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Research

ASSESSMENT OF GRAVITY COMPONENT OF MOISTURE FLOW IN RAW PEAT IN CONDITIONS OF CONVECTIVE AND RADIATIVE-CONVECTIVE HEAT INPUT

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ABSTRACT

It was found that one of the main obstacles to active use of local peat fuel is the low reliability of existing technological schemes of peat extraction in the operating conditions of relatively small peat factories. It was shown that in some cases, such technologies may be reduced to small-scale year-round production of peat by excavation method or milled peat of high moisture, which greatly increases the peat fuel production reliability, its supply to the end users. It was found that the target range for the humidity of the peat raw material entering the workshop/facility for production of peat fuel by extrusion is that of 60% to 70%.

The results of theoretical and experimental research to study the technological parameters of the peat raw material production within the developed technological scheme of operating peat factory unit are considered.

INTRODUCTION

In In the current economic conditions, where the energy component takes up one third of the total volume of the Russian freight, more and more acute becomes the question of enhancing energy security, one of the ways being ensuring the intensive involvement by power generating enterprises of local fuel and energy resources, and in particular those based on peat fuel.

One of the main obstacles to active use of local peat fuel is the low reliability of existing technological schemes of peat extraction in the operating conditions of relatively small peat factories.

The transition to exclusive shop floor production of peat fuel may greatly simplify the technology of extraction of raw materials, reducing the need for the preparation of fields for production and drying of peat in the field's area, warehousing, storage and transportation, substantially reducing the dependence of production cycle on weather conditions, fire, etc. In some cases, such technologies may be reduced to small-scale year-round production of peat by excavation method or milled peat of high moisture, which greatly increases the peat fuel production reliability, its supply to the end users, but in turn requires considerable energy for the process of removing more water from the raw material at the shop floor stage of agglomerated fuel production (Rozhkova, 2014; Klavins, *et al*., 2009; Lishtvan, 2008; Lishtvan, 2001; Zaitseva, 2004; Piralishvili, *et al*., 2016; Peat production in Finland, 1996).

With the implementation of the technological scheme of peat extraction via excavation, all the tasks of the field production phase can be solved at a small area of the deposit with a minimum set of equipment for general purpose (swamp excavator, swamp bulldozer, machine-tractor units, wheel loader) and its organization requires minimum investment, which is very attractive for small companies. The studied technological production scheme is described in the patent "Modular technological complex of

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peat extraction and production of fuel agglomerates" (Kremcheev, *et al.*, 2012; Afanasiev, 2003; Efremov, 2014; Afanasiev, 1984).

One of the ways to improve the energy efficiency of production of agglomerated peat fuel at small-scale year-round production factories is the combination of processes in the field and in the shop to remove moisture and operational control of production, depending on the changing environmental conditions (Sulman, *et al.*, 2007; Kremcheev, 2014).

The choice of rational parameters when performing the technological operations on enrichment of high moisture peat raw materials should be based on the maximum drying rate in these weather conditions, as well as optimization of energy costs for dehydration of raw peat. Solving this problem requires a comprehensive study of the dehydration process of waterlogged peat raw material with moisture 84% to 90% under the action of gravity and capillary-osmotic forces, as well as due to evaporation.

On the basis of previous studies, it was found that the target range for the humidity of the peat raw material entering the shop unit for production of peat fuel by extrusion is that of 60% to 70% (Misnikov, *et al.*, 2015). In some cases of diversification of production, the range can be 50% to 70%. Thus, the goal of the field phase of peat enrichment in mining and quarrying is to make moisture from 84% to 90% to 50% to 70%.

METHODS

In the study of hydraulic conductivity of waterlogged peat deposits broken structures under the influence of gravity P_g and capillary-osmotic forces P_k the conditions are created, when $P_k = P_g$, at which the intensity i_g of moisture flow tends to zero ($i_g \to 0$), and the height of the peat layer h tends to limit (minimum) $H_{cr} = const$ with a corresponding value of the effective pore radius r. After reaching the critical pile height, the dehydration of peat ceases, and further reduction of moisture requires mechanical forced press of raw peat or drying operations (field drying or in the factory conditions).

