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PHYSICAL MODEL OF SIMULTANEOUS DISPARAGING AND DEHYDRATION OF FINE POROUS MATERIAL IN THERMAL VACUUM INSTALLATION

Introduction

Carbon materials represent difficult chemical compounds [1, 2]. They demand not only dispersing (crushing), and dehydration (removal of moisture) [3], but also cleanings of harmful impurity which negatively influence the environment at their further use in the industry.

Now there are many installations and techniques of dehydration and dispersing of rheological material, including coals of different types.

Their list includes vertical roll mills. The equipment of such mills provides dry and wet crushing of all types of ores and other ground materials. A grinding subtlety within 330-380 μm /kg with average specific energy consumption – 72 kJ/kg (for installations of different productivity) [4]. They have received widespread introduction on thermal power plants and represent the complex equipment uniting crushing, drying, crushing, sorting and conveyor supply of the crushed material. Their productivity can vary in the range of 5-70 t/h, at the engine capacity from 110 kW to 1400 kW.

Granularity of a grinding – 80 μm 3%, initial and final humidity of materials of 10% and 0.5 ~1.0% respectively, average specific energy consumption of installations of different productivity – 71 kJ/kg [4].

Use of spherical mills for crushing of coal with a productivity from 5 t/h up to 210 t/h, the engine capacity of 280-1250 kW provides granularity of a grinding – 80 μm 3%. At the same time, averages on a model range of installations specific energy consumption make size – 101 kJ/kg [4].

It should be noted that initial humidity of the brown coal processed in the listed above installations makes the size of 10%. With increase in humidity by 4 times specific energy consumption on average will grow also by 4 times, i.e. will make 284-440 kJ/kg.

However, high wasting of energy and big duration of process of drying characterize the listed above devices for crushing and drying of various materials. These indicators can be carried to shortcomings of process of crushing and drying since they increase products cost.

However, the shortcomings stated above can be excluded when using of the method of thermal vacuum drying and simultaneous crushing of rheological material [5-7] developed recently. This method is environmentally friendly, effective, and rather transient. It represents engineering procedure of simultaneous dehydration and dispersing of fine material.

One of the fine materials needing crushing and removal of moisture is brown coal. It connected with the fact that moisture in brown coal worsens its flow ability, leads to freezing during transportation

and storage in stock during the winter period. Besides, availability of moisture reduced by the energy efficiency of brown coal [1].

In the real work, results of pilot study of temporary dynamics of dehydration and dispergating of brown coal given during processing in thermal vacuum installation, and the theoretical description of process of simultaneous removal of moisture and change of the size of particles of brown coal is given.

Technique of pilot study and parameters of samples

In a heating hollow element of thermal vacuum installation [5] brown coal with humidity of 40% and 6 mm in size arrives. Temperature of the heating $T = 250$ element of °C. In process of promotion on the spiral channel the part of brown coal adjoins to walls of a heating element, receives powerful inflow of heat for a short period, and therefore, the part consistently breaks up to rather large number of small fragments [6]. Process of dehydration and dispergating of brown coal lasts page. As a result of drying at the exit from installation brown coal with humidity 0.8 is received... 1% with content of parts with the minimum size about 40 nanometers [7]. Temperature of fine brown coal at the exit from installation constituted, and not optimized specific costs of energy for evaporation of moisture constitute about 720 kJ/kg and corresponds to performance of installation of 40 kg/h. In case of performance improvement of installation to 10^3 kg/h specific costs of energy will decrease to 36 kJ/kg that there is much less average value of specific energy costs of industrial plants for drying of crushing of coals of the same humidity [4].

Physical model of dehydration and dispergating of fine porous material

Dehydration of fine porous material

It known that at the water, temperature below 100°C and pressure below atmospheric water begins to boil, and forms steam. Properties of this steam approach properties of ideal gas. Is in process of steam formation of couples in contact with the condensed phase (water). With the established pressure and temperature, steam and water are in an equilibrium state: the quantity of the evaporated molecules of water is equal to quantity condensed [8].

Process of drying of the porous material containing water can be described conditionally two-level system which type given in Figure 1. In this drawing level 1 corresponds to steam molecules, the rarefied air which is in with a temperature and pressure. Level 2 corresponds to steam molecules withheld by a porous body. In the stable environment, energy of a molecule of water in air ε_1 is more than energy of a molecule in a porous body ε_2 since air temperature is higher than temperature of a porous body. Therefore, we will consider further that energy of level 1 is more than energy of level 2 ($\varepsilon_1 > \varepsilon_2$).

