Recycled plastics: processing of waste from polyethylene terephthalate bottles

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By some estimates, within more than a 10 year period for which drinks have been sold in polyethylene terephthalate (PETP) packaging in Russia, at least 2 million tonnes of used plastic containers, a valuable chemical feedstock, has built up at solid domestic waste (SDW) sites.

The explosive growth in bottle preform production and the increase in world oil prices, and, accordingly, in primary PETP prices, influenced the active formation in Russia in the year 2000 of a market for the processing of used PETP bottles.

The recycled PETP market is developing dynamically and has a huge potential. According to data of the Association of European PETP Bottle Processors, PETCORE, in the period from 1995 to 2000 the amount of processed feedstock grew from 80 000 to 340 000 t/year, and within the past year a 23% increase in the volumes of processing has been observed. According to different estimates, 250 000–500 000 t PETP was imported into Russia in the year 2000 (mainly from the South Korean company “Kokhap”, and to a lesser extent from Mogilev), processed into preforms, blown into bottles, filled with drinks, and shipped to consumers. Under current conditions, this chain ends at the SDW site.

There are several methods for processing used bottles. An interesting procedure is the intense chemical processing of recycled PETP with the production of dimethyl terephthalate (DMT) in the process of methanolysis, or with the production of terephthalic acid and ethylene glycol in a number of hydrolytic processes. However, such processing methods have an important shortcoming—the high cost of the depolymerisation process. Therefore, fairly well-known and widely used mechanochemical processing methods are currently more often applied, during which the final products are formed from a polymer melt. A considerable range of articles produced from recycled PETP bottles has now been developed. The main large-tonnage production is that of Lavsan PETP fibres (mainly staple) and the production of Sintepons and non-woven materials. A large segment of the market comprises the extrusion of sheets for thermal moulding on extruders with sheeting heads, and, finally, the most promising processing method is universally acknowledged to be the production of granulate suitable for contact with foodstuffs, i.e. the production of material for the recasting of preforms. Such material is produced by repeated recrystallisation and extraction under deep vacuum using high-tech equipment of such well-known manufacturers as EREMA, Bühler, OH!L, Kreyenborg, and Berstorff. The comparatively low investments and service costs make such projects extremely attractive, and undoubtedly a huge amount of feedstock will be produced by this method in Russia in the near future.

Bottle semi-products can be used for technical purposes:
• during processing, recycled PETP can be added to the primary material;
• compounding—recycled PETP can be melted down with other plastics (for example, with polycarbonate) and filled with fibres for the production of technical parts;
• the production of dyes (superconcentrates) for the production of coloured plastic articles.

Likewise, purified PETP flakes can be used directly for the manufacture of a wide range of goods:
The bottles must be stored in a dry place. Wet labels (the result of storage in the rain or snow) can affect separation in an air flow, and consequently, this has an adverse effect on the quality of the PETP flakes. Therefore, before processing, wet bottles must be held for some time in a dry area of the plant.

It is recommended that the bottles be sorted beforehand, removing foreign matter, so-called "undesirable materials." Polyvinyl chloride (PVC) bottles must be removed particularly thoroughly, since even small amounts of PVC can create difficulties in the subsequent processing of PETP. The maximum permissible PVC content in pure PETP flakes is 0.25%.

Plastic sacks with PETP bottles are emptied into a loading hopper. After the bale has been loaded into the hopper, the twine holding the bale together must be removed manually. A big bag is hung on hooks over the loading hopper and turned inside out. After the loading hopper has been filled, it is raised by an electric hoist mechanism, and the bottles fall out into the feed hopper.

The bale feeder is used simultaneously as a storage hopper with a uniform feed system and as a bale separator. The conveyer positioned on the floor of the hopper advances the bale towards three rotating screws which break up the agglomerates into individual bottles and feed them onto a discharge conveyer positioned in the transverse direction.

