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Plastics Recycling

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Content

PLASTICS RECYCLING

1. INTRODUCTION

In many countries up to 80 per cent, and sometimes more, of domestic and industrial wastes are at present disposed of on the land. In some countries crude dumping on marshes, in ravines or quarries is the practice. The refuse is left to rot and serves as a breeding place for flies, rats and other pests, creating bad smells and nuisance through smoke from fires.

But as living standards increase so also does the demand for improved environmental benefits, and insanitary practices, including crude dumping of waste, becomes increasingly unacceptable to a better educated and well-informed public.

The dumping of waste into the sea is still being done by some countries, but it is to be hoped that with the growing awareness of the increasing pollution of the oceans far more effective restrictions to such dumping will come into force (for example, following the 1990 United Nations Conference on the Mediterranean).

Recycling of plastics is a relatively young and developing industry which shows a trend towards an increasing growth. This also applies to reclamation of plastics from discarded industrial and consumer products, which contain plastic components.

New technologies, with examples of related plant and equipment are described in this report. It is felt that new developments in some countries can be successfully applied to others, resulting in "know-how" and licensing agreements.

This report includes information on

Forms of Recycling Collection of Plastics Waste Basics and Problems Economics of Different Transport Systems for Refuse Disposal of Waste - Basics and Technologies

About a third of the total plastics consumption finds applications in products of less than a ccuple of years life span, such as films, one-way bottles and other packages.

Recycling of homogeneous plastics is a straight-forward operation. However, the recycling of mixed plastics, including plastics from Municipal Solid Waste streams and the recovery of plastics from products incorporating plastics, requires special technologies.

Amongst the earliest applications of plastics recycling was the production of polyethylene(PE)-films where the process uses scrap and trims either by mixing it with virgin polymers in film production or using the regrind in the core layer of the multilayer extruded film, the two outer layers being made from virgin material.

The recycling to energy by various technologies is growing, and the calorific value of polymers offers great advantages when compared to other materials.

Nevertheless, there is very little acceptance of waste incineration facilities in public opinion. It should therefore be taken as a recommendation for these countries where it is still possible to establish waste-fuelled power stations (i.e. waste incineration plants) not to delay, but to immediately start with the drafting and designing of such plants.

Some commentators feel that recycling of plastics waste to energy is to be recommended only when recycling to materials is not economically feasible. On the other hand, the high calorific value of plastics is an important factor in recycling to energy by incineration combined with production of hot water and steam.

The cost of the growing amount of rubbish in landfill operations is steadily increasing. Recycling to materials and/or energy is becoming an urgent task.

The economics of recycling operations should be taken into account when considering the costs of landfill (negative factor). This means that the economics of recycling have to be calculated as follows:

$$a - b + c - d$$

a = the revenue from recycled material or produced energy
b = cost of recycling
c = savings from non-disposal in landfill
d = cost of disposal in landfill of the remaining tonnages after recycling [24]

The world consumption of plastics is estimated at approx. 70 million tonnes. The production figures for Western Europe and the USA being 20 million tonnes respectively and about 10 million tonnes in Japan. The following table shows Western European plastics consumption for 1987 by end-use industries, indicating that:

short lifetime use (less than one year) accounted for 20 per cent medium lifetime use (1-10 years) accounted for 35 per cent long lifetime use (more than 10 years) accounted for 45 per cent.

