EFFECT OF INITIAL MOISTURE CONTENT ON DRYER PARAMETERS

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The author describes a method of determining the variable parameters of a pneumatic gas dryer as a function of initial moisture content. The results of a typical computer calculation are presented together with an analysis of the characteristics of a dryer used in peat briquette production.

To describe the variable processes in pneumatic gas dryers, in the presence of considerable deviations of the initial moisture content of the material from the nominal value, it is possible to use the heat balance equation and the equations of drying kinetics and aerodynamics. The latter equation should reflect the relation between the resistance of the system, the temperature of the exit gases, and the dryer fan characteristic (when the fan is installed at the end of the drying channel).

In relation to the technical conditions typical of certain processes, this system of equations establishes a mathematical relation between the principal drying parameters ω, L, G' and t" at constant ω" and t'.

To determine the various parameters and operating characteristics of the dryer under variable conditions, all the terms entering into this system of equations m must be expressed in terms of the principal variable parameters and the constants.

The heat balance equation of the dryer

$$L\left[c_g't' - c_g''t'' - k_{\text{ia}}c_0(t'' - t_0)\right] = Q_1 + Q_3 + Q_5 + Q_m \quad (1)$$

at constant ω'', t', ϑ', t_a and Q_5 can be represented in the form

$$f_1(\omega', L, G', t'') = 0. \quad (2)$$

The expression for ϑ'' entering into Q_3 can be determined from [1], and the ω_{em} for fuel materials from [2]. The expression for Q_m is presented in [3].

In this case, to construct the equation of drying kinetics, it is desirable to use the linear heat-transfer coefficient. For certain materials α_l, as distinct from α, is characteristized by relative stability in the presence of changes in such factors as the moisture content and granulometric composition of the material, the degree of utilization of the drying potential, and the absolute gas velocity [4].

Under these conditions, the equation of drying kinetics [4]

$$\alpha_l hA(t' - t_{wb}) = q_1(u' - u'') \quad (3)$$

can, in general case, be represented in the form

$$f_2(\omega', L, G', t'') = 0. \quad (4)$$

To derive the equation of aerodynamics, we consider the following expression for the dry-gas flow rate:

$$L = \frac{\gamma'' V''}{1 + k_{\text{ia}}}. \quad (5)$$

For a given form of fuel burned to generate the gas,

$$\gamma'' = \varphi_1(\omega', L, G', t''). \quad (6)$$

The expression for V" is found from the empirical equation of the aerodynamic characteristic of the dryer fan:

$$V'' = V_f = \varphi_2(H_f) = \varphi_3(H, t''). \quad (7)$$

The resistance H of the fan network can be arbitrarily divided into components corresponding to three zones: before the gases reach the material (H_1); the pneumatic transport and drying zone (H_2); and the "pure" gas channel beyond the separator (H_3):

$$H = H_1 + H_2 + H_3. \quad (8)$$

On the basis of the known relations between the aerodynamic parameters, H_1 can be represented in the form

$$H_1 = H_{1,n}\frac{L^2\gamma_n'}{\gamma' L_n'}. \quad (9)$$

Denoting

$$K_1 = \frac{H_{1,n}\gamma_n'}{L_n^2}, \quad (10)$$

from Eq. (9) we obtain

$$H_1 = K_1 L^2. \quad (11)$$

We write the expression for H_2 in the form

$$H_2 = H_{2,n}\left(\frac{V_{av}}{V_{av,n}}\right)^2 \frac{\gamma_{av}}{\gamma_{av,n}} \frac{(1 + \mu_{av})}{(1 + \mu_{av,n})}. \quad (12)$$

After transformations, and introducing the complex

$$K_2 = \frac{H_{2,n}\gamma_{av,n}}{L_p^2(1 + \mu_{av,n})} \quad (13)$$

we can rewrite Eq. (12) as

$$H_2 = K_2\frac{L^2}{\gamma_{av}}(1 + \mu_{av}). \quad (14)$$

The average values of the specific weight of the gas and the material concentration can also be expressed in terms of the principal variables:

$$\gamma_{av} = \varphi_4(\omega', L, G', t''), \quad (15)$$

$$\mu_{av} = \varphi_5(\omega', L, G'). \quad (16)$$

From expressions (14), (15), and (16), we obtain an equation of the type

$$H_2 = \varphi_6(\omega', L, G', t''). \tag{17}$$

Similarly,

$$H_3 = K_3 \frac{L^2}{\gamma''}, \tag{18}$$

where

$$K_3 = \frac{H_{3.n}\gamma''_n}{L_n^2}. \tag{19}$$

From (6) and (18) we obtain

$$H_3 = \varphi_7(\omega', L, G', t''). \tag{20}$$

Substituting (11), (17), and (20) into (8) and then into (7), we obtain the expression

$$V'' = \varphi_8(\omega', L, G', t''). \tag{21}$$

After substituting (6) and (21) into (5), we obtain an equation of aerodynamics of the type

$$f_3(\omega', L, G', t'') = 0. \tag{22}$$

Clearly, to construct Eq. (22), it is necessary to know the operating parameters of the dryer at one value of ω' only.

In the general case, the system of nonlinear equations (2), (4), and (22) is solved on a computer. As a result, we obtain the dryer characteristics in the form of relations between the principal variables and ω'.

We consider, as an example, the determination of the variable parameters and characteristics of a pneumatic gas dryer used in peat briquette production.

The dryer consists of the following equipment: furnace; tube dryer; first- and second-stage cyclones; fans; and scrubber.

The principal starting data are as follows: $t' = 800°$ C, $t''_n = 120°$ C, $t_0 = 20°$ C, $\vartheta' = 20°$ C, $\omega'_n = 45\%$, $\omega'' = 14\%$, $G' = 13\ 300$ kg/hr, $H_n = 2740$ N/m^2, $q_5 = 167$ kJ/kg moisture, $k_{ia} = 0.15$; $\alpha_l = 1.67$ kJ/kg · m · deg.

After all the terms have been expressed in terms of ω', L, G', t" and the constants, the heat balance equation of the dryer (2) takes the form

$$86L(1008-1.74t'') - G'(\omega' - 14)\left[2731 + 2.2t'' + 2.26(t'' - 20)\left(\frac{100-\omega'}{\omega'}\right)\right] - 69\cdot10^6 = 0. \tag{23}$$

After similar transformations, Eq. (4) can be written in the form

$$\frac{24.3[\omega'(t''+47)-11900]}{(2420+1.97t'')(1.16\omega'-16{,}3)} - \ln\left[\frac{\omega'(t''-72)}{119(100-\omega')}\right] = 0.$$

The particular form of the equation of aerodynamics (22) has been omitted to save space.

This system of fifth-degree nonlinear equations was solved on a Minsk-2 computer. Graphs of the principal characteristics of the investigated apparatus are presented in Fig. 1.

As may be seen from Fig. 1, the temperature of the gases leaving the dryer increases with increase in the initial moisture content of the material, which is associated with the need to reduce the concentration so that the moisture content of the dried material is held constant. In this case, the mass flow rate L of dry gases entering the dryer at first increases to $\omega' = 37$–40%, then falls. This variation of L is attributable to the opposite effect on L of changes in fan output V" and in the specific weight γ'' of the exit gases. As ω' increases, as a result of the reduced concentration, the resistance of the system falls, and, hence, the gas flow rate increases. On the other hand, γ' falls as a result of the increase in t". The change in L is determined by the resultant of the factors V" and γ''; at low values of ω', the effect of V" prevails, and at high values of ω', the effect of γ'' is predominant. The amount of moisture W extracted from the material falls as ω' increases, which is associated with a certain decrease in the amount of heat transferred to the material as a result of the simultaneous increase in t" and fall in L. In analyzing Fig. 1, it should be noted that, if the change in the resistance of the system were not taken into account, we would obtain a sharp decrease in L as ω' increases as a result of the increase in t". In fact, this is not observed in dryers with a flat fan characteristic, since the fall in $L = F_1(t'')$ is automatically partially compensated by the increase in $L = F_2(H)$.

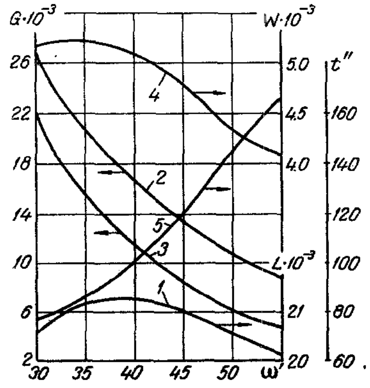

Fig. 1. Dryer operating parameters as a function of the initial moisture content of the material ω' (%): 1,2,3,4) L, G', G", W (kg/hr); 5) t" (°C).