The bottom of the feed hopper is a scraper conveyer with claws, equipped with a variable drive. The bottles are moved slowly forward along the hopper and discharged onto the sorting conveyer. Loosely compressed bottles (bales with a maximum density of 150 kg/m³) are automatically broken up inside the hopper. However, tightly compressed bottles (strongly compressed bales with a density of over 150 kg/m³) are occasionally encountered, and these cannot be broken up in the hopper. Such bales can be broken up in a special high-power, expensive unit for the breakdown of compressed packs.

Depending on the degree of purity of the processed material, its sorting requires 3–4 workers. The bottles of coloured and uncoloured PETP must be separated, and foreign matter such as rubber, glass, paper, metal, and other types of plastic (PVC, PEN, PEVD, PS, etc.) must also be removed. The productivity of a single worker can be of the order of 125 kg/h.

In a single-rotor crusher equipped with a hydraulic pusher, PETP bottles are comminuted into coarse fractions with a particle size of up to 40 mm. During comminution, most labels are removed from the plastic.
The comminuted material passes through a vertical air classifier. Heavy particles (PETP) fall against the air flow onto the screen of a vibrating separator. Light particles (labels, film, dust, etc.) are entrained upwards in the air flow and collected in a special dust collector beneath the cyclone.

On the vibrating screen of the separator, the particles are divided into two fractions: coarse particles of PETP “leak” through the screen, while fine particles (mainly heavy fractions of contaminants) pass into the screen and are collected in a vessel beneath the separator.

A flotation tank is used to separate materials with different relative densities. PETP particles fall onto the inclined bottom, and a screw continuously discharges the PETP onto a water-separating screen. The floating particles (mainly polypropylene (PP) or polyethylene (PE) tops and rings) are moved to the rear part of the tank and removed by means of a rotating impeller. This material is collected in a special vessel with a perforated bottom, which is emptied manually.

The screen is used simultaneously to separate the water delivered together with the PETP from the flotation unit and to separate the fine fractions of contaminants. The precrushed material is washed efficiently in a two-step inclined rotating drum with perforated walls.

The material moves forward along a spiral inside the drum and at the same time is turned over by vanes. At the first stage, the flakes are washed in an aqueous medium (water or a washing solution) using a system creating turbulent water flows (the cavitation effect applies). At the second stage, the material is continuously treated with jets of hot water fed from sprayer nozzles, and at the second stage water separation occurs. The wash water is collected in a heating water tank and fed back to the sprayer nozzles. The fine fractions of contaminant (residue) are collected in a filter basket.

The flakes are dried in a rotating drum manufactured from perforated sheet. The material is turned over in hot air flows. The air is heated with electric heaters. At the request of the customer, the electric heaters can be replaced with gas heaters, paid for separately. The humid air from elements of the unit (a, b, and c) is vented out of the building. This air can be used to intensify the process of predrying of wet bottles stored in the feedstock accumulation room.

At this stage, coarse PETP particles are comminuted into flakes, the size of which amounts to about 10 mm. It must be pointed out that the idea of processing consists in the material not being comminuted into commercial product flakes at the first comminution stage. The bottles are precrushed, forming pieces of about 40 mm size. Such process management makes it possible to avoid losses of material in the system, achieve the optimum separation of labels, improve the washing effect, and reduce blade wear in the second crusher, since glass, sand, and other abrasive materials are removed before the stage of recomminution.

The final process is similar to the process of primary air classification. Label remnants and PETP dust are entrained in an air flow and collected in a special vessel beneath the cyclone. The final product, pure PETP flakes, is poured into barrels or octabins beneath the classifier.

The efficient dust collection system guarantees the absence of dust in the ambient atmosphere. The dust is drawn from several points of the line, and over 98% is collected in a large vessel beneath the cyclone. Less than 2% gets into the filter bank bags, which must be emptied from time to time.

