LIFE12 ENV/GR/000427 reclaim project

"Landfill mining pilot application for recovery of invaluable metals, materials, land and energy"

ACTION B3

Experts report by the scientists of SMME and HELECTOR

THE CONTRIBUTION OF MINERAL PROCESSING TO THE RECOVERY OF USEFUL MATERIALS FROM MSW

Beneficiaries of LIFE12 ENV/GR/000427 reclaim:

ENVECO S.A. ENVIRONMENTAL PROTECTION MANAGEMENT & ECONOMICS; HELECTOR; Municipality of Polygyros; NTUA School of Mining & Metallurgical Engineering

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Chapter 1. THE CONTRIBUTION OF MINERAL PROCESSING TO THE RECOVERY OF USEFUL MATERIALS FROM MSW

1.1. Introduction

Processing, by definition, falls under the heading of physical treatment by using physical techniques for changing the composition and character of the waste. Every recycling process represents a conversion of the material. So the process of recycling is also a process of production of new materials. It describes the process of producing secondary raw material and compares a series of activities that involves collecting, sorting, processing or converting used materials into useful materials and finally goods. The abovementioned activities aim at reducing the amount of waste that is permanently landfilled.

The basic phase of this recycling process is material separation. A separation of waste at the beginning of the process supports the treatment of the materials and helps raising the efficiency of the waste processing facilities.

The technology that is essential for waste material recovery is actually derived by the mining industry. All conventional mining and beneficiation methods, developed over time, can be used in the recovery of useful values from ores or improve the quality and the physicochemical characteristics of industrial minerals. In parallel the same methods can be used not only in the classification, the mechanical separation by type and the recovery of useful materials from Municipal Solid Wastes (MSWs), but for the treatment of wastewater as well.

The Mineral Processing methods are based on the exploitation of various differences in physico-chemical properties and characteristics unique for various minerals, including:

- Chemical and mineralogical composition;
- Density;
- Magnetic susceptibility (the behaviour in a magnetic field);
- Electrical conductivity;
- Surface properties of minerals; and
- Optical properties (e.g. color, reflectivity), [58].

In parallel, critical factors are size and shape (rounded, angular, elongated, flat etc.), before and after the size reduction of the material to be separated. The selection of the appropriate machinery and equipment depends on a well-defined mix of physicomechanical methods that take advantage of the properties of the material and of separation methods that follow the size reduction process.

According to mineral processing techniques (Wills & Napier-Munn, 2006), the most abstract flow-sheet for processing is presented in **Figure 3.1-1**. The raw material (be it run-of-mine ore or waste) undergo the stage of comminution, i.e. minimization of grain size, through various techniques; then, separation takes place, taking advantage of physical and mechanical properties; and finally the product of separation can be handled, further treated or forwarded to the relevant market.

Figure 3.1-1. Simple block processing flow-sheet (reconstruction from Wills & Napier-Munn, 2006).

A more detailed although simplistic approach is presented in **Figure 3.1-2** that follows. One of the most important objectives of comminution is 'release' or 'liberation'. Liberation is based on the notion that the minerals are attached to the non-valuable material (also known as the 'gangue' in mining jargon) and, therefore, to achieve a certain degree of concentration, the ore has to be 'broken' to a to-be-defined level of particle size, highly related to the way the minerals and the gangue are interconnected. In the case of waste, this type of liberation is necessary for mixed type waste like equipment (electrical, electronic or mechanical) and unsorted municipal waste. An essential aspect of the abovementioned procedure is energy demand, which is proportional to grain size reduction and to weight of grinded material.

For low-grade ores (hence low-grade raw material) it is often advisable to utilize a two-stage separation flow-sheet (**Figure 3.1-3**) which includes:

- Coarse grinding, producing a coarse residue and middling materials
- Fine grinding of middlings, producing comminuted material which can be more easily liberated.

Using this approach, most quantity of the gangue is released at a coarse grained stage, thus reducing the energy costs of grinding.

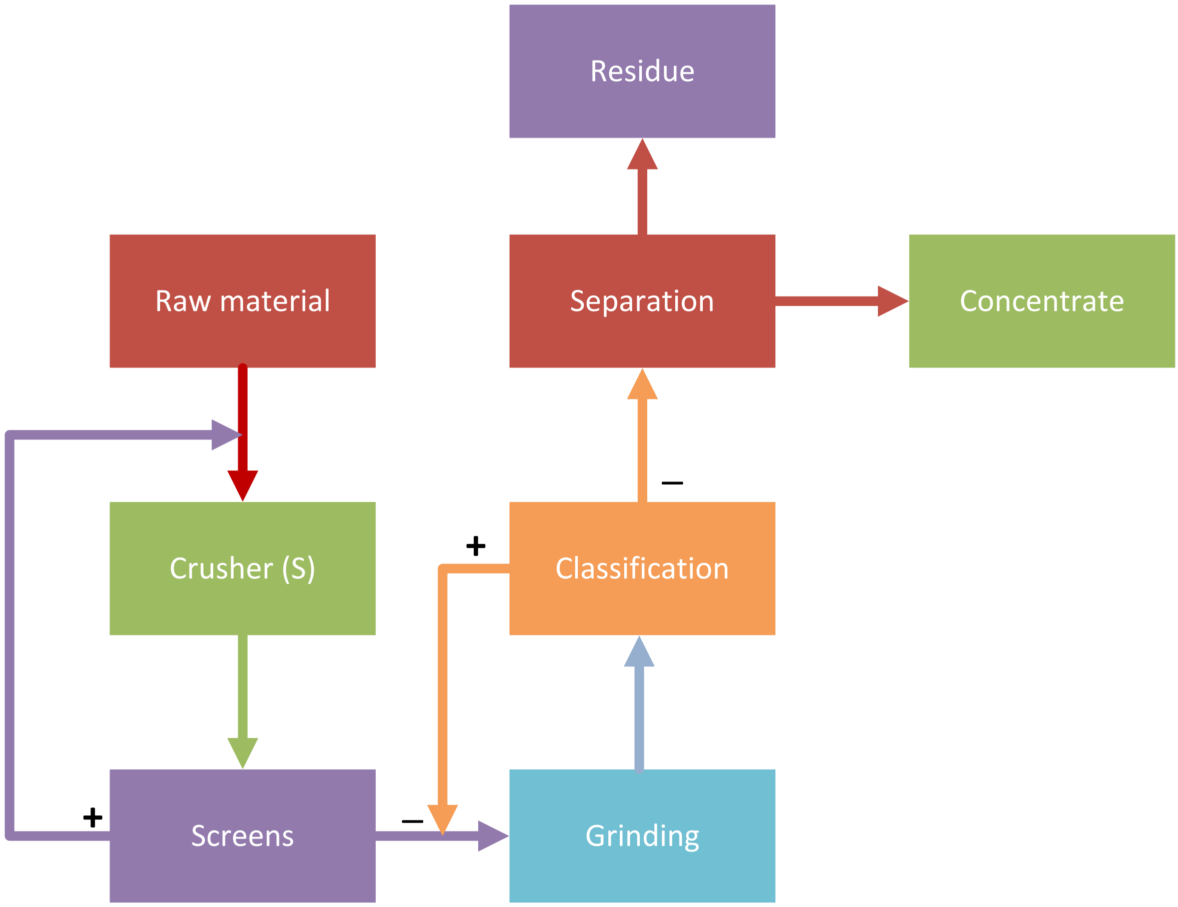


Figure 3.1-2: Simple line flow-sheet . + indicates oversized material, which is removed and recycled, and – indicates undersized material, which progresses through the line process, [1].

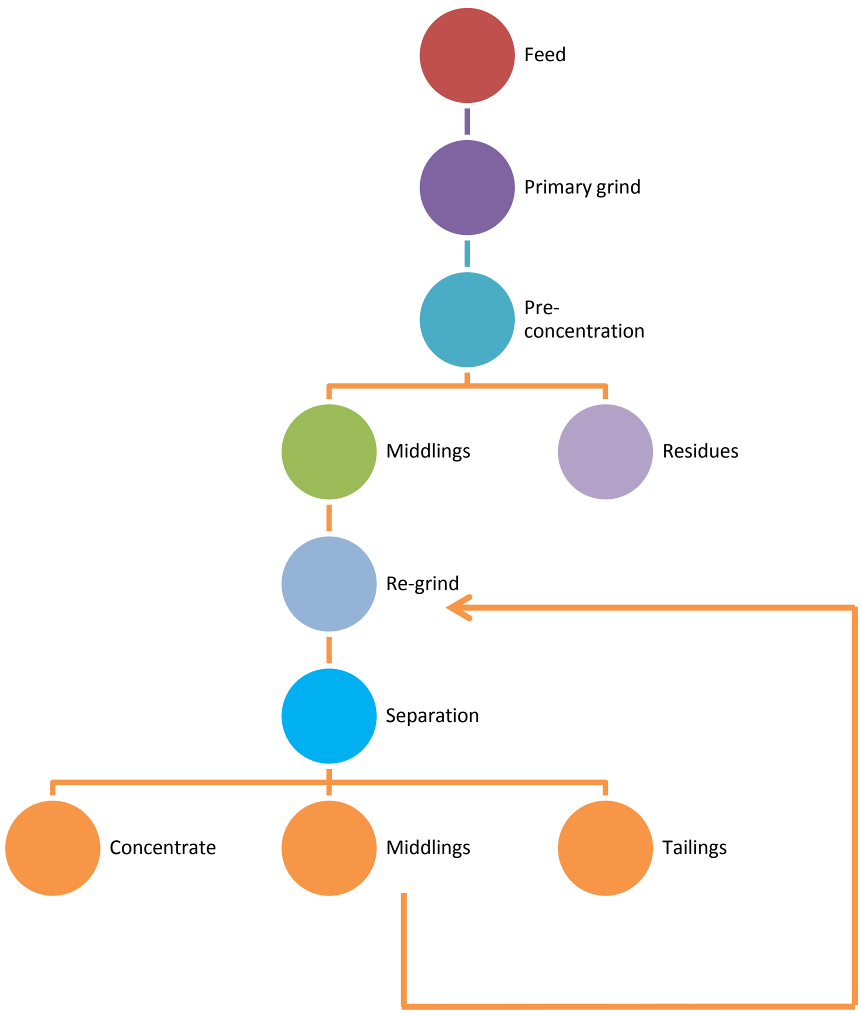


Figure 3.1-3: Two-stage separation flow-sheet (Wills and Napier, 2006)

1.2. Main methods for material separation and concentration

Regarding the methods used in material separation and production of concentrates, the following broad categories can be defined:

Size reduction: primarily known as crushing, grinding, milling, shredding in order to achieve an appropriate size to separate the different materials. The main distinction is between crushers and grinding mills. Crushing is used as a primary stage and milling as a secondary stage.

Crushing is in general a dry operation taking place in up to three stages, depending on the initial and final sizes. Between stages, if considered necessary, screening may take place to remove undersized material (fine-grained) before moving to a finer stage and clog the fine-crusher and take it directly to the system outlet. Primary crushers are heavy duty machines, which have to cope with a great down-sizing ratio, and secondary crashers are lighter machines, since their performance is much more controlled, owing to the existence of a primary crusher and/or intermediate screening.

Grind-milling is usually the last stage of comminution, where particle-size is reduced through a combined impact-abrasion effect, under dry or even wet conditions. In general, there are two types of mills, i.e. tumbling mills and stirred mills. In the former case, the shell of the mill is rotated, and rods or balls are drifting and falling on the material (in some cases, instead of rods/balls the material itself may act as the falling medium). In the latter case, the mill shell is stationary and there is a stirrer inside which regulates the particle movement. This specific type of mill is used for producing fine to extra fine particles.

Sorting and classification (screening): according to the particles size and shape various methods can be utilized for separation of materials by size and sometimes by kind (dry sieving, hydro classification, etc.). The main screening objectives are:

- ***Sizing or classifying***: separations of the particles by size to provide properly sized feed to a downstream unit.
- ***Scalping***: removal of coarse material in the feed of a process and redirect it to crushing or to remove it from the flow.
- ***Grading***: to clearly classify a product into pre-defined size ranges, whenever product size is critical for the product value
- ***Media recover***: to separate product from medium in cases of magnetic separation by means of magnetic granules
- ***Dewatering***: to drain moisture from a slurry
- ***Desliming or dedusting***: to remove fine solid material from a feed (wet or dry, usually below 0.5mm).

- ***Trash removal***: to remove irrelevant material (e.g. wood) from a fine stream (e.g. from a slurry)

The performance of screens depends largely on two factors: feed rate and screening time. The lower the feed rate and the greater the screening time, the more effective the separation is. Nevertheless, the nature of these two factors contradicts the notion of increased production. Therefore, the optimum demands compensation between separation ineffectiveness and improved production.

Magnetic Separation: different magnetic susceptibility of materials enables selective attraction of ferrous metals over other metals. The basic parameters that reflect on the system effectiveness are:

- Magnetic field intension (related to the distance between the magnet and the waste and to the capacity of the electric magnet that is usually utilized).

- Time of exposure to the magnetic field (directly proportional to the speed by which the waste passes through the field – use of conveyor)

- Burden depth, between ferrous material and other residues on the conveyor belt. The main target is to keep a shallow and even depth of material inside the magnetic field

Induced magnetic field (eddy current) separation: Non-ferrous materials conduct electricity. Therefore, whenever an alternating magnetic field induces an electrical current to a non-ferrous object, then the electrostatic forces developed can move the object to a desired direction. Typical equipment used are eddy current separators, which usually are inclined tables with magnets underneath. The waste stream that passes through should be free of ferrous metals to secure separation of non-ferrous metals. It is reported (Worrel & Vesilind, 2012) that this type of separation is not efficient, achieving approx. 50% recovery with 89% purity. Therefore, the extract of the procedure may need further purification through hand removal.

Electrostatic separation: exploitation of different surface/electrostatic behaviour of materials. The method is similar to that of the magnetic separation. Instead of creating a magnetic field that selectively attracts magnetic objects, the system includes an electrostatic field which selectively attracts or repulses electrically charged materials. More specifically, differently charged materials will behave differently inside the electrostatic field, therefore various types of materials may have a different diversion path, providing detailed separation. For example, if shredded plastic particles are forced to be electrostatically charged by friction with one another (triboelectric charging process), then different types of plastic have different potential for acquiring a charge.

Separation tables: under this category, several experimental or partially used methods are included. The common element between these methods is that they use tables (or 'beds') that exploit certain mechanical behaviours of particles (Worrel & Vesilind, 2012),i.e.

- Pneumatic tables: as a method, they come from agriculture, where they are used for removing impurities from seeds. The main principle of their use is the same as with jigs in water (used for gold nuggets in the past), replacing water with air.

- Inclined tables: they are a combination of an inclined surface and water flow. Depending on specific weight, different materials are dragged by water to various distances from the feed and can be removed through properly located outlets.

- Shaking tables: they are inclined tables that are shaken in a direction perpendicular to water-flow. It is usual in the modern types to have short barriers perpendicular to the flow (known as 'rifles'), which assist separation of particles.

Optical sorting: according to the colour, reflectivity, etc. (separation by mechanical means or handpicking). The basic principal that this method uses is that differently coloured or different density materials refract light differently. Therefore, a light sensor (photocell) that receives light through a particle can be 'trained' to respond to differences above a threshold. After the photocell is triggered by a 'different' object, a pneumatic sorter blows a quick draft to the object and diverts it from the waste stream (Bremen et al., 2009).

Usually optical sorters are binary and they separate transparent from coloured glass. Therefore, separation of differently coloured glass particles requires 2 or more passes through the optical separator, using colour-filters.

It must be noted that optical sorting equipment offer very high efficiency when asked to reject impurities from a required fraction. Nevertheless, they easily loose efficiency when sorting of two different fractions is required, because the intermediate purity materials cannot be sorted and products loose purity [2]. In addition, they require homogeneity narrow size distribution in the feed.

Infrared type sorting: This type of sorting bares many similarities with optical sorting, although the infrared and/or the near infra-red (NIR) spectrum of light is used to separate resins (special type of waste) from plastics or to sort out translucent objects based on opacity (Tchobanoglous & Kreith, 2002).

