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ECONOMIC CONSIDERATIONS OF DISASSEMBLY PROCESS AUTOMATION

The paper presents methods of recovering materials from products manufactured with defects. Particular attention is paid to material recycling, which allows reusing materials and thus improve the economic situation of a company. Recycling can be successfully implemented at a manufacturing company after applying mechanical separator systems that increase the efficiency and profitability of processes. Analysis of possibilities for automation of recovery process of raw materials used in further re-utilization is provided on the example of car fuel tanks. The analysis of effectiveness of this solution is conducted. The article also offers an innovative automated solution for mechanical separation which reduces costs of granulate production.

Keywords: *automation; recycling; disassembly; production costs reducion.*

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ЕКОНОМІЧНИЙ АСПЕКТ АВТОМАТИЗАЦІЇ ПРОЦЕСІВ ДЕМОНТАЖУ ТА ПЕРЕРОБКИ

У статті представлено методи вторинної переробки матеріалів при демонтажу виробничих об'єктів з дефектами. Окрему увагу приділено переробці матеріалів та сировини, що дозволяє підприємству покращити свій економічний стан. Механізовані системи сортування сировини та матеріалів підвищують ефективність та прибутковість процесів вторинної переробки. Надано приклад такої переробки для машинних паливних баків. Проведено аналіз ефективності даного методу. Також презентовано інноваційне автоматизоване рішення сортування сировини та матеріалів для виробництва грануляту.

Ключові слова: *автоматизація; повторна переробка сировини; демонтаж; економія витрат на виробництво.*

Рис. 8. Літ. 14.

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ЭКОНОМИЧЕСКИЙ АСПЕКТ АВТОМАТИЗАЦИИ ПРОЦЕССОВ ДЕМОНТАЖА И ПЕРЕРАБОТКИ

В статье представлены методы повторной переработки материалов при демонтаже производственных объектов с дефектами. Отдельное внимание уделено переработке материалов и сырья, что позволяет предприятию улучшить своё экономическое положение. Механизированные системы разделения сырья и материалов повышают эффективность и прибыльность процессов повторной переработки. Приведен пример подобной переработки для машинных топливных баков. Проведён анализ эффективности данного метода. Также предложено инновационное автоматизированное решение сортировки сырья и материалов для производства гранулята.

Ключевые слова: *автоматизация; повторная переработка сырья; демонтаж; экономия затрат на производство.*

Introduction. Currently a promoted sustainable development strategy, aimed at slowing down the depletion of natural resources, energy and irreversible effects on the natural environment of the Earth, assumes two models of human civilization deve-

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lopment. The first one is a closed system of production and consumption of goods, exchanging only energy with the environment. In this system, all consumer goods are made of materials that at the end of their life cycle can be recycled. The other one is a system in which all structural materials are renewable and biodegradable (Kijenski, Bledzik and Jeziorska, 2011). Both models seem to be unrealistic, however, they still contain elements that should be considered when creating a development strategy. The most important aspects here are:

- the need for increasing the share of renewable sources in acquiring raw materials and energy, not only to save the existing non-renewable resources and reducing environmental damage, but also to improve currently unfavorable energy balance;
- re-using materials and energy;
- saving raw materials and energy in particular through production of higher durability goods.

Recovery of raw materials, in addition to the benefits from the ecological point of view allows also obtaining financial benefits. Enterprises that invest in recycling methods and improve the ecological conditions of processes by their automation – improve their overall economic situation. Processes of recovering raw materials allow reducing the global manufacturing costs. This happens, among others: by reducing financial expenditures for purchasing of new materials (while re-using raw materials) and by using the energy generated in energy recycling processes (Roder, 1996). Implementation of the latest recycling technology allows also increasing the efficiency of conducting technological process, reducing workload, increasing the amount of raw materials obtained by recycling, which are often separated materials suitable for reuse.

For economic reasons and due to environment care one seeks reaching the highest level of plastics recovery (Wojcik, 2011). It can be obtained in several ways (Figure 1) of which the most common are:

- material recycling;
- energy recovery.

