ANALYSIS OF HEAT TRANSFER IN SPRAY DESICCATORS DURING THE PRODUCTION OF FOAMY POLYMER FILLER

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Results are shown of an experimental study concerning the heat transfer from gases to particles in spray desiccators during the formation of hollow microglobules from synthetic resins.

The growing demand for pulverulent polymer fillers justifies a scientific approach to production control and apparatus design.

It is well known that spray desiccators combined with ovens are best suited for the production of pulverulent fillers from thermosetting polymers [1], namely chemically very stable low-density hollow spheroids. Many data have been amassed in the technical literature pertaining to the development, the design, and the performance of spray desiccators, but many difficulties arise often when such an apparatus is used for novel technological processes. The special features of the process involved in the production of hollow microglobules from thermosetting polymers have to do with the requirement for a powder of a specific chemical composition and geometrical form. One source of problems here is the occurrence of heat and mass transfer in the same apparatus where chemical conversions of the polymer material take place. Such a combination of processes, which occur while the mass is heated, accompanies the formation of an elastic film on the surface of droplets, the generation of an excess vapor and gas pressure inside the droplets, and the formation of a hollow spherical structure of particles during subsequent solidification.

The authors have made an attempt to analyze the characteristics of heat transfer between gases and particles in such an apparatus, and to establish correlations which would be useful for design purposes. We consider the heat transfer from gases to droplets of thermosetting phenol–formaldehyde (liquid Bakelite) which contains foaming agents (1-5%) as well as surface active additives (1%). The liquid compound has a density $\rho = 1100\text{-}1200$ kg/m^3, a viscosity $\mu = 2.1\text{-}2.4$ N·sec/m^2, and a surface tension $\sigma = 0.026\text{-}0.031$ N/m. The resin contains, in addition to the oligomer products of phenol and formaldehyde condensation, also 15% "free" phenol and 23-24% water. Hollow microglobules of this formulation are widely used in the production of high-strength foams and in the drilling of oil wells.

The kinetics of the process, namely the solidification of liquid Bakelite, can be analyzed by the thermographic or the differential-thermal method with a derivatogram taken in ambient air (Fig. 1). The heating rate in our experiment was equal to 0.07 deg/sec. The thermogram revealed an endothermal peak from 320 to 420°K, with the maximum at 381°K, which may be attributed to the evaporation of water and phenol. The endothermal peak from 420 to 485°K, with the maximum at 475°K, is due to the reactions in phenol–formaldehyde resin during solidification. Within this temperature range the volatile products of the reactions are released at a high rate.

The rate of heat transfer from gases to particles inside spray desiccators is usually estimated on the basis of the mean-over-the-surface or the mean-over-the-volume coefficients. The transit time and the surface area of particles during the formation of hollow microglobules is particularly difficult to calculate, because changes in the density and the size of these particles follow complicated trends. For this reason, in our opinion, engineering calculations based on the mean-over-the-volume heat transfer coefficient for the entire apparatus will be sufficiently reliable. For these calculations we use the formula

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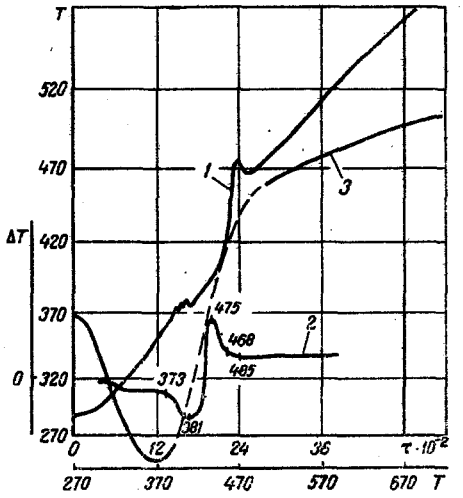

Fig. 1

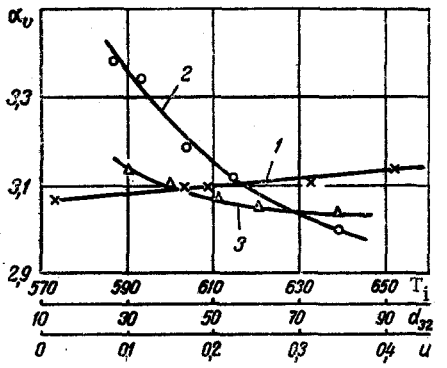

Fig. 2

Fig. 1. Thermograms (1, 2) and differential-thermal curve (3) of the heating of liquid Bakelite: 1) strip-chart record of specimen temperature T (°K) vs time τ (sec); 2) temperature difference/T (°K) between test specimen and reference specimen, as a function of the reference temperature T' (°K).