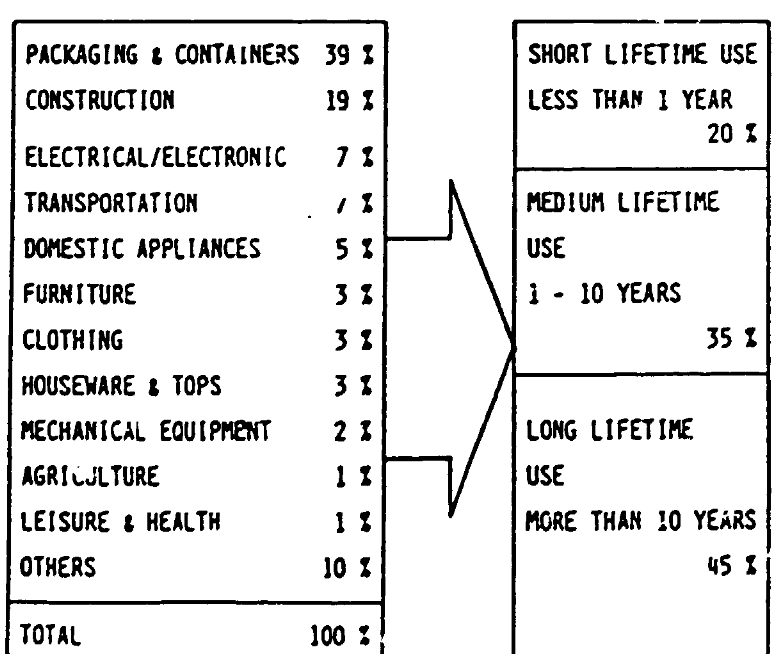


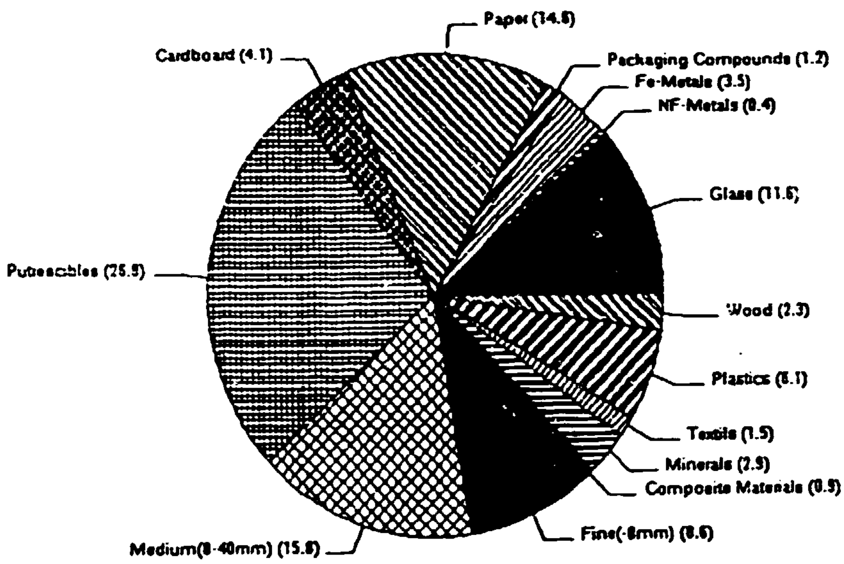
Figure:1

Municipal Solid Waste (MSW) in the Economic Community (EC) amounted to 100 million tonnes per annum, representing 4 per cent of the total solid waste of 2.200 million tonnes per annum (agricultural wastes of 1.300 million tonnes accounting for 59 per cent, and other solid wastes of 800 million tonnes accounting for 37 per cent). Plastics with about 7 million tonnes p.a. accounted for 7 per cent of Municipal Solid Waste in the EC in 1986.

The following illustration shows:

(a) the composition of MSW according to materials, (b) the composition of plastics in MSW.

Average Composition of MWS
1979/80



Average Composition of MWS
1985

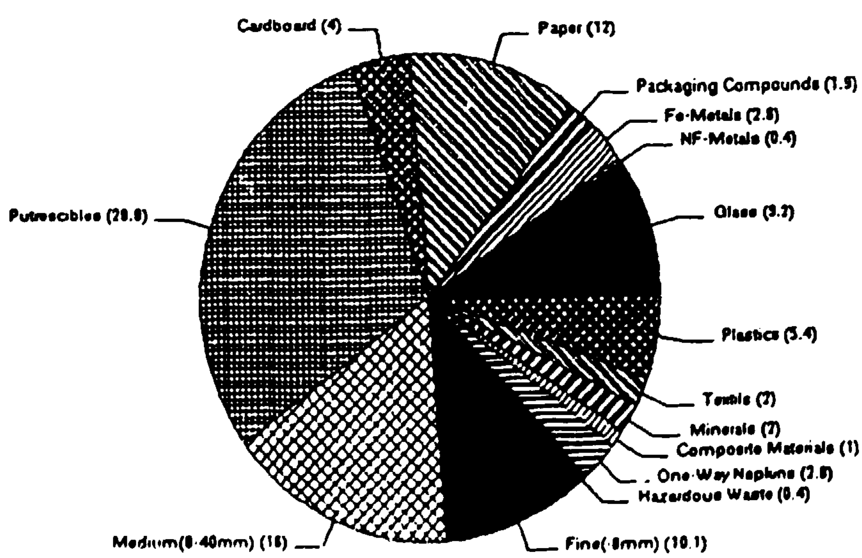


Figure:2

In general, waste management is sub-divided into four basic principles:

1. Waste reduction
2. Waste reclamation
3. Energy recovery and material-recycling
4. Waste disposal.

2. DEFINITIONS

In Austria, for example, solid waste management has been subject to standardization since the early seventies.

