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POSTUPCI RAZVRSTAVANJA OTPADA KOD POSTUPKA RECIKLIRANJA PROIZVODA

METHODS OF WASTE SEPARATION IN THE PROCESS OF RECYCLING

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Stručni članak

Sažetak: *Kod prerade otpada potrebno je otpadne proizvode, koji se sastoje od raznih vrsta materijala raznih svojstava, razdvojiti te nakon toga razvrstati kako bi se što uspješnije proveo postupak recikliranja. Opisano je ručno razvrstavanje te postupci mehaničkog razvrstavanja otpada koja se temelje na različitim svojstvima materijala kao što su razvrstavanje oblikom, magnetni postupci razvrstavanja, razvrstavanje na osnovi električne vodljivosti te razvrstavanje na osnovi gustoće. Mehanički postupci doprinose sofisticiranju razvrstavanja otpada, ali u posebnim slučajevima kod prisutnosti nečistoća, ulja i drugih zagađenja koja se ne mogu potpuno ukloniti mehaničkim postupcima, ručno razvrstavanje ima velik značaj i često ostaje glavna opcija.*

Ključne riječi: *mehaničko razvrstavanje otpada, recikliranje, ručno razvrstavanje otpada, zaštita okoliša*

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Abstract: *In the process of waste management, there is the need to separate and sort waste products, which consist of different materials that have different properties, so that the recycling process could be carried out successfully. Here are described manual sorting procedures and mechanical classification of waste products, which are based on the various properties of materials, such as sorting by shape, magnetic separation procedures, classification based on electrical conductivity and classification based on density. As much as the mechanical procedures contributed to the sophistication of waste classification, in special cases, such as in the presence of dirt, oil and other contaminants that cannot be completely removed by mechanical methods, manual sorting remains the main option.*

Key words: *Mechanical waste separation, Recycling, Waste separation by hand, Preservation of the environment*

1. INTRODUCTION

One of the major problems in preservation of the environment, especially in developed countries, is waste that is inevitably associated with the manufacturing process of every product. Objectives pursued in waste management are to reduce waste, and increase ecologically acceptable recycling processes, with promotion and application of acceptable waste management. Additionally, it is important to emphasise the development of governmental measures for recycling.

In the process of product and material recycling, it is necessary to achieve simple disassembling, or the application of easily separable compounds. Due to the high cost of human labour in manual separation, there are numerous procedures developed for the shredding and sorting of waste by the material and fraction type. In the waste classification process, there are different material properties used, such as magnetic properties, mechanical properties, electrical conductivity, surface colour, colour of the fractured surface, emission spectral analysis, X-ray fluorescence analysis, and so on. [1]

In this article, there are described manual sorting and mechanical processes of waste separation, such as the classification by shape, magnetic sorting procedures, classification based on electrical conductivity and classification based on density.

Figure 1. International symbol of recycling [2,3]

2. MANUAL WASTE SEPARATION

One well-known, but increasingly rare method of separation of materials is the manual process. Most commonly used are visual methods that distinguish the material type by colour (Table 1.). [1]

In the case of mixed waste processing, bulky items (home appliances, furniture, etc.), and certain contaminations generated in different industries, there is often performed manual waste separation before the mechanical process. Manual classification can also be used to remove impurities from previously sorted materials. [4]

The equipment used for manual separation of materials usually involves a sorting conveyor-belt or table containing a mix of materials. Workers are positioned on one or both sides of the conveyor-belt or table. The containers for the removed parts should be easily accessible. For larger amounts of materials, there is typically a conveyor-belt used that carries the parts that need to be sorted, with previously removed harmful waste products, oily components and such. Workers, that are sorting the waste, are placed on both sides of the conveyor-belt, which holds the materials that need sorting. Working length per worker (along the belt) should be about 1.50 to 1.80 meters, and the working depth should not be bigger than 0.6 meters, so that with two workers on both sides, the width of the material flow is a maximum of 1.20 meters. The flow rate is adapted to the complexity of the materials sorted, and usually amounts to 0.15 to 0.2 meters per second. Also, it is necessary that the workers can sort parts with simple hand movements that require little power. Meanwhile, they need to have a good overview of the parts on the conveyor-belt.

