Research of air-fluidized bed in the drying process of granulated hydrophobic polymers

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Abstract. This article studies the drying characteristics of granules of hydrophobic polymers. The hydrodynamics of a bed of PET granules has been studied taking into account the process of dust formation. On the basis of the data obtained, restrictions on the velocity of gas movement through the granulate bed have been revealed to reduce dust formation at the same time preserving the quality of drying. The refined dependence of the hydraulic resistance of the bed of granules on the velocity of the gas has been obtained.

Some hydrophobic polymers can absorb up to 2% of moisture. Such polymers as polyamide (PA), polyethylene terephthalate (PET), and polybutylene terephthalate (PBTF) can contain not only surface moisture, but also internal moisture from granules.

The presence of internal moisture leads to a sharp deterioration in the physical and mechanical properties of the materials molded due to hydrolytic degradation. Therefore, drying is an absolute necessity to prepare hygroscopic polymers for molding.

Drying is the most energy-intensive polymer production process, so it is necessary to search for the technological solutions that optimize this process while maintaining the quality of the dried material.

Drying of granules of hydrophobic polymers that absorb moisture, such as PET or PA, is performed immediately before melting and molding. In this case this is deep drying, as it is necessary to remove the internal moisture.

The drying system is divided into two stages. At the first stage crystallization and preheating are accomplished; at the second stage, the material is heated to 120 °C, the degree of crystallinity increases, \( \alpha_k \), to 0.4, and the moisture content is reduced, \( W \), to 0.03% (mass). This degree of crystallinity increases the temperature of hardening up to 270 degrees. At the second stage, the internal moisture is removed to become 0.005%.

Usually, a fluidized bed or mechanical mixing is used for both stages of drying. Mixing is required to prevent sintering or hardening of the product.

However, one of the disadvantages of fluid bed processes is the formation of dust. It is known [1] that before drying the amount of dust in the granulate can reach 0.25%, and after drying it may become 0.55%[2]. According to [3], an increase in the dust content in the granulate bed even to 0.2% (mass) decreases the homogeneity of the melt. This is due to different rates of melting of the granules and dust particles due to their different crystallinity.

Entrainment of dust particles is not always possible due to their sticking to the granules.

The intensification of dust formation during drying of the PET granulate occurs when the drying air velocity increases to the dust soaring velocity, and the minimum accumulation of dust particles in the granulate bed is achieved when it is dried in the filter layer.
Particles of PET dust have a size of 50x600 microns, and the speed of their drift is 0.4 m/s [4].

The effect of air velocity in vertical dryers on dust generation was studied in [4]. Three pilot batches of granules prepared by the method of underwater granulation were prepared. The granules had a shape of a cylinder with an elliptical cross section. To perform calculations, diameters of a ball having the same volume with the granule were used [5]. The obtained three types of samples of granules with equivalent diameters were: 2.98 mm, 3.3 mm, and 4.16 mm.

Experiments on dust formation were carried out at 25 °C and 165 °C. The number of dust particles (in %, mass) was calculated at air velocities from 0.05 to 0.7 m/s. The results are shown in table 1.

**Table 1. Influence of air velocity on the formation of PET dust particles.**

| Air velocity, m/s | 25(±2) sample | 165 (±2) sample |
|-------------------|---------------|-----------------|
|                   | 1 | 2 | 3 | 1 | 2 | 3 |
| 0.05              | 0.010 | 0.005 | 0.015 | 0.008 | 0.003 | 0.011 |
| 0.1               | 0.031 | 0.025 | 0.042 | 0.025 | 0.019 | 0.036 |
| 0.3               | 0.084 | 0.072 | 0.091 | 0.073 | 0.061 | 0.080 |
| 0.4               | 0.119 | 0.093 | 0.123 | 0.105 | 0.088 | 0.117 |
| 0.5               | 0.169 | 0.127 | 0.178 | 0.162 | 0.103 | 0.152 |
| 0.7               | 0.378 | 0.314 | 0.432 | 0.315 | 0.297 | 0.390 |

As can be seen from table 1 with an increase in the air flow rate, i.e. with the intensification of hydrodynamic factors during drying, the tendency to dust formation of PET increases. It is also seen that at 165 °C there is a clear tendency to a decrease in the number of formed dust particles, which is connected, apparently, with the fact that the polymer substrate is in a highly elastic state and the ability of the granulate to abrasion weakens [4].

Thus, it becomes important to study the hydrodynamics of the bed of material in the drying process and to search for optimal process parameters from the point of view of minimizing the generation of dust.

To solve this problem, experiments were carried out on the hydrodynamics of the suspended bed for PET granules with equivalent diameters of 2.98 mm, 3.3 mm and 4.16 mm. The porosity of the bed was 0.398, 0.403, and 0.413 respectively.

Firstly it is necessary to evaluate the critical velocity of fluidization and the hovering velocity of granulate.

