An effective system for recycling polyethyleneterephthalate

M V Kravtsova1,3, D A Volkov1,2, D A Melnikova1,2, M V Kravtsov1 and E V Bezheskaia1
1Togliatti State University, Togliatti, Russian Federation
2 LLC “ECORESURSPOVOLZHE”, Togliatti, Russian Federation
3Email: M.V.Kravtsova@yandex.ru

Abstract. To increase the efficiency of polyethyleneterephthalate (PET) processing, it is necessary to improve the quality of the resulting product: low moisture content in the raw materials and a minimum amount of impurities, which affects the quality of the product PET flakes. Mathematical modeling of the separation process during mechanical processing of PET is presented. To calculate the air flow rate and separation space, a mathematical model is proposed, according to which a particle of flakes and PVC are considered as a conditional body with aerodynamic properties. It is proposed to improve the quality of PET flakes by installing an air separator. An effective processing technology for producing a product (PET flakes) with a minimum content of PVC impurities was determined, which will reduce the anthropogenic pressure on the environment.

1. Relevance
In order to formalize the parameters of the efficiency of polyethyleneterephthalate (PET) processing, it is necessary to determine the degree of purity of PET flakes (moisture content of the raw materials, fractional composition, maximum amount of impurities) and process parameters. For the efficiency of PET processing, it is necessary to improve the quality of the resulting product. The main quality indicators include the low moisture content of the raw materials and the minimum amount of impurities in PET flakes. For this, it is necessary to perform additional cleaning from PVC impurities. The low content of PVC impurities allows to obtain the minimum amount of non-recyclable technological waste in the production of polyester fiber.

Based on the analysis of PET processing methods, it can be concluded that the most environmentally friendly and economical method is mechanical processing using an air separator to separate PVC. The selected method is optimal. Based on the existing capacities and output volumes, an effective processing technology for the production of the product (PET flakes) with a minimum content of PVC impurities has been determined, which will reduce the anthropogenic pressure on the environment.

Based on the existing line for processing PET containers (figure 1), the principle of which is the mechanical method of processing, it is advisable to use an air separator to separate the final product (PET flakes) from PVC impurities. It is necessary to carry out mathematical modeling to determine the type of air separator, dimensions, diameters of pneumatic conveying and electric motor capacities. Based on the calculations of the mathematical model, it is possible to design, manufacture and commission equipment for cleaning PVC impurities [1-3].
2. Technical solution to improve the process of PET processing

The task of optimizing the developed processes and improving the equipment used can be solved using the method of mathematical modeling of the separation process in a pneumatic separator. At the same time, considerable attention should be paid to improving the adequacy of the developed model, in particular, by taking into account the spatial nonlinearity of the air flow in the working area of the separator. The modeling task was to obtain quantitative dependences of the acceleration, speed and path that the particle traveled with a change in particle size and density, flow velocity and coordinates, and grain delivery speed by air flow; creating elements that provide high separation efficiency. For the calculation, we used the initial data (table 1) and compiled a model in the Ansys FLUENT software package (figure 2).

| Table 1. Initial data. |
|------------------------|
| **Productivity**       |
| Pet flakes             | 450 kg/h     |
| PVC                    | 0,31 kg/h    |
| **Mass of one particle** |
| Pet flakes             | 0,01 g       |
| PVC                    | 0,001 g      |
| **Material density**   |
| Pet flakes             | 285,7142857 kg/m³ |
| PVC                    | 47,61904762 kg/m³ |
| **Volume of one particle** |
| Pet flakes             | 0,000000035 m³  |
| PVC                    | 0,000000021 m³  |
| **Air velocity in the separator** |
| Pet flakes             | 2,5 m/s      |
| PVC                    | 1,2 kg/m³    |
| **Applied Force Archimedes** |
| Pet flakes             | 4,1202E-07 N  |
| PVC                    | 2,47212E-07 N  |
| **Aerodynamic drag**   |
| Pet flakes             | 10,79988277 N |
| PVC                    | 26,99997131 N  |
Figure 2. Scheme of particle motion in a nonlinear flow with lateral unloading: 1 - nozzle; 2 - discharge nozzle; 3 - mesh conveyor; 4 - the trajectory of light grain; 5 - trajectory of a heavy particle; hп - airflow width; Vx — particle velocity in the direction of the X axis; Vy - the particle velocity in the direction of the Y axis; Vп - air flow velocity.

The calculation of the mathematical model according to the parameters of this separator was carried out subject to the separation conditions: to create a nozzle wall in the upper part so that the vertical air velocity pulse would be maximally transformed into a horizontal one, towards the discharge nozzle. This can be achieved by changing the profile of the nozzle part, by reducing or changing the curvature, as well as by reducing the point of passage from the rectangular sector of the nozzle to the curved plane (figure 3).