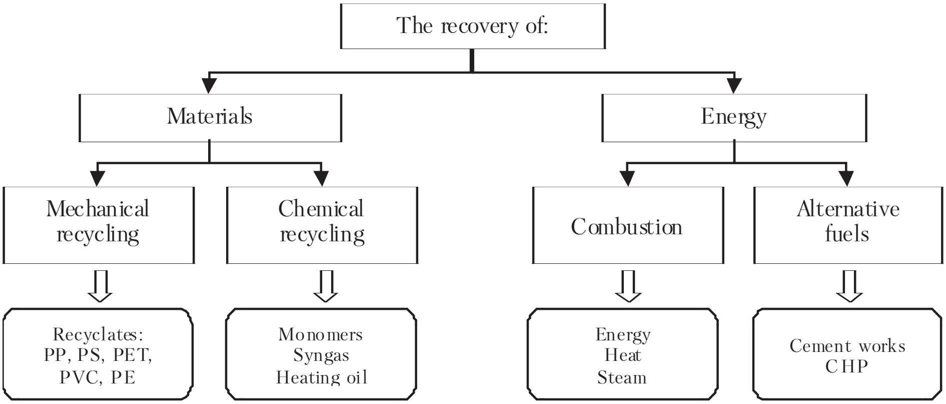

Figure 1. **Diagram of plastics recovery technologies,** *authors' development*

Mechanical recycling. As a result of the material recycling processes, small size, finely divided particles are formed. Depending on the needs, they are further cleaned and separated into different fractions. Such fragmented and sorted recycled plastic is called regrind. The example of such a process is presented in Figure 2.

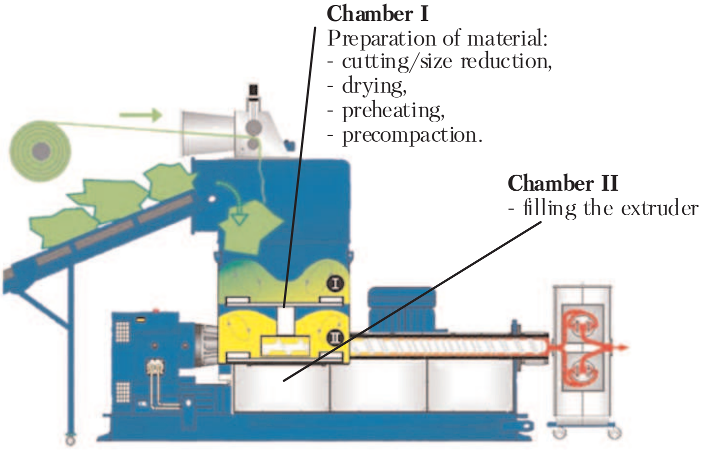

Figure 2. **Sample process of recycling plastics** (pphuanna.pl/technologia)

It is required for mechanical recycling method, that plastics entering the process are pure and homogeneous (Vilaplana and Karlsson, 2008). An example of this process is the recycling of used bottles, industrial films and window frames. The condition for the profitability of this type of processing is proper selection of wastes so that the overall expenditure on the recovery is lower than the cost of purchase or manufacture of plastics. Sorting and identification of waste is the most important step in the process of utilization. The amount of materials suitable for recycling and ready to be stored depends on this operation (Al-Salem, Lettieri and Baeyens, 2009). The general process of sorting is presented in Figure 3.

An important problem in sorting is removing all ferrous and non-ferrous metals from the wastes stream, which takes place at the very first stage of this process. To achieve it, magnetic separators are used that use the magnetic properties of materials. These devices are used to separate particles of size less than 5 mm, but depending on the installation site, it is also possible to separate smaller particles. Non-ferrous metal separators are designed to separate such metals as aluminum, copper, lead and zinc from the wastes stream. Separation of these metals is carried using eddy currents generated in the metal by the magnetic field rotating at high speed. Eddy currents induced in non-ferrous metal magnetic field are oriented opposite to the main field, which results in repulsion and ejection of metal beyond the sorted waste stream. Further sorting of waste, after the process of their initial separation, may be carried by recognition devices, which separate different color and size of wastes and direct it to suitable containers. The basic advantages of automatic sorting may include:

- higher efficiency of sorting;
- recovery of more material fractions;
- pureness of recycled material fractions;
- lower cost of exploitations;
- workplace safety by eliminating direct contact of employees with processed waste.

