Separation of high-density polyethylene/poly(ethylene terephthalate)/poly(vinyl chloride) mixtures based on differences in their hardness

(Rapid communication)

Krzysztof Królikowski[1]**, Kazimierz Piszczek**[1), *)]

DOI: dx.doi.org/10.14314/polimery.2017.599

Abstract: The separation of a three-component polymer mixture, high-density polyethylene/poly(ethylene terephthalate)/poly(vinyl chloride) (HDPE/PET/PVC), was studied on a modernized research station. The separation was performed in two stages. The first stage allowed for the separation of HDPE and the second for the separation of the remaining PET/PVC mixture. The obtained results showed a high efficiency of separation of HDPE from a HDPE/PET/PVC mixture. HDPE was separated with 100 % accuracy and 100 % effectiveness for the whole range of rotating speeds of a separating roller when the needle pressure force was 10 N. The most effective separation of the PET/PVC mixture with accuracy and recovery efficiency above 96 % was achieved for a needle pressure force of 3.5 N but the process had to be conducted at an elevated temperature (65 °C).

Keywords: needle separator with heating system, hardness, polymer blends, mechanical recycling.

Rozdzielanie mieszanin: polietylen dużej gęstości/poli(tereftalan etylenu)/poli(chlorek winylu) z wykorzystaniem różnic twardości składników

Streszczenie: Wykonano badania skuteczności separacji trójskładnikowej mieszaniny polietylen dużej gęstości/poli(tereftalan etylenu)/poli(chlorek winylu) (HDPE/PET/PVC). Separację prowadzono dwuetapowo na zmodernizowanym stanowisku badawczym. Pierwszy etap pozwalał na oddzielenie HDPE, a drugi na rozdzielenie pozostałej po pierwszym etapie mieszaniny PET/PVC. Wykazano dużą skuteczność wydzielania HDPE z mieszaniny HDPE/PET/PVC. Stosując siłę nacisku igieł równą 10 N HDPE odseparowano z dokładnością i efektywnością wynoszącymi 100 % w całym zakresie badanych prędkości obrotowych walca oddzielającego. Najskuteczniejszy rozdział mieszaniny PET/PVC, z dokładnością oraz efektywnością odzysku powyżej 96 %, uzyskano natomiast stosując siłę nacisku igieł wynoszącą 3,5 N, ale wymagało to prowadzenia procesu w podwyższonej temperaturze (65 °C).

Słowa kluczowe: separator igłowy z systemem grzania, twardość, mieszanina polimerowa, recykling mechaniczny.

The dynamic and comprehensive progress in technologies of the production, modification and processing of polymer materials mean that these materials are necessary for the production of a wide range of products used in all fields of the economy. These materials have also become very good substitutes for wood and metals. The global production of polymers in 2015 amounted to 322 million tones and the largest consumption of these materials was observed in many industrial branches: packaging (39.9 %), structural elements of various constructions (19.7 %) and the automotive industry (8.9 %) [1]. This leads to the generation of a large amount of waste materials that differ regarding their composition and properties. These materials require rational utilization [2]. Waste management of polymers can be conducted in various ways [2–7], however, material recycling is the preferred method. It is particularly recommended in relation to packaging.

The processes of separation of polymer mixtures are based on the easily understandable characteristics of chemical composition and diversified physical properties but it is generally required to combine different methods [3, 4, 8–11]. The separation can be performed by various methods by both wet sorting using a simple float-sink method or float method, and by dry methods with the use of various devices. These devices include

[1] UTP University of Science and Technology in Bydgoszcz, Faculty of Chemical Technology and Engineering, Department of Polymer Technology and Protective Coatings, Seminaryjna 3, 85-326 Bydgoszcz, Poland.

[*] Author for correspondence; e mail: piszczek@utp.edu.pl

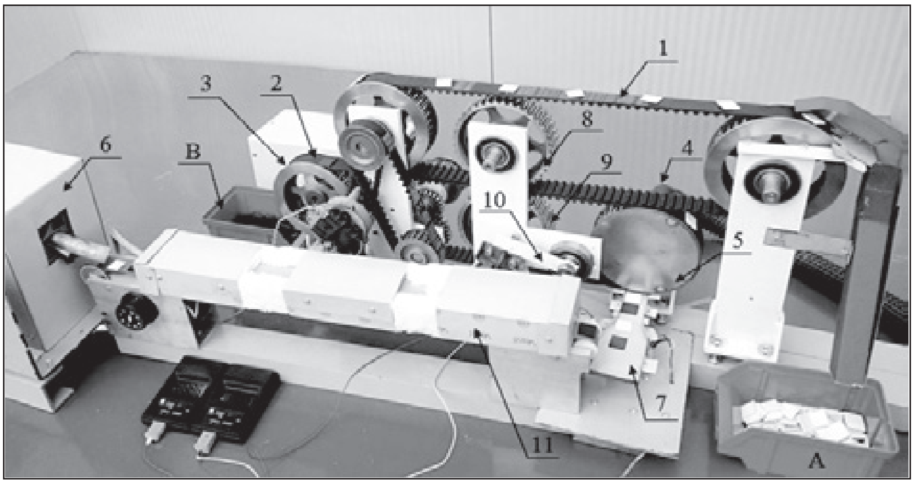

Fig. 1. A needle separator (description in the text)