X-ray detection sorting: This type of sorting bares many similarities with optical sorting, although x-rays are used to separate PVC from mixed types of plastics. X-ray fluorescence or x-ray transmission sensors are used to detect chlorine atoms in PVC (Tchobanoglous & Kreith, 2002).

Dry gravity separation: it is based on the exploitation of density difference for separation of materials. Owing to its high efficiency and low cost, gravity separation is one of the first considerations in any flow-sheet and features in any flow-sheet where there is sufficient difference between the specific gravity of the materials. Dry Gravity separation (Pascoe, 2000) requires the use of pneumatic (air) tables. Air is blown through a porous media to fluidize material. Separation is a combined result of air, table movement and table tilt angle. The result is mostly affected by the particle size and shape. Gravity separation methods are mostly used for the separation of plastic materials.

Wet gravity separation: it is also known as wet density separation (Pascoe, 2000). There are various techniques used such as:

Heavy liquid separation method: this kind of separation substitutes a denser (heavier) liquid for water. The heavy liquid has a density between water and the fraction to be extracted (Worrel & Vesilind, 2012).

Heavy media separation method: exploitation of the different densities to separate materials and recover/recycle media. To this effect colloidal solids are added and diversify the weights of the various materials.

Upflow separation method: the method belongs to the same group as the previous two. In this case the fluid is water and the method has successfully been tested for specific gravities between 1.1 and 2.0. The known use of these devices is to further treat the heavy fraction of the air-separators and separate metal/glass from heavy organics (Worrel & Vesilind, 2012).

The wet density separation (Dodbiba & Fujita 2004) of different types of virgin plastics was studied using the well-known in mineral processing Tri-Flo dynamic medium separation system. Plastic separation using this method required media with low density, say around 1000–1300 kg/m^3. For this purpose the media utilized were: water and water solutions of calcium chlorite, sodium chlorite, calcium nitrate and ethyl alcohol. The process was tested on a PS/PP mixture using a two-stage Tri-Flo separator of 100mm in diameter and water as medium (**Fig. 3.2-1**).

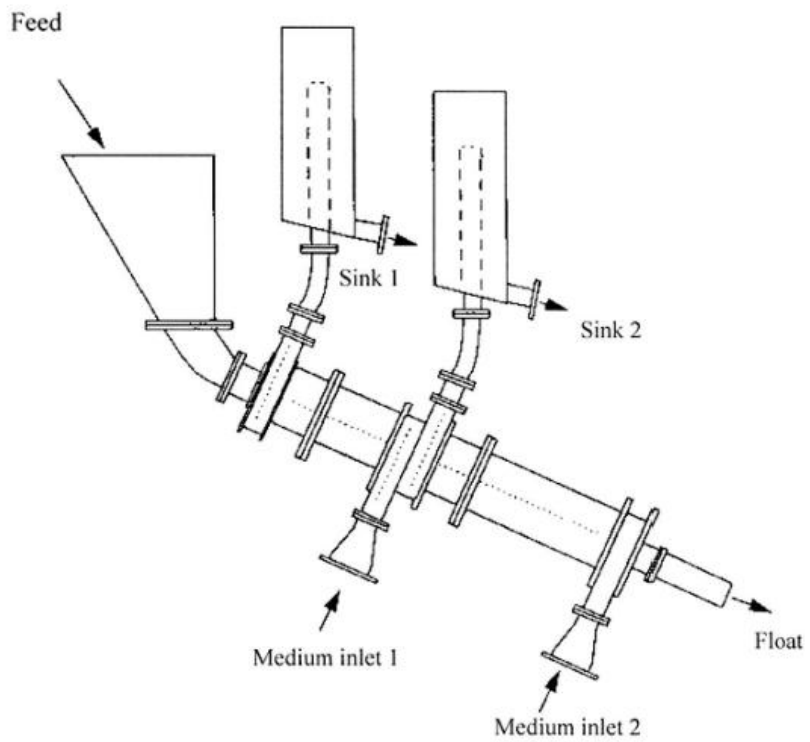


Figure 3.2-1: Schematic design of Tri-Flo separator.

The experimental results were considered as satisfactory, since the PP content in the float products was 99.9% (Bevilacqua *et al.*, 1997, Ferrara *et al.*, 2000).

Moreover, the behaviour of PVC and PET in a LARCODEMS dense medium separator (**Fig. 3.2-2**) has been investigated using calcium chloride solutions as the medium (Pascoe & Hou, 1999). It has been shown that particle thickness and surface conditioning can have a significant influence on plastic behaviour within the separator. Thus, given the complexity of a mixture of shredded plastics in terms of size, shape and thickness, density separation using the LARCODEMS is likely to be only considered as a pre-concentration step.

A specific jig (named TACUB jig, **Fig. 3.2-3**) was successfully employed (Tsunekawa *et al.*, 2004) to separate plastics from scrap electric wires. Thus, the separation of PVC from PE collecting products with purities was higher than 98%. Based on the experimental results, it was reported that the upstream speed and the amplitude of the pulsation of the water were the main parameters that influenced the efficiency of the separation process.

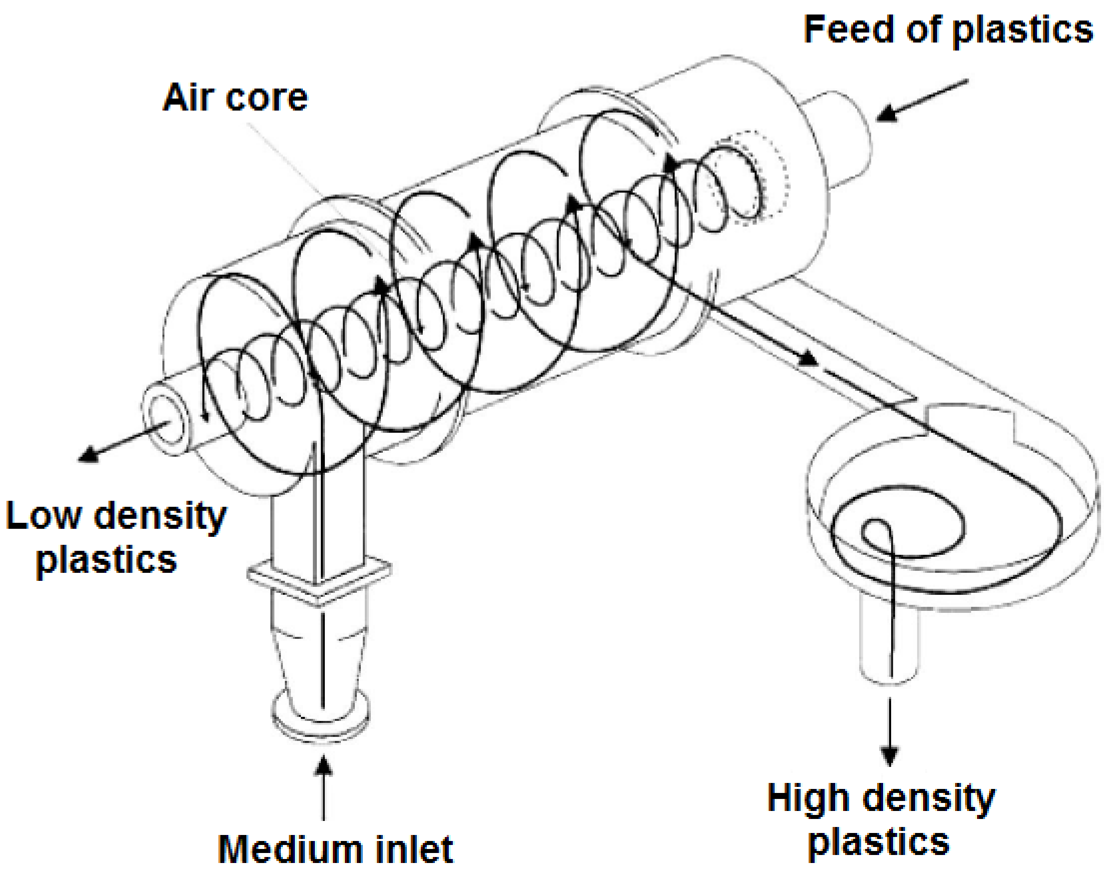


Figure 3.2-3: Diagram depicting the operation of a LARCODEMS separator.

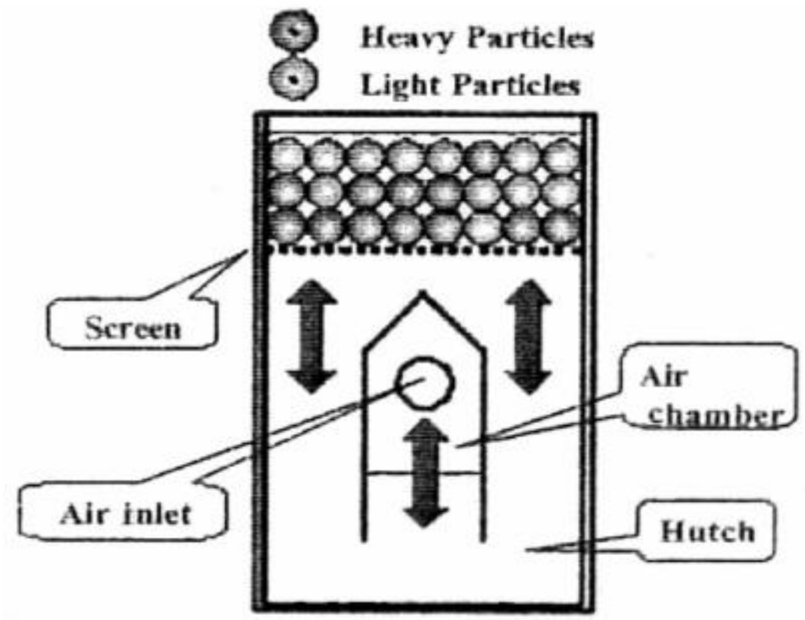


Figure 3.2-2. Schematic design of TACUB jig.

Furthermore (Shimoiizaka *et al.,* 1976), sink–float separation techniques are well-known wet methods for the separation of mixed plastics. Various mixtures of plastics of different densities were satisfactorily separated by using a laboratory-scale sink–

float separator. It was reported that the impurity of each separated product was less than 1%. Later, the separation of PET/PE and PET/PP mixtures was carried out in order to improve the purity of the raw input used in PET bottle recycling (Fujita *et al.,* 2000, Dodbiba *et al.,* 2009). Initially, PET bottles and their caps (made of PE or PP) were shredded and the floatability of each polymer was tested. Since the results did not suggest that the required purity of PET plastic could be achieved by flotation (even with the addition of the wetting reagents dodecyl-amine acetate or polyvinyl alcohol), the mixtures were then processed in a sink–float process using a drum-type sink–float separator. Finally, as the required purity of PET could not be obtained by either technique alone (i.e. neither flotation nor sink–float separation), a system utilizing a combination of the two processes was designed (**Fig. 3.2-4**). With the help of the above system, the desired purity PET (i.e. higher than 99.995%) was easily achieved.

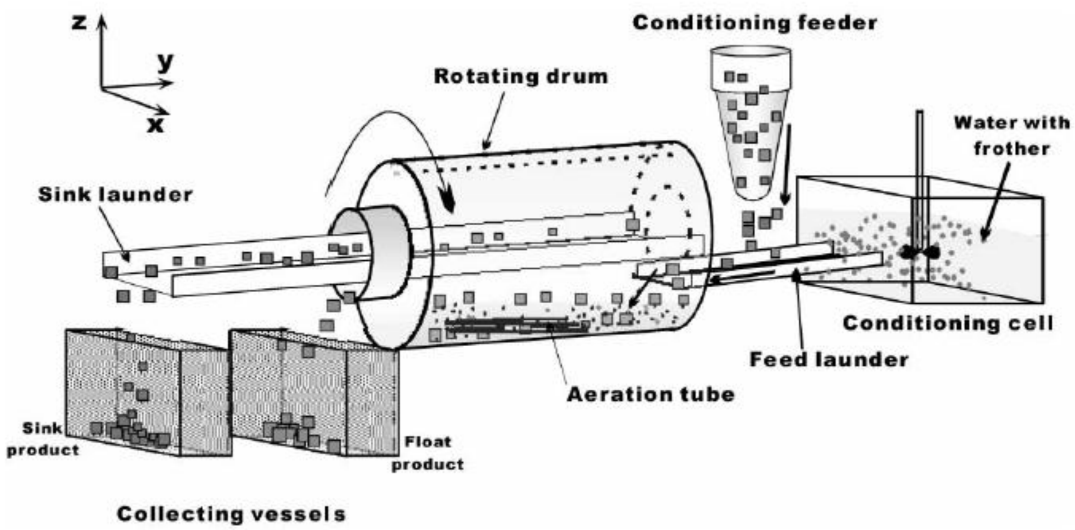


Figure 3.2-3: Arrangement of a drum separator in conjuction of sink–float separation and flotation.

CONCLUSION

Although wet separation techniques provide adequate recoveries, they have clear disadvantages over dry ones, since some potential problems associated with wet separating methods in general, such as: (1) treatment of water from the process for reuse or discharge; (2) the requirement of expensive wetting reagents, and most importantly, and (3) dewatering or drying the mixture after separation cannot be avoided. In this regard, dry separation processes offer economical alternatives.

Flotation with the use of chemical reagents: By definition, in flotation the solid-liquid separation is done with the aid of up-current injection of air bubbles. Based of attraction forces between suspended solids and water particles and on the surface and pressure of the air flow, the air bubbles catch and carry with them the solid particles in suspension to the surface, where they can be removed (Bremen et al., 2009). This technique is commonly used in wastewater treatment. In mining, flotation uses the different surface behaviour towards a frothing medium, to separate the different minerals present.

There are two possible options:

- Exploit a physical difference in the air bubble adherence
- Create an artificial particle surface modification, through chemical reagents that secures bubble adherence to the correct particles

The separation is usually made by frothing or by a shaking table (or other gravity separator). According to Worrel & Vesilind (2012), a common application of froth flotation is the separation of glass from other contaminants or ceramics, as well as the separation of invaluable metals included in printed circuits (WEEE) after shredding (Vidyadhar & Mehrotra, 2009).

Froth flotation can be applied for beneficiation of printed circuit board comminution fines was investigated in this work, via reverse flotation under a scheme described as natural hydrophobic response. With no reagents, the scheme employed variation of kinetic parameters of airflow rate and impeller speed to optimize metallic enrichment of the sink. The impeller energy and aeration rate required to keep the pulp in suspension and avoid excessive turbulence were found to be much lower compared with conventional mineral flotation.

The natural hydrophobic response was found to exist, and stable froth was observed even without the use of any frother (**Fig. 3.2-5**). It was submitted that the dynamic froth stability observed is due to fine particle stabilization.

Mass pulls obtained were high and cumulative mass pull under the varying kinetic regimes were found to fit very well to the general first order kinetics. The extents of fit, the sink enrichment and the recovery in respect of metallic values were assessed to evaluate the beneficiation performance. Many of the metallic elements were found to concentrate into the sink, while some prefer the froth phase. Notably, gold and palladium were among the best recovered to the sink; with about 64% recovery at enrichment ratio of 3.1 (676 ppm actual assay) for Au. The flotation scheme proved effective for PCB comminution fines, and performance improvement also looks very feasible (Ogunniyi & Vermaak, 2008).

Figure 3.2-6: PCB CF froth in the flotation cell under natural hydrophobic response

Solid - liquid separation: through thickening and filtration, drying i.e. increasing the % weight of solids by liquid and moisture removal of the various products (concentrates; residues; etc.).

CONCLUSIONS

For the application of any mineral processing method it is necessary to have a detailed knowledge of the feed in terms of:

1. The percent (%) content in useful material (value for recovery), which through its 'cut-off grade' value affects not only the 'feasibility', but the economics for the recovery effort as well.

2. Form, size and manner of dispersing of the useful component in the waste.

3. The physicochemical and mechanical properties of both the useful and the waste material, which gives an indication for the required effort of liberation ('release') of the valuable from the 'gangue'.

