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AN ENERGY SAVING DURING THE FILTRATION DRYING OF DISPERSIBLE MATERIALS. CHOICE OF OPTIMAL PARAMETERS OF THE PROCESS

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Abstract. The results of experimental studies of the kinetics of filtration drying of disperse materials of different structural structure and dispersible composition are presented in the paper, as well as the dynamics of saturation of the waste heat agent with moisture during the filtration drying of materials at different height of layer of the last ones. On the basis of the generalization of research results, optimal parameters for the implementation of filtration drying were determined, and the economic effect from the introduction of filtration drying into production, per 1000 kg of dry material, was calculated.

Key words: filtration drying, peat, coffee sludge, sand, coal.

Formulation of the problem

Drying is a complicated mass-exchange and technological process, which is widely used in the chemical, food and pharmaceutical industry, mainly at the final stages of production. The share of drying spending, in the cost of manufacturing of finished products, is significant, which increases their cost.

Analysis of sources of literature

To implement the drying of such type of raw material, we have proposed a filtration method, which enables to reduce the energy consumption of the dehydration process and, accordingly, the technological line of solid bio-fuel production in general. It is known that filtration drying is characterized by high efficiency due to the fact that the process of mass transfer occurs in the stationary layer of the disperse material, by filtration of the thermal agent through the pores and channels between the particles, and the surface of the mass transfer is close to the surface of all particles. Due to the fact that porosity of the layer of disperse material is within the range of 0.36–0.4 m^3/m^3, the rate of filtration of the thermal agent in the production conditions is 5–6 m/s [1], which provides high coefficients of heat and mass transfer, considerably higher than at any other drying methods at the same rates of the heat agent.

The purpose of the work

The purpose of this work is to research the kinetics and dynamics of saturation of the waste heat agent with moisture during the filtration drying of dispersed materials of different structure and disperse composition for determination of optimal parameters of the filtration drying process of the last ones.

Objects of the research

Dispersed materials of various structures were selected as the objects for the research, the drying of which is currently an actual task, and the cost is considerably determined by the energy costs of the process and the quality of which is determined by the regime parameters of the process of filtration drying.

Significant coal reserves in Ukraine and rising world market prices for primary energy sources makes it necessary to use it as a solid fuel at power plants [2–6]. Coal is a valuable raw material for the chemical industry, from which more than 2000 different products are obtained [4–5]. Coal is a complex high-molecular compound whose properties depend on the source material, the conditions of accumulation and the degree of metamorphism.

Coal is a solid body penetrated by a system of pores and cracks with dimensions from $3\cdot10^{-9}$ m to $1\cdot10^{-3}$ m. The internal porosity of coal is 4–8 % of the volume [7]. The explored anthracite coal, brand G (gas) is a poly-dispersed multi-component system with a certain amount of impurities. The ash-content of coal of different sorts is from 3 to 60 % of mass [8]. The actual density of coal depends on the degree of metamorphism and the petrographic composition and lies within 1160–1470 kg/m^3, [9].

Conditional density of coal lies within 1200–1350 kg/m^3. Bulk weight of coal depends on the type of coal, its granulometric composition and lies within 600–730 kg/m^3, [10]. Coal as an object of drying is a porous material with a system of pores and cracks, which differ in size and mutual location. The pores in the coal are opened, which are interconnected with each other and with the environment, and dead ended. According to the results of researches of many authors, the shape of the pores in coal is extremely diverse. Micropores between the planes of microcomponents of coal and crack are slit-like, pores, which preserve the structure of wood fibers, have a cylindrical shape, and closed pores have a form close to the spherical one. The share of micro and transitional pores accounted for 95 % of the entire internal surface and 80 % of the internal free volume. The humidity of the extracted coal is 18–28 %, however, according to the requirements for transportation of anthracite coal by rail, the moisture content of coal should not exceed 7.5 %. Therefore, coal after the enrichment processes must be dried [11–14].

