# WEEE Sorting Processes and Separation of Copper Wires with Support of Dem Modeling

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*Abstract*

*Recycling of wires and cables waste is very important part of copper recovery process. Small size of crushed wires leads to the technical and environmental difficulties to ensure an efficient way to successful recovery process. In this article experiment with copper separation by gravity separator was solved. Due to importance of WEEE (Waste Electrical and Electronic Equipment) global waste streams was this experiment done. Also DEM simulation support for the equipment design is demonstrated in this paper.*

*Keywords: WEEE; recycling; gravity separator, DEM*

**Introduction**

The consumption of electronic products has increased enormously in the last decades and this fact caused generating of huge quantities of Waste Electrical and Electronic Equipment (WEEE) at the end of its life. The worldwide production of WEEE is estimated to about 20–50 Mt per year, making up 1–3% (8% in rich countries) of municipal waste [1]. EU countries produced about 9.6 Mt of WEEE in 2011. The resulting WEEE deposit is expected to grow from around 8.5 Mt in 2005 to 10.5 Mt in 2014. Effective management and treatment of WEEE has become a global problem. WEEE is very variable and it consist of different materials and components [2].

Many devices contain a variety of materials that are easily recycled like metals, glass and plastics but there are also some hazardous substances, which cause major environmental and health problems. Generally, WEEE is composed of metal (40%), plastic (30%) and refractory oxides (30%). The amount of metal contains 20% copper and 1% zinc. Copper, zinc and brass are widely used in the production of electrical wire and cable, electrical contact, and various other parts [4]. Cable and wire materials were often lost in the sorting processes, which meant a financial loss due to the high proportion of copper they contain. Recovery and recycling of this kind of electrical waste is very important. Copper wires and free copper particles are valuable components which are contained in lots of waste fractions such as heavy fractions from automobile shredders (SSF), light fractions from automobile shredders (SLF), waste electrical and electronic equipment (WEEE) and residual materials and metals from dense medium separation systems (DMS). Cable processors and secondary copper smelters demand high purity mono-fractions of copper concentrate and cables. Several methods have been investigated and applied for metal recovery from WEEE, based on mechanical/physical, pyro-metallurgical and hydrometallurgical processes. Mechanical/physical processes are based on the different physical characteristics of the materials which can be found in the waste composition.

**Sensor-based separation of WEEE**

In next chapters are presented a different possibilities can be used for copper separation out of from mixed cable waste. There are a several ways based on various methods, e.g. shape and density of particles, particle size distribution, or sensor-based separators. The sensor based separators use air jets to eject a certain type of material from the mixture stream. Feed section distributes the WEEE in a single layer on a belt of belt feeder. The material is then transported so it moves under or in front of the light source. NIR technologies detect a characteristic infrared spectrum which is unique for each type of material. The laser systems work in a similar way because different object reflect different signals from the laser. Reflected light or laser signal go into a sensor which helps to computer and software find concrete parts to separation. If the system detects particle/object which is need to

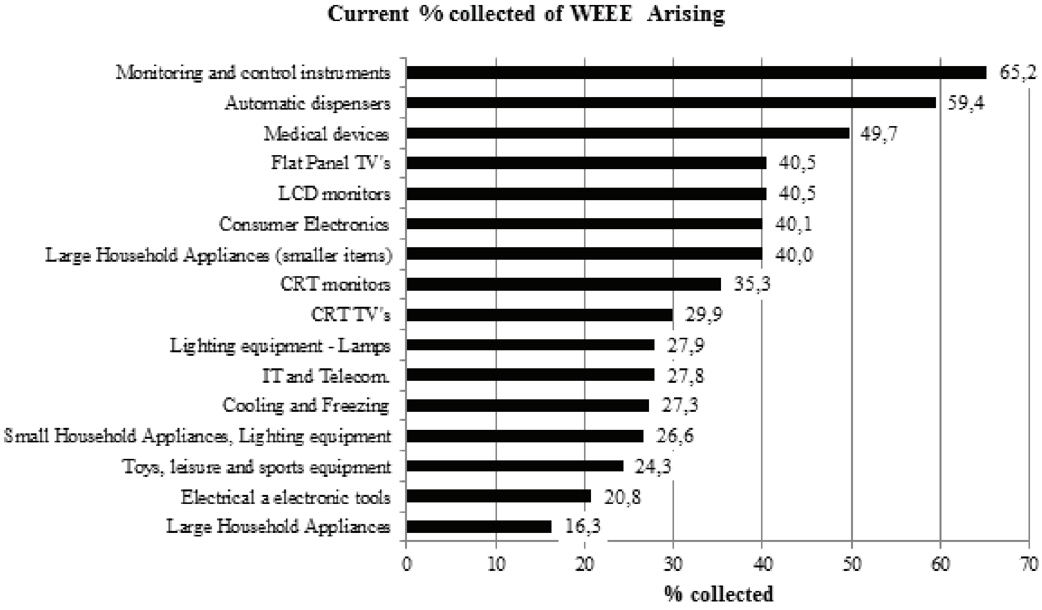


Fig. 1 Current amount of WEEE collected & treated as percentage of WEEE Arising, [3]