In this way, it is possible to solve the most serious problem of utilising recycled plastic containers with the production of a product that can bring a substantial profit.
Figure 1 Processing of PETP bottles

Stages of Process

LOADING

- Preparation of feedstock
- Storage and uniform feeding
- Manual sorting
- Crushing (coarse fractions)
- Primary air classification and vibratory separation
- Flotation
- Washing
- Rinsing
- Water separation
- Drying
- Communion (fraction of commercial product)
- Secondary air classification
- Filling of containers, boxes, octabins, big bags, etc

Contaminants and byproducts removed

- Foreign matter (rubber, glass, stones, metals, paper, other types of plastic such as PVC, PE, PC, etc.)
- Light contaminants (labels, paper, PETP dust)
- Heavy contaminants (sand, dirt, fine PEPT particles)
- Floating contaminants (PE or PP bottle tops, stoppers, paper, wood, plastic materials with density below 1 g/cm³)
- Removal of impurities: Fine particles (dirt)
- Coarse particles (paper, fine, PETP particles)
- Filtration: Very fine fractions (dirt)
- Light contaminants (labels, PETP dust)

OUTPUT
Pure PETP flakes
Figure 2 Process layout
<table>
<thead>
<tr>
<th>Position</th>
<th>Quantity</th>
<th>Specification of units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Storage and uniform feeding</strong></td>
</tr>
<tr>
<td>01</td>
<td>1</td>
<td><strong>Loading hopper (3 m³ volume)</strong>&lt;br&gt;Designed for filling of the feed hopper. It has a front door and wheels. The lifting and tipping mechanism consists of rails, a chain drive, and a 3 kW motor reducer</td>
</tr>
<tr>
<td>02</td>
<td>1</td>
<td><strong>Feed hopper VF 13000 (13 m³ volume)</strong>&lt;br&gt;Designed for intermediate storage and feeding of feedstock. It has a controllable gate. The slowly moving scraper conveyer is mounted on chain guides. It is equipped with a 0.37 kW motor reducer with an electrically controllable speed. Four supports. External dimensions: 5200 x 2000 x 3250 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Manual sorting</strong></td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td><strong>Horizontal conveyor belt (700 x 4500 mm/0°)</strong>&lt;br&gt;Designed for sorting. The belt is made of PVC and has a 0.37 kW motor reducer with an electrically controllable speed</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td><strong>Conveyor belt (500 x 2500 mm/45°) (optional)</strong>&lt;br&gt;For coloured bottles and foreign matter, with a 0.37 kW motor reducer</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td><strong>Conveyor belt (500 x 2500 mm/45°) (optional)</strong>&lt;br&gt;The same as position 11</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td><strong>Conveyor belt (700 x 2600 mm/45°)</strong>&lt;br&gt;Designed for feeding material into the crusher. It has a PVC belt with stiffening ribs and a 0.37 kW motor reducer</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Crushing</strong></td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td><strong>Crusher MRC 1500 Standard</strong>&lt;br&gt;Designed for the preliminary comminution of bottles, its housing measures 2650 x 1500 x 850 mm. It has a single row of 38 stationary tiltable blades controlled individually. The rotor measures Ø350 x 1500 mm with 76 tiltable square blades. The screen has Ø40 mm holes. The pump has a 1.5 kW electric motor and a hydraulic cylinder with a pusher which advances the bottles towards the rotor. 55 kW electric motor. External dimensions 2760 x 2510 x 1500 mm</td>
</tr>
<tr>
<td>21</td>
<td>1</td>
<td><strong>Air blower</strong>&lt;br&gt;For pneumatic conveyance, with a reinforced fan and housing and a 5.5 kW electric motor with a belt drive</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td><strong>Conveying pipes (Ø160 mm)</strong>&lt;br&gt;With connections</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Primary air classification</strong></td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td><strong>Cyclone (Ø600 x 1200 mm)</strong>&lt;br&gt;Shares a support with the column of the air classifier (position 32)</td>
</tr>
<tr>
<td>31</td>
<td>1</td>
<td><strong>Reversible valve (Ø200 x 600 mm)</strong>&lt;br&gt;It has a 0.25 kW motor reducer</td>
</tr>
<tr>
<td>32</td>
<td>1</td>
<td><strong>Column of air classifier (80 x 800 mm, height 1600 mm)</strong>&lt;br&gt;For the separation of labels and light impurities. It has an inspection window, with a gate for air flow control</td>
</tr>
<tr>
<td>33</td>
<td>1</td>
<td><strong>Air blower</strong>&lt;br&gt;For primary air classification. It has a 3 kW electric motor</td>
</tr>
<tr>
<td>34</td>
<td>1</td>
<td><strong>Vibrating screen (Ø600 x 1000 mm)</strong>&lt;br&gt;Designed for the separation of heavy fractions of contaminant, with a 0.25 kW vibration motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Flotation</strong></td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td><strong>Conveyor belt (800 x 3800 mm/45°)</strong>&lt;br&gt;It has a 0.37 kW motor reducer</td>
</tr>
<tr>
<td>41</td>
<td>1</td>
<td><strong>Flotation tank (1.2 m³ volume)</strong>&lt;br&gt;For the separation of tops, rings, and labels. It consists of four supports, a vessel with an inclined bottom, an impeller for the removal of floating particles, and a 0.11 kW motor reducer. It has a Ø250 x 3000 mm discharge screw conveyor with a 0.55 kW motor reducer, and a sprinkler device for loading of material. It is manufactured from stainless steel, with external dimensions of 2600 x 1300 x 2700 mm</td>
</tr>
<tr>
<td>42</td>
<td>2</td>
<td><strong>Vessel with filter bottom (100 bottles/ m³ volume)</strong>&lt;br&gt;For the collection of tops, rings, and labels. It has a hopper for the collection of water and a twin-chute separator (divertor) between two vessels</td>
</tr>
<tr>
<td>43</td>
<td>1</td>
<td><strong>Water separating screen</strong>&lt;br&gt;Inclined 400 x 1200 mm screen</td>
</tr>
</tbody>
</table>
**Table 1 Continued**

