5 t/ha (Fig.6, *a*, table 1), which indicates that there is a huge loss of heat energy in the underlying layer and reduction of costs for moisture evaporation (Fig.5). This condition corresponds with the existing technology of milled peat extraction with two-days duration of a cycle when the thickness of a dried crumbed peat is equal to 33-44 mm in average with relatively low peat harvesting when it is dried on the underlying peat deposit [15, 18].

Table 1

Relative values of experimental performance of drying technology in thick layers with the layer-by-layer harvesting (normalized by classical technology of milled peat)

Factor	2011	2012	2013	Range of variation	
	Factor relation N/E			N	E
Discharge of peat to the drying field, times	0.26	0.28	0.25	9-7	36-21
Peat harvesting, times	1.00	0.75	0.86	27-21	35-21
Average actual duration of a cycle, day	0.33	0.25	0.27	5.1-4.4	1.7-1.2
Average value of a cycle harvesting, t/ha	4.84	5.87	5.44	98.0-92.0	19.5-16.1
Seasonal harvesting, t/ha	1.61	1.46	1.55	846-644	576-399
Wetness of peat in the stockpile (storage base), %	0.95	0.97	0.92	47.6-450	50.7-46.1
Area of field, ha	0.3	0.5	0.1	1-0.1	

Notes: N/E – relation of factor of new scheme of drying to the existing milled technology; lowdown sedge peat, $R_т$ = 29-32 %

Further growth of H_{res} leads to increase of the values of cyclic harvesting up to 10.5 t/ha (Fig.6, *b*) and 33.5 t/ha (Fig.6, *a*) for H_{res} = 96 mm и H_{res} = 102 mm respectively ((iL/B) = 0.8-0.9, Fig.5) and decrease of deep heat flow into the peat deposit (table 2, P_{deep} = 18.3 W/m^2, $P_п = 1\cdot10^3$ W/m^2). Thus, the results of earlier led theoretical studies regarding heat and radiation balance are validated for drying of peat raw materials in thin and thick layers.

Table 2

Variation of heat flow characteristics and evaporation rate for pile of terrestrial peat of H_i thickness

Thickness $H_i\cdot10^{-3}$, m	Heat flow P, kW/m^2			Evaporation rate, kg/m^{2}s		$H_{cr}\cdot10^{-3}$, m	Notes
	P_{acc}	P_{deep}	$P_п$	$I_e\cdot10^{-3}$	$i_{max}\cdot10^{-3}$		
100	0.252	0.0183	0.2703	0.194	0.475	73	B = 0.457 kW/m^2;
150	0.378	0.0120	0.3900	0.069		110	$\alpha_R = 1.04\cdot10^{-6}$ kg/J;
200	0.504	0.0092	0.5132	−0.056		145	$\omega_н$ = 86%;
300	0.756	0.0061	0.7621	−0.317		209	$H_{opt} = 175\cdot10^{-3}$ m
400	1.040	0.0046	1.0446	−0.611		273	for $P_{deep} \approx$ 10 W/m^2

Optimization of drying time for peat raw materials. The next peculiarity of the drying process and harvesting intensification for the manufacturing of crumbed raw materials (production) is an organizational task. It includes the optimization of the time needed for drying of peat by excluding,

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if possible, secondary technological operations during drying period (harvesting for every cycle, repair of manufacturing areas and drainage network, delivery of peat raw materials to the drying fields, etc.). Such approach supposes the optimization of the periods of technological operations of peat drying realization; it follows from the analysis of the formulas (1) and (11). Therefore, the overall peat harvesting over the season will be expressed by the equation:

$$q_{\text{seas}} = nK_{\text{opt}}\tau, \qquad (12)$$

where n – number of harvesting cycles; τ – time of drying over the season of peat extraction. Whence it follows, that peat harvesting over the season will be determined by the number of cycles of harvesting, a value of K_{opt} and overall duration of drying.

Let us denote the calendar duration of the season of extraction by τ_{seas}, auxiliary time by τ_{aux}, and days with precipitations by τ_{pr}. Then

$$\tau = \tau_{\text{seas}} - (\tau_{\text{aux}} + \tau_{\text{pr}}). \qquad (13)$$

Let us plug an equation (13) in an equation (12) and we obtain the following pattern

$$q_{\text{seas}} = nK_{\text{opt}}\left[\tau_{\text{seas}} - (\tau_{\text{aux}} + \tau_{\text{pr}})\right], \qquad (14)$$

which grows with the increase in difference of time expenditures.