Apart from the Austrian Standard ÖNORM S2000, Austrian Law has its own definition of waste, but it is not very detailed.
According to ÖNORM S2000, waste is generally understood as solid refuse generated by private households, industry and public institutions. Because of its composition, it can be disposed of (by collection, transport and removal) without undertaking special measures.

Domestic refuse is waste usually originating from households, such as ash, slag, soot, kitchen refuse, food remains, textiles, leather, paper, packing materials, plastic containers, tins, beverage cans, metal goods, glass and small amounts of garden refuse. Factory waste in similar quantity and type is also called domestic refuse as opposed to street sweepings and other industrial waste, which is called special waste.

Industrial waste is refuse originating from manufacturing and processing activities caused by factories or public enterprises which is in type and quantity similar to domestic refuse. It can be liquid, solid or gaseous, vaporous or even sludgy.

Bulky refuse cannot be transported by ordinary waste collecting lorries because of its dimensions. This is generated by private households, industry and public institutions.

Special waste cannot be handled together with other waste either because of its composition or quantitity. Special safety measures or pre-treatment may be necessary.

The predominant proportion of waste is neither dangerous to mankind or the environment and is called non-hazardous special waste. After appropriate pre-treatment it can be handled together with other waste.

Hazardous special waste must be collected and treated separately. Measures concerning waste including environmental influences, are summarized under the term "waste management".

Waste removal is the deposition of waste (possibly after biological, biochemical, physical/chemical or thermal pretreatment) onto predetermined landfills.

3. FORMS OF RECYCLING

The recycling of waste is one of the oldest human activities. It may assume different forms:

1. Re-utilization of rejected articles, such as machinery, cars, appliances or clothing, often after previous examination, repair and cleaning;

2. Closed-loop recycling, i.e. the re-utilization of waste materials in applications similar to the original ones, e.g. making new steel from scrap;

3. Open-loop recycling, i.e. the re-utilization of waste materials in lower grade applications, e.g. making boards from waste paper;

4. Conversion of waste into new materials, such as fuel, compost or building materials.

The recycling potential of waste usually depends on economic factors, such as available quantites and grades, market value of the reclaimed products, available reclaiming equipment and not least, labour cost. [3]

4. COLLECTION OF PLASTICS WASTE

One of the main problems is how to organize the collection of plastics waste. The degree of contamination is determined by the mixture of the different types of plastics materials and other waste. The total amount of contamination determines the economy of the entire recycling-process.

The object of collecting plastics waste is to separate the plastics materials from the other waste already at source. i.e. at the producer. It may be worthwhile to make a distinction between the different types of plastics.

Preferably one should differentiate already waste collection at private households and industrial sites. Industrial waste is mainly generated in a form which is advantageous for recycling, while household waste is on the contrary usually mixed up with other material.

4.1 Waste stock exchanges

In many cases industrial waste recycling is complicated by the producer's ignorance, as he is not able to carry out the recovery process himself, nor does he know where to find companies who can do it for him. Waste stock exchanges are created to provide information for both the producer and the customer.

They are operated by different national and international institutions and try to obtain information on supply and demand. Their offers range from some kilograms of waste up to several tonnes per month. [4]

4.2 Plastics collection from households

Plastics waste originating from private households is principally collected together with other residual waste, contamination therefore causing a decrease in quality.

In the last few years different systems of waste collection have been introduced in order to sort out valuable material from the waste stream with little cost and high purity. There are two main systems available:

(a) Integrated collection systems (b) Additive collection systems

The integrated collection systems are sometimes called " fetch systems". The total amount of household refuse is collected in a number of dustbins (containers), each for a different type of material. The materials are collected simultaneously with the other waste.

Additive collection systems are independent from the conventional waste collection. They are based on the readiness and co-operation of the customer to transport the valuables to containers located at a central area. This system is called the "bring system".

4.2.1 The "fetch system"

To establish such a system in an area, a number of containers are used instead of a small dustbin. The number ranges from systems using two up to five or even more containers, with simultaneous or alternating removal, with combined or separated collection of different materials. One-way sacks (made of plastics or paper) can also be used.

Plastics materials are collected either together with materials such as paper, glass or metal, or separated into individual bags.