Spontaneous transitions reduce energy of a molecule of water in air. Therefore, the water molecule (in abbreviated form MV) seeks to reduce the energy, and spontaneously moves from level 1 to a level 2. We will characterize μ_{12} spontaneity of transition by the size, which answers probability of spontaneous transition of MV to 1 sec. Spontaneous transitions from the top level to lower be described by the equations:

$$\begin{aligned} \frac{dn_1(t)}{dt} &= -\mu_{12}n_1(t) \\ \frac{dn_2(t)}{dt} &= \mu_{12}n_1(t) \end{aligned} \quad (1)$$

where: $n_{1,2}(t)$ – time-dependent quantity of molecules of water at the levels of 1, 2 respectively, μ – probability of spontaneous transition.

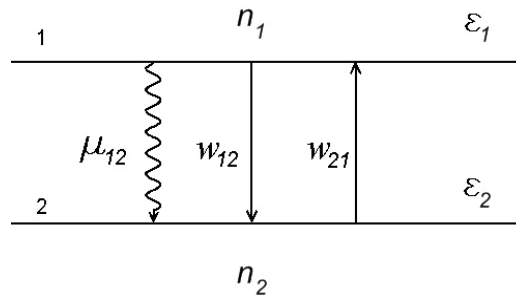


Figure 1. The Scheme of two-level system with quantity of molecules of water n_1 and n_2

Shooters have shown transitions from the top level to lower: spontaneous – μ_{12} and induced – w_{12} and the induced transition from the lower level on top – w_{21} .

If with the set pressure to begin to increase temperature, then in two-level system the induced transitions have to be shown. The accounting of such transitions can increase quantity of molecules of water at the level of 1. From above stated follows that the probability of the induced transitions depends on temperature set from the outside.

Let's designate probability of the induced transition from i level m to level expression w_{im} , where indexes i, m accept values 1, 2, but $i \neq m$. Then, taking into account that the probability of the induced transitions depends on external temperature, it can be presented in the form:

$$w_{im} = \bar{w}_{im} N \tag{2}$$

where: $N = P(kT)^{-1}$ – number of "molecules" of air in single volume; \bar{w}_{im} – proportionality coefficients with the values of indexes designated above i, m ; k – Boltzmann's constant. As "molecule" of air, we will consider a molecule with a molecular weight of 28,966 mol [9].

In initial time point, we will designate number of molecules of air size $N(t)|_{t=0} \equiv N_0$, also we will believe it rather big, such that $N_0 \gg n_{10}, n_{20}$, where $n_{10} = n_1(t)|_{t=0}$, $n_{20} = n_2(t)|_{t=0}$.

The accounting of the induced processes changes a type of the initial equations (1):

$$\begin{aligned} \frac{dn_1(t)}{dt} &= -(\mu_{12} + \bar{w}_{12}N)n_1 + \bar{w}_{21}Nn_2 \\ \frac{dn_2(t)}{dt} &= (\mu_{12} + \bar{w}_{12}N)n_1 - \bar{w}_{21}Nn_2 \end{aligned} \tag{3}$$

The equations (3) have to be added with the equation of change of number of the molecules of air $N(t)$, providing the induced processes in two-level system:

$$\frac{dN(t)}{dt} = -(\mu_{12} + \bar{w}_{12}N(t))n_1(t) + \bar{w}_{21}N(t)n_2(t) \tag{4}$$

Existence of a statistical equilibrium state in two-level system gives Einstein's condition – $\mu_{12} = \bar{w}_{12} = \bar{w}_{21}$ [10].

The initial system of the equations (3), (4) in case of domination of the induced processes over spontaneous significantly simplifies

$$\begin{aligned} \frac{dn_1(t)}{dt} &= \mu_{12}(n_2(t) - n_1(t))N(t); & \frac{dn_2(t)}{dt} &= -\mu_{12}(n_2(t) - n_1(t))N(t) \\ \frac{dN(t)}{dt} &= -\mu_{12}(n_2(t) - n_1(t))N(t) \end{aligned} \tag{5}$$

The equations (5) have integrals:

$$\begin{aligned} n_1(t) + n_2(t) &= n_{10} + n_{20} = C_1 \\ N(t) + n_1(t) &= N_0 + n_{10} = C_2 \end{aligned} \quad (6)$$

where C_1 is not the time-dependent size corresponding to the sum of number of molecules of water at the levels in initial time point – not the time-dependent size corresponding to the sum of number of molecules of water at the first level and numbers of molecules of air in initial time point.