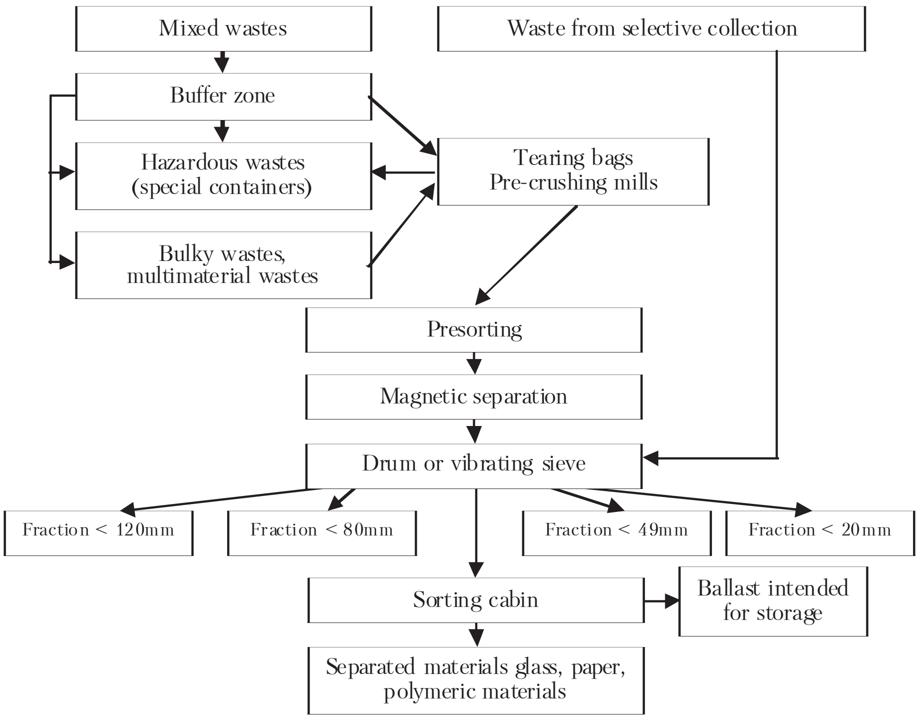

Figure 3. **Diagram of wastes sorting** (Kijenski et al., 2011)

In the process of manual sorting quality and quantity of materials recovered depends on the work efficiency of sorting employees. The performance of automatic sorting process depends on the speed of transporting systems, pre-treatment of wastes, waste placement on the tape, speed of recognition and removal of wastes (Bledzki, 1997).

Diagram of operation of an automatic sorting system is presented in Figure 4.

Sort downwards Diagram of operation of the system

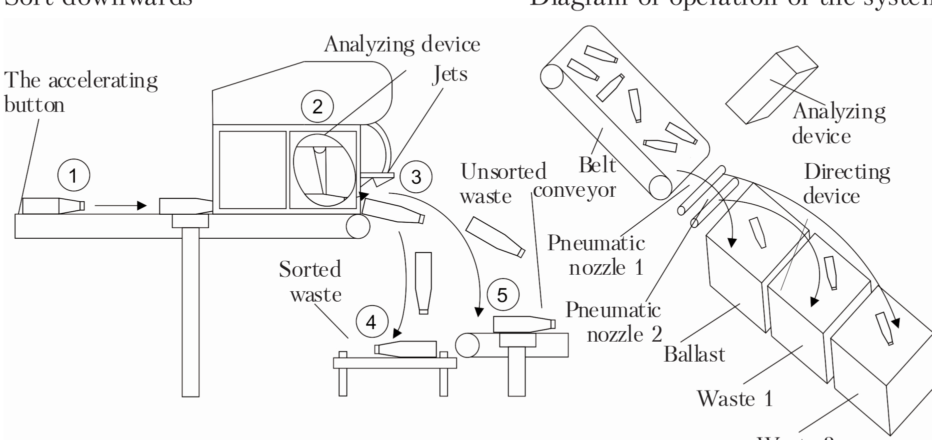

Figure 4. **Automatic sorting process** (Kijenski et al., 2011)