mechanical separators with automatic equipment for the identification of particles, electrostatic separators and gravitational separators. The needle separator can be used in dry separation [12–15]. This device is used for the identification of polymer materials based on their hardness, which uses specially shaped needles to separate the mixture.

The aim of the research described in this work was to analyze and assess the possibility of separation of components of a three-component mixture consisting of high-density polyethylene (HDPE), poly(ethylene terephthalate) (PET) and poly(vinyl chloride) (PVC) based on the difference in their hardness with the use of a modernized needle separator.

EXPERIMENTAL PART

Materials

High-density polyethylene (HDPE) with a density of 0.96 g/cm^3 and hardness of 70 °Sh D, poly(ethylene terephthalate) (PET) with density of 1.34 g/cm^3 and hardness of 78 °Sh D and poly(vinyl chloride) (PVC) with a density of 1.46 g/cm^3 and hardness of 78 °Sh D were used during tests. Density and hardness was determined at 20 °C. The specimen shapes were squares 17 x 17 mm prepared from boards with a thickness of approx. 2 mm with different colors (manufactured by Tuplex Polska Sp. z o.o.). The samples of HDPE, PET and PVC were mixed in the weight proportion of 1 : 1 : 1. The difference in the colors of the samples made it possible to analyze the separation products, which after completion of the process were weighed with an accuracy of ± 0.01 g.

Separation methodology

The mixtures were separated with the use of a modernized needle separator incorporating a heating system, shown in Fig. 1. This separator allows the adjustment of the needle pressure force.

The separator needles have the shape of a roller with a diameter of 0.30 mm, which are placed in the separating belt (1). The upper belt operates concurrently with the bottom conveyor belt (2), in which holes have been arranged (3) at the same distances as the needles, though shifted so that the needles hit the surface of the belt in front of the hole. Negative pressure is delivered to the toothed cylinder (5) generating a vacuum in the belt perforation by duct (4). From the dispenser (6), the separated mixture reaches a vibrating feeder (7), and then it is transported to the bottom conveyor belt (2). The mixture elements are sucked onto the conveyor belt (2), which transports them to the separating system through the holes (3). The separating system is composed of two gear wheels (8 and 9), an upper, immobile wheel (8), as well as a bottom wheel (9), which is mounted pendulously and resisted by a pneumatic actuator. The pneumatic actuator (10) determines the contact pressure of needles on the mixture elements. The tunnel heating system (11) is a belt conveyor placed inside the heating chamber that ensures heating of the mixture elements. Polymers of lower hardness are attached by the needles and transported by the separating belt to tank A. Elements of higher hardness remain on the conveyor belt and fall into the B tank. The process of separation was conducted in two stages – in the first stage, at a temperature of 24 °C and needle pressure of 8, 9 and 10 N, only HDPE was separated from 180 g of the mixture; in the second stage, the residue from the first stage (PET/PVC mixture) was separated. Each of the stages was repeated three times.

The accuracy of S component separation (D_S) was expressed by the following equation:

$$D_S = \frac{m_S}{m_{FS}} \cdot 100 \quad \% \tag{1}$$

where: m_S – mass of S component included in the fraction with dominant share of this component, m_{FS} – total mass of the fraction with dominant share of S component.

The effectiveness of S component recovery (E_S) is given by equation:

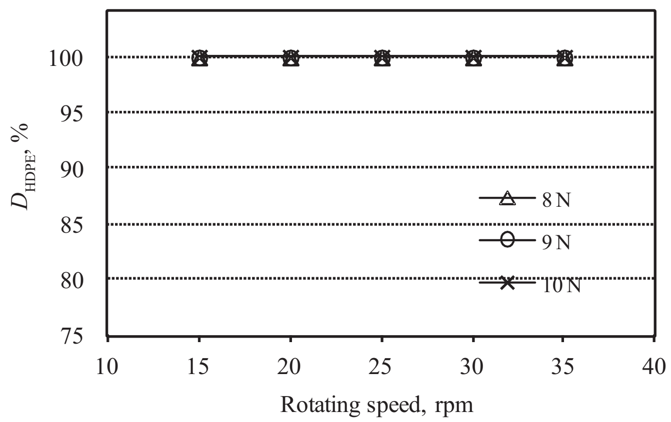

Fig. 2. The influence of rotating speed of the separating system on the accuracy of separation of HDPE from a HDPE/PET/PVC mixture (D_{HDPE})