<table>
<thead>
<tr>
<th>Position</th>
<th>Quantity</th>
<th>Specification of units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Washing/rinsing/water removal/drying</strong></td>
</tr>
<tr>
<td>Multistage washing occurs in three units:</td>
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</tbody>
</table>

50 1 **Washing unit including two stages**
- Inclined rotating drum with perforated walls: Ø800 x 1500 mm, rotational speed 1.5 rpm, with an internal spiral and vanes for the movement of material. It has a system that creates turbulent hot water flows, sprayer nozzles, a water temperature of approximately 90°C, a 0.37 kW motor reducer, and a 0.55 kW exhaust air blower for humid air. Vessel for water heating: 11.3 m³ (1.3 m³ volume).
- Equipped with:
  - a conveyor with a belt consisting of a fine-celled grid for the removal of coarse contaminant particles
  - a filter basket of stainless steel for the removal of fine contaminant fractions
  - one 4 kW, 250 l/min centrifugal pump for the creation of turbulent flows
  - one 4 kW, 250 l/min centrifugal pump for the feeding of water into the sprayer nozzles
  - an inclined bottom with a drain valve
  - four 12 kW heating elements
  - External dimensions: 2000 x 1800 x 2250 mm for conveyance, with an additional 500 mm in height for the air blower

51 1 **Unit for rinsing/removal of water, including two stages**
- Inclined rotating drum with perforated walls: Ø800 x 1500 mm, rotational speed 1.5 rpm, with an internal spiral and vanes for the movement of material. At the washing stage, the material is continuously treated with jets of hot water at a temperature of 60°C. At the water separation stage, the moisture runs off the turning particles. 0.37 kW motor reducer. 0.55 kW exhaust air blower for humid air. Vessel for heating of water (1.3 m³ volume).
- Equipped with:
  - a filter basket of stainless steel for the removal of fine contaminant fractions
  - one 4 kW, 500 l/min centrifugal pump for feeding water into the sprayer nozzles
  - an inclined bottom with a drain valve
  - three 12 kW heating elements
  - External dimensions: 2000 x 1800 x 2250 mm for conveyance, with an additional 500 mm in height for the air blower

