The influence of polyethylene processing on the plastic containers blowing

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Abstract. The materials of this article are devoted to the study of the influence of polyethylene processing on the plastic containers blowing. The aim of the study was to investigate the influence of one-time processing on the properties of high-density polyethylene, used for packing of mineral oils, as well as the indication of opportunities to use recycled material in the manufacture of new packing. The material used in the study was high-density polyethylene (HDPE) and recycled polyethylene. In the course of research, it was found that the processing led to a deterioration of the thermal properties of the polymer material, and the difference in the amount of liquidity of raw materials compared with processed, was 47.7%, which is consistent with reference studies. The conditions used during the blowing process resulted in uniformity of the final product in thickness. The difference in wall thickness of products made from raw material and recycled material was within 0.02 mm. The smallest thickness of finished products was 0.66 mm for recycled material and 0.68 mm for raw materials.

1. Introduction
Polyethylene is a semi-crystalline material that has good chemical resistance, good fatigue properties and wear resistance, and its properties vary over a wide range due to the difference in the length of the polymer chain [1,2]. It can be distinguished from other plastics by its buoyancy on the water surface. Polyethylene has a good resistance to organic solvents and electrolysis and has a higher mechanical strength than polypropylene, but its operating temperature and tensile strength are lower, its weight is relatively small, and it has a low degree of absorption [3,4].

A large increase in the population has led to an increase in the consumption of plastic materials, and as a result, the amount of waste has increased, which has led to an increase in interest in recycling and reuse operations [5]. Processing operations can be classified into basic, mechanical, chemical (tertiary) and energy recovery (quaternary) processing [6].

Control studies have shown that the properties of plastics are affected by the process of mechanical processing, which also negatively affects their properties. Mechanical properties are more dependent on the processing than on thermal properties, while the variables of fluidity, melting temperature, and melting energy are not significantly affected by the processing [7,8].

It is indicated in [8] that recycling of high-density polyethylene packings leads to changes in the thermal and mechanical properties of the raw material. The degree of change in properties depends on the processing and the time during which the material is in the device, the shorter the residence time, the smaller the change in properties.
It is stated in [9], that repeated recycling does not affect the properties of polyethylene in terms of melting and crystallization temperature but affects mechanical properties.

A study of the mechanical properties of recycled high-density polyethylene after mixing it with untreated polypropylene [10] showed that an increase in the proportion of polypropylene in the recycled material leads to a high melting point and an increase in the tensile strength of the material.

A study conducted in [11], which examined the process of mixing polyethylene with recycled polyethylene terephthalates (PET) in plastic water bottles, showed a decrease in the energy required to melt PET with an increase in the proportion of PE in the mixture, the tensile strength and elongation also increased with an increase in the proportion of PE in the mixture, and, most importantly, it was found that these two materials are incompatible, and their joint use led to a deterioration of the mechanical properties of the resulting mixture.

2. Purpose of the research
The study of the effect of a single-use processing on the properties of high-density polyethylene used in the production of packing for mineral oil filling as well as indication of the possibility of using the recycled material in the manufacture of new packings.

3. Search method
The research was conducted in two stages: laboratory experiments to determine thermal properties of polymer materials were carried out in the first stage; the second stage was computer simulation to study the process of blowing using program Ansys.

4. Research materials
The materials used in the research are high-density polyethylene (HDPE) and recycled polyethylene, which are used for making bottles with mineral oil by blowing. Figure 1 shows raw material granules and processed material.

![Figure 1. HDPE granules: a) - raw material, b) - recycled material.](image)

To determine the weight of samples needed to measure the thermal properties of the material, a device with a division price of 0.01 g was used. Samples were obtained by mixing raw materials with recycled material in the following proportions: secondary raw material / raw material: 50/50, 60/40, 70/30, 100/0, 0/100, 30/70, then a study was performed to determine the liquidity properties and their display in accordance with the melt flow rate and with the ASTM d 1238 standard [12]. Using a device for measuring liquidity in figure 1b, the values of the melt flow rate were used to derive the viscosity of the polymer material.
Figure 2. Devices for determining the liquidity of samples.

The viscosity of the polymer material was calculated using the liquidity values given in form [13]:

\[ \text{MFR} = (14.13 \mu) D^4/l (\Delta P) 1 / (\mu), \]

where: MFR - melt flow rate, g / 10 min.; \( \rho \) - density (g / cm\(^3\)); \( D \) - diameter of the extrusion nozzle (m); l is the length of the extrusion nozzle (m); \( P \Delta \) - liquidity pressure (kPa); \( \mu \) - viscosity (Pa\(s\)).

5. Results
The values shown in figure 3 have been reached after liquidity tests according to ASTM D 1238

Figure 3 shows that the liquidity values will increase as the percentage of recycled material in the mix increases. If the percentage of processed material is 100%, the liquidity will increase by about 47.7% compared with the raw material. The ratio between the liquidity and the mixing ratio can be approximated by a linear equation, shown in figure 4.

Using experimental values and returning to ratio 1, we determined that the viscosity of the raw material was 22900 (Pa\(s\)), and the recycled material - 15500 (Pa\(s\)).

6. Simulation of the blowing process
Initially, the method was used to create a blown mold model similar to the form of mineral oil packing, and then, to create a set of points in a vacuum, this model was exported into the ANSYS, in which it was described by formulas taking into account the consumption of polymer material inside the matrix. Table 1 shows the input parameters for the software solution of the set tasks.

| Input Parameters               | Numerical Values |
|-------------------------------|-----------------|
| Press mold closing speed      | 0.5 m/c         |
| Blowing Time                  | 1.5c            |
Working pressure: 400 Pa
Material density: 990 g/cm³
Raw materials viscosity: 22900 Pa*s
Viscosity of 100% recycled material: 15500 Pa*s

Figure 4 shows the press mold and the plastic blank before the blowing process.

Figure 4. Press mold and plastic before blowing.

The movement of the press mold was assumed to be a steady acceleration in accordance with a linear function at the assumed pressure constant. At the beginning, the press mold moves at a constant speed until the press mold is closed on the plastic sample for 0.5 s, then the press mold stops moving until the blowing process ends, while in relation to the pressure it is not applied for 0.5 s, at which the pressure is applied in full and continues for 1.5 s when the blowing process ends. Figure 5 shows the velocity and pressure profiles.

Figure 5. Profiles of velocity and pressure when blowing.

When the mold is closed, the original sample is compressed to take the shape of the matrix, then it is subjected to blowing and under vacuum pressure completely fills it, resulting in the final product. Figure 6 shows these stages.

When the form is closed, the initial sample is compressed to take the form of a matrix, then it is subjected to blowing and, under vacuum pressure, completely fills it, resulting in the final product. Figure 6 shows these stages.
After studying the blowing process taking into account the properties of raw material and processed material, the following results were obtained:

- The conditions used during the blowing process resulted in a uniform thickness of the final product.
- The difference in the wall thickness of products made of raw material and recycled material was within 0.02 mm.
- The smallest thickness of finished products was 0.66 mm for recycled material and 0.68 mm for raw material.

7. Conclusions
Studies have shown that the processing led to a deterioration of the thermal properties of the polymer material, where there was an increase in the material's liquidity during processing. The difference in the liquidity amount of the raw material in comparison with the recycled material was 47\%\,47.7\%, which is consistent with the reference data.

With regard to the blowing process, it has been found that the blowing process of plastic using recycled material is close to the result of blowing using raw material, which justifies the recycled material use to manufacture packings for mineral oil filling.

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