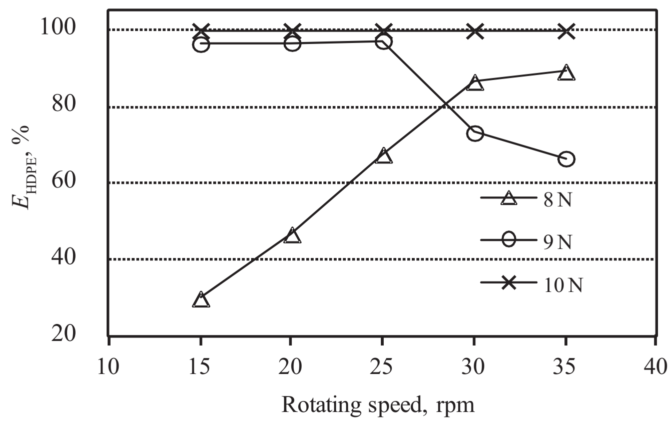

Fig. 3. The influence of rotating speed of the separating system on the effectiveness of separation of HDPE from a HDPE/PET/PVC mixture (E_{HDPE})

$$E_S = \frac{m_S}{m_{MS}} \cdot 100 \quad \% \tag{2}$$

where: m_{MS} – mass of S component included in the mixture undergoing separation.

Hereinafter, the symbol S of the mixture component will be replaced with the symbol of the corresponding substance (HDPE, PET and PVC, respectively).

RESULTS AND DISCUSSION

The first stage of separation

The results of the first stage of separation are presented in Figs. 2 and 3. During this stage, the influence of the rotating speed of the separating system on the accuracy and effectiveness of the separation of HDPE from the HDPE/PET/PVC mixture was tested.

The data presented in Figs. 2 and 3 indicate that the best effectiveness of separation of HDPE fraction from the HDPE/PET/PVC mixture stream was characterized by D_{HDPE} = 100 % and E_{HDPE} = 100 % within the whole range of rotating speeds and needle pressure force of 10 N. The attached HDPE materials were transported to tank A (Fig. 1), while the PET and PVC mixture was placed in tank B. With a separation force of 9 N, a high E_{HDPE} of 96.53–97.33 % and D_{HDPE} = 100 % was obtained for rotating speed values from 15 to 25 rpm. A further increase of rotating speed caused a decrease of E_{HDPE} to 73.30 % for the speed value of 30 rpm and to 66.67 % for the speed value of 35 rpm as a result of the increasing centrifugal force on HDPE elements attached to the needles. During separation at a pressure force of 8 N, the value of D_{HDPE} increased proportionally to the rotating speed, reaching a maximum value of 89.33 % for 35 rpm. This phenomenon is related with a slight increase of depth of immersion of the needles in HDPE elements at higher speed values. The influence of speed on D_{HDPE} and E_{HDPE} is most visible at rotating speeds of 25 rpm for which the process effects reach the highest values.

The second stage of separation

During the second stage of separation, the residue obtained in the first stage was separated at a pressure force of 10 N. The testing station was additionally equipped

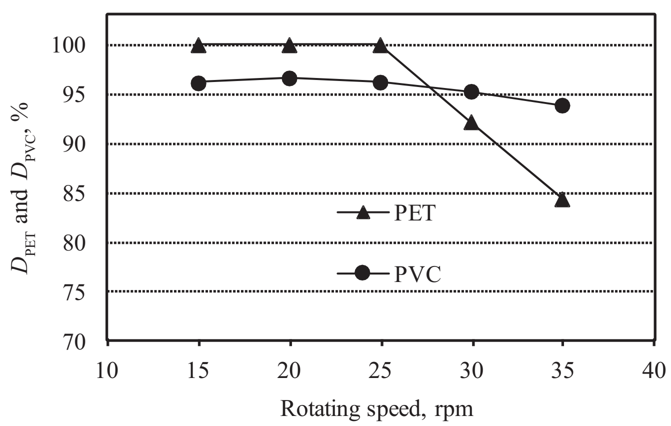

Fig. 4. The influence of rotating speed of the separating system on the accuracy of separation of PET and PVC elements (D_{PET} and D_{PVC}, respectively)