Rys. 1 Obecna ilość WEEE, jaka została zebrana i przetworzona WEEE [3]

move out of the mixture, the computer activates the air jets and the chosen object is blown out from the main stream at the end of belt conveyor. The material which is not ejected falls into the reject fraction. Figure 2 shows the principle of sensor-based sorting systems.

Sensor based sorting is well working in many applications; for plastic packaging, in food processing and also in metal separation. The main challenge for sensor based sorting in WEEE separation is that the particles which need to be separated are much smaller than those found in plastic packaging recycling applications, typically 8-12mm. The splitter plate design is very important for correct functionality of sorting systems. Particles must not bounce off into the wrong fraction. These kind of systems are very efficient in use for the waste which is formed by a larger pieces of WEEE, for example from the large domestic appliances but they are not suitable for small pieces of copper from wire waste. The limiting particles size is about 6 mm [5]. Some systems cannot distinguish a different types of plastics what can be also important for some applications. The sensor-based separators are also quite expensive and structurally and electronically complicated. The magnetic separators have very similar construction with belt conveyor but air jets are replaced by magnets. Magnetic separation is a process in which magnetically susceptible material is extracted from a mixture using a magnetic force. The magnets throw metallic parts out of the belt or make them sticked on the belt before its wiped off to the correct section.

**Density separation techniques**

Many of the separations methods are based on shape or densities of particles use a wet techniques. Wet methods use a different sinking speed. The parts with higher density will go down through the liquid faster than lighter ones. Particles with lower density than the liquid will float on the surface of the liquid. Wet jigs can be used to separate a wide range of particle sizes from 1 mm up to 150 mm. The size of the particles which can be separated by a wet jig depends on both absolute densities of the particles in the mixture and the densities of the different material types in the mixture relative to each other. Figure 3 shows two types of the density based separators.

In the first type of a wet methods the material to be separated is suspended in a water and flows across a perforated bed. The pulsed water flow helps the particles to settle past each other and stratify into layers of similar density. The lighter material flows off the end of the bed, via an overflow, and the heavier fractions are captured by splitter plates to produce either a heavy and a middling fraction or just a heavy fraction, depending on the application [5]. Figure 3 shows the main vessel of the kinetic gravity separator. Material is fed from the feed hopper into the kinetic gravity separator itself by a vibratory feeder. This equipment exploits differences in the terminal falling velocities of particles in water to achieve a separation. It is capable of separating the feed material into more than two fractions and has been used by Delft University to separate light and heavy non-ferrous alloys in the size range 2–10 mm along with various types of plastics. Material which floats in the separator is collected separately [7].

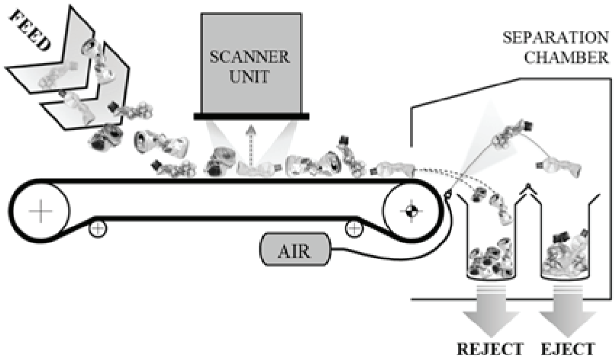


Fig. 2 Schematic of the sensor-based sorting system

Rys. 2 Schemat systemu sortowania bazującego na sensorach

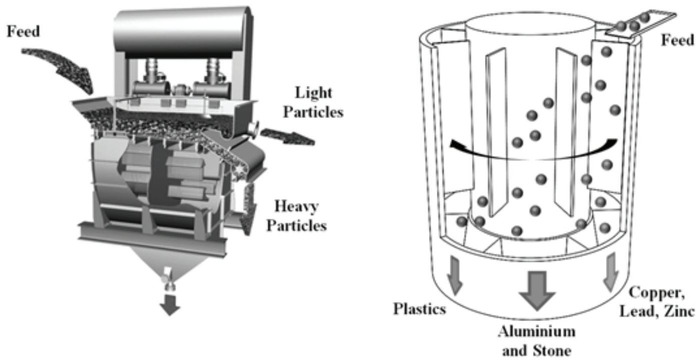


Fig. 3 Water-operated jigging machine alljig® (left) [6], Kinetic Gravity Separator (right) [7]