Figure 3. Trajectories of medium grain (7 mm) in separators with a modified nozzle shape.
One of the options for upgrading the surface and shape of the outlet nozzle is the inclusion of additional air flow in the upper sector of the working area of the air separator, which will facilitate the unloading of light fractions, namely PVC. As a result, an air flow pressure is achieved at which the particle trajectory reduces the probability of its return to the light and heavy fractions. As a result of modeling, it is necessary to change the shape of the exit nozzle, which will significantly reduce the length of time particles of PET flakes and PVC are in the working area, and the time spent by particles with sizes of 14-18 mm is reduced by 1.15 - 1.35 times.

The result of mathematical modeling is the calculated particle trajectories with a size of 5-15 mm, with an average linear air velocity of 10 m/s, respectively, all particles fall into the wall of the outlet nozzle. As a result, a “snail” is created in which, as a result of the rebound, the particles intersect in the air stream and return to the separation zone.

The degree of "depreciation" of the rebound (recovery coefficient) significantly affects the "rebound" of the particle. In the “soft” mode of impact, the particle is unloaded under the influence of horizontal nonlinear air flow. From the data obtained it follows that particles with sizes from 4 to 8 mm fall into the exit nozzle and at most with a few collisions with the walls of the exit nozzle. Particles 10 and 12 mm in size after the first impact are thrown into the distribution zone and fall into the discharge nozzle after 5-7 collisions with the walls of the exit nozzle. The lighter fraction particles, which are boundary in aerodynamic dimensions, produce multiple collisions with the walls of the outgoing nozzle, which greatly increases the time spent in the working zone of the air separator [1,4].

Thus, as a result of modifications to the separator design, a more efficient separation of PET flakes can be achieved. The calculations were verified based on the analysis of the sound series of motion of a single particle. All collisions were recorded by the amount of tonality of the sound signals. To obtain the most correct results, a qualitative measurement of the number of collisions for twenty experiments is necessary.

The results of the experiment showed good efficiency of the developed mathematical model, as well as the correctness of the conclusions made about the need to improve the air separation due to a constructive change in the shape of the nozzle and the surface of the hopper.

The principle of operation of the device is based on the specific gravity method for separating flakes and labels. Flakes and labels fall into the sealed tank at the same time, and at the same time, the suction fans go in their way and form negative pressure. Heavier flakes will fall, and lighter labels will be sucked out due to negative pressure, and thus the flakes and labels will be separated (figure 4).

**Figure 4.** PVC Separator: 1- Blow fans; 2- Supply fan; 3- Bags for collecting labels; 4- Cyclone.
The internal space is processed, consider the roughness not more than 0.5 microns (not more than Ra 3.2). The separation of the mixture takes place due to the difference in the weight and for this the optimal mode of suction pumps is selected (table 2).

Table 2. Actual data.

| Air intake velocity | 2.7 m/s |
|---------------------|--------|
| Pressure inside the separator | 0.8-0.95 atm |

The motion is considered: turbulent with a Re number ranging from 1000 to 10000. The analysis carried out in the ANSYS FLUENT software package shows that:

1. In order to increase productivity, an increase in separation space and an increase in the productivity of pumps are required.
2. To create a more efficient separation, reduce the moisture content of the mixture to be reduced to 0.01%.

The control standards for flakes are presented in table 3.

Table 3. Control standards for flakes.

| Residual Alkalinity (pH) | 6.5 – 7.5 |
|--------------------------|-----------|
| Residual adhesive content | ppm | no more 80 |
| PVC Content | ppm | no more 150 |
| The content of polyethylene, polypropylene (pop-up pollution, other plastics) | ppm | no more 150 |
| The content of other non-melting contaminants (stone, glass, paper, wood, label) | ppm | no more 50 |
| Elastomer Content | ppm | no more 100 |
| Metal content | ppm | no more 50 |

Conclusions
A mathematical description is presented for calculating the effective values of the air velocity and separation space based on the principle of the known aerodynamic properties of materials.

During the drying of PET flakes, the content of PVC impurities does not decrease and its quality decreases, therefore, it is proposed to improve the quality of PET flakes by installing an air separator. For this, an air separation unit is selected that meets the specified requirements. To determine the operational and design parameters of the separator of the selected installation and evaluate its effectiveness, the separation space and air flows were calculated.

The economic effect of the introduction of a new piece of equipment showed a high margin profit and short payback periods.

References
[1] Kravtsova M V and Volkov D A 2015 IOP Conf. Ser.: Materials Science and Engineering 46 012075
[2] Glagolev S N, Sevostyianov V S, Gridchin A M, Uralskiy V I, Sevostyianov M V and Iadykina V V 2013 Bulletin of BSTU named after V. G. Shukhov 6 102-6
[3] Glagolev S N, Sevostyianov V S, Sverguzova S V, Shaiyhev I G, Uralskiy V I, Sevostyianov M V, Fetisov D D and Shinkarev L I 2012 Bulletin of KTU 10(15) 198-200
[4] Chen D, Yin L, Wang H and Pyrolysis P He 2015 Waste Management 34(12) 2466-86