PROCESS PARAMETERS OF DESICCATION IN COLLIDING JETS OF A GASEOUS SUSPENSION

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Results are shown of studies concerning the desiccation of sewage water sediments, which have been dehydrated mechanically, in apparatus with colliding jets of gaseous suspension. Heat transfer relations and technological parameters of this desiccation process are analyzed.

Apparatus with colliding gaseous-suspension jets (Fig. 1) has been in recent years used by various industries for drying and roasting various disperse material, for fuel combustion, and also for comminution and mixing [1-3].

The advantages of treating materials in such an apparatus are the feasibility of attaining rather high velocities in the phases combined with a longer dwell time for the disperse phase, and of attaining stream turbulization by hydrodynamically braking two colliding axially symmetrical gaseous-suspension jets.

At the Institute, in collaboration with the NIIKhIMMASh, laboratory and pilot field studies were made concerning the desiccation of sewage water sediments in colliding gaseous-suspension jets.

The results of laboratory tests are shown in Table 1. The tests were performed under conditions conforming to the equation of convective heat transfer (desiccation of sediments during the first process stage with hot air at t_m = 80-140°C):

$$\mathrm{Nu} = B\,\mathrm{Re}^n. \qquad (1)$$

In colliding jets the solid-phase particles undergo a reciprocating damped vibratory motion. The average relative velocity of the phases may be assumed here equal to the gas velocity within the jet interference zone [1].

The greatest difficulty in designing the desiccation process for pastes in colliding jets is to define the governing geometrical dimension of solid-phase particles. During desiccation in colliding jets, according to our studies, the size of fluidized sediment particles decreases from a few tens of millimeters at the desiccator entrance down to fractions of a millimeter at the exit.

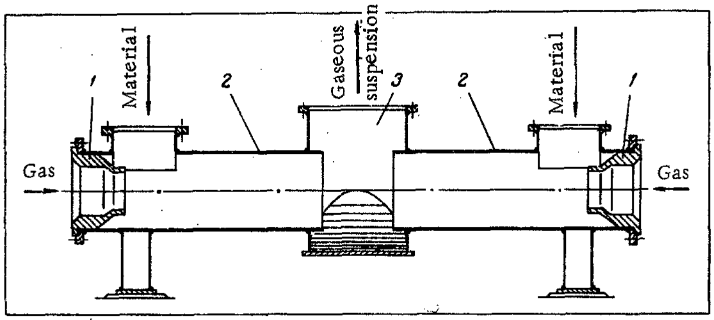

Fig. 1. Schematic diagram of an apparatus with opposing gaseous-suspension jets: 1) nozzle; 2) acceleration tube; 3) receiving chamber.

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TABLE 1. Test Results: the Desiccation of Mechanically Dehydrated Sewage Water Sediments in a Laboratory Apparatus with Colliding Jets

Performance parameter	Variation limits
Moisture content in mechanically dehydrated sediment, %	70–80
Moisture content in recirculated sediment mix entering the desiccator, %	57,3–72,4
Moisture content in the dry sediment	39,8–53,0
Desiccator capacity, in terms of evaporated moisture, kg/h	4,2–12,3
Air pressure before enetering the nozzle, atm	1,1–1,4
Air temperature before entering the nozzle, °C	130–250
Air temperature after leaving the nozzle, °C	110–205
Air temperature after leaving the desiccator, °C	50–75
Velocity of air discharge from the nozzle, m/sec	129–267
Air velocity in the acceleration tube, m/sec	16,6–34,1
Governing geometrical dimension (diameter) of dry sediment particles, m	$(0,440-0,637)\cdot 10^{-3}$
Delivered volume concentration of sediment in the desiccator	$(0,059-0,152)\cdot 10^{-3}$
Specific heat of desixxation, kcal/kg of evaporated moisture	1090–1230
Specific air consumption, kg/kg of evaporated moisture	20,4–45,4

Inasmuch as the velocity of the heat carrier at the sediment inlet to the apparatus ranged from 130 to 300 m/sec, almost 10 times higher than the velocity in the jet interference zone, most of the sediment comminution occurred at the first contact with a gas jet.