The conventional mineral processing methods [58], exploiting the physicochemical, mechanical differences and form and shape of the various materials contained in MSW are those successfully applicable to the separation and recovery of these useful materials, with minor modifications. Thus, traditional mineral processing contributes to the environmental protection and the proper use and management of exhaustible natural resources used in the manufacture of various everyday products.

To conclude, it has been well demonstrated, that MSW (with their variable content) must be considered and faced in the same way as the conventional ores.

1.3. Composition and properties of waste – domestic waste

INTRODUCTION

The composition of the waste is the primary consideration in the choice and design of an appropriate system of mechanical separation, influenced by numerous factors such as:

- The nature of agglomeration: the waste composition is different for urban areas, rural areas, industrial areas or mixed type areas (Gidarakos et al., 2006).
- Climate and season: Seasonal variation usually reflects on total waste production throughout the year but also on specific waste streams, such as yard trimmings, kitchen vegetables organics, ashes et al. (Koufodimos & Samaras, 2002).
- The level of life: the average income and type of life affects the composition of MSW, regarding specific waste streams such as: WEEE, packaging & printed paper waste and household hazardous waste (chemicals et al.).

Special sampling is designed based on statistically acceptable methods (Gidarakos et al., 2006) and are based on statistics on employment, education and general living level of local residents. A representative composite sample must cover at least 1% of the total quantity of waste. The statistical areas should be as homogeneous as possible. Analyses of waste usually refer to three different categories:

1. Groups of materials;
2. Physical and chemical properties; and
3. Size

According to the first of the abovementioned categories, waste is divided into:

1. Paper – Cardboard;
2. Metals;
3. Glass;
4. Plastic;
5. Fabric, wood, leather, rubber;
6. Aggregates;
7. Organic;
8. Balances/residues.

The second category (physical and chemical parameters) includes:

- moisture;
- dry solid residue;
- volatile compounds;
- ash;
- organic, inorganic and total carbon;

- total nitrogen;
- ammonia nitrogen; hydrogen; and
- calorific content.

In addition, some of the basic parameters to be specified are:

- C/N ratio;
- Phosphorus;
- sulphur;
- chlorine;
- fluorine;
- potassium;
- sodium;
- chromium;
- nickel;
- copper;
- cadmium;
- zinc;
- lead; and
- total combustible residue

According to size, refuse divided into three categories:

- Category I: refuse size 0-40mm, approx. 12 -35%
- Category II: refuse size 40-120mm, approx. 35-43%
- Category III: refuse greater than 120mm, approx. 30 – 43%

WASTE COMPOSITION IN EU MEMBER STATES

The average waste composition varies considerably from country to country, dependent wide variety of factors (standard of living, nutrition, program material recycling, etc.). Some typical analyses of domestic waste and similar in low-income countries, middle-income countries upper-income countries (**Table 3.3-1**) also management costs waste varies from country to country Table 5.

In the EU27, 503 kg of municipal waste was generated per person in 2011, while 486 kg of municipal waste was treated per person. This municipal waste was treated in different ways: 37% was landfilled, 23% incinerated, 25% recycled and 15% composted, compared with 56% landfilled, 17% incinerated, 17% recycled and 10% composted in 2001 (STAT/13/33, 4-3-2013).

The amount of municipal waste generated varies significantly across Member States. Denmark, with 718 kg per person, had the highest amount of waste generated in 2011, followed by Luxembourg, Cyprus and Ireland with values between 600 and 700 kg per person, and Germany, the Netherlands, Malta, Austria, Italy, Spain, France, the United Kingdom and Finland with values between 500 and 600 kg. Greece, Portugal, Belgium, Sweden, Lithuania and Slovenia had values between 400 and 500 kg, while values of below 400 kg per person were recorded in Hungary, Bulgaria, Romania, Latvia, Slovakia, the Czech Republic, Poland and Estonia.

Table 3.3-1: Composition and properties of waste – domestic waste, (KFW, 2008).

Income group	Low-income countries	Middle-income countries	Upper-income countries
Organic components			
Food wastes / leftovers	50 - 70%	30 - 60%	25 - 40%
Garden waste	5 - 15%	10 - 20%	10 - 30%
Subtotal:	50 - 80%	40 - 70%	30 - 60%
Dry Recyclables			
Paper, Cardboard	2 - 6%	8 - 12%	20 - (40) %
Plastics	1 - 5%	4 - 10%	2 - 8%
Glass	0.5 - 2%	1 - 3%	4 - 12%
Metals	1 - 2%	1 - 3%	2 - 8%
Textiles	1 - 2%	2 - 5%	2 - 6%
Rubber, Leather	1 - 2%	1 - 3%	1 - 3%
Subtotal:	5 – 15%	12 – 25%	30 – 50%
Others			
Fine fraction(<8mm)*	10 - 30%	15 – 30%	5 – 10%
Miscellaneous	1 – 5%	2 – 10%	10 – 15%
Subtotal:	50 – 90%	40 – 70%	30 – 60%
Physical Properties			
Water content	50 – 70%	40 – 60%	50 – 60%
Dry Solid Matter	30 – 50%	40 – 60%	60 – 70%
Dry organic matter**	50 – 80%	35 – 50%	50 – 60%
Dry an organic matter	20 – 50%	50 – 65%	40 – 50%
Calorific value ***	3 – 6 MJ/kg	4 – 7 MJ/kg	8 – 12 MJ/kg
*Sand, ash, sweepings, dust, coffee and tea grounds etc. ** in % of dry substance *** Minimum required for self-sustaining combustion: > 6 MJ / kg			

Table 3.3-2: Cost of waste management in low-income, industrializing and industrialized countries, (Waste Management in German Financial Cooperation).

	Low-income countries	**Medium income countries**	**Industrialized countries**
Waste quantity (t/cap/a)	0.15 – 0.3 t	0.25 – 0.4t	0.3 - 0.6t
Average income (€/cap/a)	<100 - 500	1500 - 4000	12000 - 18000
Costs in € per t for			
• Waste collection	15 - 30	25 - 50	40 - 80
• Waste transport	3 - 5	5 - 10	10 - 15
• Landfill	0 - 3	12 - 25	60 -120
• Composting	-	5 - 25	40 - 90
• Incineration	-	40 - 100	100 - 200
Total cost per capita per year (€/a)	4 – 8	35 – 80	50 – 120
In % of available per capita income	1.5 - > 5%	0.8 – 1.5%	.8% 0.3 - 0

Information in **Table 3.3-1** has been published by Eurostat, the statistical office of the European Union. Recycling is most common in Germany, while incineration is prevailing in Denmark and composting is prevailing in Austria.

The treatment methods differ substantially between Member States. In 2011, the Member States with the highest share of municipal waste landfilled were Romania (99% of waste treated), Bulgaria (94%), Malta (92%), Latvia and Lithuania (both 88%).

The highest shares of incinerated municipal waste were observed in Denmark (54% of waste treated), Sweden (51%), Belgium (42%), Luxembourg and the Netherlands (both 38%), Germany (37%), France and Austria (both 35%).

Recycling was most common in Germany (45% of waste treated), Ireland (37%), Belgium (36%), Slovenia (34%), Sweden (33%), the Netherlands (32%) and Denmark (31%). The Member States with the highest composting rates for municipal waste were Austria (34%), the Netherlands (28%), Belgium and Luxembourg (both 20%), Spain and France (both 18%).

Recycling and composting of municipal waste together accounted for more than 50% of waste treated in Germany (63%), Austria (62%), the Netherlands (61%) and Belgium (57%). **Table 3.3-3**:

Table 3.3-3. Municipal waste in EU member-states and other countries(Eurostat, 2011), [18].

COUNTRY	Municipal waste generated, kg per person	Total municipal waste treated		Municipal waste treated, %			
		kg per person	% treated	Landfilled	Incinerated	Recycled	Composted
EU27	503	486	96.6	37	23	25	15
Belgium	465	460	98.9	1	42	36	20
Bulgaria	375	371	98.9	94	0	3	3
Czech Republic	320	319	99.7	65	18	15	2
Denmark	718	718	100	3	54	31	12
Germany	597	597	100	1	37	45	17
Estonia	298	257	86	70	0	20	10
Ireland	623	560	89.7	55	5	37	4
Greece	496	496 ?	100 ?	82	0	15	3
Spain	531	531	100	58	9	15	18
France	526	526	100	28	35	19	18
Italy	535	505	94.4	49	17	21	13
Cyprus	**658**	**658**	**100**	**80**	**0**	**11**	**9**
Latvia	350	292	83.4	88	0	10	1
Lithuania	441	387	87.8	88	1	9	2
Luxembourg	687	687	100	15	38	27	20
Hungary	382	382	100	67	11	17	5
Malta	584	536	91.8	92	1	7	0
Netherlands	596	502	84.2	1	38	32	28
Austria	552	528	95.7	3	35	28	34
Poland	315	255	80.9	71	1	11	17
Portugal	487	487	100	59	21	12	8
Romania	365	293	80.3	99	0	1	0

COUNTRY	Municipal waste generated, kg per person	Total municipal waste treated		Municipal waste treated, %			
		kg per person	% treated	Landfilled	Incinerated	Recycled	Composted
Slovenia	411	351	85.4	58	2	34	6
Slovakia	327	312	95.4	78	11	5	6
Finland	505	505	100	40	25	22	13
Sweden	460	460	100	1	51	33	15
United Kingdom	518	514	99.2	49	12	25	14
Iceland	571	530	92.8	73	11	14	2
Norway	483	473	97.9	2	57	25	15
Switzerland	689	689	100	0	50	35	16
Croatia	373	371	99.5	92	0	8	1
FYROM	357	357 ?	?	100	-	-	-
Serbia	361	281	77.8	100	0	0	0
Turkey	395	333	84.3	99	0	0	1
Bosnia and Herzegovina	410	391	95.4	100	-	-	-

*Data for the EU27, the Czech Republic, Germany, Ireland, Spain, France, Italy, Cyprus, Luxembourg, Austria, Poland, Portugal, Romania, the United Kingdom, Iceland, Turkey and Bosnia and Herzegovina are estimated

*** 0** equals less than 0.5%, while

"-" indicates a real zero.

WASTE COMPOSITION IN GREECE

Based on literature data, **Table 3.3-4** presents the methods of Mineral Processing to the Recovery of Useful Materials from each waste type. **Table 3.3-5** gives the composition of domestic waste from different areas of Greece. Basic characteristics of the composition of Greek domestic waste are the high percentage of fermentable organic materials and plastics. The average composition of MSW in Greece (wt %) is shown in **Figure 3.3-1** that follows.

Fluctuations in the categories of paper, plastic, metals, glass, fabric - wood - leather, aggregates and balances are not considered significant. In contrast, fermentable materials increase significantly during summer. When sorted by size, class II (40-120 mm) is not much different from class I (0-40 mm), while class III (> 120 mm) has the highest percentage.

The composition of waste varies depending on the time of year. Characteristics are given in **Table 3.3-6**, which shows the seasonality of composition of waste in the region of Thessaloniki.

Table 3.3-4: Methods of Mineral processing to the Recovery of of Useful Materials from type waste

Type of waste	Typical Mineral processing technique employed	Substances Recovered
End of life Vehicles	Crushing, Magnetic separation, Heavy media separation, sink float, Density separation, Electrostatic separation	Aluminum, Copper, Glass, Magnesium, Plastics, Rubber, steel, zinc
Solid Waste	Crushing, Magnetic separation, Gravity separation, Forth Flotation	Cu, Al, Zn, Cr, Fe, Cd, Pb, Mn, Ni, As, Hg, etc.
Metallurgical Slag	Crushing, Magnetic separation, Density separation, Electrostatic separation, Classification	Cu, Zn, Cr, Fe, Cd, Pb, Ni, Co, V, Mo, Al, etc.
Plastics Wastes	Sorting, Gravity separation, Froth Flotation and Electrostatic separation	Organic, compounds/ polymers
Paper	Filtration, Density separation, Via centrifugal cleaners, Forth flotation and washing	Clean Fibres of Paper
CRT	Crushing, Magnetic separation, Eddy Current Separation, Washing, Optical Sensing	Fe, Al, Glass, Cu, Plastics
PCB	Crushing, Grinding, Density separation, via Shaking tables	CU, AU, Fe, Stannum and Non metals

Table 3.3-5: Composition of MSW in Greece, (wt %).

Waste Composition	Athens	Thessaloniki	Rhodes	Chania	Kalamata	Kos	Naxos
Organic waste	56	52	41	55	37	47	48
Paper	20	18	15	19	25	25	22
Fabric, Wood, leather	4	8	4	4	5	6	5
Metals	3	5	10	4	5	3.5	3
Plastic	7	7	12	8	11	7.5	9
Glass	2,5	4	16	4	12	3	6
Aggregates + Other	7.5	6	2	6	5	8	7

Table 3.3-6: Composition of waste in Thessaloniki according to season (wt %).

Waste Composition	Spring	Summer	Fall	Winter
Fermentation	54.7	57.3	49.2	45.9
Paper	17.2	15.0	20.4	18.1
Fabric, Wood, leather	7.7	7.3	10.2	12.5
Plastic	6.9	6.5	6.4	9.5
Aggregates	3.5	4.3	3.1	4.2
Metals	6.2	5.7	6.0	5.0
Glass	3.8	3.7	4.7	4.8

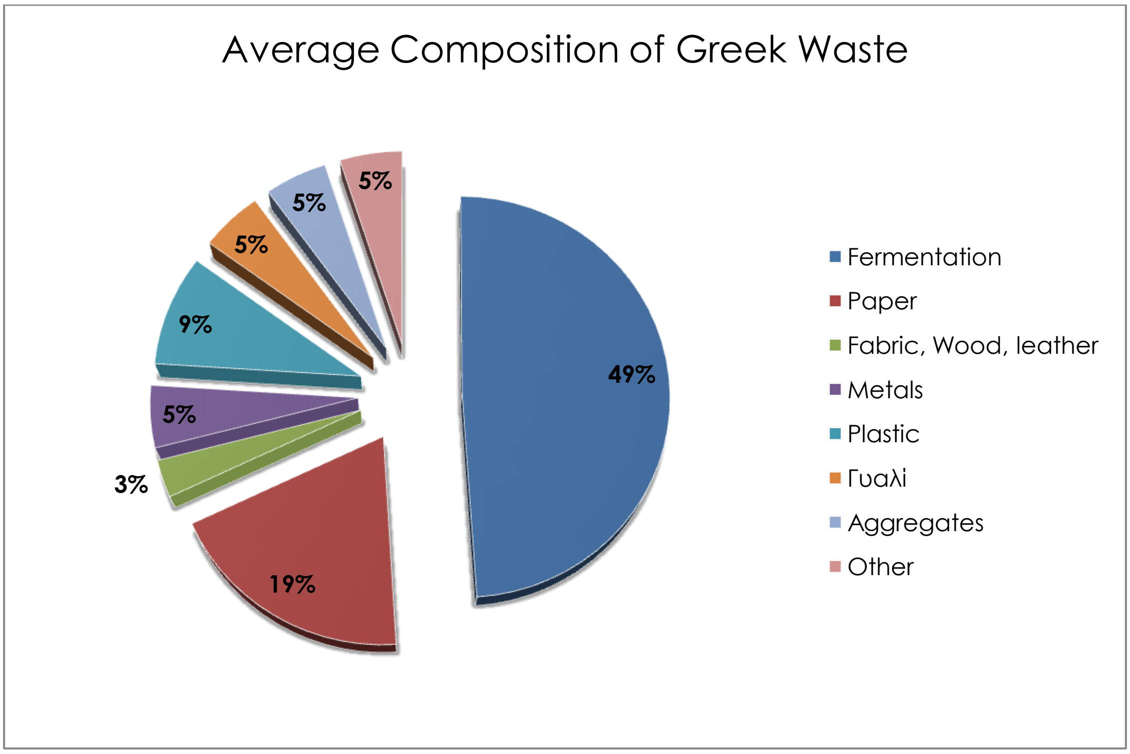


Figure 3.3-1: Average composition of Greek MSW (based on weight).