Designing processes that rely on manual sorting require a good understanding of the basic principles of time and movement, composition of the waste feed, and requirements of comfort and worker safety. In the application of simple, labour-intensive designs, safety and process control cannot be neglected.

Table 1. Surface colour of metals and their alloys [1]

COLOUR	METAL / ALLOY
red, reddish	Copper
yellow to gold-yellow	Alloys Cu-Zn, Cu-Sn
bluish to dark grey bluish white at fresh break or cut, later becomes dark grey	Lead, Pb-alloys
bluish white at fresh break; later becomes bluish-grey	Zinc, Zn-alloys
pale to light grey white, light grey oxidized layer	Magnesium
white to pale grey	Aluminium, Al-alloys
almost silver-white, with faint grey shine	Nickel
almost silver-white	Tin, Sn-alloys, Cu-Ni-alloys, Cu-Ni-Zn-alloys

One of the indicators in selecting the procedure for processing waste products is the weight of parts. With increase in weight, the efficiency of mechanical (automatic) classification decreases, so in such cases it is justified to resort to manual procedures. This also applies to parts with lower mass, if the fraction is valuable (for example, due to the content of precious metals).

Figure 2. Example of a conveyor-belt for manual classification of materials [5]

3. MECHANICAL WASTE SEPARATION

Mechanical classification is relatively cheaper than the manual kind. A requirement for economical profitability of manual separation is a significant difference in the observable characteristics of the materials. Distinguished features must be apparent quickly and accurately. For example, iron is easily separated from other materials using ordinary magnets. Other metals can be sorted out by eddy current separators with slightly less accuracy. Fast separation of polymers can be achieved via density. Specifically, fluids, such as liquid and gas, can be used to separate two types of polymers. The lighter polymer with lower density than the fluid will float, while the polymer with higher density will sink. If two polymers have approximately the same density, separation is not possible.

Mechanical classification is based on three related operations:

- isolating parts or pieces for individual identification,
- identifying parts or pieces based on distinguished features and evaluating of gained measurements,
- separation of the identified parts or pieces in separate containers.

Their individual efficiency determines the overall efficiency of the individual mechanical classification process.

3.1. Separation by shape

Classification procedures based on shape and size of particles ("screening") are used to prepare raw materials of uniform size for certain mechanical processes, and for improvement of the metal content. This is necessary, because the particle size and shape characteristics of metals are different than those of plastic and ceramics.

Screens are used for achieving efficient separation of particles through dependence on differences between particle sizes. The separation results in a division of the feedstock into at least two size fractions, one of which has the minimum particle size larger than that of the individual screen openings, and the second that has a maximum particle size smaller than the individual screen openings.

The first group is retained on or within the screen, because the particles are too big to pass through the openings. The second group passes through the screen openings and contains particles with sizes under average. Screens may also be used to separate materials into three or more size classes. In such cases, several screen surfaces of different size openings are fitted in series in the frame of the screening equipment. [4]

Predominantly, three types of screens are used by the solid waste industry for sizing particular fractions of processed and unprocessed mixed waste and previously sorted materials. These three types are the vibratory flat bed screen, the disc screen, and the trommel screen. Of the three, the trommel has proven to be quite effective and efficient for processing mixed waste and other mixtures where large, flat particles (e.g., paper) and aggregated-type particles (e.g., crushed glass) must be separated and represents the most commonly used type of screen used for separation by the shape and size of particles.

This device has a high resistance against clogging, which is important according to the diversity of the shapes and sizes of particles that the waste consists of. The vibratory flat bed screen is also largely used, especially in facilities for non-ferrous material recycling, but with the frequent problem of wire clogging.

In the case of size classification of formerly separated materials, vibratory flat bed and trommel screens are used in a number of facilities. The size classification of waste feedstocks that contain components with similar particle size distributions or that contain materials that can capture smaller particles and, therefore, hinder their flow through the openings of thee screen surface requires tumbling in order to be efficient.