Rys. 3 Osadzarka wodna alljig® (po lewej) [6], kinetyczny separator grawitacyjny (po prawej) [7]

Also a number of dry methods are developed and used in practice. These techniques operate on a similar principle like a wet ones when the lighter particles are raised or blown out by an air stream. There are many variants a design possibilities. Some types of air separators work with cyclone and systems of pipes, or the other ones are based on vibrating conveyors and work with a gravity. The gravity separators are more closely described in this work.

**Experiment and Methods**

In any WEEE separation process is necessary the removal of unwanted metallic contamination from the mixed plastic waste. This metal needs to be removed in order to protect polymers size reduction equipment from potential damage and also to ensure that the end plastic product is 'metal-free'. The second reason why to do a metal separation is recycling of precious metal, e.g. copper from the cable waste.

There is a wide range of equipment available for metal removal, some of which are listed below [8]:

- Permanent or over-band magnets – for large ferrous removal
- Magnetic head rollers – ferrous and some stainless removal
- Eddy-Current Separators – for removal of non-ferrous metals
- Inductive Metal removal methods – all metal types
- Gravity Separators – for fine particles (used for copper wires separation experiment)

Gravity separators are useful for the removal of fine metal particles from a stream of plastic waste. These type of separators is used mainly in agriculture, but in WEEE recycling processes it can be used very effective as well. The gravity separator is designed to separate by a bulk density. Principle of gravity separation is useable on any dry particle stream. Essentially we feeding particles to the upper end of the deck which are fluidised by blowing air. The gravity separator or air shaking-table is thus a flexible method of sorting particulate mixtures which can be adjusted to give both heavies and lights removal from the main product stream. Gravity separators consist of a vibrating mesh table through which a stream of air is blown by an integral fan. The table can be rotated around two horizontal axes for the correct and effective move of material across the table surface. There are five main variables

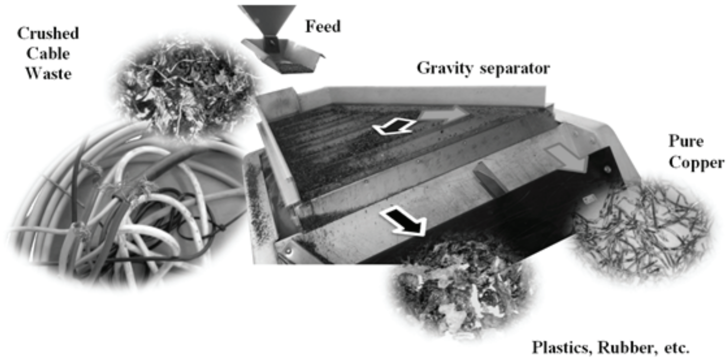


Fig. 4 Scheme of experimental cable waste recycling process

Rys. 4 Schemat eksperymentalnego procesu recyklingu kabli odpadowych

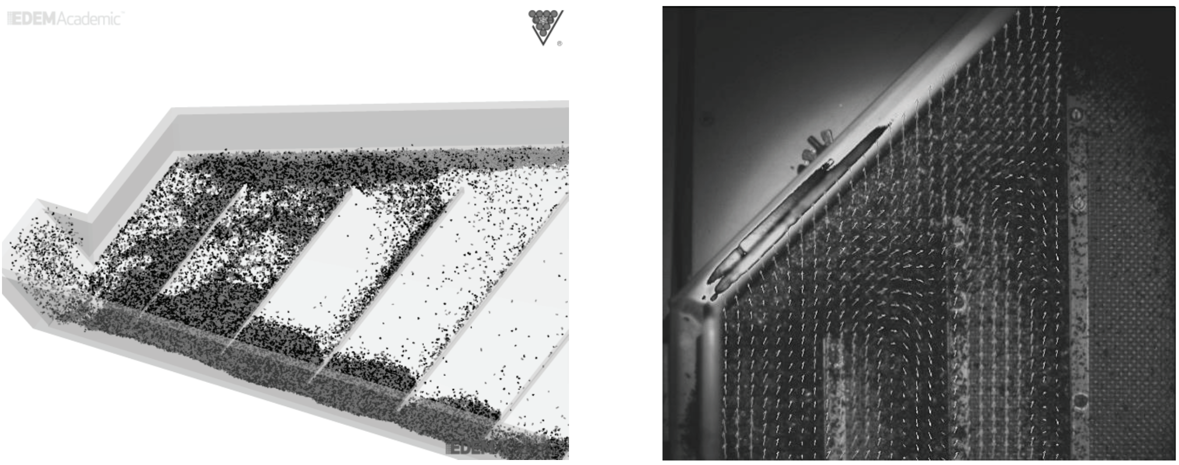

Fig. 5 DEM simulation material flow (left), PIV analysis of validation experiment (right)