CONCLUSIONS

MSW consists, to a large extent, of waste generated by households, but may also include similar wastes generated by small businesses and public institutions and consequently collected by local municipality services; this part of municipal waste may vary from municipality to municipality and from country to country, depending on the local waste management system. The abovementioned estimations also include areas not covered by a municipal waste collection scheme, nevertheless, waste from agriculture and industry are not included, despite the fact that in many areas of Greece may still be mixed in municipal waste.

The reported quantities of waste generated and treated for some Member States may deviate from reality, for the following reasons:

- There are differences in estimates for the population not covered by collection schemes;
- There are weight losses and alteration owing to dehydration of water content;
- There might be double counts of waste undergoing two or more treatment steps, exports and imports of waste and time lags between generation and treatment (temporary storage).

Despite local differences between various waste streams, it can be deducted that the percentage of each waste streams fluctuates between certain bounds which may vary from the annual averages for each season, especially in winter and summer periods.

1.4. Main equipment commonly used for the separation and recycling of waste

1.4.1. Crushing equipment

Primary Shredder

Primary shredders use two unique intertwining shredding shafts, that can be configured according to requirements and operate at a maximum speed of 46 revolutions per minute (rpm). The material placed into the hopper is drawn in by the shafts, torn and broken down to be routed directly to the horizontal belt. If the hydraulic end pressure is reached during the shredding process, the shafts of the HAMMEL shredder reverse automatically. The shafts run backwards, throwing the material apart and clean themselves (**Figure 3.4-1**) (Hammel.de, Weinstein, 1977, Mineral Processing Handbook, 2011).

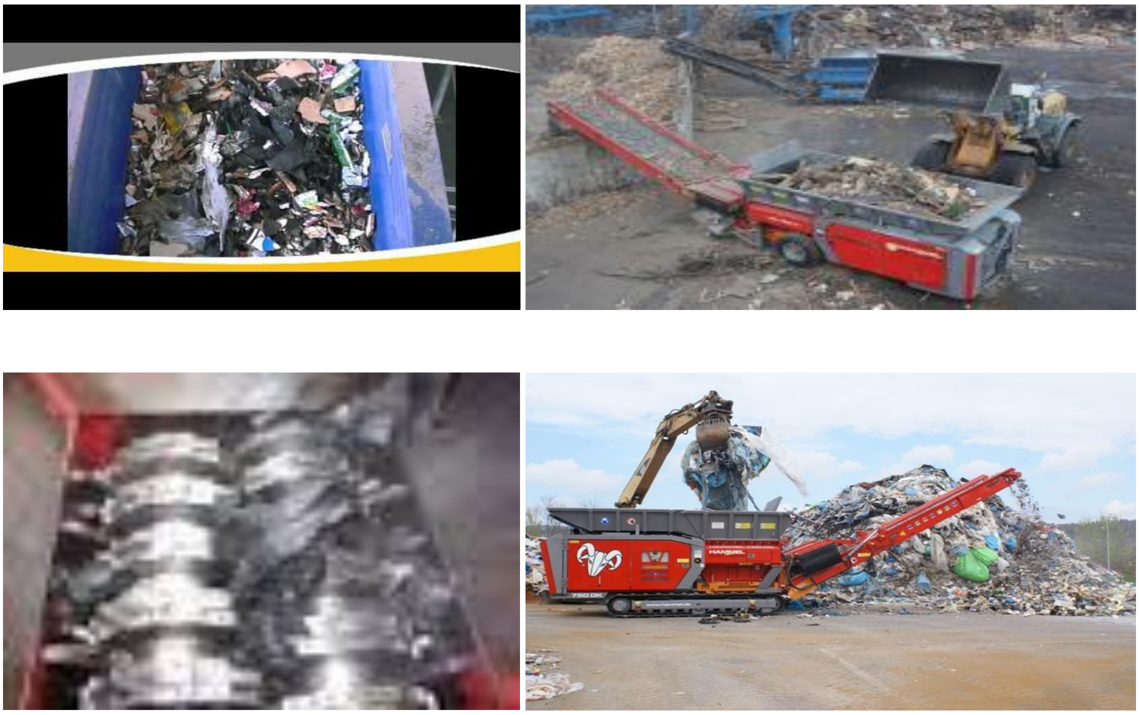


Figure 3.4-1: Primary Shredder (Hammel.de, Weinstein, 1977, Mineral Processing Handbook, 2011).

Shaft shredding

Crushing is performed by a revolving vertical rotor and the material is fed from the top. The mechanical actions resulting from the interaction of the revolving rotor with the glass and the chamber walls produce the requested glass size reduction (**Figure 3.4-2**). A screening system, in a closed loop with the impactor, allows obtaining the desired particle size. The shredder allows for large productions, but a pre-broken feedstock, usually obtained utilizing a primary crusher, is required. The wear rate is minimized; the resulting particles are round shaped, (Hs-Bremen.de, Directindustry.com, Mgmineralprocessing.com, Weinstein, 1977).

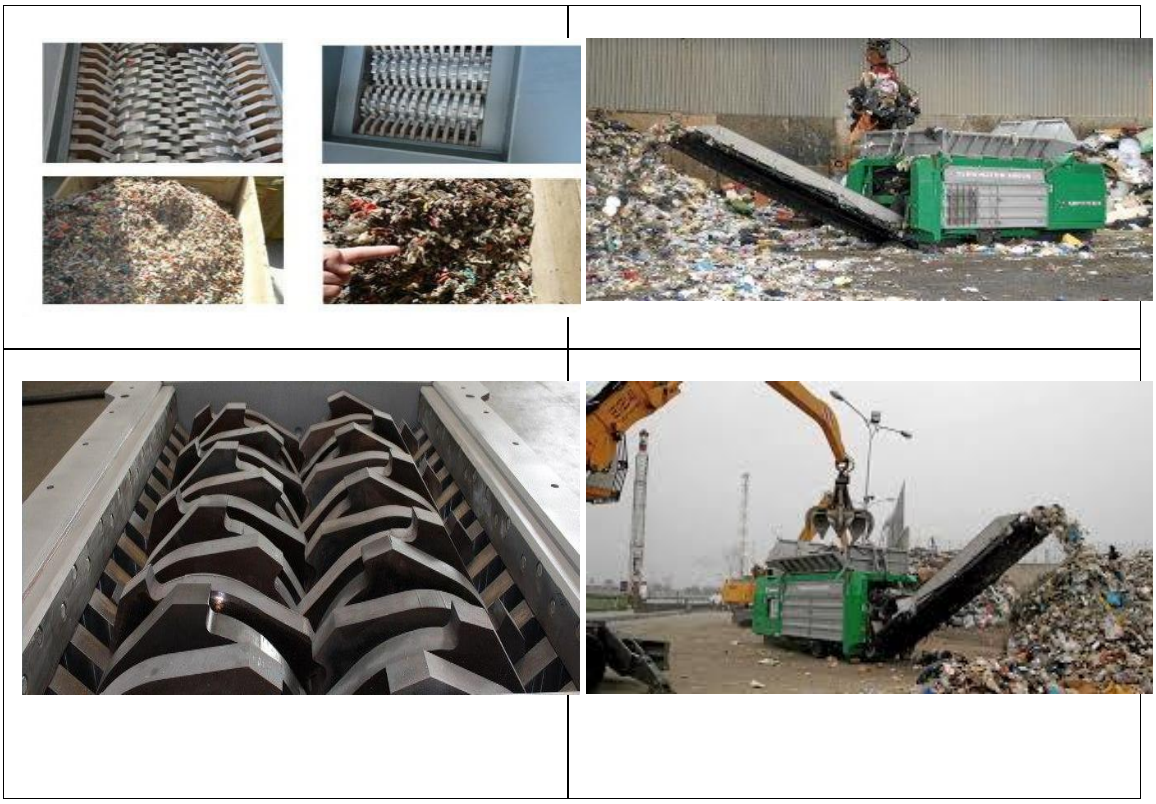


Figure 3.4-2: Shaft Shredder (Hs-Bremen.de, Directindustry.com, Mgmineralprocessing.com, Weinstein, 1977).

Impact Crushers

Impact crushers are made up of multi-sectional body and breaker plates. A rapidly rotating roller is equipped with exchangeable hammers (considered consumable). It is possible to adjust the distance between the breaker-plates and the hammers, as well as the inclination of the breaker-plates. Impact crushers are filled from above and discharged below. If crush-resistant material enters the crusher, the breaker-plates can withdraw upward and the material is ejected downward (**Figure 3.4-3**).

The charging material of the crusher is grabbed by the hammers and they slam the material against the breaker-plates. The plates are arranged so that the material remains in the crushing cycle until the material has the right size of the particle that it can pass through the opening between the rotor and the breaker plates. If such a crusher is used for waste including either construction debris or metal wires, it is essential that bars and wires are cut-up or shortened so that they do not wind around the rotor and cause the system lock-up, (Hs-Bremen.de, Directindustry.com, Mgmineralprocessing.com, Telsmith, 2011).

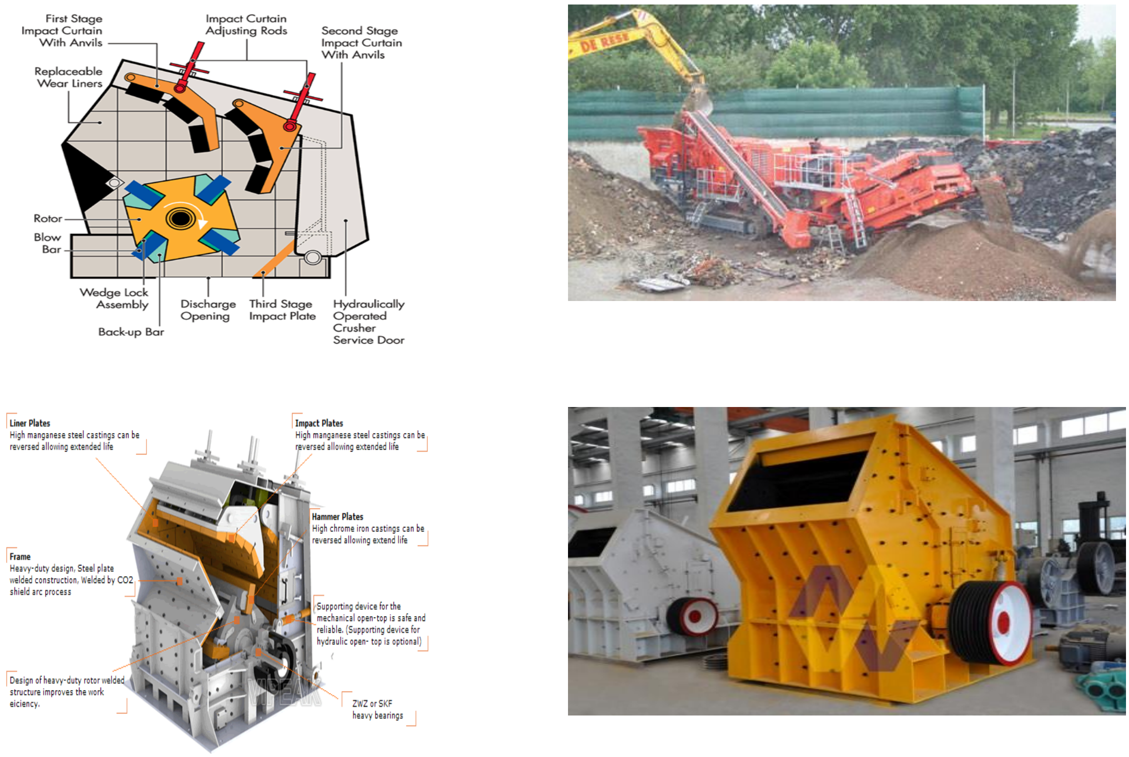


Figure 3.4-3: Impact crusher (Hs-Bremen.de, Directindustry.com, Mgmineralprocessing.com, Telsmith, 2011).

Jaw Crusher

A jaw crusher is usually used for hard and brittle material. The material is entering the crusher from above in between two swinging jaws (**Figure 3.4-4**). Owing to the moving jaws, the material is crushed and ground. It is possible to influence the particle size of the final product adjusting the space between jaws. Usually, jaw crushers are used in construction and demolition industries, (Hs-Bremen.de, Directindustry.com, Mgmineralprocessing.com, Telsmith, 2011).

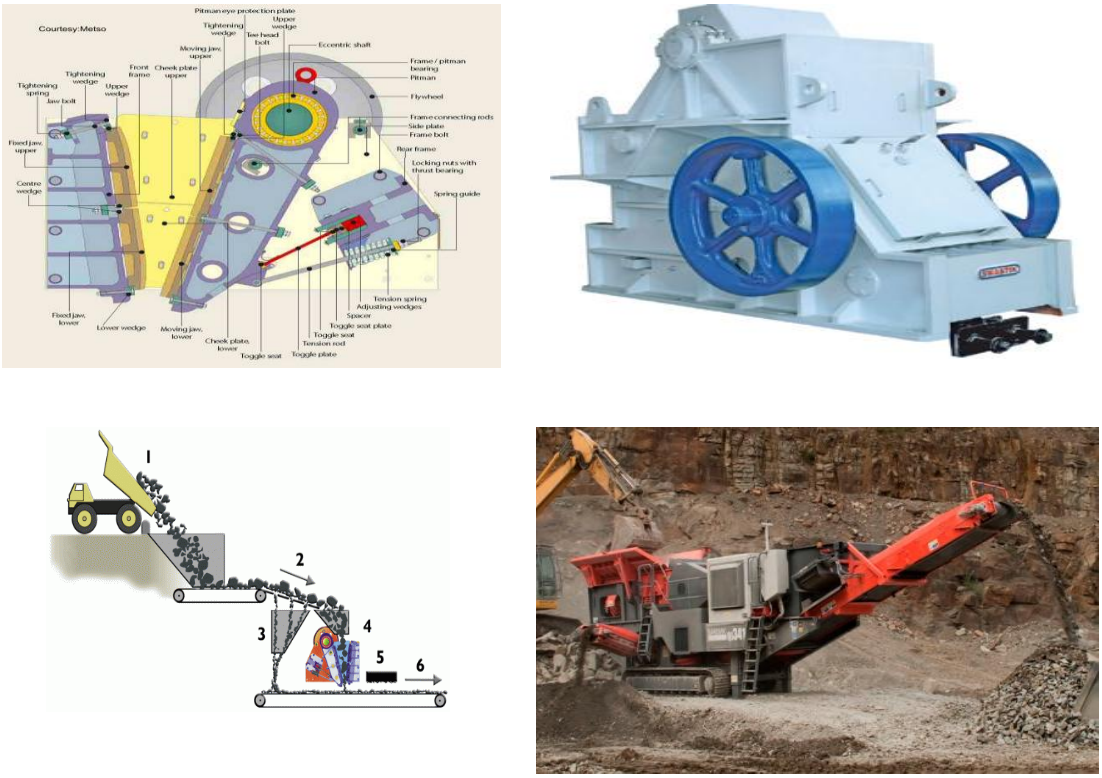


Figure 3.4-4: Jaw Crusher (Hs-Bremen.de, Directindustry.com, Mgmineralprocessing.com, Telsmith, 2011).

Hammer Mills

Hammer mills have various versions which only vary in the construction of the rotor of the mill. The usually conduce to minimize scrap automobiles, construction, commercial and paper waste pieces. It is possible to differentiate between horizontal or vertical shafts with attached flexible blades (**Figure 4.1-5**).

The vertical version of the mill is characterized by a vertical rotor, which is equipped with hammers. It was designed for the preparation of household wastes. Because of the low initial input, air is drawn out through a side vent at the time of charging. So it is possible to minimize also light weight fractions like paper or plastics with a high capacity. Since there is no limit for the particle size, the particle size distribution is varied by the number of hammers inside the mill. By a raising number of hammers follows a finer particle size and a lower capacity. To control the size of the particle it is necessary to check the distance between the single hammers.