Automated sorting processes most often involve (Brandrup et al., 1996):
a) preparation of wastes;
b) dividing into fractions;
c) separation on ferrous and non-ferrous metals;
d) pneumatic separation by suctioning of light fractions;
e) ballistic separating;
f) sorting in the infrared light by type of wastes.

Identification is an important step in the process of wastes sorting (Scheirs and Kaminsky, 2006). Most of the methods described in literature are not applicable due to high costs of their implementation. This results in the need for looking for separation methods, the use of which will be profitable for specific types of wastes.

Recycling process in an industrial company. At industrial enterprises a number of waste types appear during conducted processes. One of them are the waste generated by defects detected in manufactured products or the need for products utilization. The global increase in production of plastic products enforces the need to take specific actions to maximize the reuse of production wastes in the process of creating new products (Rusik-Dulewka, 2009).

As a part of the research on detecting the possibilities recycling within the fuel system fuel tanks are to be examined. The main problem hindering for the use of automated recycling processes is the overall dimensions of these elements, especially of fuel tanks as well as their complicated structure. Generally, it can be assumed that due to its size, this type of elements should be shredded. Some machines used in shredding process are:

- mills for waste;
- crushing and agglomerating devices.

The form of wastes, different types of materials, their physical parameters such as stiffness, brittleness, flexibility and further destination has significant impact on selecting the type of shredding (Gorrasi et al., 2002). During the production of fuel systems mainly high-density polyethylene (PE-HD) is used (Sikora, 2002). To manufacture the fuel tank body the multilayer technology is used which improves the properties of a final product.

Components connected to the base element are often manufactured using a uniform polyethylene and in most cases include metallic elements. Therefore, fuel system manufacturing bases on extrusion and machining processes, including welding.

The use of regrind to produce tanks forces companies use their own production lines for this raw material. Production technology for regrind is original because of technical and technological solutions which increase the quality of granules. Regranulate can be treated as valuable products suitable for processing by conventional processing techniques (injection and extrusion). Recyclate is free from mechanical impurities, as well as gas inclusions in the form of gas bubbles. To obtain high quality and valuable product, it is necessary to remove metal wastes and other substances used in these products, as shown in Figure 5.

In order to produce a regrind from waste materials including defective products it is necessary to use a production line presented in Figure 6. The cost of purchasing and running the line in relation to potential benefits is often unacceptable for manufacturing companies, therefore such lines are mostly used by companies specializing only in recycling and production of regrind. For companies manufacturing using plastics, cheaper and more simple solutions are needed, such as manual separation of materials. This approach assures a uniform and pure input material, which after grinding is fully recovered. The remaining waste, often mixture of polyethylene, metals and other materials is then passed to companies holding equipment that allows its separation. Unfortunately, manual separation is time consuming and may be dangerous for employees. It involves using mechanical tools during this process, significant amount of dust can be generated while processing, against which workers must be efficiently protected.

Figure 5. **Recovery of thermoplastics within the fuel system**
(Solvay Company handouts)

The usage of automated production lines to obtain regrind from the defectively manufactured fuel system is an opportunity for a company to reduce the cost of its processes and increase revenues. Despite having to incur large capital expenditures for the purchase or design and construction of such a line, a company achieves significant benefits. Automatic execution of recycling is much more efficient than the same process performed manually. Automated process allows obtaining much more regrind. As a result, a company can purchase less raw materials, thus reducing running costs of new product production. Price for a new product can also be lowered which may lead to increasing the demand for goods at markets. Company may also acquire new customers by the fact of using recyclates as ecological awareness is becoming one of the factors behind the choice of a product by customers. Enterprises that use recycled materials are seen as more advanced in their development.