52 1 **Drier**
- Inclined rotating drum with perforated walls: Ø800 x 3000 mm, rotational speed 1.5 rpm, with an internal spiral and vanes for the movement of material. 0.37 kW motor reducer.
- Two air blowers for hot air, throughput 1800 m³/h each. Equipped with 1.1 kW electric motors.
- Controllable drying temperature up to 95°C
- One 0.55 kW exhaust air blower for humid air
- Two 1 kW heating elements
- External dimensions: 3500 x 1100 x 2250 mm for conveyance, with an additional 500 mm in height for the air blower
- Material used to manufacture units 50–52, and also the water heating vessels: stainless steel, with 50 mm thermal insulation

53 1 **Vessel with filter bottom**
Designed for the collection of contaminants. The same as position 42

54 1 **Water pipes**
Complete set of pipes, pumps, valves, thermometers, fittings, etc.

**Crushing**

60 1 **Conveyor belt (500 x 2800 mm/45°)**
- Designed for the feeding of material into the crusher. It has a PVC belt with stiffening ribs and a 0.37 kW motor reducer

61 1 **Crusher GR 30-660**
- Designed for the comminution of coarse fractions of PETP into flakes, the size of which amounts to roughly 10 mm (commercial product fraction). The crusher has the following main parts: a base on vibratory pads; a housing with two stationary blades; a loading hopper, and a discharge tunnel: Ø360 x 660 rotor with 2 x 3 blades; a flywheel; a 30 kW electric motor with a belt drive. It is possible to use all four faces of the stationary blades. Rapid and easy access is provided to the screen and blades. The screen has a hole diameter of 10 mm (other dimensions according to the user requirements).
<table>
<thead>
<tr>
<th>Position</th>
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<tbody>
<tr>
<td><strong>Secondary air classification</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 70 | 1 | **Cyclone** (Ø600 x 1200 mm)  
The same as position 30 |
| 71 | 1 | **Air blower**  
For the pneumatic conveyance of PETP flakes. It has a 4 kW electric motor |
| 72 | 1 | **Reversible valve** (Ø200 x 600 mm)  
The same as position 31 |
| 73 | 1 | **Column of air classifier** (80 x 800 mm, height 1600 mm)  
The same as position 32 |
| 74 | 1 | **Air blower**  
For secondary air classification. It has a 3 kW electric motor. The same as position 30 |
| 75 | 1 | **Twin-chute separator** (diverter)  
Manual control |
| **Dust collection** | | |
| 80 | 1 | **Pipes of dust collection system**  
Set of ventilation system pipes with supports, gates, fittings, etc. |
| 81 | 1 | **Cyclone** (Ø1100 x 2900 mm)  
For the continuous entrapment of dust. The floor stand is in the form of a case of dust-impermeable galvanised sheet with a door |
| 82 | 1 | **Reversible valve** (Ø300 x 300 mm)  
It has a 0.25 kW motor reducer |
| 83 | 1 | **Air vent**  
Air blower of average throughput with a gate and support. The 1.5 kW electric motor has a belt drive. Its throughput is 11 000 m³ air/h with a total pressure of 2000 N/m² |
| 84 | 1 | **Dust collector filters**  
A bank of filters designed for the collection of very fine dust fractions. It consists of 16 filter bags. It is emptied manually |
| **Electrical part** | | |
| 100–1-02 | 3 | **Control panel**  
Manufactured in accordance with international IEC standards. It contains all the necessary start and stop buttons, indicator lights, ammeters, relays, switches, fuses, temperature-sensitive elements, "star–triangle" start-up system, successive emergency shutdown (interlocking) system, etc.  
Basic voltage 3 x 400 V, 50 Hz, control voltage 1 x 230 V, 50 Hz |