For this reason, our analysis was based on the assumption that the particle size remained constant in the jet interference zone. The governing geometrical dimension of sediment particles could then be determined from a sieve analysis of the dry sediment. Following the recommendations by Gorbis [4], we included a form factor in our calculations.

The heat transfer coefficient was determined from the equation of convective heat transfer, where the heat necessary for raising the temperature of a sediment and for removing the moisture from it by evaporation was calculated on the basis of test data and by applying the equations of heat and material balance to the desiccator [5].

In defining the active heat transfer surface, we have assumed that the desiccation process in colliding jets occurs only within the active zone of the apparatus, where the solid particles vibrate. The heat transfer surface in this zone is larger than in a plain gaseous suspension, in the same ratio as the average dwell time of a particle in the active zone to the passage time of gas through this zone.

The heat transfer surface was calculated by the formula

$$F = \frac{6f^{1.5}}{d_s} V_a \beta_p \frac{\tau_s}{\tau}. \tag{2}$$

The length of the active zone and the retention factor were calculated by the formulas in [2, 6]:

$$l_a = 2\left(12.6 - 2{,}8\frac{H}{D}\right) 10^{-4} \mathrm{Re}\, d_s \frac{\rho_s}{\rho}, \tag{3}$$

$$\frac{\tau_s}{\tau} = 1.7\cdot 10^{-4} \mathrm{Re}_f^{1.4} \left(\frac{D}{d_\tau}\right)^{1.33} (1 - 2.74\,\beta_p^{0.2}), \tag{4}$$

valid within the ranges $10^2 < \mathrm{Re} < 10^3$ and $\beta_p < 0.9\cdot 10^{-3}$, respectively.

The test data on heat transfer during desiccation of sediments in colliding gaseous-suspension jets have been based on formulas (2)-(4), with a mean-squared-error of ±12.5% and shown in Fig. 2, can be approximated by the relation

$$\mathrm{Nu} = 1.9\,\mathrm{Re}^{0.83}, \tag{5}$$

applicable within the ranges: $440 < \mathrm{Re} < 570$, $20 < \mathrm{Re}_f < 50$, $\beta_p < 0.9\cdot 10^{-3}$, and $60 < D/d_s < 90$. This yields

$$\alpha = 1.9\left(\frac{w}{\nu}\right)^{0.83} \frac{\lambda}{d_s^{0.17}}, \tag{6}$$

$$Q = 3.04\cdot 10^{-7}\left(12{,}6 - 2.8\frac{H}{D}\right) D^{3.33} \left(\frac{w}{\nu}\right)^{1.83} \frac{\lambda}{d_s^{0.5}} \cdot \frac{\rho_s}{\rho} f^{1.5} \mathrm{Re}_f^{1.4} \beta_p (1 - 2.74\,\beta_p^{0.2})\,\Delta t. \tag{7}$$

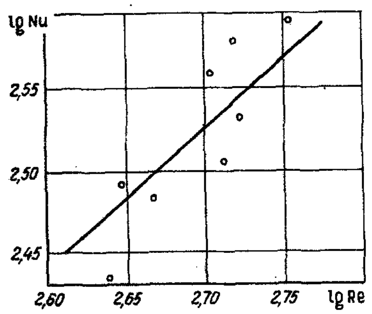

Fig. 2

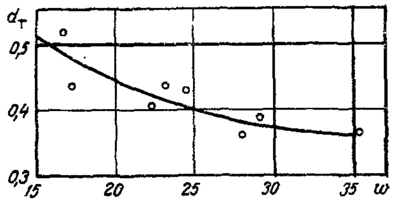

Fig. 3

Fig. 2. Test data on heat transfer during desiccation of dehydrated sediments in an apparatus with colliding jets.