A special version of the hammer mill is the roll crusher used for pre-processing of construction debris. A horizontal travelling grate conveyor feeds the debris to the crusher. The rapidly rotating hammer roller positioned above the conveyor crushes the material (Hs-Bremen.de, Directindustry.com, Weinstein, 1977).

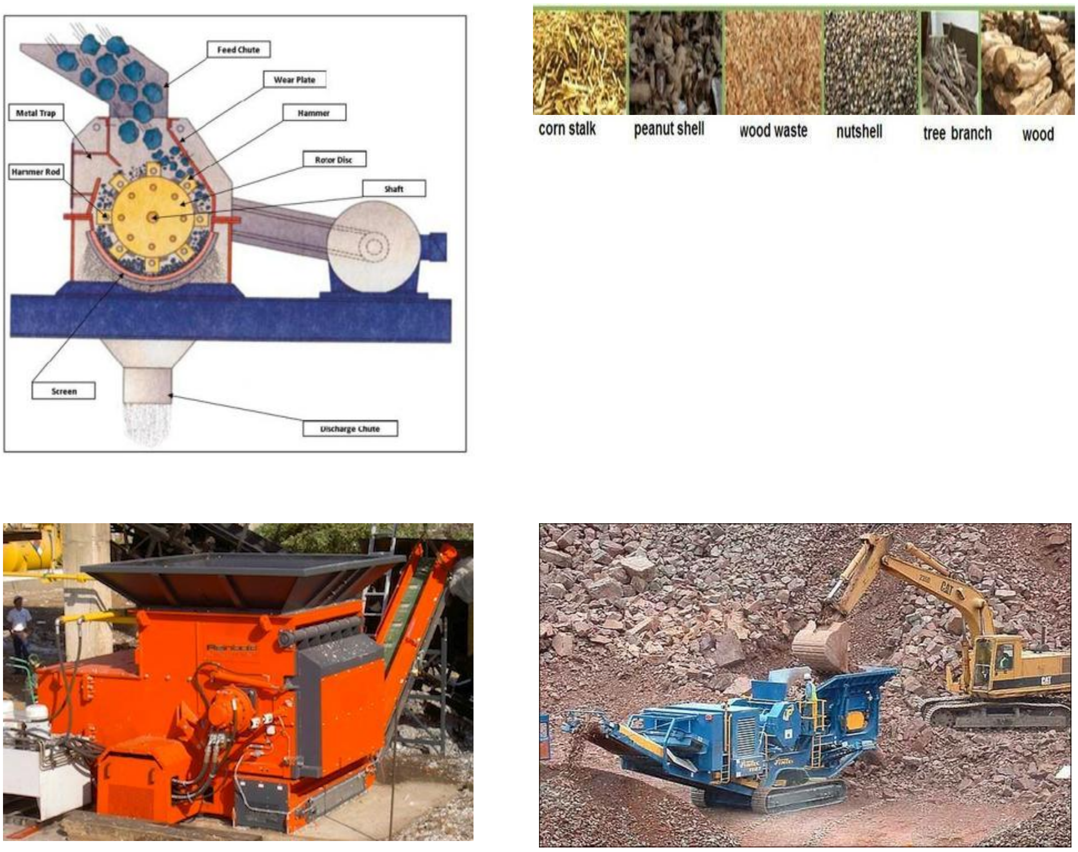


Figure 3.4-5: Hammer Mills (Hs-Bremen.de, Directindustry.com, Weinstein, 1977).

Chippers

In comparison the hammer mills which are high speed mills (up to 1200 rpm), chippers and roll crusher operates with lower speed. The speed of the shaft has only around 20 to 60 rpm. The mill can be equipped with one or even two horizontal shafts (**Figure 3.4-6**). Because of the rotation of the shafts in opposite direction against a cutting edge the material is drawn towards them.

The minimization occurs between the cutting edges regardless if it is hard or soft material. The degree of reduction is decided by the choice of the pitch between the blades and also the width of the tooth face of the rotary cutter. If there is an insufficient size reduction of the particle, it is possible to switch the several aggregates back-to-back. To realize a high feed rate of voluminous or bulky waste it is useful to install hydraulic presses to force the material toward the cutting blades. Massive metal pieces or other unbreakable material cannot be reduced. When the force of the motor is exceeded, the rotary blades automatically reverse and the material must be removed by hand. Usually it is better to remove bulky and unbreakable material before it goes to the mill. A better control of the particle size is achieved by adding rapidly turning rotary drum cutters with mesh bottoms. The major problem is the abrasive influence of the material on the mill. Rotary drum cutters are most often used for size reduction of plastics (Hs-Bremen.de, Schmidtequipment.com).


Figure 3.4-6: Chippers (Hs-Bremen.de, Schmidtequipment.com).

Cascade Mills

A cascade mill is a slowly rotating rotary drum. The ratio of diameter to length is approximately 3:1 and the end walls are sloped conical. Round about 17 % of the mills interior capacity is filled with steel balls (**Figure 3.4-7**). At an optimum rotation of 14 to 20 rpm, a mixture of the steel balls and the waste, form an ideal surface area against which the feedstock rolls. With the help of the grinding and rolling action of the steel balls against the waste it is possible to realize a reduction of the particle size. If the waste achieves the right size of the particle, it can discharge through holes in the housing of the mill. Also the steel balls can exit the mill via these holes when sufficient wear has reduced their size. They must be routinely replaced. In this kind of mills also unbreakable materials or massive metal pieces can serve as grinding body. Then the size reduction is called semi-autogenous grinding process (Hs-Bremen.de, Katangamining.com).

Figure 3.4-7: Cascade Mills (Hs-Bremen.de, Katangamining.com)

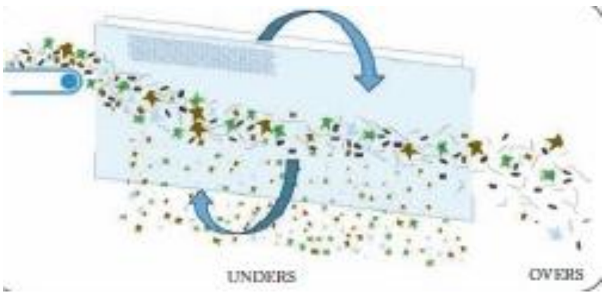
Rasp Mills

This process is specially developed for the treatment of waste in composting facilities. The rasp mill contains alternating screen segments with 25-44 mm size holes and shredding teeth. The material is dragged in and around by a rasping arm that turns above the screen at 8 to 10 rpm. Easily shredded materials (e.g. kitchen waste, glass, paper and cardboard) discharge the mill after a dwell period of about 20 minutes. The materials which are more resistant (e.g. textiles, metals, plastics) are caught up on teeth segments and are periodically pushed out by the rasping arm through a side discharge. Nowadays rasp mills are less used for size reduction of waste, because of a less efficiency in size reduction of the waste in comparison with hammer mills. And, the other disadvantage is its discontinuous operating control (Hs-Bremen.de).

1.4.2. Screening equipment

Trommel screen

One of the proven classification systems is the trommel screen. It can be used for primary screening as well as for the final screening of the material after the size reduction (Figure 3.4-8). Trommel diameter, rotational speed, the size of the screen openings, the type and number of baffles and the inclination of the cylinder are factors which have an influence on the input and screening efficiency. Since the effective screen area is relatively small, deflectors and other wall assemblies are installed to carry the waste as high as possible up the trommel wall in order to receive the maximum screening potential. To increase the screen efficiency rating, spiral shaped deflectors are installed on the trommel walls to transport the material through the trommel regardless of the degree of the trommel. It is also possible to classify the material in more than two fractions by installing different screen openings in succession inside the trammel (Hs-Bremen.de, Cpgrp.com, Cpmfg.com, Richard, 1993).



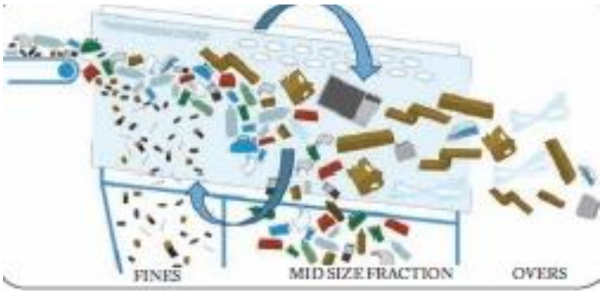


Figure 3.4-8: Trommel screen, (Hs-Bremen.de, Cpgrp.com, Cpmfg.com, Richard, 1993).

Oscillating screen

An oscillating screen belongs to the dynamic screening methods and is been classified as a clog free and productive screening method. It is often used for screening composts (**Figure 3.4-9**). The screen consists of a flexible woven mesh made of rubber or plastic attached to oscillating arms moving in opposite directions. The automatic opposing operation of the arms causes a wave-like motion of the woven mesh with considerable amplitude (30 to 50 mm). Oscillating frequencies of 1/600 to 1/800 minutes are reached, which causes a relatively strong impact of the screening material against the woven mesh (Hs-Bremen.de, Hofmanngroup.com).

Figure 3.4-9: Oscillating screen (Hs-Bremen.de, Hofmanngroup.com)

Bucket screen

Because of the ease of operation and the clog free nature, bucket screens are used for construction and demolition wastes as well as for fine grained materials (**Figure 3.4-10**). By using this aggregate the fine fraction falls into buckets and is carried away from the highest point of the machine via a conveyor. The bucket screen is open at the top and is S-shaped in the active screening area. The coarse grained fraction slides down the inclined surface of the machine. Gravity causes the course fraction to fall back into the wave trough and a conveyor carries the coarse grained fraction away (Hs-Bremen.de, Recyclingproductnews.com).

Figure 3.4-10: Bucket screen (Hs-Bremen.de, Recyclingproductnews.com).

Ballistic separator

The ballistic separators were developed for the separation of household and commercial wastes. It allows a separation into 3 fractions: fine, light and heavy (**Figure 3.4-11**). The operation of this aggregate can be described as screening classifier. The main working part of a ballistic separator is the moveable, inclined and perorated plate screen deck. The deck is divided into rows of vibrating elements and the material, depending on gravity and form, is transported up or down. The heavy parts of the waste move to the lowest level. The lighter particles (e.g. plastic foil and paper) move in the opposite direction toward the highest level of the deck. Falling through the perforated bottom of the deck, the third, fine fraction is produced (Hs-Bremen.de, Tinsleycompany.com, Hartner-maschinenbau.de).

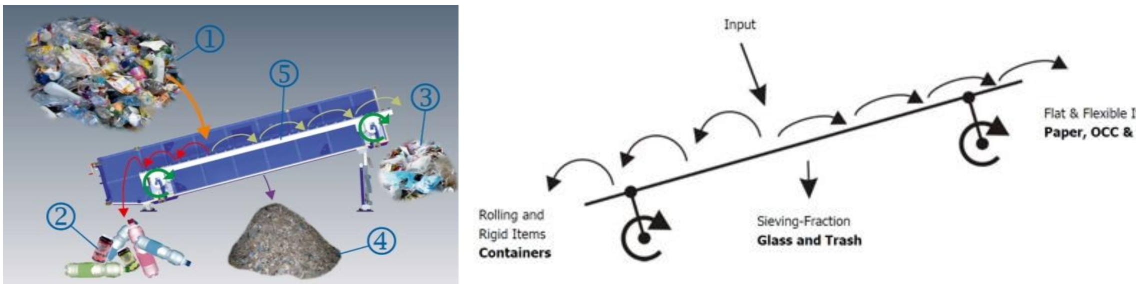


Figure 3.4-11: Ballistic separation (Hs-Bremen.de, Tinsleycompany.com, Hartner-maschinenbau.de).

Disc Screen

A disc screen is a cascading-type classifier constructed of sorting grates with a number of step-like arranged (**Figure 3.4-12**). The discs are installed so that every disc is spaced in the open notch of the neighbouring shaft. The interstitial distance between the discs determines the size of the screen opening of each grate (Hs-bremen.de, Cpmfg.com).

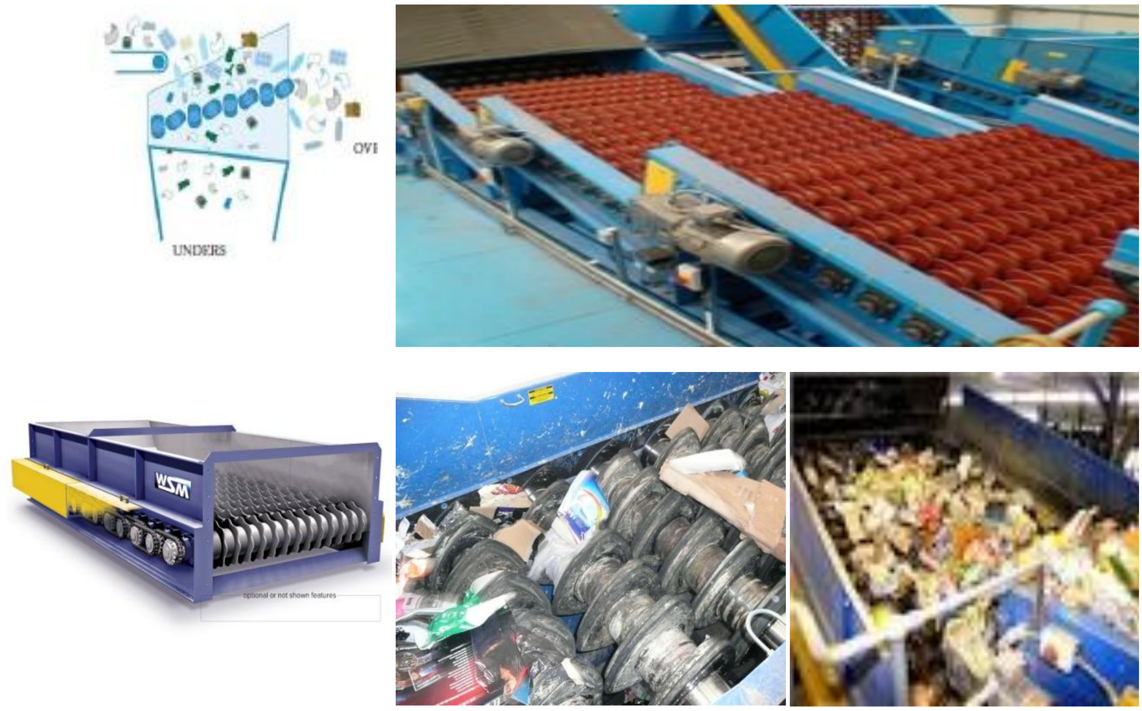


Figure 3.4-12. Disc Screen (Hs-bremen.de, Cpmfg.com).

Vibratory Screen

VS usually work in a closed loop with crushing unit. As for TRO cullets can pass through, or not, the sieving surface, according to their size, usually larger particles are fed again (closed loop) to the comminution unit (crusher) or rejected if recognized as pollutants (**Figure 3.4-13**). According to the requested cullets size class characteristics, vibratory screens can allow to classify particles population up to - 75 μm. When such dimensional grades are requested obviously throughputs are lower. Usually multi-deck VS, up to five, are utilized when the final cullet product has to be divided in several dimensional classes (Chinahongji.com, Crusherasia.com).

Figure 3.4-13: Vibratory Screen (Chinahongji.com, Crusherasia.com).

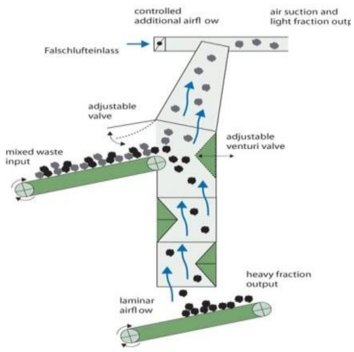
1.4.3. Air classification equipment

Introduction

These types of classifiers are based on the utilization of air flow to classify particles. Different from sieving, particles are thus classified / separated according to their size, shape, and density. An AC is a vessel where an air flow is generated. Wastes are usually fed from the top, coarse (larger or heavier) and fine (smaller or light) particles follow a different path according to flow characteristics, that can be set to achieve the required classification/separation. Classification/separation can be achieved simply utilizing gravity or/and free or forced vortex generated by static vanes or a dynamic classifier wheel. The equilibrium between the forces determines the "cut point." ACs represent a good alternative to screening, especially when the materials to classify are characterized by the presence of large fraction of fines (particles below 250 µm). When a well classified coarse fraction is requested, air classifiers are utilized prior to screening (Weinstein, 1977).