Solutions of system (5) have an appearance:

$$\begin{aligned} N(t) &= \frac{N_{eq}}{1 + \frac{n_{10} - n_{20}}{2N_0} \exp(-2\mu_{12}N_{eq}t)} \\ n_1(t) &= \frac{\frac{n_{10} + n_{20}}{2} + \frac{n_{10} - n_{20}}{2} \exp(-2\mu_{12}N_{eq}t)}{1 + \frac{n_{10} - n_{20}}{2N_0} \exp(-2\mu_{12}N_{eq}t)} \\ n_2(t) &= n_{10} + n_{20} - \frac{\frac{n_{10} + n_{20}}{2} + \frac{n_{10} - n_{20}}{2} \exp(-2\mu_{12}N_{eq}t)}{1 + \frac{n_{10} - n_{20}}{2N_0} \exp(-2\mu_{12}N_{eq}t)} \end{aligned} \quad (7)$$

where $N_{eq} = N_0 + \frac{n_{10} - n_{20}}{2}$.

In case of dry air in initial time, point when, $n_{10} = 0$ and in case $N_0 \gg n_{20}$ of quantity of molecules of water at the level of 1 changes in time under the law:

$$n_1(t) = \frac{1}{2} n_{20} (1 - \exp(-\gamma t)) \quad (8)$$

where $\gamma = 2\mu_{12}N_0$.

The functional dependence (8) received for two-level model contains the size of probability of the induced transitions μ_{12} .

Let us determine size, proceeding from the experimental data obtained when drying brown coal on thermal vacuum installation [5-7].

In a series of experiments it is established, that the amount of the moisture dm_B/dt extracted from brown coal in unit of time depends in direct ratio to the mass of moisture, m_B (kg); capacities of the heater, P_N (W); a temperature pressure (a difference of temperatures of the heater and the heated body), ΔT (K); to heat exchange coefficient, α (W/m²K); the areas of evaporation, $S = 6a^2$ (m²) (the part of the dried-up material has the cube form); and in inverse proportion to pressure difference in a heating element, ΔP (Pa); kinematic viscosity, ν (m²/c); impact strength (specific superficial energy of destruction), W (J/m²); and to the volume of the dried-up material, $V = a^3$ (m³) [5]:

$$\frac{dm_B}{dt} = m_B \frac{P_N \cdot \alpha \cdot S \cdot \Delta T}{\Delta P \cdot \nu \cdot W \cdot V} \quad (9)$$

From expressions, (9) and (1) follows from expressions that the probability of the induced transitions is defined by expression:

$$\mu_{12} = \frac{P_N \cdot \alpha \cdot S \cdot \Delta T}{\Delta P \cdot \nu \cdot W \cdot V} \quad (10)$$

Tabular data entering (10) coefficients α , ν , W are absent, are contradictory or incomplete. Therefore, we will estimate the size of probability of the induced transitions μ_{12} , proceeding from a physical picture of process.

The work $\alpha \cdot S \cdot \Delta T$ corresponds to the empirical law of Newton – Rikhmana, and describes a thermal flow between the heater and the dried-up part in unit of time. Therefore, this work can be presented in the form $\alpha \cdot S \cdot \Delta T = Q/t_c$. On the other hand, according to P.A. Rehbinder's representations, when crushing a solid body the energy equal to the amount of work of deformation of a solid body and work of creation of new surfaces is spent [11]:

$$A = A_d + A_s = \kappa \cdot V + W \cdot S \quad (11)$$

where: A – complete crushing work; A_d, A_s – work strain and work creation of new surfaces, respectively; κ – proportionality coefficient equal to the volume of the grinding unit body deformation.

The volume of the deformed body differs from initial a little while, according to experimental data, the area of the surface received at deformation significantly increases (in $10^4 \dots 10^6$ times). From this, it follows that practically all full work of crushing of a solid body defined by work on creation of new surfaces, i.e. $Q = W \cdot S$.

The work $P_c \cdot a \cdot \nu$ in a denominator μ_{12} corresponds the developed part of power when overcoming viscous forces $\Delta P \cdot a \cdot \nu = F \cdot \bar{\nu}$, where $F = \Delta P \cdot a^2$ – force operating on a part because of pressure difference ΔP ; $\bar{\nu} = \nu/a$ – the characteristic speed of a part determined through the characteristic length of an edge of a cube and kinematic viscosity of the environment ν [12].