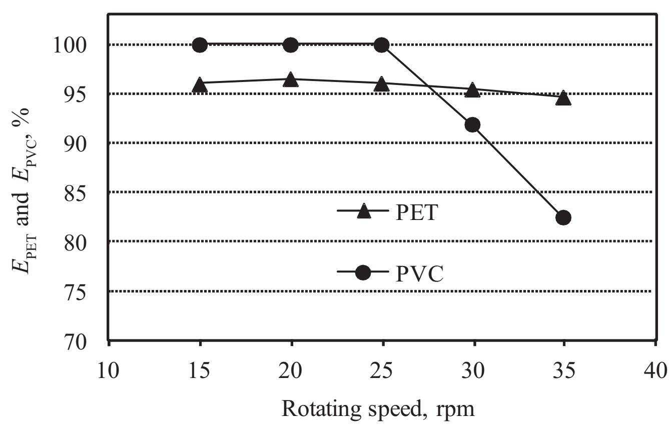

Fig. 5. The influence of rotating speed of the separating system on the effectiveness of separation of PET and PVC (E_{PET} and E_{PVC}, respectively)

with a conveyor belt with a tunnel heating system. The PET/PVC mixture, heated to a temperature of 65 °C, was separated at a needle pressure force of 3.5 N with variable rotating speeds. The influence of the rotating speed on the accuracy and effectiveness of PET and PVC separation is presented in Figs. 4 and 5.

The results show that the highest E_{PET} and E_{PVC} were obtained at rotating speed values from 15 to 25 rpm. The D_{PVC} values were from 96.15 to 96.65 % with E_{PVC} = 100 %, whereas D_{PET} was 100 % with E_{PET} of 96.00–96.53 %. The decrease of D_{PET}, as well as E_{PVC}, during separation with higher rotating speeds was due to the attachment of PVC elements and transport of them to the tank with PET elements.

CONCLUSIONS

The presented test results conducted on a modernized testing station confirm the general construction correctness of the modernized station. The method of separation of mixtures involving differences in their hardness indicates considerable potential for the effective removal of HDPE from a three-component HDPE/PET/PVC mixture, as well as for the separation of polymers with similar densities such as PET and PVC. The best effectiveness of separation of the HDPE stream from HDPE/PET/PVC mixture was obtained in the process at a pressure force of 10 N for the whole range of rotating speeds. Satisfactory results were also obtained during separation of the PET/PVC mixture. During separation at a temperature of 65 °C, and needle pressure force of 3.5 N, a high effectiveness of 96 % for each of the streams was obtained within the range of rotating speeds from 15 to 25 rpm.

REFERENCES

[1] "Plastics – the Facts 2016", http://www.plasticseurope.pl/Document/plastics--the-facts-2016-15787.aspx?Page=DOCUMENT&FolID=2 (access date 04.05.2017).
[2] Resolution of the Council of Ministers of the Republic of Poland: "Krajowy Plan Gospodarki Odpadami 2020", Monitor Polski 2016, pos. 784.
[3] „Recykling materiałów polimerowych", (Ed. Błędzki A.K.). WNT, Warszawa 1997.
[4] „Recykling odpadów polimerowych z elektroniki i pojazdów", (Eds. Kozłowski M., Rydarowski H.), Publishing Department of ITiE-PIB, Radom 2012.
[5] Rejewski P.: *Polimery* **2008**, *53*, 711.
[6] Kijeński J.: *Polimery* **2014**, *59*, 393. http://dx.doi.org/10.14314/polimery.2014.393
[7] Moroni M., La Marca F., Cherubini L. *et al.*: *International Journal of Environmental Research* **2013**, *7* (*1*), 113.
[8] Żenkiewicz M., Żuk T., Królikowski K.: *Przetwórstwo Tworzyw* **2012**, *6* (*150*), 692.
[9] „Podstawy recyklingu tworzyw sztucznych", (Ed. Kozłowski M.), Publishing House of Wroclaw University of Technology, Wroclaw 1998.
[10] Yuce A.E., Kilic M.: *Journal of Environmental Protection and Ecology* **2015**, *16* (*2*), 705.
[11] Menad N., Guignot S., van Houwelingen J.A.: *Waste Management* **2013**, *33* (*3*), 706. http://dx.doi.org/10.1016/j.wasman.2012.04.007
[12] Żuk T., Pietraszak J., Żenkiewicz M.: *Polimery* **2016**, *61*, 519. http://dx.doi.org/10.14314/polimery.2016.519
[13] Żenkiewicz M., Żuk T., Pietraszak J. *et al.*: *Polimery* **2016**, *61*, 835. http://dx.doi.org/10.14314/polimery.2016.835
[14] *Polish Pat. Appl.* 405364 (2013).
[15] Królikowski K., Piszczek K., Żuk T.: *Inżynieria i Aparatura Chemiczna* **2014**, *53*, 91.
[16] Królikowski K., Piszczek K., Żuk T.: *Przetwórstwo Tworzyw* **2014**, *6*, 547.
[17] Królikowski K., Piszczek K., Żuk T.: *Przetwórstwo Tworzyw* **2015**, *6*, 456.

Received 2 II 2017.