Fig. 3. Equivalent diameter of dehydrated sediment particles as a function of the velocity of the drying agent.

As is well known, the aerodynamic drag in colliding jets in an apparatus is proportional to the velocity of the gaseous-suspension squared [1].

The power exponent of velocity in formula (7) for the drying agent is also almost equal to 2. During sediment desiccation in colliding jets, therefore, an increase in the velocity of the drying agent is not limited by an even more increasing drag in the desiccator, and this is an important feature of the process.

As the velocity of the drying agent increases, the increase in the rate of heat transfer to the sediment is somewhat slowed down by the accompanying reduction in the size of sediment particles on account of their comminution. According to Fig. 3, however, this reduction of the equivalent particle diameter occurs slower than the rise in velocity. Owing to comminution, moreover, the moist sediment surfaces are restored and this makes it feasible to extend the first stage of desiccation with the highest rate of drying.

It follows from Eq. (7) that, for sediment desiccation by colliding jets, it would be worthwhile to increase the concentration of solid-phase particles in the gaseous suspension. This can be achieved by partial recirculation (retouring) of the dried material.

In apparatus with colliding jets, because of the short process time, one passage of the material does not produce thorough enough desiccation. For instance, by one passage through the desiccator, the moisture content in the sediment could, in our case, be reduced from 57.3-72.4% to 39.8-53.0%.

For materials containing physicomechanically bonded surface moisture, a more thorough desiccation can be achieved in multistage counterflow apparatus, as proposed by El'perin in [1], or by multiple recirculation of the material. Many materials contain, besides surface moisture, also physicochemically bonded moisture, which is difficult to remove by desiccation, and its content in dehydrated municipal sewage sediments, for example, constitutes 30% or more of the total moisture. The desiccation of such materials is best achieved by variable-process treatment, namely by an appreciable reduction of the drying agent velocity during the second stage and by a larger contact between material and gas.

Considering this, we propose a method of drying pastes and loose materials with a subsequent treatment by a hot drying agent in colliding jets with an air spout mechanism [7].

On a pilot stand operating in this mode with flue gases at 600-700°C and with recirculation of the material, we obtained the following desiccation performance levels: volume intensity of moisture evaporation 715-800 $kg/m^3 \cdot h$, specific heat of desiccation 790-875 kcal/kg of evaporated moisture, and specific consumption of electric energy 73-81 kWh/ton of evaporated moisture.

NOTATION

$Nu = \alpha d_s/\lambda$	is the Nusselt number for heat transfer;
$Re = wd_s/\nu$	is the Reynolds number;
$Re_f = w_f d_s/\nu$	is the Reynolds number for free fall of solid particles;
α	is the heat transfer coefficient, $kcal/m^2 \cdot h \cdot {}^\circ C$;
d_s	is the governing geometrical dimension of sediment particles, m;

t_m	is the mean temperature of the gas in the desiccator: $t_m = 0.5(t_{in} + t_{out})$;
λ	is the thermal conductivity of the gas at temperature t_m, kcal/m·h·°C;
ν	is the kinematic coefficient of the gas at t_m, m^2/sec;
w	is the velocity of gas in the accelerating tubes at temperature t_m (with moisture evaporating from the sediment also taken into account);
w_f	is the velocity of free fall of dried sediment particles (diameter d_s), m/sec;
ρ_s	is the density of the dried sediment particles, kg/m^3;
ρ	is the density of the gas at temperature t_m, kg/m^3;
f	is the geometrical form factor of dried sediment particles;
F	is the heat transfer surface, m^2;
l_a	is the length of the active zone, m;
$V_a = \pi D^2 l_a/4$	is the volume of the active zone, m^3;
D	is the diameter of the accelerating tubes, m;
H	is the distance between the open ends of the accelerating tubes, m;
τ_s/τ	is the retention coefficient;
β_p	is the delivered concentration of solid particles in gaseous suspension;
Q	is the heat consumption for raising the temperature of the sediment and evaporating the moisture from it, kcal/h.

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