The equations (12), (13), (14) may be connected with the theoretical patterns of drying process optimization.

Thus, the optimization of technological process of drying consists in the increase the difference of time expenditures, number of harvesting cycles and criterion of optimality for all other conditions constant, with the implementation of the technology of production of crumbed peat with drying in thick multilayer spreading and separate harvesting from the multicycle rolls. In case of developing earlier dried up deposits with respect to the factors of already formed technological areas it is reasonable to use one large-sized roll for terrestrial type of peat deposit and two large-sized rolls for lowdown type of peat (Fig.7).

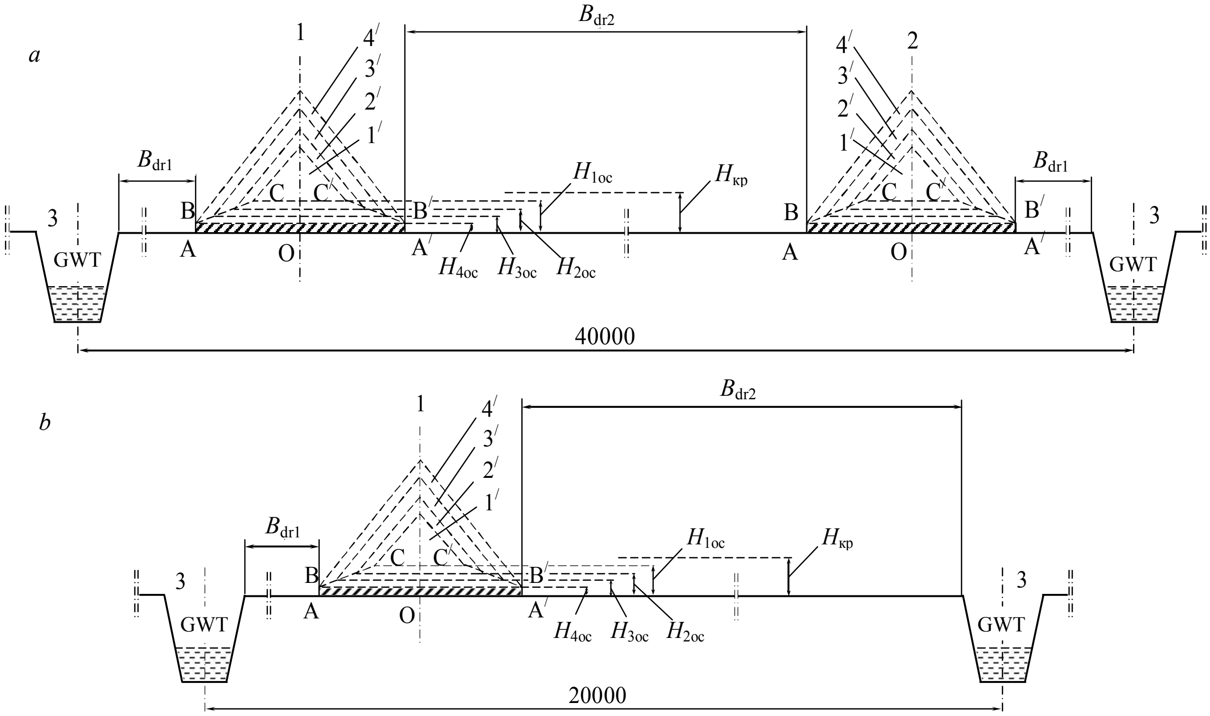

Fig.7. Scheme of location of large-sized rolls (4 harvestings) for lowdown (*a*) and terrestrial (*b*) peat deposit

1, 2 – rolls; 3 – field drain; OABCC′B′A′ – residual layer for multicycle roll; 1′, 2′, 3′, 4′ – piles of dried peat; B_{dr1} – section of drying field with edge of ditch (9.2 m); B_{dr2} – section of drying field in the inter-roll space (18 m); GWT – groundwater table

In case of such organization of operations regarding peat drying in thick layers with the layer-by-layer cycle harvesting (3-5 harvestings per one laying out in the drying field) into the intermediate large-sized roll, the delivery of peat to the storage premises will be performed during time periods between drying operations.

The presented schemes of cuttings of multilayer rolls (Fig.7) for lowdown and terrestrial deposits clearly demonstrate that the crumbed peat is situated under the multilayer rolls in the section OABCC/B/A/O; this peat was underdried to the conditional moisture (ω ≥ 53 %). During harvesting of such rolls an active mixing of peat takes place; this provokes averaging out of moisture over the flow of peat raw materials and leading to conditional state; the more dried peat was collected into the roll, the higher will be the probability of reaching the conditional state.

