Maciej GLINIAK[1], Maciej OZIEMBŁOWSKI[2], Magdalena DRÓŻDŻ[2], Tomasz DRÓŻDŻ[1], Piotr NAWARA[1], Paweł KIEŁBASA[1], Marek OSTAFIN[3]

University of Agriculture in Krakow, Faculty of Production and Power Engineering (1),
Wrocław University of Environmental and Life Sciences, Faculty of Biotechnology and Food Science (2),
University of Agriculture in Krakow, Faculty of Agriculture and Economics (3)

doi:10.15199/48.2018.06.26

The possibilities of automation of the manual line for dismantling waste electrical and electronic equipment

Abstract. *The authors introduced automatic processing line for electrical and electronical equipment wastes as an alternative for semi-automatic WEEE lines. The efficiency of semi-automatic line was characterized for small WEEE with LCA and AHP algorithms. The problem nodes showed by algorithms was optimized and replaced by automatic devices. Optimized automatic WEEE processing line generated `groups of sources with min. 98 wt% purity. Comparison of the results obtained for the semi-automatic line to the automated line, 83-times increase in productivity was observed.*

Streszczenie. *W artykule przedstawiono automatyczną linię do przetwarzania odpadów elektrycznych i elektronicznych (WEEE) jako alternatywę dla linii półautomatycznych. Wydajność linii półautomatycznej charakteryzowała się małą wydajnością przetwarzania WEEE. Do oceny możliwości poprawy jej wydajności wykorzystano algorytmy LCA i AHP. Węzły problemów wskazane przez algorytmy zostały zoptymalizowane i zastąpione przez urządzenia automatyczne. Zoptymalizowana automatyczna linia do przetwarzania WEEE generuje materiały o minimalnej czystości 98% wag. Porównanie wyników uzyskanych dla linii półautomatycznej i linii zautomatyzowanej wykazało 83-krotny wzrost wydajności. (**Możliwości automatyzacji ręcznej linii do demontażu zużytego sprzętu elektronicznego**).*

Keywords: electronic waste, electric waste, e-scrap, processing line
Słowa kluczowe: odpady elektryczne, odpady elektroniczne, e-odpady, linia technologiczna

Introduction

Recycling of electrical and electronic equipment waste (WEEE) is a challenge for companies dealing with waste disposal. The issue of recycling of these wastes (Fig.1) results from their high complexity of the material − on average 50 wt% iron and steel, 25 wt% plastic, 10 wt% non-ferrous metals and 15 wt% of impurities (e.g. glass, rubber, cast iron, concrete, ceramics). The presence of toxic substances such as lead, mercury, cadmium, zinc and precious metals (gold, platinum) among non-ferrous metals, classify WEEE as hazardous waste. The elements present in the electronic equipment, which are the most toxic waste are Printed Circuit Board (PCB) [1-3].

Fig. 1. Typical electrical and electronic equipment waste (source: http://redwave.com, date of access: 15.01.2017).

The current problems concerning the disposal of WEEE is centered around the recycling opportunities of PCBs. This is related to the common presence of PCBs in electrical devices causing their increased frequency failure, and increased repair costs. The above mentioned problem combined with a decrease in prices of new components cause a decrease in the profitability of repairing broken machines and use of their components for the repair of damaged equipment (in the case when repaired element is not available on the market) [4].

In the recent years the amount of WEEE increases annually. Due to the enormous material complexity e-waste disposal is carried out in two processes − the physico-mechanical and chemical) [1,5]. The physicochemical processes are based on the use of manpower combined with the use of electromagnetic phenomena and processes of gravity (air separation, flotation). The usage of this type of solution allows to separate from the waste stream its particular components broken divided into plastics, metals, non-metals and impurities that are transmitted for subsequent disposal [6-8]. Much more effective technologies in the WEEE disposal are the chemical processes. The main methods of chemical processing of e-waste include pyrolysis, the thermal distribution in the plasma stream, hydrometallurgical techniques. The use of complex processes is to recover the valuable components from WEEE (e.g. gold, palladium, platinum, copper) that can be re-used for the production of electrical and electronic equipment [9-12].

The article presents the basic principles of the semi-automatic, physico-mechanical line for WEEE processing and the possibilities of its automation. Launching the advanced solutions on the market in terms of waste disposal is a key factor of any waste disposal management system in the world, increasing its efficiency and purity of obtained raw materials.