Thus, the estimates given above give value of probability of the induced transitions – $\mu_{12} \propto t_c^{-1}$.

As material dehydration in experiments occurs quickly enough, from (8) follows that $2 \cdot \mu_{12} \cdot N_0 \cdot t_c \gg 1$. The accounting of the condition used above $N_0 \gg n_{20}$ gives an assessment for dehydration time $t_c = (\mu_{12} n_{20})^{-1}$.

Dispergating of fine porous material

Let us describe the sequence of drying and simultaneous crushing of parts of the dried-up material.

Discrete model of dispergating

Let us consider that the dried-up parts have the cube form. In initial time point, the edge of a cube has a length. Disintegration of a part in the course of drying results from of rapid release of steam. Ideally, in the direction from the heated surface to the center of vacuum volume, the part breaks up to 2 fragments, i.e. cube edge length from the heater in vacuum volume halved. Further, the greatest length of an edge divides these two fragments until not all 8 fragments take the cubic form. After that process of division of cubic parts repeats.

Reduction of length of an edge of a cube leads twice to the fact that the probability of the induced transitions after the first disintegration of a part becomes twice more since in inverse proportion to a cube edge length. Each subsequent disintegration of again formed parts also leads to increase probability of the induced transitions twice. Thus, on n a step of division of a part the probability of the induced transitions will be equal $\mu_{12,n} = 2^n \mu_{12}$, where $n = 0, 1, 2, 3, \dots, M, M \gg 1$.

On a measure of growth of probability of the induced transitions, the quantity of molecules of water at the level of 1 in each of the formed 2 fragments, according to expression (8), decreases twice. Thus, on $n - m$ a division step the quantity of molecules of water at the level of 1 will be equal:

$$n_{1,n}(t) = \frac{1}{2} n_{20,n} (1 - \exp(-\gamma_n t)) \tag{12}$$

where: $n_{20,n} = 2^{-n} n_{20}$, $\gamma_n = 2^n \gamma$.

Follows from expression (12) that the total quantity of molecules of water at the levels of 1 and 2 is equal:

$$n_{1,\Sigma}(t) = \sum_{k=0}^M n_{1,k}(t) = \frac{n_{20}}{2} \sum_{k=0}^M 2^{-k} (1 - \exp(-2^k \gamma t)) \tag{13}$$

$$n_{2,\Sigma}(t) = n_{20} - n_{1,\Sigma}(t)$$

At rather big times, $\gamma t \gg 1$ the total of the taken molecules of water aspires to the initial content of water $n_{1,\Sigma}(t)$ in the dried-up sample, minus chemically connected water. It experimentally defined that the quantity of chemically connected molecules of water varies within $(0.005...0.01)n_{20}$ [1]. Further, when calculating it is necessary to consider that the quantity taken from the dried-up sample of water is limited to size $(0.995...0.99)n_{20}$.

The continuous model of dispersion

Let us assume that the probability of induced transitions increases in time under the law $\mu_{12}(t) = \mu_0 \cdot e^{\lambda t}$. In this case, in the right member of equation (8) it is necessary to replace time t for a new variable, time-dependent: $t \rightarrow \xi = \lambda^{-1}(e^{\lambda t} - 1)$, where λ is the constant defined from a condition of extraction of all water from the dried-up material in case of rather big time of drying.

Passing in (12) to a new variable ξ , and replacing summing with integration, we will receive expression for summary quantity of molecules of water at the levels of 1 and 2:

$$n_{1,S}(t) = n_{20} \int_0^{M/2} e^{-y} (1 - \exp(-e^y (e^{\lambda t} - 1))) dy \tag{14}$$

$$n_{2,S}(t) = n_{20} - n_{1,S}(t)$$

where $\lambda = 2\mu_0 N_0 = \gamma$.

For values of parameters $M \gg 1$ and $\gamma t \gg 1$ the right part of the first expression (14) aspires to the initial content of water in the dried-up material - n_{20} .

In Figure 2 dependences of amount of the extracted water from the dried-up material from time defined from expression (13) - a curve 1, and from expression (14) - a curve 2 are shown.