A complex of technological operations for peat excavating. In compliance with the technological scheme of peat excavation considering stage dewatering in spreading and intermediate storage units, a winning module should include a quarry, sections of gravity dewatering and drying. A section of gravity dewatering should be organized in the immediate vicinity to the excavation section or at special areas, where peat dewatering occurs inside the piles of optimal height up to the moment when the piles reach a critical height which is determined by the balanced condition of moisture under the action of gravity forces and capillary osmotic forces taking into account moisture evaporation.

It makes sense to consider technical support step-by-step. A structure of a complex of performed

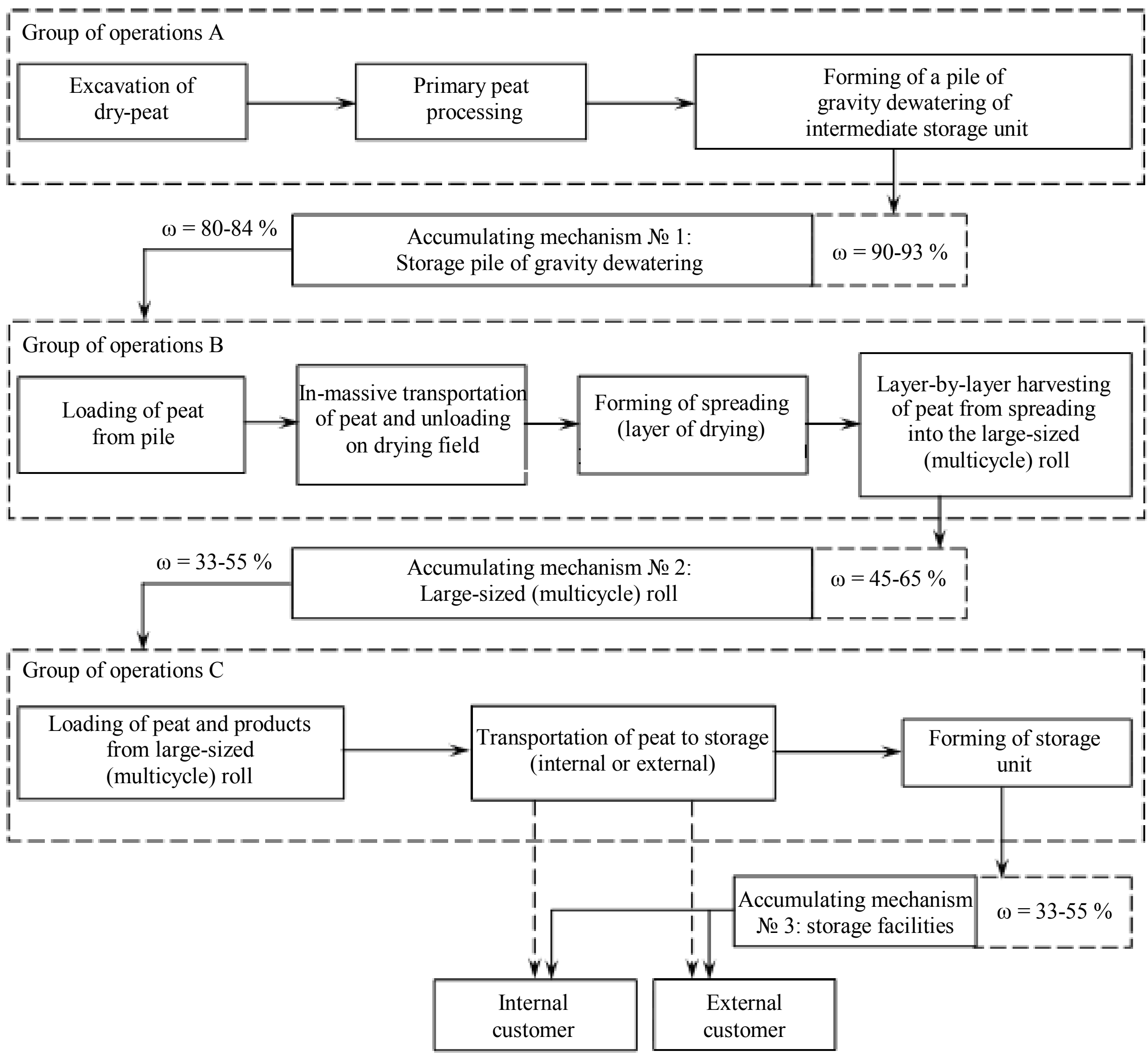

Fig.8. Structure of complex of technological operations for peat excavation with the stage dewatering in the spreading and intermediate storage units