Material and methods

For the analysis was used classical, semi-automatic line for the recycling of waste electrical and electronic equipment. Line diagram is shown in Fig. 2. The analyzed line is operated by 10 employees and is a common example of the WEEE disposal in Poland. Electrical and electronic equipment, which is subject to recovery includes small electrical home appliances − kettles, irons, vacuum cleaners, hair dryers, radio receivers etc. Due to the irregularity of the supplies of the above mentioned broken equipment to the Factory, the installation processes also elements of large household appliances (components of refrigerators, washing machines, microwaves), electrical wiring and other electrical devices that do not include sophisticated equipment for disassembly.

In the first stage of analysis the efficient operation of the line shown in Fig. 2 was determined, which is expressed through its hourly productivity and the level of purity of obtained raw materials (plastic materials divided into polypropylene, polyethylene, acrylonitrile-butadiene-styrene copolymer, and ferrous and non-ferrous metals) expressed in % of the mass of waste input. In the second stage of the study there was performed the review and the analysis of the available technical solution that allow for more efficient processing of WEEE, using the method of AHP. The criteria taken into account in the analysis were related to the availability of devices on the market, the cost of their maintenance and service, efficiency and purity of the obtained products. In the last stage of the analysis there was conducted comparison of semi-automatic and fully automated line productivity, and the purity of the obtained products of WEEE disposal (at the example of mixture of kettles, dryers and vacuum cleaners) using algorithms of product life cycle (LCA) in SimaPro 8 program (Fig. 3, 4).

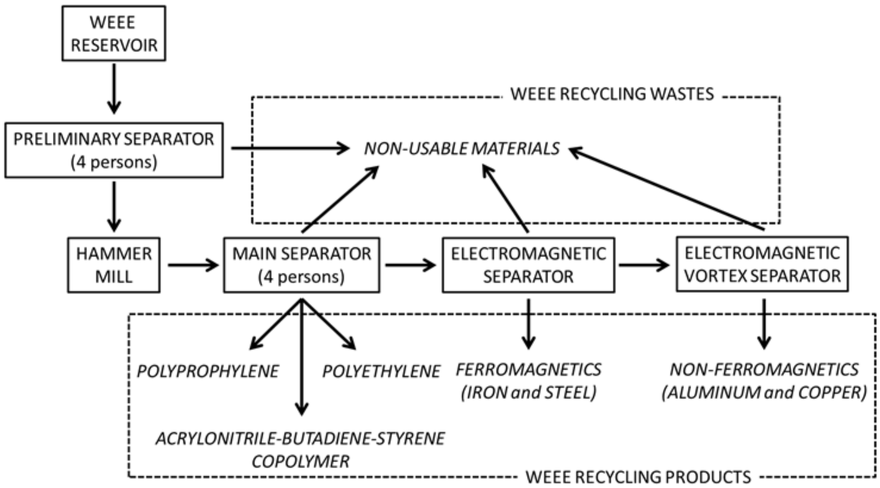

Fig. 2. Scheme of a semi-automatic line for the WEEE recycling (own elaboration).

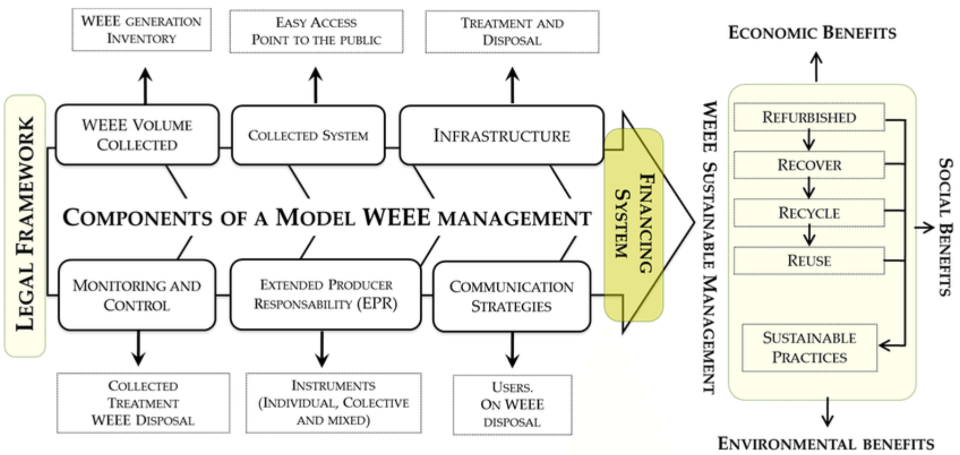

Fig. 3. Components of a sustainable management model of electrical and electronic waste [13]

After LCA and AHP analysis, the Return on Investment (ROI) indicator has been defined. ROI measures the gain or loss generated on an investment relative to the amount of money invested. ROI is usually expressed as a percentage and is typically used for personal financial decisions, to compare a company's profitability or to compare the efficiency of different investments.