Fig. 2. Volume coefficient of heat transfer from gases to particles α_V (W/m^3·deg), as a function of: 1) initial gas temperature T_i (°K); 2) droplet diameter d_{32} (μ); 3) mean gas velocity in the desiccator u (m/sec).

$$Q = \alpha_v V \Delta T_m, \tag{1}$$

where ΔT_m denotes the mean temperature difference between the ambient medium and the surface of particles.

The tests were performed in parallel-flow spray desiccators with a capacity of 5 and 100 liters/h. The desiccators, 1.2 and 2.5 m in diameter, respectively, had been equipped with metering pumps, ovens, wet scrubbers, and receptacles for the end product, with control and measuring instruments. The spray was generated by means of two-stage or three-stage pneumatic nozzles with external mixing. In the larger desiccator (2.5 m in diameter) we operated with the three-stage pneumatic nozzle of a special design, allowing for adjustments of the liquid annulus within a 0.4-1.0 mm range of thickness. The mean-over-the-surface diameter of droplets d_{32} varied within the 27-78 μ range. The dispersivity of droplets was estimated by the method in [2]. Both the thermal and the hydrodynamic modes of operation in both desiccators were made to correspond to the thermogram and to the process technology. The inlet gas temperature T_i was varied from 573 to 653°K, the mean-over-the-section gas velocity u was varied from 0.1 to 0.38 m/sec. The mean thermomotive force ΔT_m was calculated as the logarithmic mean difference between the initial and the final gas and particles (droplets) temperatures. The mean-over-the-volume heat transfer coefficient was determined, as a function of the particle diameter as well as of the gas temperature and velocity. The heat of chemical reactions was calculated according to the data in [3].

The coefficient α_V is shown in Fig. 2, as a function of T_i, u, and d_{32}, on the basis of the test data for the smaller desiccator (1.2 m in diameter). It is quite evident here that variations in T_i and u within the given ranges have little effect on α_V. An increase in the diameter d_{32} from 27 to 78 μ causes an approximately 10% decrease in α_V. Analogous relations have also been obtained for the larger desiccator (2.5 m in diameter). A computer-aided evaluation of the test data (85 test runs) in terms of the Nusselt number, the Reynolds number, the ratio $G/\rho L$, and the ratio d_{32}/D has made it possible to generalize them by the following relation:

$$Nu_v = 4.33 \cdot 10^3 \frac{G}{\rho L} \frac{d_{32}}{D} Re^{0.97}, \tag{2}$$

where

$$Nu_v = \frac{\alpha_v d_{32}^2}{\lambda}; \quad Re = \frac{4Ld_{32}}{\pi D^2 \nu}; \quad L = u\frac{\pi}{4}D^2.$$

Relation (2) is valid for Re = 0.06-0.80 and G = (0.8-22.0)·10^{-3} kg/sec. The physical parameters were measured at a gas temperature in the desiccators within the 483-565°K range.

The low values obtained for α_v in these tests can, apparently, be attributed to the complication of the process by chemical conversions of phenyl–formaldehyde resin, these chemical conversions being sufficiently fast at high temperatures only. A product of chemical reactions which occur throughout the solidification process is water. The pattern here resembles the second stage of a desiccation process, characterized by a low rate of heat transfer. The discrepancy between calculated and measured values does not exceed 12%.

Relation (2) has been used for setting up a production of filler foam. The results of this study may also be helpful for analyzing the spray desiccation of various polymers and for designing the appropriate apparatus.

NOTATION

Q is the quantity of heat transferred to the material, J/sec;
V is the volume of the desiccator chamber, m^3;
T is the temperature, °K;
d_{32} is the volume-surface diameter of droplet, m;
u is the gas velocity, referred to the desiccator section, m/sec;
G is the flow rate of liquid, kg/sec;
L is the flow rate of gas, m^3/sec;
D is the desiccator diameter, m;
μ is the dynamic viscosity of the liquid, N·sec/m^2;
ρ is the density of the liquid, kg/m^3,
σ is the surface tension of the liquid, N/m;
ν is the kinematic viscosity of the gas, m^2/sec;
λ is the thermal conductivity of the gas, W/m·deg;
α_v is the volume coefficient of heat transfer, W/m^3·deg;
π is a constant;
Nu is the Nusselt number;
Re is the Reynolds number.

Subscripts

v denotes the volume;
i denotes the initial conditions;
m denotes the mean value.

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