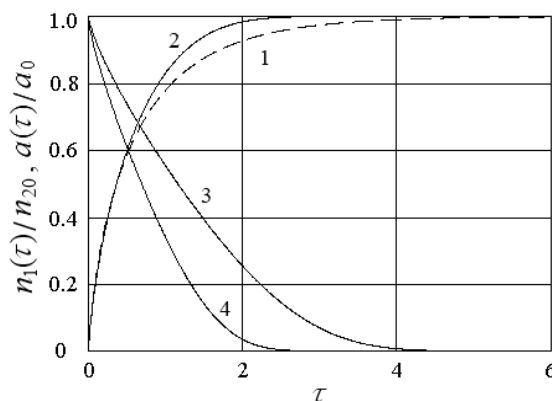


FIGURE 2. Dependence of amount of the extracted water from the dried-up material $n_1(\tau)/n_{20}$ from dimensionless time $\tau = \gamma t$

The curve 1 corresponds to a formula (13), a curve 2 – a formula (14).

The analysis of curves shows that dependences of amount of the extracted water on time for the models considered above are almost identical on big times of drying. At the initial stage of drying, the maximum difference on the mass of the extracted water makes size about 7%. Speed of leaving of moisture at the initial stage of drying for both models of the description rather big. In Figure 3 dependence on time of speed of withdrawal of water from the dried-up material is shown. It is visible that curves are almost identical.

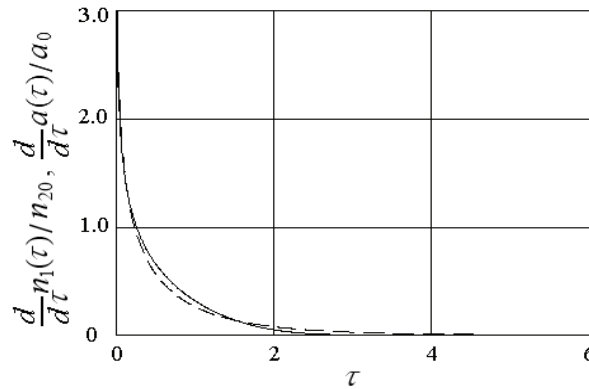


Figure 3. Dependence of speed of withdrawal of water from the dried-up material $d(n_1(\tau)/n_{20})/d\tau$ on dimensionless time τ

Accessory of curves corresponds to Figure 2.

Rapid withdrawal of water from a sample explains rather intensive process of crushing of the dried-up material at the initial stage of drying.

Follows from experiments that the size of an edge of the dried-up part decreases by 10^4 times [5-7]. Numerical calculations of dependence of the size of the dried-up part from time on model (14) at various temperatures of the heater shown on Figure 2, curves 3, 4. The curve 3 answers temperature of the heater of water, close to temperature of a heater T , with the set lowered pressure. A curve 4 – temperature of the heater exceeding boiling temperature by 1.68 times.

Follows from result of calculations that on times of an order $\tau = 3$ and excess of temperature T of the heater by 1.68 times over temperature of boiling of water with the lowered pressure change of length of an edge of a cubic part makes part size $a(\tau)/a_0 = 7.265 \cdot 10^{-5}$.

Thus, at excess of temperature of the heater by 1.68 times over temperature of boiling of water with the lowered pressure of a part of the dried-up material are crushed in the same number of times quicker.

Assessment of size of probability of the induced transitions on the basis of Figure 2 gives size: $\mu_0 t_c \approx 3/(2 \cdot N_0) \ll 1$.

Conclusions

Thus, in the real work the comparative analysis of standard technologies and technology of thermal vacuum dehydration and dispergating of brown coal carried out. The experimental technique of dehydration and dispergating of brown coal described. Temperature, pressure, time of dehydration and dispergating of brown coal are determined. The physical model of simultaneous dehydration and dispergating of fine porous material offered. Dispergating of the dried-up material described by means of two models of disintegration of a part in the course of drying: discrete and continuous. It shown that at the initial stage of drying the maximum difference on the mass of the extracted water calculated on two models makes size about 7%. On big times of drying dependence of amount of the extracted water on time for the models considered above is almost identical. Calculations show that rapid withdrawal of water from a sample explains rather intensive process of crushing of the dried-up material at the

initial stage of drying. At the same time with excess of temperature of the heater by 1.68 times over temperature of boiling of water with the lowered part pressure in the same number of times are crushed quicker. Comparison of theoretical calculations with experimental data shows adequacy of the offered models of dehydration and dispersing of fine rheological material.

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