Zig-zag air Classifier

Zig-zag air classifier are well proven and often used for the separation of household wastes. The wastes are fed into a zig-zag shaped vertical column while being subjected to a stream of air introduced from the bottom (**Figure 3.4-14**). At each corner of the classifier the waste is resorted because the air stream is forced to flow cross-current. This permits a sorting with a low error rate. The components of the waste are sorted into heavy and light fractions. By changing the input or the speed of the air stream it is possible to get a higher selectivity (Hs-bremen.de, Globalspec.com, Genoxtech.com).



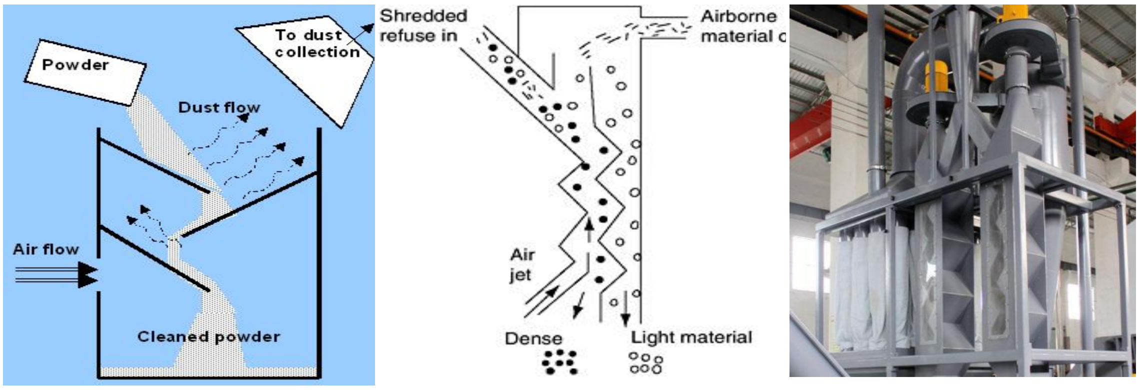
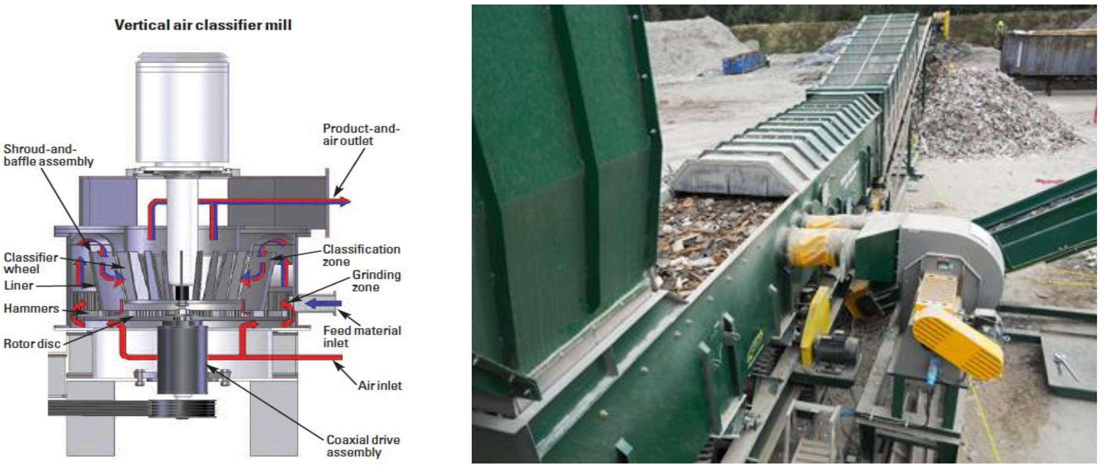


Figure 3.4-14: Zig-zag air Classifier (Hs-bremen.de, Globalspec.com, Genoxtech.com)

Rotary Air Classifier

The rotary air classifier is constructed of three major components: a rotating drum, a screened settling chamber and a compressed air system. It is necessary to use shredded and sorted the waste for the rotary air classifier (**Figure 3.4-15**). Compressed air is injected and so the lightweight material becomes airborne and it is blown down toward the settling chamber. The heavy particles are further transported and dropped from the drums smaller, lower end. The cutting edge can be influenced by a lot of parameters. To minimize the emissions, the majority of the air can be recirculated (Hs-bremen.de, .Cdworldmag.com, Metaltechsystems.com).



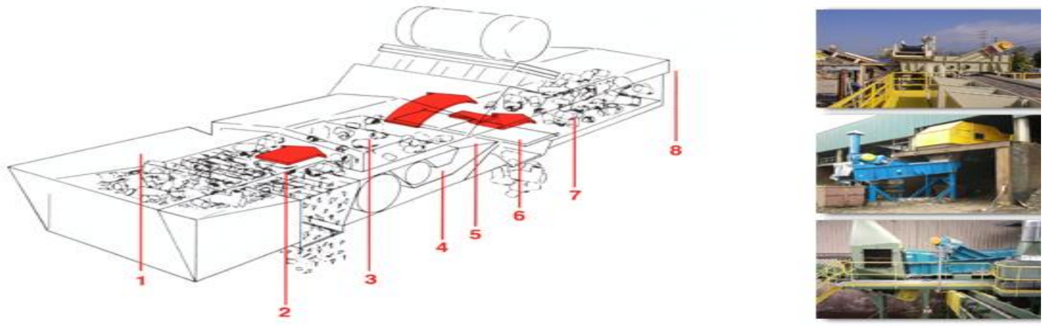


Figure 3.4-15: Rotary Air Classifier, (Hs-bremen.de, .Cdworldmag.com, Metaltechsystems.com).

Cross-current Air Classifier

In this kind of air classifier the air is blown perpendicular to the fall direction of the material. Because of the short contact time between the falling material and the air stream, there is a marginal separation. If there is a widely density range of the waste (e.g. shredded automobiles) then there is a successfully use of these classifiers possible (**Figure 3.4-16**). When a focused high velocity air stream is used, the unit is called an impulse air classifier and this one is used successfully in the waste industry (Hs-bremen.de, karlschmidt.com).

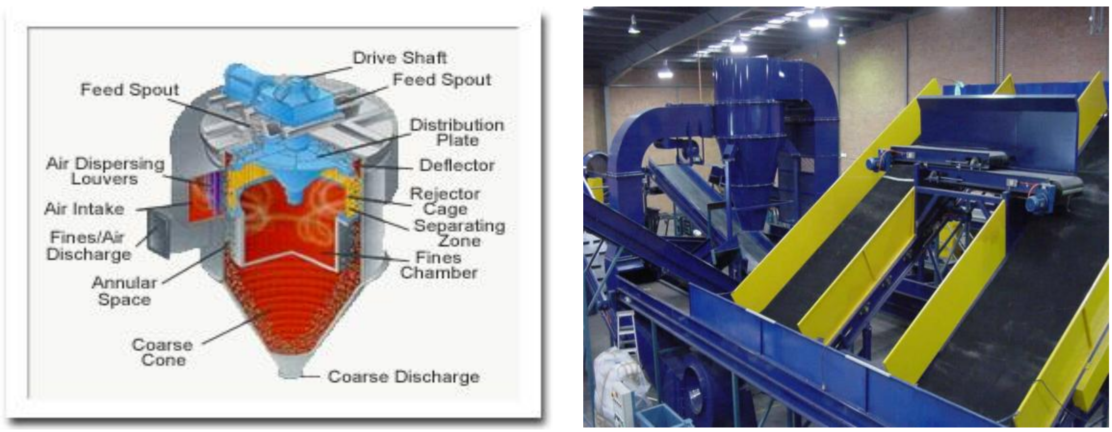


Figure 3.4-16: Cross-current Air Classifier (Hs-bremen.de, karlschmidt.com)

1.4.4. Separation equipment

Introduction

The process of sorting takes advantages of the individual physical characteristics of each fraction of the waste. The various kinds of sorting techniques include density, flotation, optical, magnetic and electrical sorting. In practice a lot of developed aggregates prove to be too expensive or not useful for the heterogeneous waste stream. The established separators in the field of waste management are magnetic separators, hydrocyclones, density sorters and flotation separators.

Magnetic Separation

For magnetic separation generally overhead magnetic separation systems are used. This system attracts ferrous material from the waste stream and conveys it away. To be effective the separation system needs one pre-treatment step (**Figure 3.4-17**). It is necessary to reduce the size of the particles in the waste stream. So the ferrous material is separated from the other materials and can easily catch by the magnetic separator. The size of the material is no criterion of limitation, because magnets of all dimensions are available. The ideal particle size of municipal solid waste ranges between 10 to 100 mm (Hs-bremen.de, Tinsleycompany.com, Startraceltd.com).

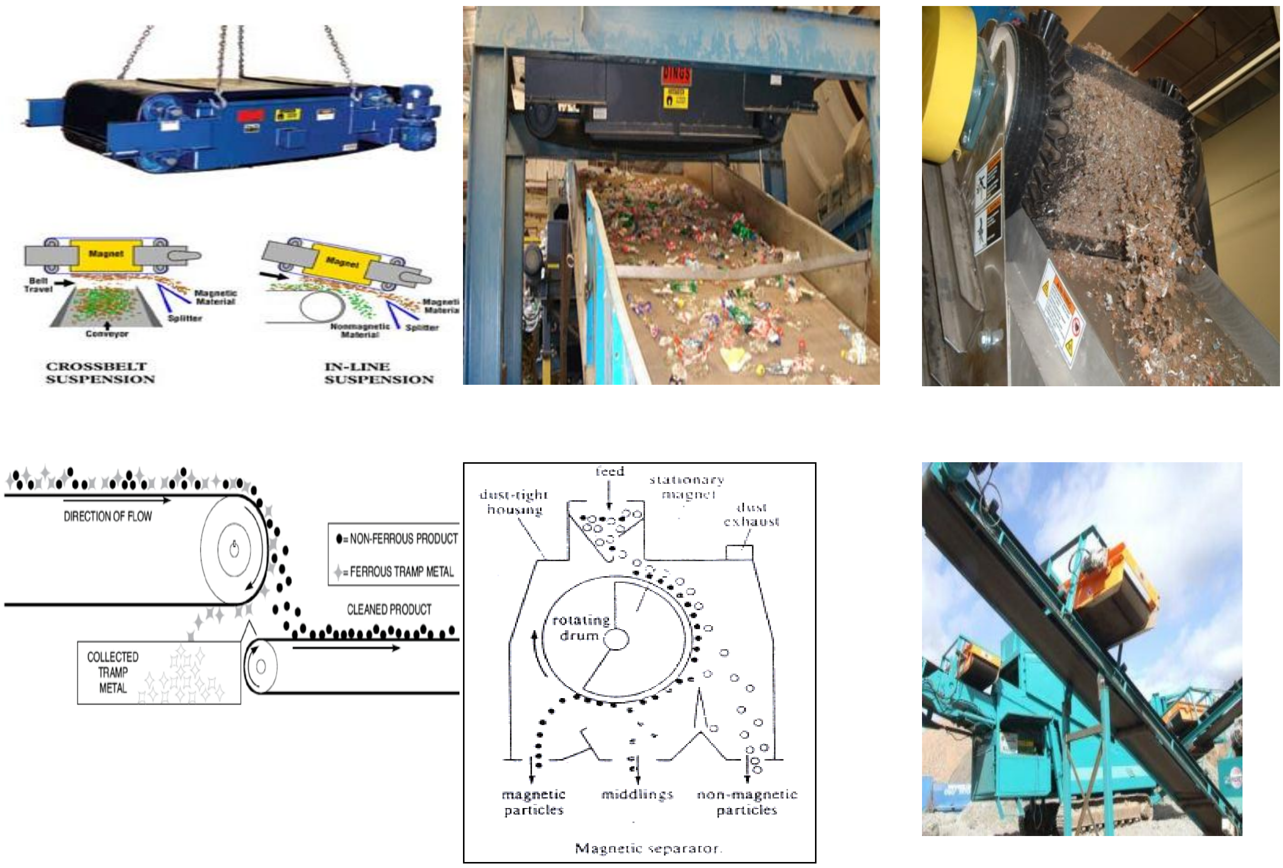


Figure 3.4-17: Magnetic Separation (Hs-bremen.de, Tinsleycompany.com, Startraceltd.com)

Eddy Current Separators

The edge current separator provides a mechanism for sorting a waste mixture of similar density grade (**Figure 3.4-18**). This technology relies on the induction of eddy currents in metal objects in response to an electromagnetic field. Eddy currents are created when conductive objects are located in or exposed to a spatially or temporally alternating magnetic field. Eddy currents, irrespective of the circuits form, flow in closed loops within the conductor. According to Lenz's law, the induced electric current produces a magnetic field opposite of the field to which it is exposed. A force is produced against the conductive object which trusts the object out of the magnetic field. Less conductive objects require less force. With increasing density, greater hurling force is necessary due to the mass inertia of individual objects. Extensive use of this technology began in the United States, where aluminum used beverage cans were reprised (Hs-bremen.de, Tinsleycompany.com, Startraceltd.com, Richard, 1993).

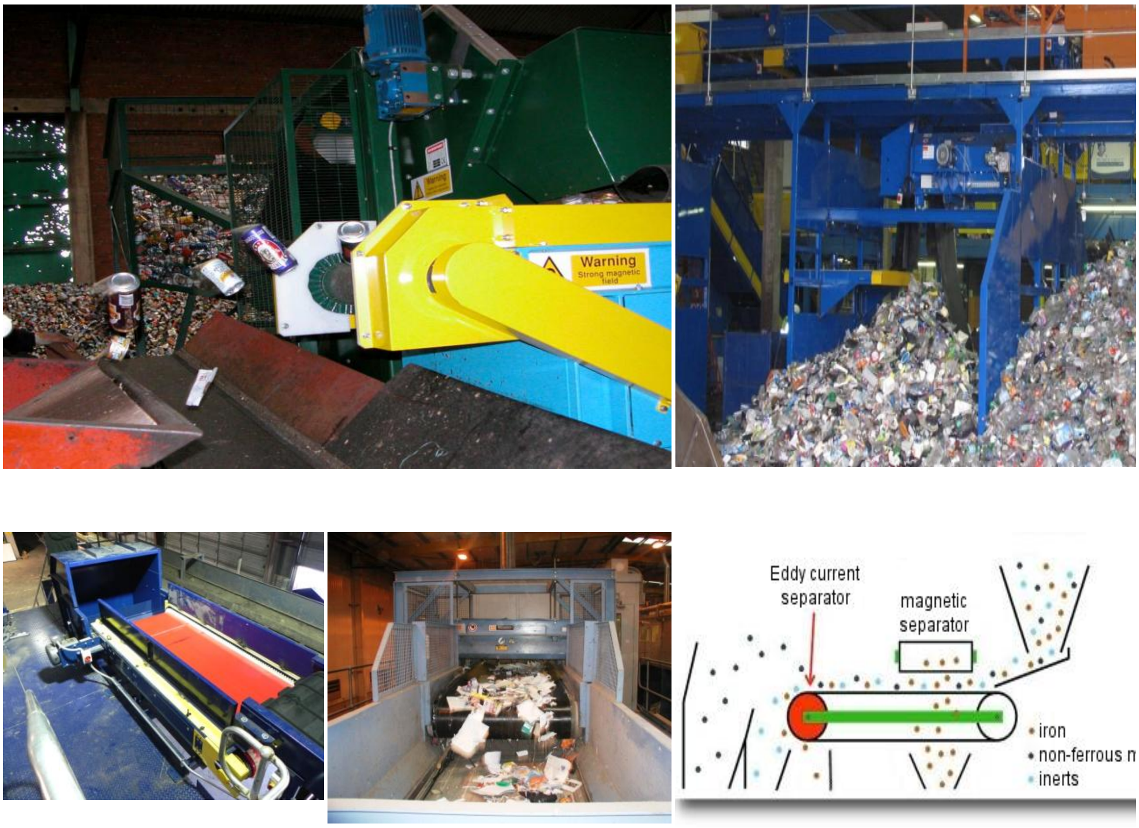


Figure 3.4-18: Eddy Current Separators, (Hs-bremen.de, Tinsleycompany.com, Startraceltd.com, Richard, 1993).