Peat as object of drying is a complex, multi-component, heterogeneous, poly-disperse, capillary-porous colloidal system consisting of three phases: dry substance (containing organic and inorganic compounds), water and air. The most versatile characteristic of peat is the degree of its biochemical decomposition (1–75 %), which shows the content of unstructured substances in peat that have lost the cellular structure, and determines its basic physical and chemical properties [15]. In the natural state the peat represents a three-phase system (solid skeleton – water – gas). The particles of peat mostly have an elongated shape. The ratio of the largest particle size to the smallest one is 1.59–1.74 [16]. In the detailed analysis of the dispersion in the peat the following fractions were found (mm):3; 3–1; 1–0.5; 0.5–0.25; 0,.25–0.1; 0.1–0.05; 0.05–0.02; 0.02–0.01; 0.01–0.005; 0.005–0.002; 0.002–0.001 [15].The main characteristics of the porous structure of peat are: general and active porosity, sizes of pores, complete and kinetic specific surface area. In the natural state, the general porosity of peat is extremely high $e = 0.85 - 0.98$, and the active porosity is 1.7–2.0 times smaller. The complete surface area of different types of peat is $60 - 190\cdot10^3\ m^2/kg$, and kinetic – $0.2 - 4.0\cdot10^3\ m^2/kg$ [15].

Coffee sludge as an object of drying is a multi-component, polydispersed capillary-porous material. The detailed analysis of granulometric composition of coffee beans before extraction revealed the following particle sizes, mm [17]: 5 – 0.9–1.5 %; 3 – 32–33 %; 2 – 37–39 %; 1 – 20–22 %; 0.5 – 3.5–4 %. After extraction, the sludge consists of 75–80 % of water and 20–25 % of solid mass. The temperature of the sludge is 65–80 °C, and pH is within the range of 4.3–4.8. Based on the research of many authors of roasted coffee beans by the method of electron microscopy, it was found that the average size of the macropores is within the range $r = 10 - 20\cdot10^{-6}\ m$. The investigation of the size of micropores by absorption of CO_2, showed that their size is $17 - 33\cdot10^{-10}\ m$, and by the method of mercury porosimetry $r = 10 - 50\cdot10^{-9}\ m$ [17–18]. The porosity of the layer is $e = 0.33\ m^3/m^3$.

Sand is a friable fractional breed, which is a polydisperse mixture of different form grains with the size of $0.05 - 2.0\cdot10^{-3}\ m$. The sand particles, depending on the deposit, are spherical, spherical-angular, angular and longitudinal. In the form of sand particles, they are divided into rounded, spherical, round-spherical, scaly and longitudinal. By the nature of the surface of the particle there is a smooth, uneven and rough surface [19–22]. The true density of the river sand is equal to $r = 2620\ kg/m^3$, bulk density is $r_{нас} = 1550\ kg/m^3$, and the porosity of the layer is $e = 0.4084\ m^3/m^3$, for coarse-grained mountain sand respectively – $r = 2650\ kg/m^3$, $r_{нас} = 1450\ kg/m^3$ and $e = 0.4528\ m^3/m^3$. The specific surface of finely divided sand is $10 - 30\ m^2/kg$ $\left(16000 - 48000\ m^2/m^3\right)$, and of medium grain size $0.4 - 7.0\ m^2/kg$ $\left(600 - 10500\ m^2/m^3\right)$ [21].

Experimental part

Experiments were carried out on the equipment and by the methodology given in [23]. The results of experimental researches of the kinetics of filtration drying of the materials mentioned above are shown in Fig. 1. As we can see for coal and sand (Fig. 1, *a*, *b*), mechanical removal of free moisture is present during filtration drying, which is held by forces of surface tension. This moisture is removed due to the difference in pressure, and the costs for its removal are much less than in the case of its thermal drying, when this moisture needs to be evaporated. In the case of filtration drying of peat and coffee sludge (Fig. 1, *c*, *d*) mechanical removal of free moisture is absent.