The expenditure for the customer is low, about 75 per cent of all plastics materials found in the refuse can be collected. The average composition of waste, determined by an analysis in Hamburg - Bergedorf in the Autumn of 1986 is shown in the table below: [5]

Composition of Plastics Waste	weight per cent
Polyethylene/Polypropylene	44
Polystyrene	25
Polyvinylchloride	15
Residual plastics	12
Non-plastics	04
total	100

Table:1

The total costs arise from the higher expenses of the system, determined by its type. Additional costs, extra to the basic costs, are about 45 to US$ 80 per tonne of plastics material. [6]

If only plastics are collected separately in addition to the normal municipal waste disposal, the specific cost would be about US$ 1,000 to 1,500 per tonne of plastics waste, which demonstrates that this would not be economical. [7]

4.2.2 The "bring system"

The "bring system" works on a number of containers being placed at central areas. The materials must be deposited by the consumer. The volume of the containers range from 0.5 to 5 m^3. Plastics materials are collected separately from the others.

The problem with this system is that a high motivation by the public is necessary. In practical experiments only about 3 to 8.5 per cent of the plastics materials in waste are returned. [5]

The success of this method is also influenced by the number of containers at a special area and their distance from individual households.

The results of the investigation of the composition of plastics collected in Hamburg - Bergedorf in Autumn 1986 are summarized in the following table: [5]

Composition of Plastics Waste	weight per cent
Polyethylene/Polypropylene	56
Polystyrene	19
Polyvinylchloride	13
Residual plastics	9
Non plastics	3
total	100

Table:2

The cost is reported to be approx. US$ 200 to 350 per tonne of plastics waste. [3]

4.3 Examples for the collection of plastics from household waste

In the following some examples of practical experiments are described. One was carried out in 1980 in the Federal Republic of Germany in the community of Radolfzell.

1980, Radolfzell - Böhringen, FRG

The duration of the test was three months. Bags for plastics waste were distributed to private households. The waste was collected weekly. The composition is described in the table below. [3]

Composition in per cent by weight

Plastics Material	Average	Minimum	Maximum
Film	36.0	5.0	52.3
Sheet material	8.2	1.4	19.2
Rolling containers	7.6	6.4	10.0
Non-rolling containers	8.3	6.3	10.9
Containers 30 cm	12.3	7.8	20.8
Containers 10 cm	3.1	1.4	5.7
Margarine and Yoghourt cups	15.7	8.6	25.6
Massive parts	7.1	1.1	21.6
Foams, e.g. polystyrene	1.7	0.3	3.8

Table:3

France

Since 1970 a separate collection of plastics bottles is carried out in France. About one fourth of beverages are filled in PVC bottles, which amounts to 20,000 t/a; that is, approximately 20 per cent of the total PVC consumption in France. The PVC manufacturers are associated in a club named GREPP, which aims to recycle 40,000 tonnes of PVC (including PVC bottles) per year. At the moment 37 per cent of the waste PVC is collected and converted into products as such cable insulation and drainpipes.

Japan

Since about 1973 the separate collection of plastics materials as well as glass, metals and ceramics is practiced in the city of Tokyo, Japan. The proportion of the separately collected material is about 20 per cent of the total waste, of which 20 per cent are again plastics.

Vienna, Austria

In Vienna a test for separately collected material lasting one year was carried out in 1974/75. Special bags (refuse sacks) were distributed to 420 households and collected weekly. Thus 30 per cent of the plastics waste could be collected.

5. BASICS AND PROBLEMS

5.1 Influence of contamination

Contamination can be by three causes and can be divided into three different groups:

1. Contamination caused by contact with other waste materials 2. Defilement originating from use of the product 3. Non-plastics materials collected by mistake.

The highest external contamination (caused by other waste materials) occurs with the conventional single container collection. The degree of defilement is about 5 per cent. It can be decreased by separating the different components of waste in the households themselves. [8]

Contamination originating from the application of the product consists mainly of labels, metal closings and remains of the contents.

Because of the low density of plastics materials (compared to the contents of the package) is only about one volume per cent of the contents, which increases the weight of the package by 10 to 35 per cent. [3]

Parameter	Einheit	Quark-becher	Joghurt-becher	Spül-mittel
Füllinhalt	g	500	150	500
Restinhalt	g	4,5	5	18
Restanteil	Gew.-%	0,9	3,3	3,3
Leergewicht	g	9	3,3	47
Verschmutzung	Gew.-%	33	60	28

Table:4

The contaminations of three typical packages make up 28 to 60 weight per cent of the total weight of the package, by drying it can be reduced to 5 to 15 per cent.
The contamination of the collected plastics material is determined by the collection system. About 5 per cent of non-plastics material is added by the consumers because of ignorance. [5]

Thus, recycled plastics from household waste for use in high-grade applications require an intensive cleansing-process and separation from non-plastics. Contaminations sticking to the plastics material can usually be removed by washing with water; the remains must be separated.