The theoretical studies revealed the dependence of the coefficients of the gravitational dehydration efficiency on the initial conditions of dehydration, caused by the pile height and the moisture content.

Given the fact that the experimental value of the critical height of pile H_{crE} is connected with its theoretical value H_{crT} through coefficient β taking into account the features of the real structure and indirectly reflects the resistance to moisture transfer (Kremcheev, 2012), $H_{crE} = H_{crT} \cdot \beta$, we obtained the expressions for calculating the coefficients of the gravitational dehydration efficiency in the form of:

$$K^{/}_{EF} = 1 - \frac{\beta}{h_p}\frac{2\sigma\cos\Theta}{r\rho_l g} \quad (1)$$

$$K^{/}_{EW} = 1 - W_{cr}/W_p \quad (2)$$

where σ – surface tension, *N/m*; r – pore radius, *m*; Θ – wetting angle of solid phase with the liquid, *deg.*; g – acceleration of gravity, *m/s²*; ρ_l – density of associated fluid $\rho_l = (0.81 \div 1.32)\cdot 10^3$ *kg/m³*, respectively, at $T = 273 \div 311$ *K*; W_{cr}, W_{in} – moisture content at the filtration balance and initial moisture content, respectively, *kg(w)/kg(d)*.

Considered filtration equilibrium ($P_k = P_g$, $i_g = 0$) will be violated as a result of moisture evaporation from the surface of the peat raw pile,

$$P_k \le P_g,\ i = (i_g + i_e) > 0 \quad (3)$$

where i_e -the intensity of moisture evaporation at $h_i \ge H_{cr}$. In this case, the additional moisture loss will be due to evaporation from the surface of the resulting film, the menisci of large and narrow pores, and also due to capillary moisture feeding into the evaporation zone. Thus, when determining the total moisture flow from pile of peat raw materials, the gravitational flow i_g and evaporation i_e will develop.

In the case of radiation-convective heat supply, the radiant component of heat flow q_r must be entered which can be expressed in terms of the radiation balance B with net loss Δ of heat through the base of the pile, especially for small height samples

$$q_r = \frac{B(100-\Delta)}{100} \quad (4)$$

Therefore,

$$i_e = \frac{q_r + \alpha_q(t_{env} - t_{sur})}{R_{vap}}, \quad (5)$$

Which at low energy losses ($\Delta \to 0$) will be

$$i_{\grave{e}} = \frac{B + \alpha_q(t_{env} - t_{sur})}{R_{vap}} = \frac{B + q_k}{R_{vap}} = \frac{q_0}{R_{vap}}, \quad (6)$$

where $q_0 = B + q_k$ -total heat flow, *W/m²*; R_{vap} -latent heat of vaporization, *J/kg*; α_q -coefficient of heat transfer *W/m²K*; t_{env}, t_{sur} -environment and surface temperature, respectively, *K*.

RESULTS AND DISCUSSION

The theoretical studies performed provide expression for the total water flow of pile of peat raw materials:

$$i = i_g + i_e = -k_b\left(\frac{2\sigma\cos\Theta}{r_i h_i} - \rho_g g\right) + \frac{q_L + \alpha_q(t_{env} - t_{sur})}{R_{vap}} \quad (7)$$

For real media with the efficiency of hydraulic conductivity (effective coefficient of moisture transfer), the equation (7) takes the form:

$$i_e = -K_E^{/}\left(\frac{P_k - P_g}{h_i}\right) + \frac{B + \alpha_q(t_{env} - t_{sur})}{R_{vap}} \qquad (8)$$

That is, when , $P_k < P_g$ $h_i > H_{cr}$ i_e the value is reciprocal of pile height h_i and the pore radius r, proportional to the heat flow q_0 and differential pressure $\Delta P = (P_g - P_k)$.