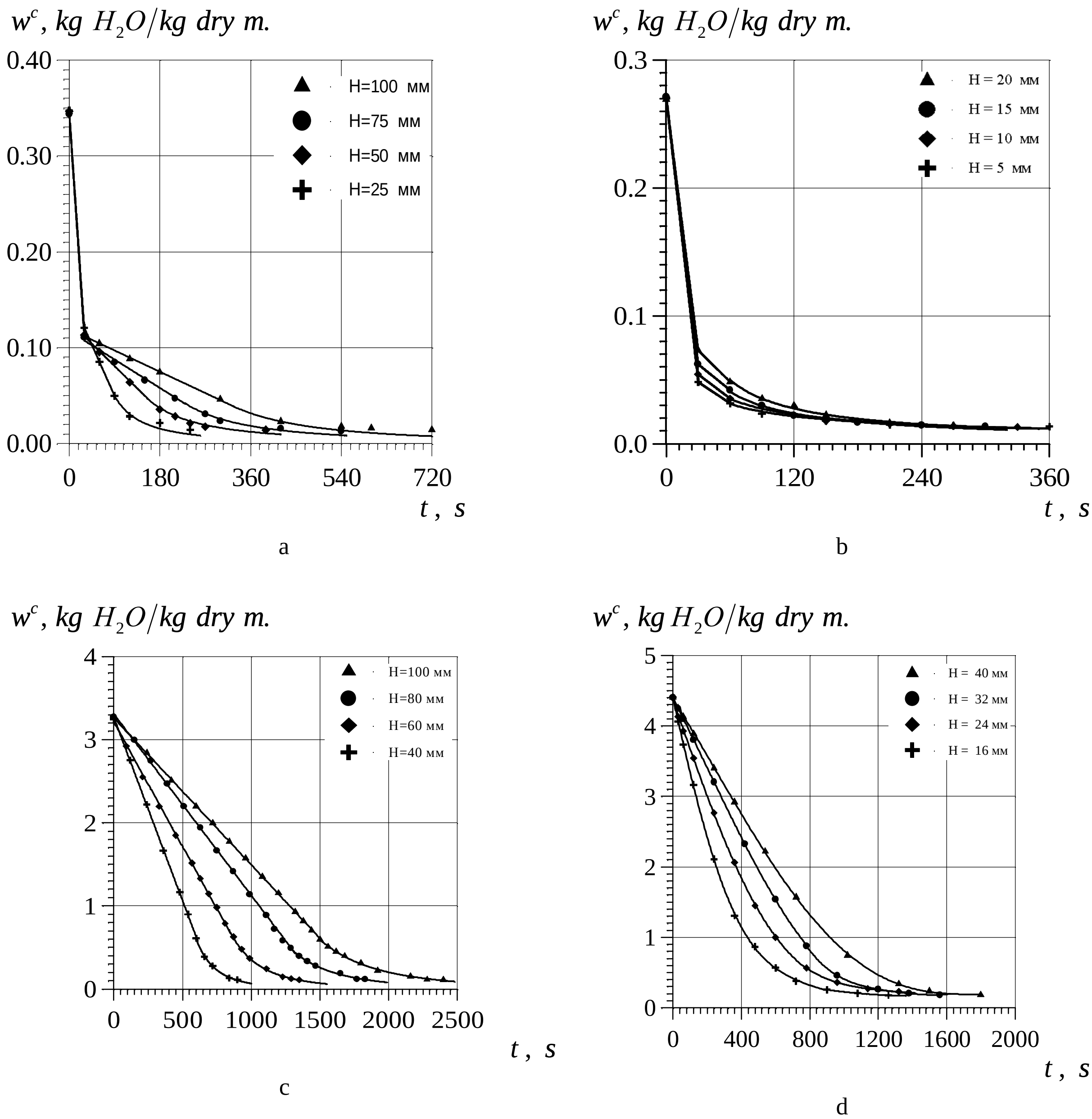

Fig. 1. The kinetics of filtration drying $t = 50\ °C$: a – coal fraction $(0.315-0.63)\cdot 10^{-3}\ m$, ($u_0 = 1.75\ m/s$); b – medium grained sand ($u_0 = 1.7\ m/s$); c – peat ($u_0 = 1.94\ m/s$); d – coffee sludge ($u_0 = 1.76\ m/s$)

