Analysis of the influence of dust formation on technological processes in the production of PET

Yu A Geller, I S Antanenkova and M A Aparushkina
National Research University “Moscow Power Engineering Institute”
17 Krasnokazarmennaya Street, Moscow, 111250 Russia
Federal State Budgetary Educational Institution of Higher Education “Russian State University named after A.N. Kosygin (Technology. Design. Art)”
33 bldg. 1 Sadovnicheskaya Street, Moscow 117997, Russia
E-mail: yul4@yandex.ru, antanenkovais@mail.ru, paxt@yandex.ru

Abstract. Possible methods of dust formation during the production of polyethylene terephthalate granulate and its preparation for molding are considered. The features and patterns of dust formation during drying in an active hydrodynamic layer at different speeds and temperatures are revealed.

1. Introduction
One of the by-products of polyethylene terephthalate (PET) manufacturing is fine polyester. Its presence deteriorates the quality of the finished product. The main processes in the technology, where finely dispersed polyester is formed, are:

- granulation of amorphous PET,
- preliminary crystallization of the granulate,
- solid-phase PET polycondensation,
- storage and packaging of high-viscosity crystalline PET,
- pneumatic transport of granulate from the hopper,
- drying in active hydrodynamic modes.

Amorphous PET granulate is obtained by cutting polyester strands formed as a result of water cooling of the jets of polyester melt coming from the granulator spinnerets. Cutting is accompanied by the formation of a certain amount of fine material (dust). The average particle size is 100–800 mkm [1].

Pre-crystallization occurs in fluidization mode, when the granules pass for 2–8 minutes through the active zone with a temperature of 185–190°C. During this time, the sharp edges of the granules and the particles of amorphous PET adhered to them begin to crystallize and harden, becoming brittle, and are separated as a result of intense movement and impact.

The main crystallization process, necessary to achieve a crystallinity of 40%, develops in a crystallizer under static conditions at a temperature of 210–215°C and with forced mixing with screw shafts. In this case, the granulate can experience mechanical stress, which leads to partial reversible deformation and destruction of sharp edges and corners of the granules.

At the stage of solid-phase polycondensation in the mass of individual granules, the chain length of PET macromolecules grows and ethylene glycol (EG) is released as a result of the reaction. Ethylene
glycol diffuses to the surface of the granules, while the rate of its diffusion is greater than the rate of evaporation.

Ethylene glycol, accumulating on the surface of the granules, partially reacts with glycolysis with PET macromolecules. As a result, a thin layer of oligomers is formed on the surface of the granules – PET molecules, in which the number of identical units \( n \leq 6 \).

In the process of crystallization and polycondensation, the density of PET increases from 1.34 to 1.38 g/cm\(^3\). This leads to a decrease in the volume of the granules, and the more fragile and fragile oligomer is separated from the surface of the granules in the form of very small (25–70 µm) particles, which, as a result of the EG reaction, are converted into finely dispersed PET.

Despite the fact that fine-dispersed PET corresponds to the chemical composition of the granulate, they should not be processed together, since a homogeneous melt is not obtained as a result.

According to \([2]\), the intrinsic viscosity of dust particles (PP) is higher than that of the base polymer. According to \([3]\), in the process of granulation and subsequent drying, low molecular weight fractions of PET diffuse to the surface of the granules, deteriorating their frictional properties. It should be noted that, according to \([2]\), the crystallinity of PS is higher than that of the polymer substrate of granules. The heat of fusion, \( Q_{pl, PC} \), is 20 kJ/kg, and for PET granulate it is 17.3 kJ/kg. This circumstance leads to a decrease in the melting rate of the PS during the transfer of PET to the melt, and hence, to a decrease in its homogeneity \([4]\).

Statistical analysis of dust formation during drying of PET granulate in the production of synthetic filament yarns \([5]\) shows that for each ton of processed granulate, about 1.2 kg of PC is formed, i.e., 0.12% (mass), and in the process of drying, the content of PCs on the granules increases almost 2 times. In \([1]\) it is noted that for the entire technological process, dust can be released up to 0.7%. It is known that even at 0.2% of dust during molding, the strength properties of the finished product deteriorate \([2]\).