Figure 3. End view of a trommel screen [4]

The trommel is a downwardly inclined, rotary cylindrical screen; its screening surface can be either a wire mesh or perforated plate. It can be used to process raw mixed waste prior size reduction, as well as to process shredded mixed waste. The characteristic tumbling movement, caused by the rotating screen, results in efficient separation. [4]

3.2. Magnetic separation

Magnetic separation or classification is a process used to segregate magnetic (i.e., ferrous) metal from a mixture of different types of materials, e.g., mixed waste or commingled metal, glass, and plastic containers. The process is technically simple and relatively low cost. Magnets used in the separators can be either permanent or electromagnetic. Magnetic separators are available in three configurations: magnetic head pulley, drum, and magnetic belt. The magnetic head pulley-conveyor consists of a magnetic pulley that serves as the head pulley of a conveyor.

In this kind of operation, the material to be sorted passes over the magnetic pulley, and the magnetic particles are pulled way around the rotating pulley while the non-magnetic particles follow a separate unrestrained path. Figure 4. shows a magnetic belt that consists of a stationary magnetic assembly that is mounted between the head and tail pulleys. Their function is to attract the magnetic particles and carry them away against the belt surface while the non-magnetic particles fall under the influence of gravity.

In the case of the drum magnet, the electromagnetic assembly is usually mounted inside the rotating drum where the assembly remains stationary.

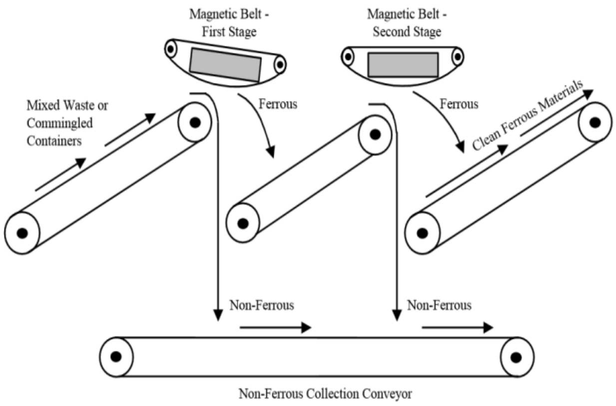

Figure 4. Device with multiple stages of magnetic separators (schematic) [4]

Figure 5. Magnetic belt for separation [4]

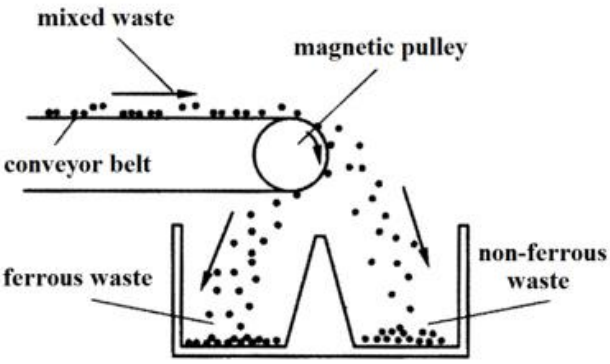

Figure 6. Example of magnetic separation – separating ferrous waste with a magnetic pulley [1]

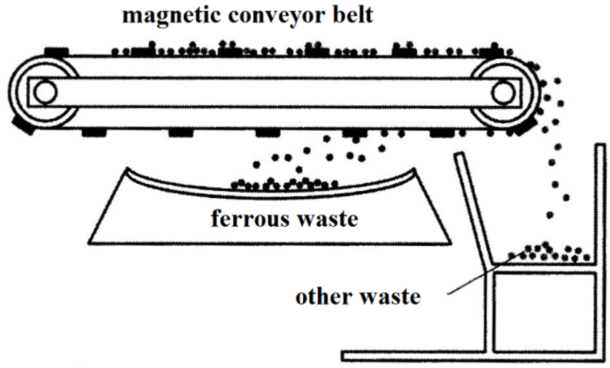

Figure 7. Example of magnetic separation – separating ferrous particles with a magnetic conveyor belt [1]

According to [6], magnetic separation procedures can be divided into:

- Ferromagnetic techniques – shredded waste travels with the conveyor belt over a magnetic pulley with a strong magnetic field. The ferromagnetic materials are drawn by the magnet to the conveyor belt, and the non-magnetic particles fall due to gravity.
- High gradient magnetic separation – can be used to separate paramagnetic materials from non-magnetic materials by directing the waste flow through a strong magnetic field with high gradients.