Optical Sorting

This treatment version for the waste stream was especially developed for sorting mixed, crushed glasses into the different colours (**Figure 3.4-19**). For separation manufactures have developed electro-optical sorters which recognize the colour of the glasses based on their opacity and with the aid of a blast of compressed air, deflect the particle from its flight path into appropriate catch bins. While sorting of glass it is practicable to achieve a purity grade of 98 %. To achieve this degree of separation it is necessary to sieve, to reduce the particle size and to individualise the glasses. Singular glass particles are optically inspected in the following order: flint glass, green glass, brown glass and non-transparent (Hs-bremen.de, Karlschmidt.com, Magsep.com).

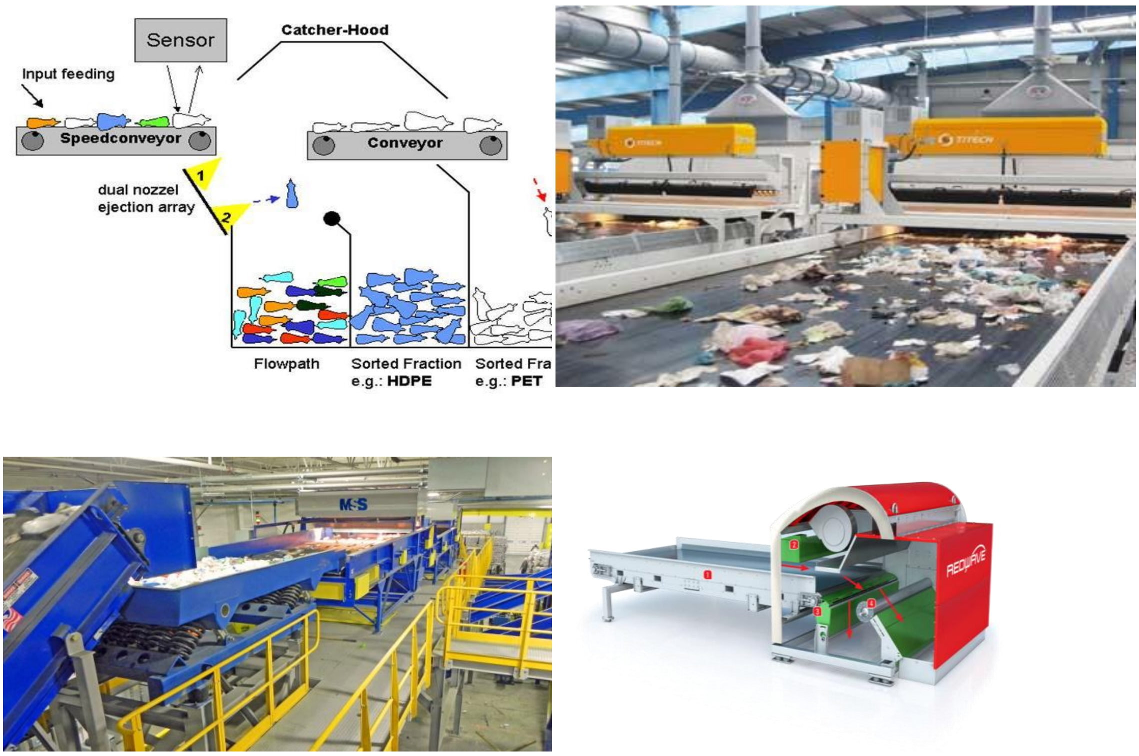


Figure 3.4-19: Optical Sorting, (Hs-bremen.de, Karlschmidt.com, Magsep.com).

Flotation

The typical use for flotation is the sorting of a material mixture having similar specific densities. In the field of waste management flotation is used for removing contaminants in plastics and especially flotation is used at German paper mills (**Figure 3.4-20**). There, they use the flotation for the deinking process to produce high quality graphic paper from paper waste. Because of this process paper waste recycling has increased in the last decade. The principal of deinking relies on the physical wettability of the fibres and the printing ink. Various surfactants are added to aid the flotation process. These surfactants are made up of hydrophobic, long-chained molecules with attached hydrophilic functional groups, usually soaps. To cause the attraction of the hydrophilic soap molecules to the originally hydrophobic ink particles in the air bubbles, they must react with hard water. (primarily Ca^{+2} ions). The precipitated soaps, having reacted with the hard water, become collector agents, and carry the light flocs of ink to the surface while non-precipitated soaps stay in solution. Due to the change of the production process of paper by using new chemicals also efficiency of the waste paper recycling changes and become lower (Hs-bremen.de, Hawkesdale-Mortlake College, Flsmidth.com, Panamenv.com).

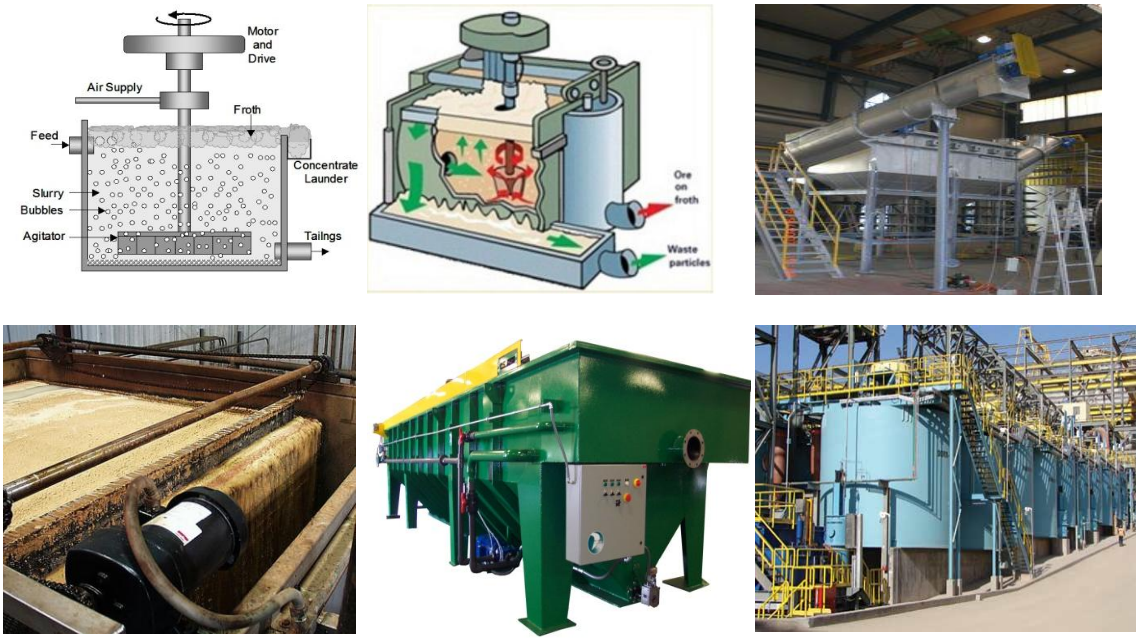


Figure 3.4-20: Flotation cells (Hs-bremen.de, Hawkesdale-Mortlake College, Flsmidth.com, Panamenv.com)

Density Sorting

The source of this technology was the mining industry and the processing of the ores. They developed a fluid medium for the density sorting. This technology was also applied for sorting waste components, nonferrous metals, glass, plastics and contaminants found in MSW stream. Today, density sorting is often used for sorting plastics. There are two types for the density sorting with fluid mediums:

- Float-sink method and
- Hydrocyclones

Sink - Float method

This technology can result in purity grades of over 98 % for mixed plastics. However, the soft PVC fraction cannot be separated with this technology. The hydrophobic nature of plastics is easily enhanced during sorting with the aid of wetting agents. The separating liquid is adjusted to the density range of mixed plastic components from household and commercial waste by adding $CaCl_2$ (**Figure 3.4-21**).

Better sorting occurs when additional chemicals that increase the wettability of the plastic surfaces were added. The heavy fraction was comprised of PS and PVC. Pre-processing the waste stream through an air classifier can be used to collect most of the fines. An essential point for the success of this method is that no turbulences must occur in the separation zone that could cause the heavy fraction to become suspended. For economic reasons, only continuously operated float-sink separators should be considered in the waste management industry (Hs-bremen.de, Haith-recycling.com, Navarini.com).

Figure 3.4-21: Sink - Float method (Hs-bremen.de, Haith-recycling.com, Navarini.com)

Hydrocyclones

The separation of various types of plastic form a granular mixture which is accomplished in the centrifugal force field within a hydrocyclone (**Figure 3.4-22**). The geometry of a cyclone creates an upwardly spiralling innervortex that carries out the light fraction while an outer-vortex spirals downward and brings out the heavy fraction. The hydrocyclone is distinguished from a float-sink separator by its simpler construction, lack of complicated components and a higher feed rate. The type and quality of units used for the initial pre-processing or size reduction of the input, play an important role in the quality and concentration of the output generated by a hydrocyclone (Hs-bremen.de, Lenntech, 2007, Oilfield GN Solids Control).

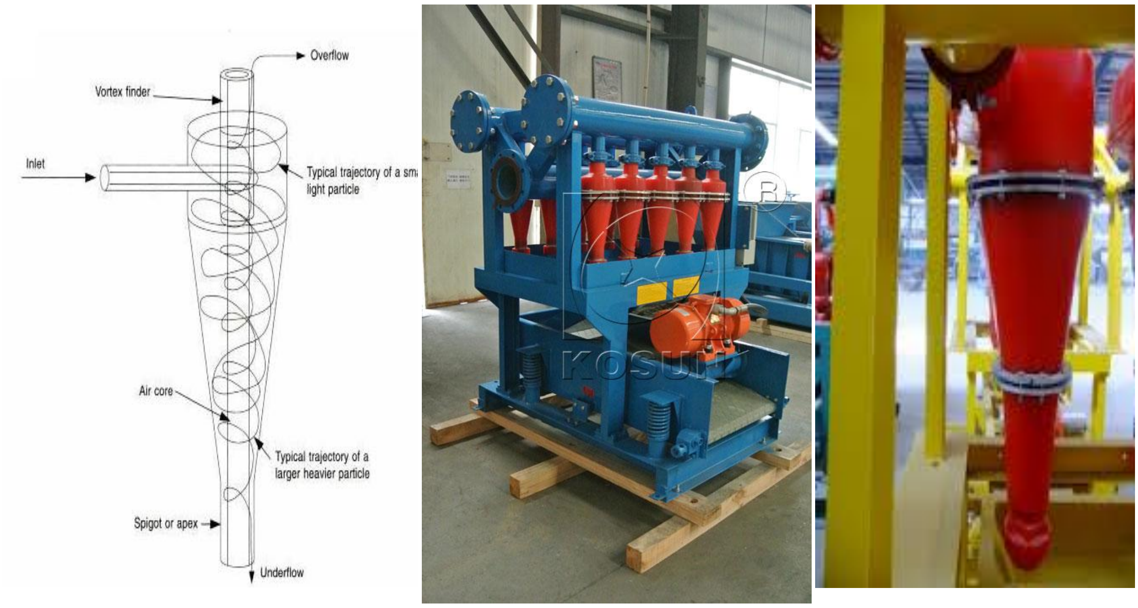


Figure 3.4-22: Hydrocyclones (Hs-bremen.de, Lenntech, 2007, Oilfield GN Solids Control)

1.5. Special systems

1.5.1. S.O.R.T. Recycling Systems

Description of the System operation

The S.O.R.T. can handle household, commercial and industrial waste, office waste and single stream curbside waste. Materials include: Printer cartridges, Electronic goods, Mixed paper, Corrugated cartons, Plastic film, Polystyrene foam, Carpet, More

The S.O.R.T. is an efficient system from start to finish. An automatic bag opener receives incoming waste. This includes a metering bunker. This allows for a continuous input of waste without using the loader. To deal with waste containing a high percentage of glass, a vibratory finger-screen takes material as it leaves the bag opener. This allows for the easy removal of broken glass and OCC and extends the life of the equipment. A 3 fraction separation of incoming waste is performed by the ballistic separator. This reduces the need to sort the waste manually.

The ballistic separation technology utilized in the S.O.R.T allows for a very efficient process and the entire system is capable of handling multiple streams. Large tonnages can be processed every hour. The small footprint of this recycling system allows it to be installed in smaller facilities (**Figure 3.5-1**, Metaltechsystems.com).

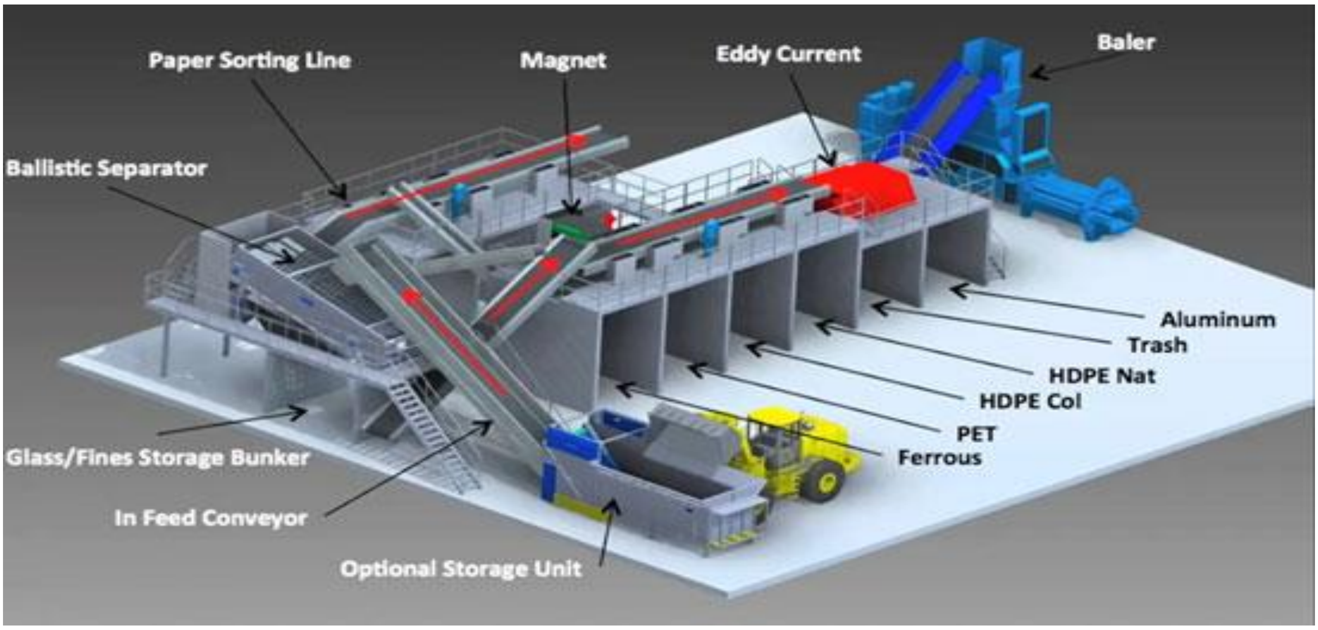


Figure 3.5-1: S.O.R.T. Recycling Systems (Metaltechsystems.com)

1.5.2. Materials Recovery Facility (MRF) equipment

1. As incoming material moves along a **conveyer belt**, workers pull out large items, cardboard and plastic bags and toss them into bins. Unusable trash is thrown away.

2. The recyclables move into a double-deck **screening machine** that separates newspapers, mixed paper and containers into separate streams. Material bounces over rows of square wheels spinning 1,000 times per minute. Blasts of air dislodge cans and bottles from newspapers. Gaps between rollers allow smaller items to fall onto conveyer belts.