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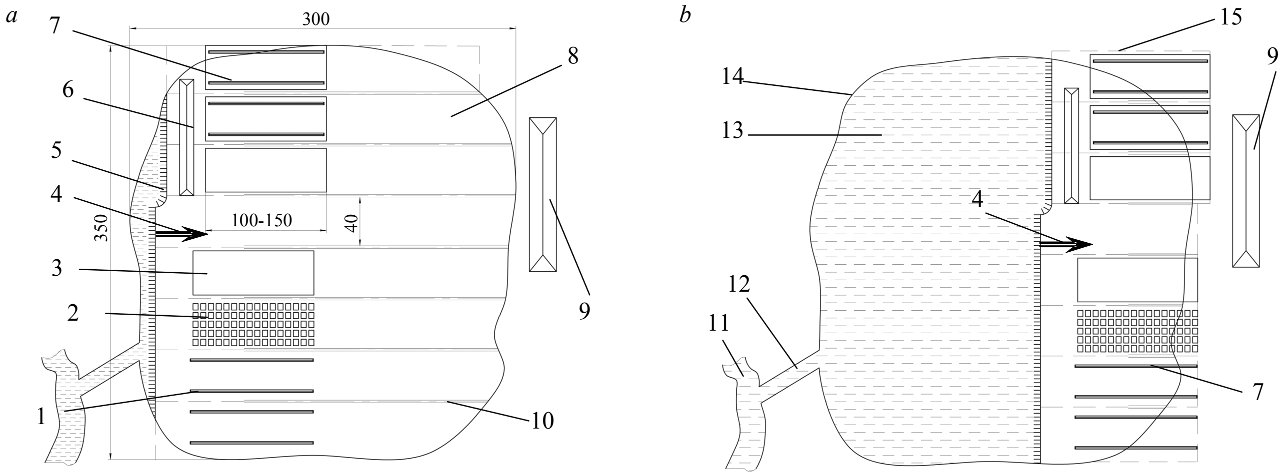

Fig.9. A scheme of technological area of peat excavation with stage dewatering in the spreading and intermediate storage units (during initial period of exploitation (*a*) and final (*b*) period of pile exploitation)

1 – crossing; 2 – loading of peat to drying field; 3 –spreading; 4 – direction of extracting front; 5 – border of peat quarry; 6 – storage pile of gravity dewatering; 7 – large-sized roll; 8 – peat deposit prepared to excavation; 9 – storage pile of field products; 10 – field drain; 11 – water receiver; 12 – principal channel; 13 – vacant plane; 14 – border of peat deposit; 15 – border of frying field

operations for adaptive technology of peat excavation with the stage dewatering in the spreading and intermediate storage units may be represented as a scheme with the linear and parallel links between processes; excavation and gravity dewatering; spreading operations; drying operations and harvesting into the large-sized roll; transportation operations and storage of raw materials and products (Fig.8). A visualization of a suggested scheme of a processing area is shown in Fig.9.

Conclusions. Energy consumption of extraction of crumbed peat by milled technology depends on the variation of meteorological factors and due to unfavorable weather conditions increases by 7-10 %. When using the adaptive technology of peat excavation with the stage dewatering in the spreading and intermediate storage units 65 % of time saving is provided for recycling of technology after precipitations. A potential of technological scheme of peat excavation is fully unlocked through the extraction of crumbed peat of high moisture for factory production of fuel agglomerate. One of the important advantages of the technology refers to an opportunity of its profitable application at fine-limit fields (up to 10 ha) and shallow-peat lands (average thickness of deposit reaches 1.0 m). It is necessary to note that application of the developed technological scheme for manufacturing of crumbed field production of 33-55 % wetness at the deposits of more than 40 ha area and at huge deposits of 6.0 m thickness is limited. Manufacturing of crumbed peat production of high wetness (65-70 %) is limited for the areas of more than 50 ha. For manufacturing of a crumbed production for providing energy resources saving it is reasonable to use intensive layer-by-layer surface technologies by including the developed approaches regarding drying of thick layers with layer-by-layer harvesting.

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