The robotic system of PE-HD wastes separation. The presented above analysis of the problem shows that the improvement in profitability of thermoplastics recycling may lead to increase of manufacturing companies economic condition and competitiveness, but it can be mainly obtained by simple and low-cost solutions that allow companies self-recover their raw materials. So far, this process was carried out manually, which not always reduce the costs of further manufacturing significantly. This type of solution can be used for small quantities of raw materials or when the cost of storage and transport to companies specializing in recycling are large. In case of polyethylene, in particular while producing PE with regrind addition it is recommended to use automated systems which allow direct recovery of part of materials, that after grinding can be used again in production. Such a cycle is presented in Figure 7.

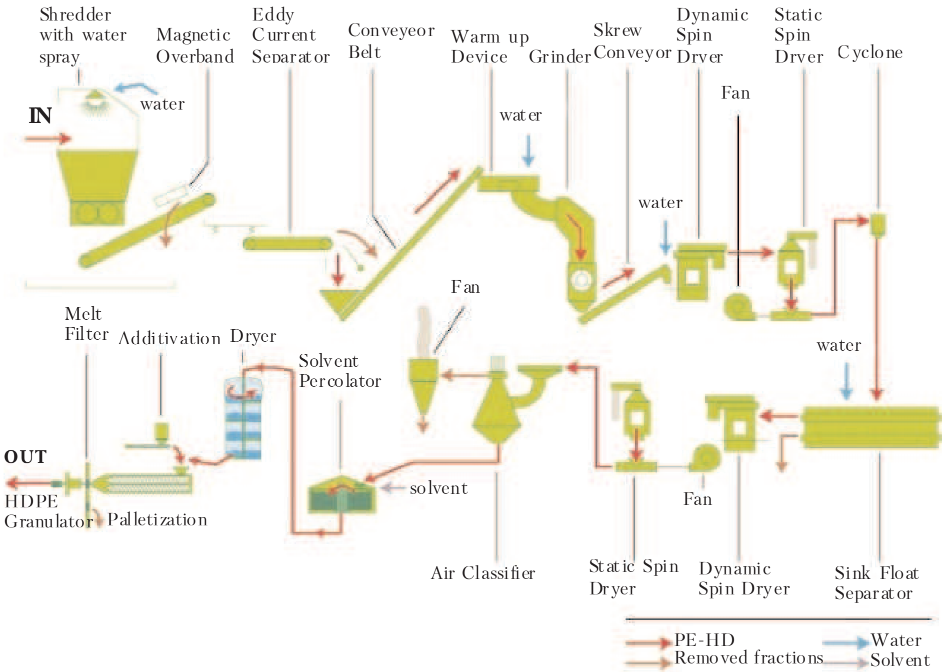

Figure 6. **Diagram of fuel tanks recycling process** (Solvay Company handouts)

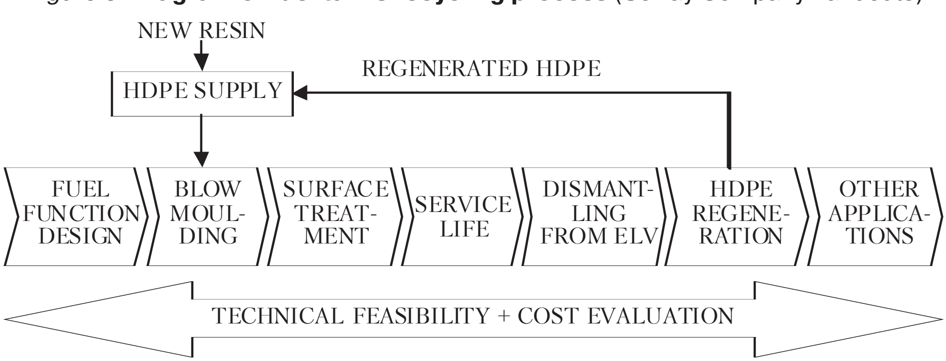

Figure 7. **Diagram of product life cycle in company**
(Solvay Company handouts) *and authors' development*