### 2. Experiment
The study of the effect of air velocity in vertical dryers on the dynamics of dust formation during drying was carried out in \([5]\). The experiments were carried out for three pilot batches of granulate (Table 1) at temperatures of 25 °C and 160 °C, under the assumption that before and after the glass transition temperature, the polymer had different frictional properties.

| Characteristics                        | Sample |
|----------------------------------------|--------|
| Geometric sizes of granules:           | 1      |
| Diameter of a ball equal to the volume of a granule, \( d_e \), mm | 4.16   |
| Form factor, \( f^* \)                | 1.19   |

| Geometric sizes of granules:           | 2      |
| Diameter of a ball equal to the volume of a granule, \( d_e \), mm | 3.30   |
| Form factor, \( f^* \)                | 1.18   |

| Geometric sizes of granules:           | 3      |
| Diameter of a ball equal to the volume of a granule, \( d_e \), mm | 2.98   |
| Form factor, \( f^* \)                | 1.17   |

* The shape factor (coefficient of non-sphericity of a granule) is defined as the ratio of the surface area of the granule to the surface area of a sphere of equal volume \( f = S_g/S_{sh} \)

### 3. Experimental data processing
The processing of statistical and experimental data allows evaluating the effect of temperature, speed of movement of the drying agent, particle size on dust formation.

This graph shows a clear tendency towards a slight decrease in the amount of formed dust particles at 160°C, which is apparently due to the fact that in this case the polymer substrate is in a highly elastic state and the abrasion capacity of the granulate is weakened \([4]\).
To characterize the hydrodynamic regime through a layer of granular material, a modified [6] Reynolds criterion is used:

\[
Re = \frac{w \cdot d_{eq}}{\nu}
\]  

(1)

Figure 1. Dependence of dust formation on air velocity.

Where \(d_{eq}\) is the diameter of a ball equivalent in volume.

Figure 2 shows the values of the experimental results (points), and the lines indicate the obtained dependences.

Figure 2. Dependence of dust formation G,% on the Re number.
As can be seen from the figure, with an increase in the air flow rate, i.e., with intensification of hydrodynamic factors during drying, the tendency to dust formation in PET increases.

In the description of the dependence of dust formation during fluidization, it is obvious that it is divided into three stages: before reaching the onset of fluidization of the bed (Re$_{cr}$), from Re$_{cr}$ to Re$_{h}$ and above Re$_{h}$ (Reynolds value at the hovering velocity). The first and third stages are well described by direct dependence, and the second is described by the exponential one. Since the dependence is shown on the modified Reynolds number (1), therefore, the calculation includes both the granule size and the physical characteristics of the drying agent.

3.1. Calculating the characteristic values of Reynolds numbers

To determine the critical speed and soaring speed, the well-known formulas are used:

$$ Ar = \frac{g \cdot d^3_{eq}}{v^2} \left(\rho_u - \rho_\infty\right) \rho_\infty $$

(2)

The critical value of the Reynolds criterion [8]:

$$ Re_{cr} = \frac{Ar}{1400 + 5.22 \cdot \sqrt{Ar}} $$

(3)

According to the data of work [7] for $f = 1..1.5$ the hovering speed is calculated by the equation:

$$ Re = \left[\left(8100 + 22.18 \cdot \left(11 - \frac{10}{f}\right) \cdot Ar\right)^{0.4} - 90\right] \cdot \left[2.77 \cdot \left(11 - \frac{10}{f}\right)\right]^{-1} $$

(4)

The results are shown in Table 2.

**Table 2. Fluidization Characteristics of PET Granules at Temperature.**

| $d_{eq}$ | 25 | 160 |
|----------|----|-----|
|          | $Ar_{cr}$ | $Re_{cr}$ | $w_{cr}$ | $Re_h$ | $w_h$ | $Ar_{cr}$ | $Re_{cr}$ | $w_{cr}$ | $Re_h$ | $w_h$ |
| 4.2 mm   | 3.216 | 298.83 | 1.105 | 1880 | 6.95 | 1.292 | 176.18 | 1.028 | 1187 | 6.92 |
| 3.3 mm   | 1.561 | 197.02 | 0.927 | 1324 | 6.229 | 0.627 | 113.32 | 0.841 | 834 | 6.2 |
| 2.98 mm  | 1.151 | 164.39 | 0.857 | 1151 | 6.0 | 0.462 | 93.41 | 0.768 | 725 | 5.96 |

3.2. The first stage before the start of fluidization

To describe the process, it was decided to combine pellets of different sizes, but consider them at different temperatures. As a result, when considering the first stage, until the liquefaction rate is reached, i.e., up to Re$_{cr}$, it turns out that the temperature does not have a special effect, and this dependence can be generalized both in terms of granule sizes and temperatures (Fig. 3). The critical values of the Reynolds number for all granules and temperatures are shown in Table 2.
Figure 3. Dependence of dust formation on the modified Reynolds number at $Re < Re_{cr}$.