3.3. Separation based on electric conductivity

Electric conductivity-based separation separates materials of different electric conductivity or resistance. There are three typical types of techniques: eddy current separation, corona electrostatic separation, and triboelectric separation. This type of separation was initially developed to recover non-ferrous metals from shredded automobile scrap or for treatment of municipal solid waste. [7]

Currently, eddy current separators (Figure 8.) are almost exclusively used for waste reclamation, where they are particularly suited for handling the relatively coarse sized feeds. The separation criteria in this process are electric conductivity and density. Principles of this kind of separation are repulsive forces exerted in the electrically conductive particles due to the interaction between the alternative magnetic field and the eddy currents induced by the magnetic field (Lorentz force).

When a conductive material fraction is in an alternate magnetic field, an induction of eddy currents occurs in it. Conductive particles rotate away from the electric current while the non-conductive particles don’t. It is used for separating non-ferrous metals away from ferrous, or only for separating non-ferrous metals. With this procedure, particles larger than 5 millimetres can be processed.

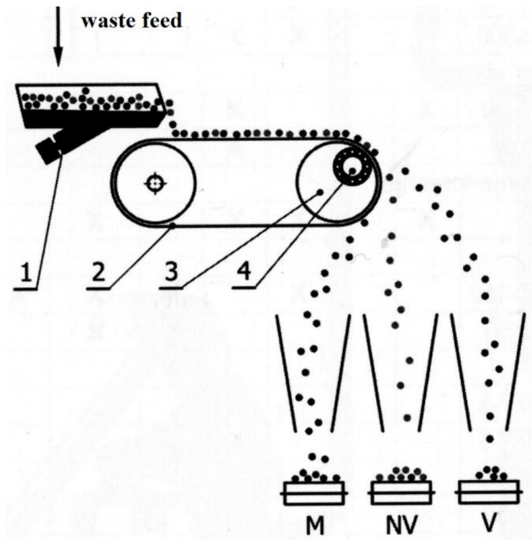

Figure 8. Separating particles with eddy currents by the company Steinert (M – magnetic particles, NV – non-conductive particles, V – conductive particles, 1 – vibrator, 2 – conveyor belt, 3 – pulley, 4 – polarizer) [1]

The rotor-type electrostatic separator, using corona charging, (Figure 9.) is used to divide raw materials into conductive and non-conductive fractions. Extreme differences in electric conductivity or specific electric resistance between metals and non-metals supply an excellent condition for the efficient application of this kind of separators in waste recycling.

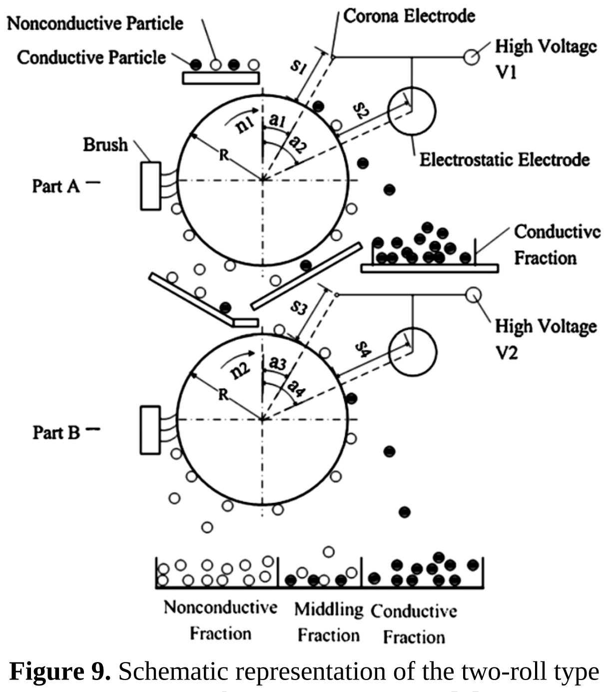

Figure 9. Schematic representation of the two-roll type corona-electrostatic separator [8]