Results

Performance analysis of semi-automatic line for the recycling of WEEE has demonstrated its capacity for disposal of 12 kg/h (Fig. 2). The purity of obtained raw material was 99 wt% for ferrous and 83 wt% for non-ferrous metals. Separation of plastic materials was only possible for two groups of plastic − acrylonitrile-butadiene-styrene, and the sum of polypropylene and polyethylene. The purity of generated groups amounted to 54 wt% and 61 wt%.

The problem with the distribution of plastic materials resulted mainly from their manual dismantling, during which employees are guided only by factory markings on the particular elements of devices. The diversity of the separation of plastics is also influenced by the introduction of process elements diverted from large appliances that do not contain information on the composition of raw materials and are misclassified by employees. Low efficiency of the separation of non-ferrous metals results from the impossibility of their barking in the process of dismantling. Accordingly, during eddy current separation of metals wire covers which are made of plastic materials, get to the product, reducing the purity and quality of the obtained material.

The performed preliminary analysis imply, that the weakest element of the line operation is firstly division of plastic materials, and then separation of non-ferrous metals. The AHP analysis is focused on the selection of appropriate milling equipment used to prepare the raw materials, and separators of plastic materials. The analysis of the availability of equipment for the separation of non-ferrous metals failed to demonstrate reasonable changes in the process (Fig. 5).

On the basis of the machines and devices review Fig. 5 shows a diagram of an automated line for WEEE recycling.

For the line automation shown in Fig. 5 was used an embankment mill with an automatic drawer press, which was used for waste pre-shredding to particles with a diameter of 10 mm. The particulate material is directed to a multi-stage triboelectric electrostatic separator in which the separation of plastic materials fraction (divided into polyethylene, polypropylene, acrylonitrile-butadiene-styrene copolymer), rubber and glass occurs. The residue after separation is directed to the separation of ferrous metals, and then to the electromagnetic mill in which the fragmentation of electric wires takes place, comprising non-ferrous metals, up to 0.1 mm. The mixture leaving the mill gets into electromagnetic separator, to recover the grinding bodies, coupled with the eddy currant separator.
After completion of the separation process, dust forming ballast remains, which does not present a commercial value.

In order to compare the efficiency there was performed a simplified life cycle analysis of the product using the SimaPro 8 program for electric kettles, dryers and vacuum cleaners. Simplification of the analysis consisted in performing calculations related to the process of device recycling in installations shown in Fig. 2 and 5. The LCA analysis of semi-automatic line for the WEEE recycling confirmed its operating parameters presented in this article. Modifying the line with additional equipment and implementation of control system based on multipoint weight automation of each element of the process made it possible to achieve significantly better performance of WEEE recycling. In comparison to the baseline, the automatic line is able to process 1Mg/h of waste while maintaining the same number of employees. The increase in productivity is caused by the replacement of manual disassembly and separation by people. Comparing the purity of the obtaining products of plastic materials separation, the line has a possibility of automatic release of 5 streams of products with a purity of min. 98 wt%, while at the same time reducing the process waste to 1 wt% introduced WEEE. A similar situation exists in the case of separation of non-ferrous metals, which in fragmentation of 0.1 mm have a high commercial value due to granulation facilitating further fractionation process.

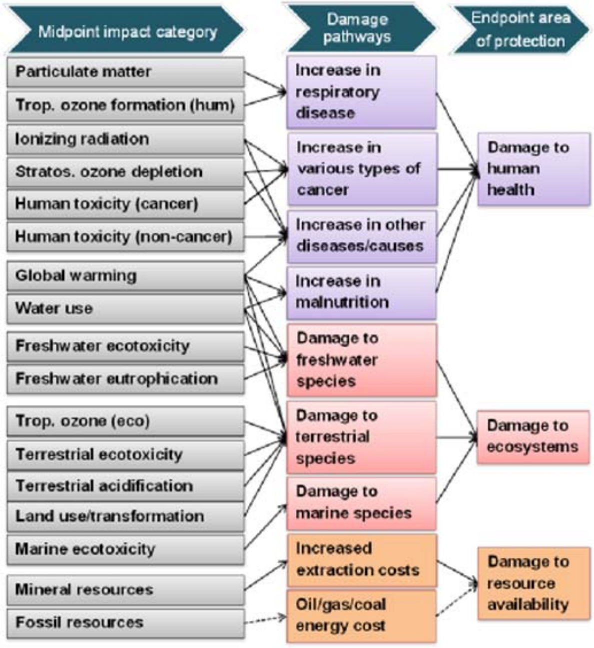

Fig. 4. Overview of structure ReCiPe (source: RIVM, date of access: 15.01.2017)