Rys. 5 Symulacja DEM przepływu materiałów (po lewej), analiza PIV eksperymentu weryfikującego (po prawej)

which we need to set up. Flow rate of air, eccentric motion and deck tilt affect a quality of separation. On the other hand capacity is affected by a feed rate and end raise. The main advantages of gravity separator include very similar weight and size product separation, dust extraction, product discharge control, easy and quick setup for any kind of material, continuing process and automatization.

Figure 4 shows scheme of experimental cable waste recycling process. At first cables are crushed to size about 3 mm. Mixture of copper wires and plastic (or rubber) isolation is fed to the gravity table by vibrating feeder after crushing. Lighter plastic particles are fluidized by the air and flow down on the table while much heavier copper wires go to the upper edge of table and they are transported apart. Results of experiment show very good usability of gravity separator in field of copper wires recycling. Re-used electric cables make 48% of copper recycling in Europe. Copper is one of the few materials that can be repeatedly recycled without degradation of its properties. There is no difference between the quality of recycled copper (secondary production) and mined copper (primary production). Copper recycling is a very effective way to rejoin valuable materials back into the economy. Copper recycling requires up to 85% less energy than primary production. Throughout the world, thus saving 40 million tons of $CO_2$ per year and the equivalent of 100 million MWh of electricity.

**Results and Discussion**

Sample of 1 kg mass was used in experiment described above. At the end of test 537 g of copper and 463 g of plastic was gained. Further, this experiment was used like a validation test for a simulated sorting process. During the test the process was recorded with high-speed camera LaVision Imager Pro HS. This record was used for the Particle Image Velocimetry (PIV) analysis. Vector fields of material movement can be displayed by this method. Figure 5 shows DEM simulation material flow streams and PIV analysis of validation experiment which are compared for process validation.

A basic understanding  of the granular systems physics is very important for academic interests as well as for industrial applications. Nowadays computational techniques like the Discrete Element Method (DEM) are frequently applied as a tool to bulk matters behavior prediction [9]. This work presents a possibilities of using DEM simulations for engineering equipment design, shape optimization and bulk solid behavior prediction. For example mass flow rates or particles velocities in different locations of device can be determined [10]. In this paper is DEM used for design of the gravity separator which is used for separation of copper wires out of cable waste. Many device configurations can be tested before a prototype is made, e.g. size and shape of the table, frequency, table inclination, mass flow rates, transport capacity, etc.

**Conclusion**

Growing demand for copper will require a combination of raw materials from mines (primary copper), as well as recycled materials (secondary copper). Over the last decade derives about 35% of annual consumption of copper from recycled sources. However, to be effective recycling is also required innovation. Efforts to promote recycling can be implemented in the design of new products, to facilitate recycling of end of life and industrial recycling processes to increase overall yield. In addition, regulatory policy must continue to support the recovery and recycling, both at the industry and individual citizens. Cable waste recycling makes an important part of copper recovery process in the world. The above described experiment with gravity separation showed that more than a half of cable weight consist of copper part. With suitable separation methods we can get this valuable part of the waste and re-use it again. For design and innovative approaches of these methods in engineering, numerical simulation methods (FEM, DEM, etc.) is necessary to use.

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*Procesy sortowania elektroodpadów (WEEE) oraz separacja drutów miedzianych za pomocą modelowania DEM*

*Recykling drutów i kabli, będących odpadami jest bardzo ważną częścią procesu odzysku miedzi. Mały rozmiar rozdrobnionych drutów prowadzi do technicznych i środowiskowych trudności w zapewnieniu efektywnego procesu odzysku. W artykule przedstawiono wyniki doświadczeń nad rozdziałem miedzi za pomocą separatora grawitacyjnego. Eksperyment ten został wykonany ze względu na istotność i ważność WEEE (Waste Electrical and Electronic Equipment – Odpady Elektryczne i Elektroniczne). Ponadto, zastosowano symulację DEM do zaprojektowania urządzenia sortującego.*



*Słowa klucze: WEEE, recykling, separator grawitacyjny, DEM*