The critical velocity can be estimated by the Todes’s equation [6]

\[ \text{Re}_{c,1} = \frac{\text{Ar}}{1400 + 5.22\sqrt{\text{Ar}}} \],

(1)

here \(\text{Ar}\) is Archimede criterion

\[ \text{Ar} = \frac{gd_e(\rho_m - \rho_g)}{\nu_g^2 \rho_g} \],

(2)

here \(d_e\) is the equivalent granules diameter, m; \(\rho_m\) is the the average density of the material, kg/m\(^3\); \(\rho_g\) is the the average density of gas, kg/m\(^3\); \(\nu_g\) is the the average coefficient of kinematic viscosity of gas, m\(^2\)/s. \(\rho_g\) and \(\nu_g\) are taken at the average temperature of the gases in the layer.

The average density of the material
\[ \rho_m = \frac{\rho_{m1} + \rho_{m2}}{2}, \]  

(3)

here \( \rho_{m1} \) and \( \rho_{m2} \) are the material densities at the inlet and outlet of the drying chamber, respectively, kg/m\(^3\).

The hovering velocity of granulate is calculated according to the equation

\[ \text{Re}_{h/2} = \frac{\text{Re} \cdot \varepsilon_0^{4.75}}{18 + 0.61 \sqrt{\text{Ar} \cdot \varepsilon_0^{4.75}}}. \]  

(4)

The Reynolds criterion is determined by the conditional average speed when calculating the airflow through the entire area of the layer.

The results of the calculation of the described velocities for PET granules at an air temperature of 22 °C are presented in the table 2.

| Equivalent diameters, mm | \( \text{Re}_{h/1} \) | The critical velocity of fluidization, m/s | The hovering velocity, m/s |
|--------------------------|----------------------|---------------------------------------------|---------------------------|
| 2.98                     | 129.7                | 0.80                                        | 8.87                      |
| 3.3                      | 161.8                | 0.90                                        | 9.38                      |
| 4.16                     | 259.5                | 1.14                                        | 10.61                     |

The obtained results indicate that the velocity of fluidization beginning significantly exceeds the velocity of dust particles entrainment. Earlier it has been also noted that dust formation is intensified at a velocity of about 0.7 m/s, which is also below the critical velocity. Thus, it can be concluded that the minimum accumulation of dust particles in the granulate is achieved when drying in a fixed bed.

For practical calculations, it is necessary to find the dependence of the hydrodynamic resistance of the bed on the velocity. Many authors use the Ergun’s equation to calculate the resistance of a fixed bed [5-7]

\[ \Delta \rho = \frac{150 \bar{\mu} w (1 - \varepsilon_0)^2}{d \varepsilon_0} + \frac{1.75 \bar{\mu} w^2 (1 - \varepsilon_0)}{d \varepsilon_0^3}, \]  

(5)

here \( H \) is the bed height, m; \( \bar{\mu} \) is the average coefficient of dynamic viscosity, Pa·s; and \( w \) is the air velocity, m/s.

The first term shows the effect of surface friction, and the second stands for the resistance of the flow around the particles.

The constants 150 and 1.75 in equation (5) are not universal. Thus, equation (5) does not provide a correct calculation of the pressure drop in layers with random packing of non-spherical particles. In addition, some authors [6] indicate that the experimental data differ from the results of the calculation with software (5) by more than 50%. However, the equation (5) may well describe the experimental data, if the proper pair of constants is found for each type of particle. The constants in equation (5) are functions of the Reynolds criterion.

Equation (5) can be represented as

\[ f_v = \frac{\Delta \rho}{H \bar{\mu} w (1 - \varepsilon_0)^2} = \frac{150 + 1.75 \text{Re}}{1 - \varepsilon_0}. \]  

(6)

The complex \( f_v \) shows the ratio of pressure drop to energy losses due to viscous friction. Obviously, it depends on the Reynolds criterion.

In the literature there is no information on the hydrodynamic resistance of the fixed bed of PET granules.

To obtain the dependence of the hydrodynamic resistance of the PET granule layer, experiments were carried out at a bed height of 0.15, 0.25, 0.35, 0.45 and 0.55 m. Air was supplied at a temperature
of 22 °C. It makes no sense to study a wide range of Reynolds criterion, since the flow rate in the bed is limited by dust formation conditions. The flow rate was limited by the condition of \( \text{Re} \leq 200 \).

The dependence \( f_v \) on \( \text{Re}/(1-\epsilon_0) \) at different equivalent diameters of the granules is shown in figure 1. It is also shown how much the experimental data differ from the calculation of equation (6). The obtained data can be approximated by the equation of the line

\[
f_v = 220 + 3.785 \frac{\text{Re}}{1-\epsilon_0}
\]  

Formula (7) is applicable within \( 30<\text{Re}/(1-\epsilon_0)<300 \). The approximation accuracy is equal \( R^2=0.785 \).

![Figure 1. Dependence \( f_v \) on \( \text{Re}/(1-\epsilon_0) \) at different equivalent granule diameters.](image)

### Conclusion
1. The factors causing the dust generation during drying of PET have been analyzed. The velocity limits of the drying agent have been determined.
2. According to the results of the experiment, the dependence of the resistance of the PET bed on the velocity at different bed heights and granule sizes has been obtained.
3. The results can be used in the calculation and design of drying plants for hydrophobic polymers

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