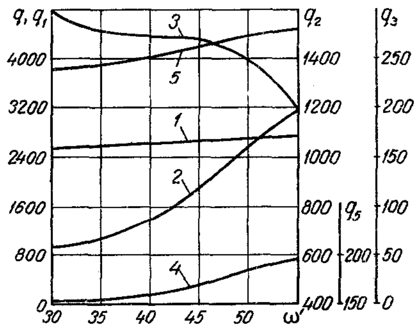

Fig. 2. Expenditure of heat (kJ/kg moisture) as a function of the initial moisture content of the material ω' (%): 1) q_1, 2) q_2; 3) q_3; 4) q_5; 5) q.

On the basis of the dryer parameters obtained, we determine the individual components and the total specific expenditure of heat on drying (Fig. 2).

As may be seen from Fig. 2, the effect of ω' on the total expenditure of heat is more marked in the region of values of ω' close to the nominal value. At low and high ω', fluctuations of the initial moisture content have only a slight influence on q. As ω' increases, the component corresponding to the evaporation of moisture increases somewhat as a result of the increase in the expenditure of heat on superheating the water vapor to t". The loss of heat with the exit gases increases sharply, which is associated with the simultaneous increase in t" and in the specific gas flow rate per 1 kg of evaporated moisture. This evaporated-moisture component is the principal source of losses in the dryer heat balance and determines the variation of the total expenditure of heat. The expenditure of heat on heating the material falls as ω' increases. The slower rate of fall of q_3 in the region $\omega' = 40-45\%$ is attributable to a certain mutual compensation between the decrease in the amount of dried material and the increase in its temperature.

The heat losses associated with mixing of the gas and the evaporated moisture and the intake of outside air increase somewhat with ω' under the influence of t". It should be noted that, in the example considered, taking Q_m into account causes an increase of 8% in the total expenditure of heat on drying the nominal regime, which exceeds such components as Q_3 and Q_5.

On the basis of the dryer characteristics and the dependence of boiler and separator efficiency on ω', it is also possible to determine the various power and economic characteristics under variable dryer operating conditions [5].

The use of the proposed method of calculating the dryer characteristics makes it possible to reduce the time spent on testing or making alternative calculations at various initial moisture contents. To determine the dryer parameters and operating characteristics in the presence of variable initial moisture content, it is sufficient to have test or calculation data for a single value of the initial moisture content. The dryer characteristics can be used to analyze dryer operation and also for regulating and automating drying processes.

NOTATION

A is the coefficient of the drying regime [4]; c is the specific heat; G is the throughput of material, kg/hr; H is the resistance; H_f is the fan pressure at 20° C; H_1, H_2, and H_3 are the zonal resistances; h is the length of the drying channel, m; k_{ia} is a coefficient equal to the ratio of the amount of intake air to the dry gas flow rate; L is the dry-gas mass flow rate, kg/hr; Q_1, Q_3, Q_5 and q_1, q_3, q_5 are the hourly and specific expenditures of heat for: evaporation of moisture, heating of the material, and losses to the surrounding medium, kJ/hr and kJ/kg moisture; Q_m is the expenditure of heat as a result of mixing of the gas and the evaporated moisture, kJ/hr; q and q_2 are the specific expenditures of heat, total and with exit gases, kJ/kg moisture; t is the gas temperature, °C; u is the moisture content of the material; V is the volume gas flow rate, m^3/hr; V_f is the fan output, m^3/hr; W is the amount of evaporated moisture, kg/hr; α is the heat-transfer coefficient; α_l is the linear heat-transfer coefficient, kJ/kg · m · deg; γ is the specific weight of the gases, kg/m^3; ϑ is the temperature of the material, °C; μ is the concentration of the material in the gases; ω is the relative moisture content of the material, %. Subscripts: (') relates to the state upstream of the dryer; (") relates to the state downstream of the dryer; g denotes gases; a denotes the surrounding air; n indicates the nominal value; av indicates the average value; wb relates to the wet bulb thermometer; em relates to the equilibrium moisture content.

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