Electrostatic separation has been utilized for the recovery of copper or aluminium from chopped electric wires and cables, or the recovery of copper and precious metals from printed circuit board scrap. Particle sizes that can be separated by this process are 0.1 to 5 millimetres, that is, 10 millimetres for laminar particles. Fragmented particles get electrostatically charged and guided through boards with different charge. Conductive materials are detracted from the electrode, because of the same charge as on the board. Nonconductive particles are drawn to the board surface.

Triboelectric separation (Figure 10.) makes it possible to sort plastics depending on the difference in their electric properties. There are many advantages of triboelectric electrostatic separation, such as independence of particle shape, low energy consumption, and high throughput. It is used to separate plastic particles with the size of 5 millimetres, exceptionally 10 millimetres.

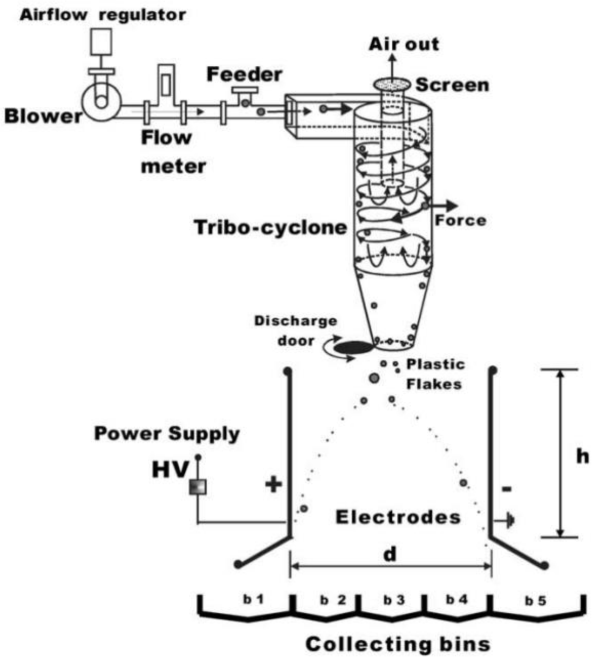

Figure 10. Schematic design of the triboelectric separator [9]

3.4. Separation based on density

Several different methods are employed to separate heavier materials from lighter ones. The difference in density of the components is the basis of separation. This method separates materials of different specific gravity by their relative movement in response to the force of gravity and one or more other forces, the latter often being the resistance to motion offered by a fluid, such as water or air. The motion of a particle in a fluid is dependent not only on the particle's density, but also on its size and shape, large particles being affected more than smaller ones. In practice, close size control of feeds in gravity processes is required in order to reduce the size effect and make the relative motion of the particle specificly gravity dependent. [7]

Air classification is a process of separating categories of materials by the differences in their aerodynamic characteristics. The aerodynamic characteristic of a particular material is primarily a function of the size, geometry, and density of the particles. The process consists of the interaction of a moving stream of air, shredded waste material, and the gravitational force within a confined volume. In the interaction, the drag force and the gravitational force are exerted in different directions upon the particles. The result is that waste particles that have a large drag-to-weight ratio are suspended in the air stream, whereas components that have a small ratio tend to settle out of the air stream. Paper and plastic materials are usually found in the light fraction, whereas metals and glass are components of the heavy fraction. Air classifiers, also called wind sifters, appear in a number of designs, such as vertical, horizontal and zigzag tubes (Figures 11.-14.).