The filtration drying of dispersed materials takes place according to a complex zonal mechanism characterized by mechanical removal of moisture for certain dispersed materials, in particular for coal and sand, and by the periods of complete and partial saturation of the heat agent with moisture, therefore the dynamics of saturation of the waste heat agent with moisture has its peculiarities in comparison with other methods of dehydration [24–25]. In addition, the height of the stationary layer of the material, which is given to the drying zone, influences the dynamics of saturation of the waste heat agent with moisture.

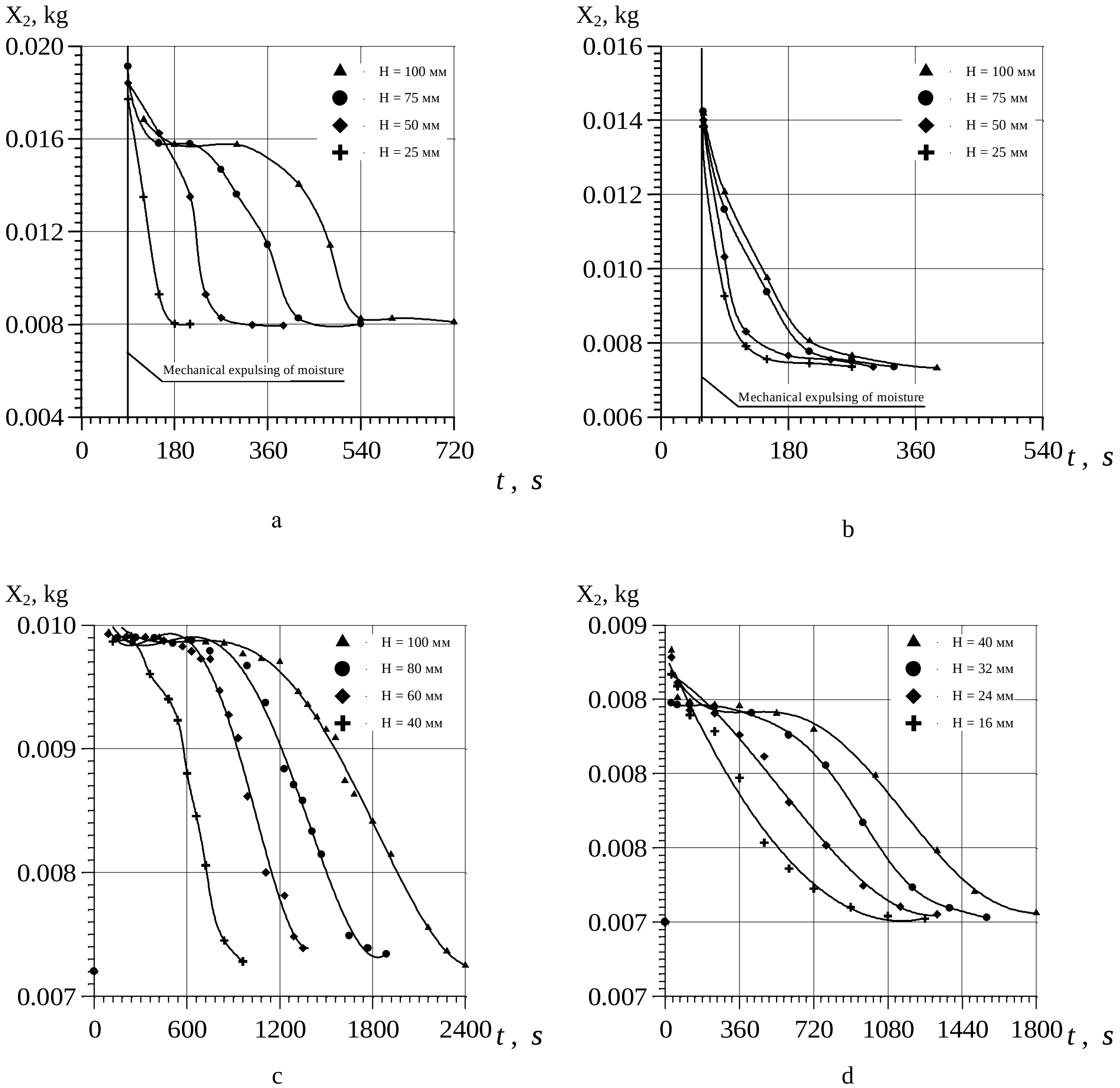

Fig. 2. The dependence of the change in the moisture content of the heat agent in time for different heights of investigated dispersed materials: a – coal fraction $(0.315-0.63)\cdot10^{-3}\ m$, ($u_0 = 1.75\ m/s$); b – medium grained sand ($u_0 = 1.7\ m/s$); c – peat ($u_0 = 1.94\ m/s$); d – coffee sludge ($u_0 = 1.76\ m/s$)

The dependence of the change in the moisture content of the heat agent in time for different heights of the investigated dispersed materials is presented in Fig. 2. From the presented graphic dependences (Fig. 2, *c*, *d*) it is clear that for peat and coffee sludge the curves are characterized by two sections, which correspond to the periods of full and partial saturation of the heat agent with moisture. From the beginning of the drying process to reaching the mass transfer of the perforated partition by the front, the amount of moisture passing into the waste heat agent and, accordingly, the moisture content of the last one increases and at the moment of reaching the mass transfer of the perforated partition by the front they reach maximum values. Saturation of the heat agent with the maximum moisture content under these conditions is characterized by horizontal sections on the corresponding curves. After reaching the mass transfer of the perforated partition by the front, the period of partial saturation of the heat agent with moisture begins, that is characterized by a