This dependence can be described by the following empirical formula:

$$G(Re) = A \cdot Re$$

where $A = 0.00015$.

3.3. Second stage: from the beginning of fluidization to soaring

Figure 4. Dependence of dust formation on the modified Reynolds number at $Re_{cr} < Re < Re_{vit}$.

These dependences may be described by the formula:

$$G(Re) = B \cdot e^{C \cdot Re}$$

B is the pre-exponential coefficient, which is in the range of 0.018-0.025.
C is the coefficient with the values varying depending on the temperature 0.0002-0.0003.
3.4. The third stage: over the speed of hovering

The last stage is more convenient to describe depending on the speed of the drying agent. In this case, it may be described by one dependence.

\[
G(w) = D \cdot w + \left( B \cdot \exp(C \cdot \text{Re}_{w_0}) - D \cdot w_{cr} \right)
\]

(7)

As mentioned above, the possible amount of dust that will not affect the further process is 0.2%. This dust emission ensures the air velocity before the start of the hovering. At the same time, such a speed will provide the entrainment of the appeared or already existing dust-like particles.

3.5. Dust particles.

The size of dust particles, depending on their origin, can be from 20×70 microns (for granulation) to 50×800 microns (in active hydrodynamic drying and crystallization modes). Accordingly, the speed of their entrainment will be in the range from 0.04 m/s to 0.12 m/s, which is even less than the critical fluidization speed.

From the foregoing, it may be concluded that minimizing the content of dust particles on the granules is necessary to ensure a stable spinning process for polyester fibers and filaments. In processes with active hydrodynamic modes with the help of various dust collectors, the granulate is partially freed from dust particles. But it is crucial that practically no dust is formed in subsequent processes. Therefore, in order to reduce the formation of dust particles during drying in shaft dryers, the following requirements may be imposed on the speed of the drying agent:

a) above the critical fluidization rate;
b) lower hover speed;
c) higher than the speed of dust particles entrainment.

Conclusions

1. With an increase in temperature, the amount of dust particles decreases insignificantly at the same speed of the agent.
2. The dependences of dust formation on the hydrodynamic regime have been obtained.
3. Prior to the particle soaring speed, the amount of dust remains within acceptable limits and minimally affects the molding processes; after reaching this speed, the amount of dust increases sharply. This is also evident at temperatures of 25°C and 160°C.

Acknowledgments

This work was supported by the Russian Foundation for Basic Research (project 19-08-00704 A).

References

[1] Urmantsev U R, Grudnikov I B, Tabaev B V, Lakeev S N and Davydova O V 2015 Chemistry and technology of polyethylene terephthalate production: textbook. allowance 130
[2] Geller V E 2000 High speed spinning of polyester filaments (Tver, TO K-Zhi) 136
[3] Perepelkin K E 2001 Chem. Fibers 5 3–7
[4] Geller Yu A 2002 Research and development of an engineering method for calculating the process of deep drying of granular polyethylene terephthalate dis. Cand. those. sciences (Moscow state University named after A.N. Kosygin, Moscow)
[5] Reutskiy V A, Bulekov A P and Geller Yu A 2002 Proceedings of VNTK Modern technologies and equipment of the textile industry (Textile-2002) (M., MSTU)
[6] Dytnersky Yu I 1995 Processes and devices of chemical technology. Part 1. Theoretical foundations of chemical technology processes. Hydromechanical and thermal processes and apparatuses (M: Chemistry) 400
[7] Mushtaev V I, Timonin A S and Leyuev V Ya 1991 Design and calculation of devices with weighed layers (M: Chemistry) 344
[8] Aerov M E and Todes O M 1968 Hydraulic and thermal foundations of the operation of devices with a stationary and fluidized granular bed (L : Chemistry) 510