3. Workers again pull out any trash and discard it.

4. Next is the **trommel-mag** – a large, rotating tube with small holes in the sides and an **electromagnet** at one end. Small items such as bottle caps fall through holes. The electromagnet snags tin cans. Then it's on to the **air classifier**, where a powerful fan blows lightweight aluminum and plastic onto one conveyor, and heavier glass falls onto another. Workers sort manually glass and plastics.

5. An **electromagnetic device** diverts aluminum cans into a storage bin (**Figure 3.5-2**, Titan-machinery.com).

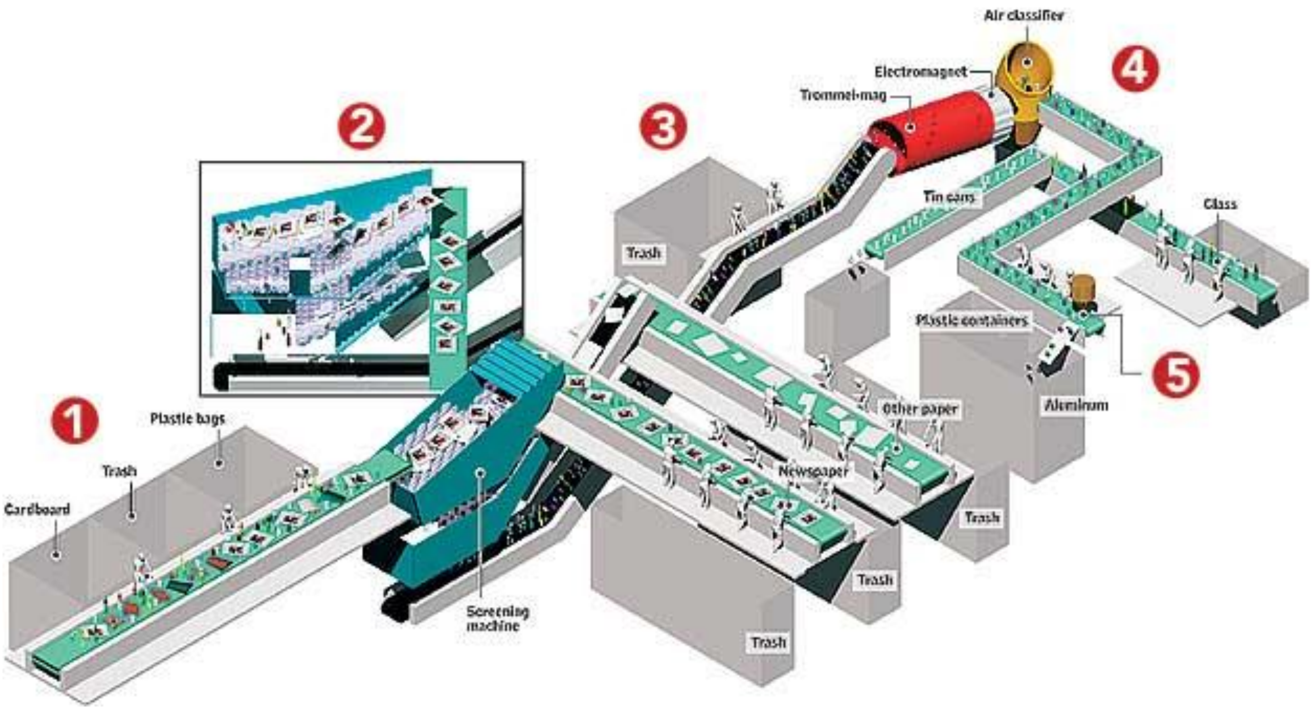


Figure 3.5-2: Materials Recovery Facility (MRF) equipment (Titan-machinery.com)

1.5.3. MSW (Municipal Solid Waste) Automatic Sorting System

3.1. It is a set of system to produce RDF (Refuse Derived Fuel) by crushing combustible waste that can't be recycled after recyclable waste is selected through the process of pre-treatment of waste discharged from homes, collection of food waste, ferrous metals, glass bottles, plastics by substance, etc.

3.2. Units of Equipment

Bag Opener, Rake Separator, Magnetic Separator, Trommel, Glass Bottle Automatic Colour Sorting System, Plastic Automatic Colour Sorting System, Ballistic, Vinyl Crusher, RDF Maker, Conveyor etc.

3.3. Characteristics of equipment

Customized design by properties, etc. of regional waste.

Biological treatment can be possible through efficient separation of organic matter (food waste, etc.). Maximum recovery and recycling of recyclable waste (iron can, aluminum can, plastics, etc.) are available. Combustible materials such as small vinyl, films, packaging materials, etc. can be energized by the recovery. Through the selective recovery of incinerating waste, recycling efficiency can be improved, and through energizing of waste, recycling effect of waste resources can increase

3.4. Characteristics of Each Device

Bag Opener: Opens a bag by minimizing damage to the contents. Rake Separator: Selective recovery of vinyl only out of waste. Minimizes environmental pollution such as dust, noise and vibration, etc.

Ballistic: Good separation efficiency of remnants such as high-level waste, low-level waste, soil, etc. through the proportion of waste and the elastic action of the separator paddle.

Trommel: Through separation by grain size of the waste, screening efficiency of the sorting system is improved

Glass Bottle Automatic Colour Sorting System: Automatic sorting by colour of glass bottle (in clear, brown, green), throughput and screening efficiency are excellent

Plastic Automatic Colour Sorting System: Plastics included in the waste are separated by material (PET, PE, PP, PS), and high screening efficiency and high purity facilitate recycling

Disc Screen: Selective separation of biodegradable substances such as the relatively small size of the food waste, etc. and the efficiency of biological treatment facilities increase

Plastic Crusher: It is equipment to crush plastic and combustible waste into a certain size after a series of screening process. It has better crushing efficiency and less pollution than conventional crushers.

Vinyl Crusher: It is equipment to crush recovered vinyl into the size as required, and it is a pre-treatment facility for recycling Refuse Derived Fuel (RPF) or materials.

RDF Maker: It is a facility to manufacture crushed combustible waste in pellet-form of Refuse Derived Fuel. It resolves the issue including water impact, etc. of an existing machine, and it has a very high productivity (**Figure 3.5-3**, Ioniaent.en).

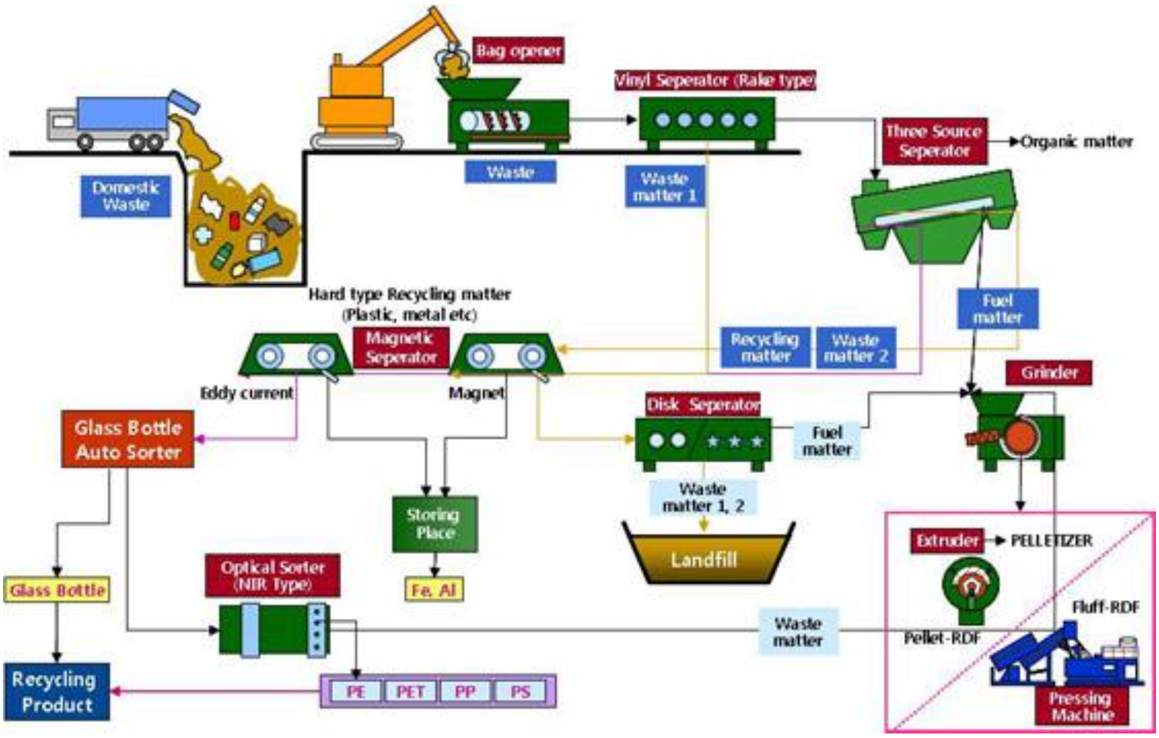


Figure 3.5-3: MSW (Municipal Solid Waste) Automatic Sorting System (Ioniaent.en)

1.5.4. Integrated Solid Waste Management Plant / MSW Treatment System

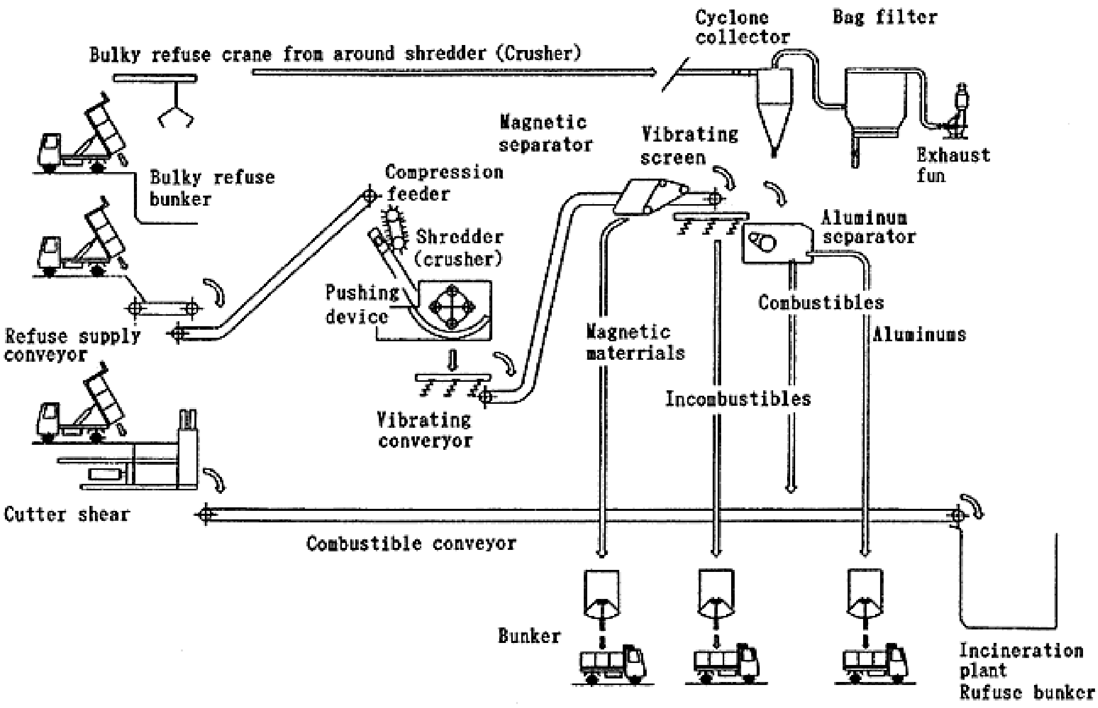


Figure 3.5-4. Integrated Solid Waste Management Plant / MSW Treatment System

1.5.5. Household waste sorting flow diagram

Sorting system including:

1. Receiving System, 2. Bag-breaking system, 3. Mechanical separating system, 4. Air separating system, 5. Optical separating system, 6. Sub-pressing sorting system and 7. Manual sorting system. (Figure 4.5-5, Shenjiasanwa.en).

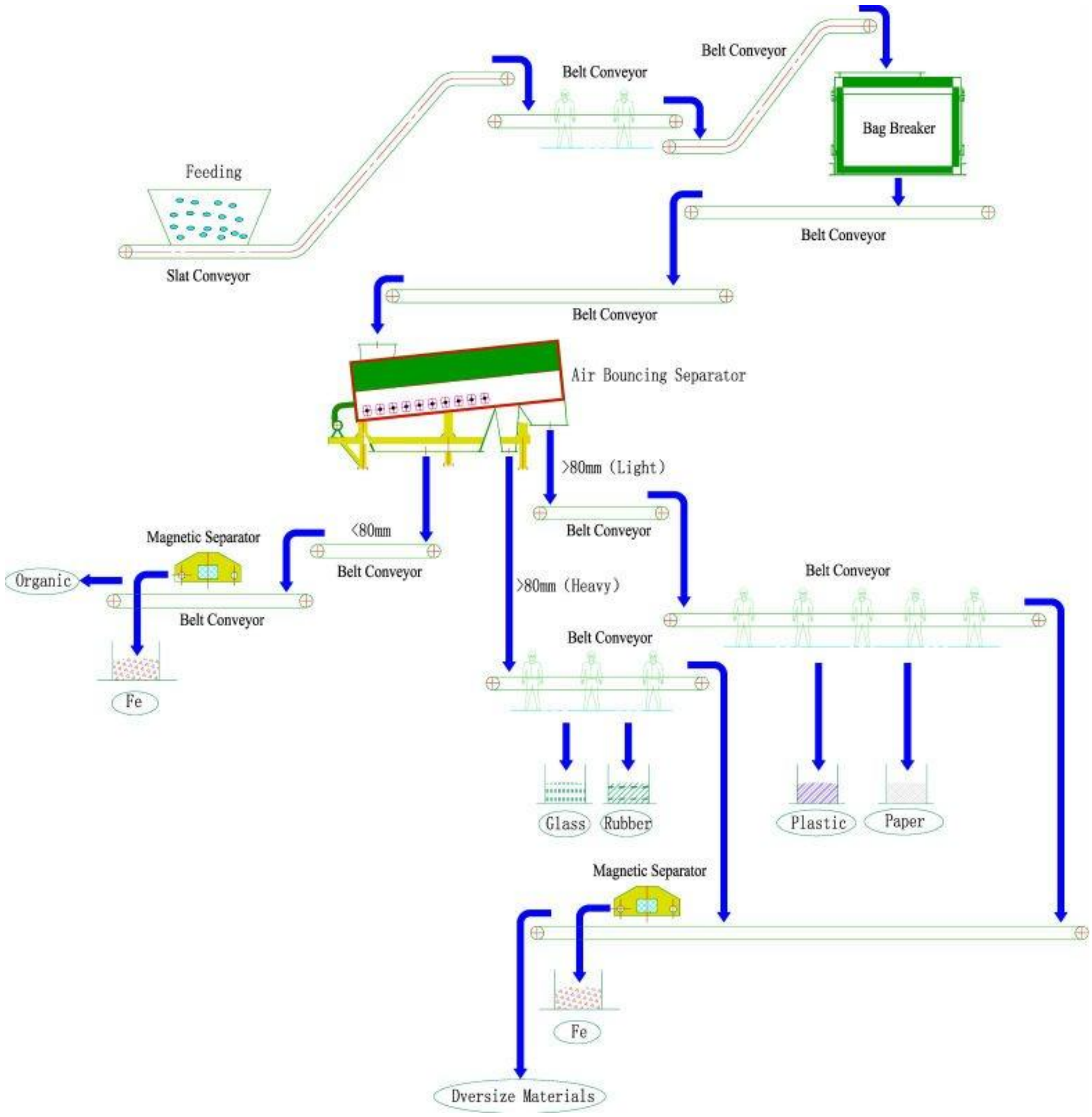


Figure 3.5-5. Household waste sorting flow diagram (Shenjiasanwa.en)