gradual decrease in the amount of moisture that passes into the heat agent and, accordingly, the moisture content of the last, until the time the drying is stopped. An increase of the height of a layer of moist material, which is applied to drying, leads to an increase in the moisture content that passes into the waste heat agent at the time of its full saturation, and hence the moisture content of the last one, in the period of its full saturation with moisture, as it is seen on the graphic dependencies presented in Fig. 2.

Taking into account multi-tonnage of production of the investigated materials, introduction of the obtained results into production will have a significant economic effect.

For example, today more than 90 million tons of coal is extracted annually, about 70 % of it needs enrichment, which is 63 million tons per year, and the use of filtration drying would save $5.75 \cdot 10^4\ GW \cdot h/year$.

The economy during the filtration drying of the sand would be about $2.17 \cdot 10^3\ GW \cdot h/year$.

In the case of production of 800 thousand tons of milling peat per year, saving would be $3.79 \cdot 10^3\ GW \cdot h/year$.

As a by-product, a significant amount of coffee sludge is produced at coffee production enterprises. The application of the filtration method of drying with the productivity of the filtration equipment 20 tons per day, allows to save $4.28 \cdot 10^4\ kW \cdot h/year$ energy in comparison with other drying methods.

Conclusions

The kinetics and dynamics of saturation of the waste heat agent with moisture during the filtration drying of dispersed materials of different structural structure and disperse composition was investigated, which allows to recommend optimal conditions for conducting filtration drying of the last ones. The economic effect from introducing filtration drying in production per 1000 kg of dry material is: $915\,kW \cdot h$ for coal; $2170\,kW \cdot h$ for medium-grained sand; $4740\,kW \cdot h$ for peat; $7130\,kW \cdot h$ for coffee sludge.

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