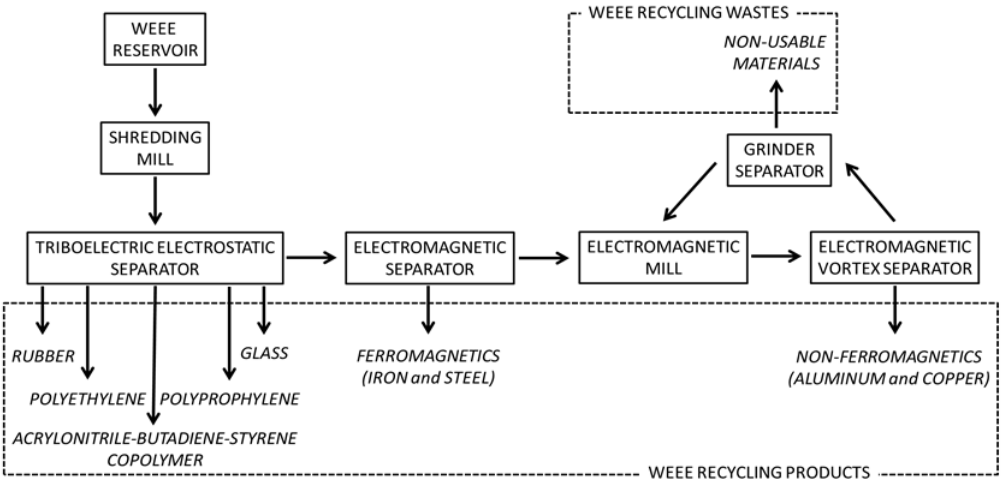

Fig. 5. Scheme of automatic line for WEEE recycling (own elaboration).

Considering the cost effectiveness of semi-automatic line modernization in LCA and ROI algorithm there was achieved return on investment after 3-5 years, depending on market prices of obtained raw materials, what is confirmed also in works of Hurka and Malinowski [14], Grzesik-Wojtysiak and Kuklinski [15] and Debnatha et al. [16]. This time can be shortened if we consider the entire stream of WEEE reaching the installation because the life cycle analysis focuses only on the 3 most popular devices.

Summary

In the last decade, electronic devices have become very common. Every year there are plenty of electrical devices sold in the world and at the same time there is recorded an increase in the production of WEEE. The issue presented in the publication concerns an important aspect, which is the recycling of WEEE taking place on simple, semi-automatic disassembly lines. Due to the large diversity of WEEE stream, the article concentrates on the most popular devices − electric kettles, dryers and vacuum cleaners.

Comparing the results obtained for the baseline (with manual dismantling pieces of devices) to the automated line, 83-times increase in productivity was observed. Similar results were obtained when analyzing the purity of the obtaining products of WEEE recycling, which was related to the market prices in Poland. Economic analysis of the issue of line automation for the WEEE recycling shows that it is profitable and cost-effective modernization, which may reimburse investment costs even in the third year of its operation.

***Authors**: dr inż. Maciej Gliniak, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Mickiewicza Av. 21, 31-120 Krakow, E-mail: maciej.gliniak@urk.edu.pl; dr inż. Maciej Oziembłowski, Wrocław University of Environmental and Life Sciences, Faculty of Biotechnology and Food Science, C. K. Norwida Str. 25, 50-375 Wrocław, E-mail: maciej.oziemblow@upwr.edu.pl; mgr Magdalena Dróżdż, Wrocław University of Environmental and Life Sciences, Faculty of Biotechnology and Food Science, C. K. Norwida Str. 25, 50-375 Wrocław, E-mail: magdalena.drozdz@upwr.edu.pl; dr inż. Tomasz Dróżdż, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Mickiewicza Av. 21, 31-120 Krakow, E-mail: Tomasz.Drozdz@office.urk.edu.pl; dr inż. Piotr Nawara, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Mickiewicza Av. 21, 31-120 Krakow, E-mail: piotr.nawara@urk.edu.pl; dr hab. inż. Paweł Kiełbasa, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Mickiewicza Av. 21, 31-120 Krakow, E-mail: pawel.kielbasa@urk.edu.pl; dr inż. Marek Ostafin, University of Agriculture in Krakow, Faculty of Agriculture and Economics, Mickiewicza Av. 21, 31-120 Krakow, E-mail: marek.ostafin@urk.edu.pl*