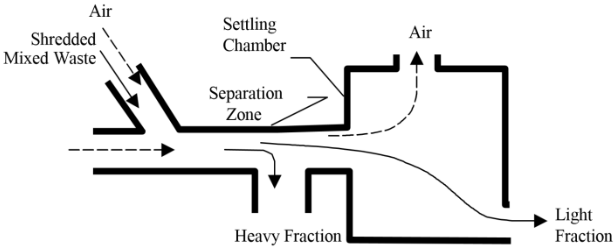

Figure 11. Horizontal air classifier [4]

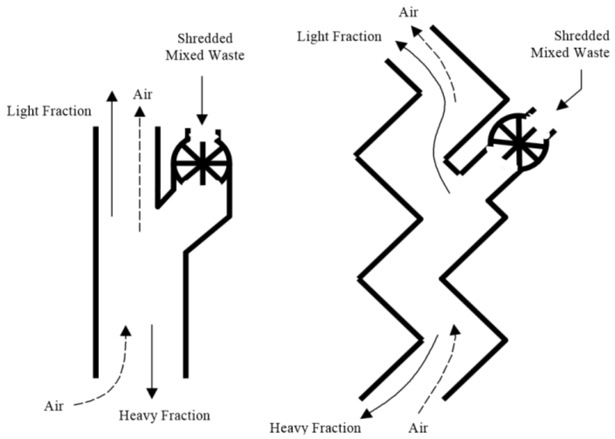

Figure 12. Vertical straight and vertical zigzag air classifiers [4]

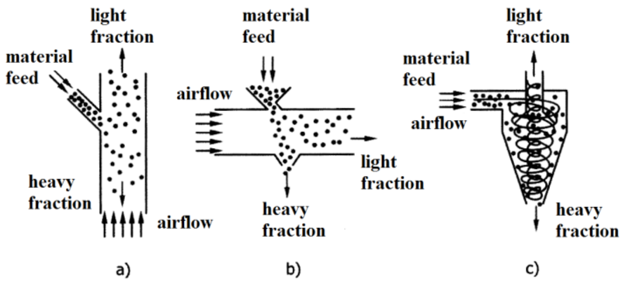

Figure 13. Air classifiers (a: counter current method, b: cross current method, c: centrifugal method) [1]

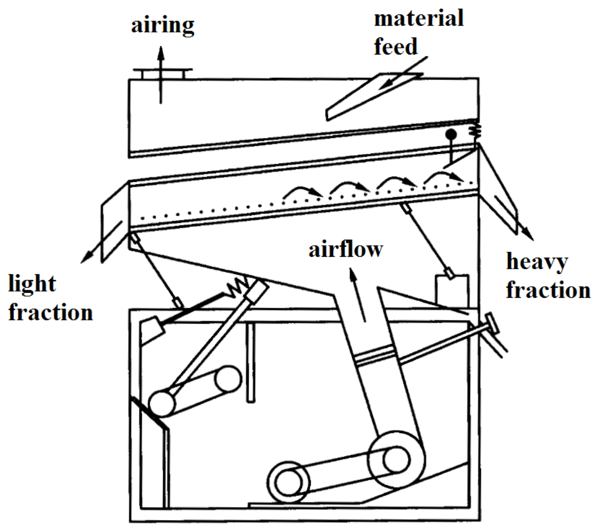

Figure 14. Table for air classification [1]

The gas-cyclone separates solid particles from a gas by means of centrifugal forces that appear due to differences in density and dimensions of the particles. They are mainly used to extract dust from air (Figure 15.).

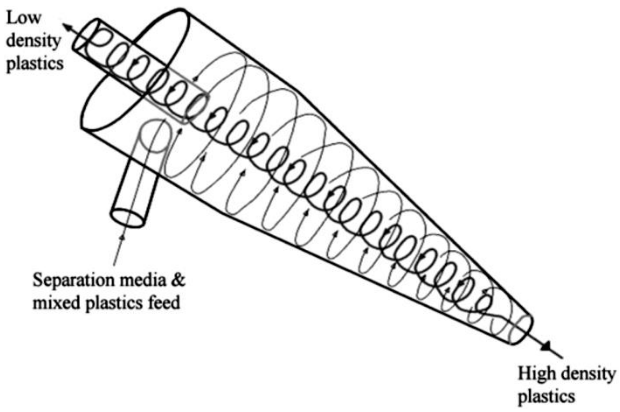

Figure 15. Conocylindrical cyclone [10]