Based on the analysis of effectiveness and cost one should point that using industrial robots in production systems is the best solution at present (Rabek and Marciniak, 2009). Figure 8 shows an example of the application of industrial robots for separation of non-plastic elements (metallic or other materials) from polyethylene body. Two robots in the presented solution are required due to relatively large fuel tanks. Recycling other, smaller waste products or separation of waste where high performance is not required can be conducted by a single robot. A robot can also be placed on the guiding rail, which significantly increases the range of its operations. Working robots need to be equipped with operating heads. The solution presented in Figure 8 allows processing different types of containers, which makes the workstation functional and flexible. Fuel tanks of any geometry can be placed in robots working and tool reaching space and if necessary rotary table providing rotation of the tank in horizontal or vertical axis can be additionally mounted. The choice of the final solution depends on the complexity of the problem, which occurs in processing. It should be noted that it is also possible to automate the process of dismantling smaller products, as there are technical possibilities for using commercial systems for the presented solution (Honczarenko, 2011).

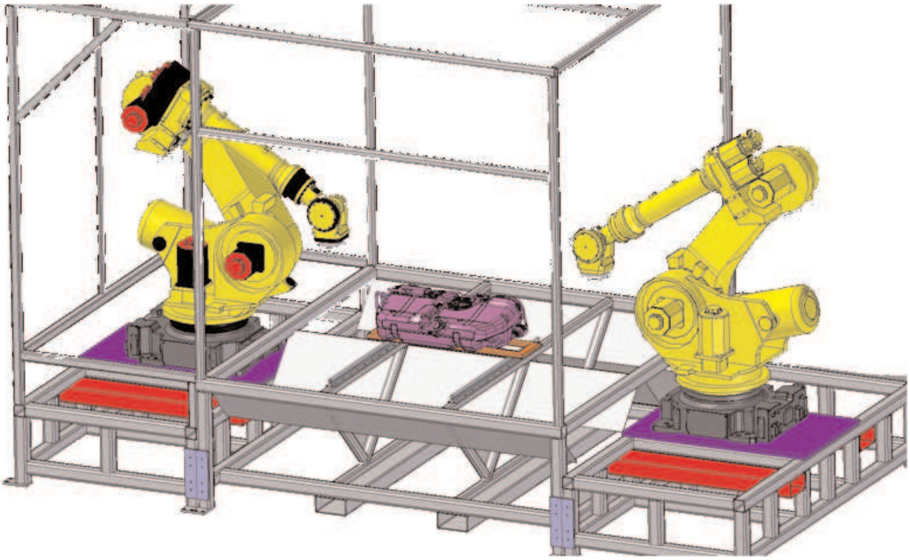

Figure 8. **The sample application of industrial robots to the recycling process,** *authors' development*

Summary. Plastics recovery processes conducted by companies are cost-effective only when the costs of introducing and running a recycling system are smaller than the costs of purchasing new raw materials. The current strategies in the field of resource management show the necessity for obtaining the maximum amount of recycled materials. This means that companies are looking for technology, which will not affect the price of the product increasing it, but allow its reduction. One of such solutions is proposed in the study use of simplified system for recovering raw materials for own processing needs as well as manufacturing recyclates. New innovative approach gives the opportunity to develop the company by reducing manufacturing costs and reducing the involvement of human in environmentally dangerous operations. Using flexible manufacturing systems in sourcing raw materials seems to be the right direction. Automated recycling presented in this study significantly differ from

the solutions analysed in literature regarding processes automation (Szalatkiewicz, 2011). They relate to separation of materials connected inseparably, for which traditional disassembly methods cannot be applied. One must note that use of the new solution allows significant reduction of process time. For the presented fuel tanks it will be possible to complete it in approximately 60 seconds (time depends on the complexity of processes to be conducted). Currently it is 3 times longer. The combination of new production technologies and ecology in the presented solution allows enterprises involved in processing plastics achieve additional benefits.

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