REFERENCES

[1] Cui J., Forssberg E., Mechanical recycling of waste electric and electronic equipment: a review, *Journal of hazardous materials*, 99 (2003), no. 3, 243-263.

[2] Pant D., Joshi D., Upreti M.K., Kotnala R.K., Chemical and biological extraction of metals present in E waste: a hybrid technology, *Waste Management*, 32 (2012), no. 5, 979-990.

[3] Rajarao R., Sahajwalla V., Cayumil R., Park M., Khanna R., Novel approach for processing hazardous electronic waste, *Procedia Environmental Sciences*, 21 (2014), 33-41.

[4] Bîrloagă I.P., Buzatu T., Matei E., Physical methods for processing electronic and electrical equipment waste (WEEE) for nonferrous metals recovery, *U. P. B. Science Bulletin, Series B,* 73 (2011), no. 4, 227-239.

[5] Grause G., Ishibashi J., Kameda T., Bhaskar T., Yoshioka T., Kinetic studies of the decomposition of flame retardant containing high-impact polystyrene, *Polymer Degradation and Stability*, 95 (2010), no. 6, 1129-1137.

[6] Zhang S., Forssberg E., Mechanical separation-oriented characterization of electronic scrap, *Resources, Conservation and Recycling,* 21 (1997), no. 4, 247-269.

[7] Zhang S., Forssberg E., Arvidson B., Moss W. Aluminum recovery from electronic scrap byhigh-force eddy-current separators. *Resources, Conservation and Recycling,* 23 (1998), no. 4, 225-241.

[8] Hall W.J., Williams P.T., Separation and recovery of materials from scrap printed circuit boards, *Resources, Conservation and Recycling,* 51 (2007), no. 3, 691-709.

[9] Kumar M., Lee J.C., Kim M.S., Jeong J., Yoo K., Leaching of metals from waste printed circuit boards (WPCBs) using sulfuric and nitric acids, *Environmental Engineering and Management Journal*, 13 (2014), no. 10, 2601-2607.

[10] Tuncuk A., Stazi V., Akcil A., Yazici E. Y., Deveci H., Aqueous metal recovery techniques from e-scrap: hydrometallurgy in recycling, *Minerals Engineering*, 25 (2012), no. 1, 28-37.

[11] Bidini G., Fantozzi F., Bartocci P., D'Alessandro B., D'Amico M., Laranci P., Zagaroli M., Recovery of precious metals from scrap printed circuit boards through pyrolysis, *Journal of Analytical and Applied Pyrolysis*, 111 (2015), 140-147.

[12] Bryan C.G., Watkin E.L., McCredden T.J., Wong Z.R., Harrison S.T.L., Kaksonen A.H., The use of pyrite as a source of lixiviant in the bioleaching of electronic waste, *Hydrometallurgy*, 152 (2015), 33-43.

[13] Cruz-Sotelo S.E., Ojeda-Benitez S., Sesma J.J., Velazquez-Victorica K.I., Santillan-Soto N., Garcia-Cueto O.R., Conception V.A., Alcantara C., E-Waste Supply Chain in Mexico: Challenges and Opportunities for Sustainable Management, *Sustainability*, 9 (2017), no. 4, 1-17.

[14] Hurka M., Malinowski M., Assessment of the use of EWA bioreactor in the process of bio-drying of undersize fraction manufactured from mixed municipal solid waste, *Infrastructure and ecology of rural areas,* 4 (2014), no. 1, 1127-1136.

[15] Grzesik-Wojtysiak K., Kukliński G., Screening Life Cycle Assessment of a laptop used in Poland. *Environment Protection Engineering,* 39 (2013), no. 3, 43-55.

[16] Debnatha B., Roychowdhury P., Kundu R., Electronic Components (EC) Reuse and Recycling – A New Approach towards WEEE Management, *Procedia Environmental Sciences,* 35 (2016), 656-668.