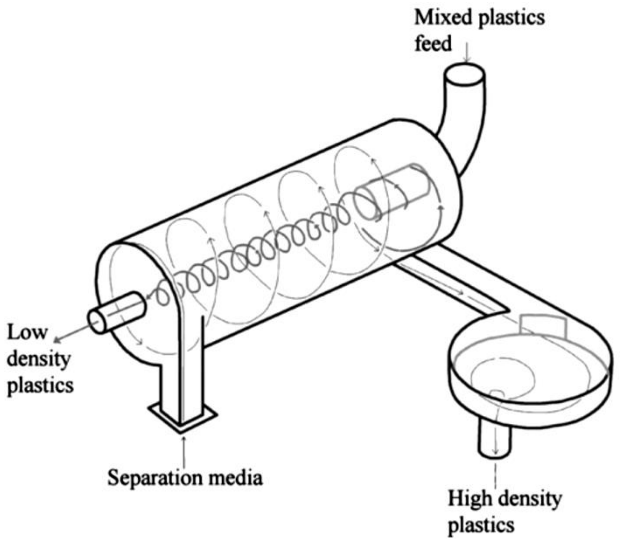

Figure 16. Cylindrical cyclone [10]

The float-sink technique is used to separate solid particles by means of differences in density. The particles are immersed in a liquid having a density value between the densities of the two components that need to be separated. Heavier particles sink to the bottom, while lighter particles float on the surface.

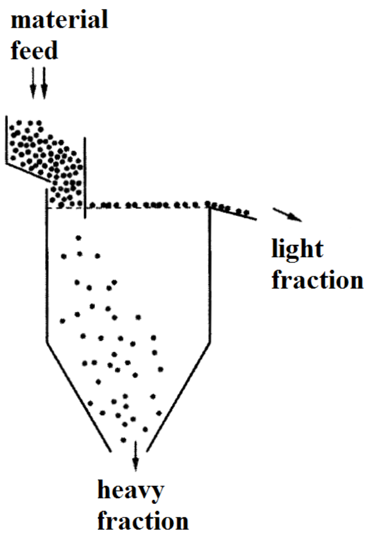

Figure 17. Float-sink technique in liquids [1]

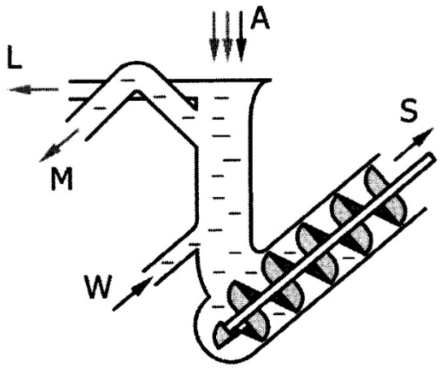

Figure 18. Schematic display of separation in fluid current - counter current method: A – material feed, L – light fraction, M – medium fraction, S – heavy fraction, W - water [1]

The hydrocyclone is used to separate solid particles from a fluid stream based on differences of particle density and dimensions, affected by centrifugal forces generated by the whirly motion of the fluid that passes through a circular tube. It is also used to separate contamination from a liquid.

4. CONCLUSION

The advantage of manual separation is that the recovered material is more pure than that recovered from mechanical separation, and therefore has a higher value. The disadvantage is the high cost due to the worker labour expenses. As the mechanical separation techniques are improved, the disadvantages of manual recycling will become overwhelming for materials used in small quantities or low weight materials. [11]

Magnetic separators, particularly those of low intensity in the form of a pulley, are commonly used for the separation of ferromagnetic materials from non-ferrous or other non-magnetic waste. The classification based on electrical properties separates materials of different electrical conductivity or different electrical resistance. The most important methods are: eddy current separation, electrostatic separation and triboelectric separation. In order to separate heavier materials from lighter ones, methods are used based on the difference in densities of components. This type of classification includes: gas- and hydro-cyclone, float-sink technique and air classification.

Processing of municipal waste or previously sorted waste to recovered materials includes a number of processes depending on the level of the previous separation, as well as the type of material that needs to be processed. The principles of each process are influenced by the physical and chemical characteristics of certain materials or types of material for which they are intended.

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