For another case where $h_i \le H_{cr}$ gravitational flow ($i_g = 0$) is excluded, and the gradient of the moisture content is changing only through evaporation. Consequently, from the conservation of mass of a substance it can be obtained that the amount of fluid released in the evaporation zone equals the number of evaporated moisture.

To assess the possibility of using the theoretical expression in the practice of calculation of technological parameters for the process of field enrichment of peat raw material, a series of experimental studies on natural peat samples for convective and radiative-convective heat supply were conducted.

Comparison of gravitational dehydration i_g with evaporation i_e of moisture from the surface of the pile was carried out on the basis of functional dependence $i_g = f(\tau)$ at different heights h_p of peat pile.

When calculating the evaporation rate for convective and radiative-convective heat supply for the average summer months, the data values obtained i_e differ more than 2.5 times, indicating that the increased role of evaporation in the gravitational dehydration of raw peat under favorable weather conditions (Panov, 2015).

A detailed analysis of Table 1 confirms the need to take account for the sooner evaporation from the surface of pile, the smaller its height h_p and the higher heat flux at $h_i > H_{cr}$. At $\tau = \tau_\partial$ evaporation intensity value i_e equals the intensity of gravitational dehydration i_g, but for very small values i_e which contribution to the total flow of moisture at different h_h is small, it can be ignored in the period $\tau < \tau_{eq}$. At low intensities of dehydration, the contribution i_e grows and its accounting is required when $\tau > \tau_{eq}$, i.e., when $h_h \to H_{cr}$. At $h_h = H_{cr}$, i_g is excluded from the balance of total moisture of $i = i_g + i_e$ ($i_g = 0$. $P_k = P_g$) and $i = i_u$.

CONCLUSION

Thus, the gravitational dehydration of peat pile is decisive to $h_i > H_{cr}$ compared with the evaporation of moisture from the surface of pile, increases with temperature and radiation balance ($q_L = B$), decreasing the relative humidity φ_c. We believe that taking into account the evaporation boundary is the "equilibrium" τ_{eq} at $i_g = i_i$, i.e., when evaporation is for 50% moisture flow. In view of the data, we consider it possible to encourage the developed approaches in selecting rational parameters of pile of raw peat with broken structures in preliminarily dehydration operations, and to assess the optimal duration of the gravitational dehydration period of pile under changing (over a wide range) weather conditions of extended peat extraction season.

Table 1. Comparison of gravitational dehydration with moisture evaporation from the surface of the peat pile at different heat supply (K and RK-modes)

The pile height, $h_p \cdot 10^3$, m	**Time τ, h**						**The equilibrium time τ_{eq}, h**	
	0.5	**4.5**	**21**	**49**	**109.5**	**225.5**	**K-mode**	**RK-mode**
	The intensity of the dehydration i_g, kg/(m²h)							
100	12.99	0.76	0.12	0.06	0.003	0	18.0	8.0
150	18.39	1.57	0.25	0.05	0.002	0	20.0	15.5
200	19.51	2.69	0.35	0.15	0.003	0	37.0	15.0
300	26.14	4.48	0.90	0.18	-	0.005	45.0	30.0
400	31.35	5.58	1.46	0.44	0.069	0.015	60.0	43.0

Note: 1. We used an upland scheuchzerite-sphagnum peat $R_T = (22...25)\%$. The research was conducted under ambient conditions (convective heat supply) at $t_{env} \approx 21.8\,^\circ C$, $t_m \approx 15.2\,^\circ C$ φ, = 47% $q_L = 0$, blower speed $v \le 2$ m/s, $W_N = 16.432$ kg/kg. When evaluating the moisture movement in the conditions of radiative-convective heat supply, taking the value $q_L = 0{,}38$ kW/m², $t_{env} \approx 21.8\,^\circ C$, $t_m \approx 15.2\,^\circ C$, $\Delta t = 6.6\,^\circ C$, $v \le 2$ m/s. 2. K and RK-the convective and radiative-convective heat supply, respectively. 3. Values τ_{eq} obtained by extrapolating the intersection of the graphs $i_g = f(\tau)$ and $i_e = f(\tau)$ on the axis τ.

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