5.2 Influence of plastics mixtures in recycling

Mixtures consisting of different types of plastics can decrease the quality of the endproduct considerably. The table below shows the miscibility (1 ... miscible) and non-miscibility (6 ... non-miscible) of different types of plastics materials. The table refers to quality standards for new materials.

	Polystyrol	Styrol-Acrylnitril-Copolymer	ABS	Polyamid	Polycarbonat	Polymetylmethacrylat	Polyvinylchlorid	Polypropylen	Polyethylen
Polystyrol	-								
Styrol-Acrylnitril-Copolymer	6	-							
ABS	6	1	-						
Polyamid	4-5	6	6	-					
Polycarbonat	3-6	2	2	6	-				
Polymetylmethacrylat	4	1	1	6	1	-			
Polyvinylchlorid	6	2	3	6	5	1	-		
Polypropylen	6	6	6	6	6	6	5	-	
Polyethylen	6	6	6	6	6	6	6	6	-

Table:5

The three main fractions occuring in household waste (PE/PP, PS, PVC) are non-miscible. This prevents the application of mixed polymers for high-grade products.

If used only in low-grade applications, mixtures of plastics occuring in household waste can mainly be processed. Usually only the main-fraction, PE/PP, (50 - 65 per cent) is used for the production of plastics articles. [2]

In some cases, the separation proves to be impossible, e.g. sandwich materials are disadvantageous. This should be avoided by approp⁻ ⁻te planning.

5.3 Additives in plastics materials

Normally the majority of plastics materials contain additives: they can be divided into those additives which increase performance, and those additives which facilitate processing. Processing additives do not exceed 5 per cent, but the proportion of fillers, reinforcing materials and plasticisers can be up to 70 per cent of the polymer, causing a severe problem:

The quantity and type of additives in recycled materials are unknown and therefore the performance of recycled plastics cannot be accurately predicted

5.4 Variations in design

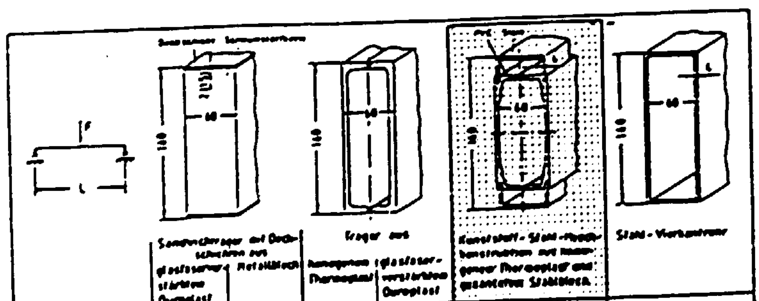
Usually consideration of the recycling process starts when the refuse should be disposed of. Thus only a small proportion of the total amount of waste can be recycled, and often only by means of expensive and complicated techniques, such as pyrolysis and hydrolysis.

It would be of advantage, if the designers would consider three points: marking of the end-product, homogeneity and appropriate assembling techniques to fit the part into the recycling process. There are two further points to consider:

1. Selection of the plastics type and the processing technique

2. Application of compounds (e.g. metal - plastics) inst‿ ‿ of reinforcements.

The application of compounds provides a much easier recycling than glass- fibre reinforced products.



Recycling-aufwand	sehr groß	groß	sehr klein	groß	klein	mittel
Gewicht (kg/m)	4	5	5	4,5	7,9	13,5
Biegesteifigkeit (N·mm²·10¹¹)	2	6	0,2	2,6	9,4	11
DM/kg	5	6	2,40	11	2,60	2,70

Figure:3

The above table shows that the price/load ratio and the weight/load ratio is a minimum with a steel-thermoplast compound.

5.5 Marking of plastics articles

No perfect and economic separation method is available today. It is possible to separate the PP/PE fraction, but the PVC and PS fraction cannot be separated for economic and technical reasons. Therefore, a separation in the households by the customers themselves would be desirable. Thus it is essential to mark the plastics articles in order to give the consumer the chance of performing such a separation.

On the other hand, the chemical industry and the association of the plastics processing industry are afraid of prejudice against several types of plastics materials, especially against articles made of PVC, again because of ignorance.

5.6 Bio-degradable plastics

Basically, plastics were developed to obtain a corrosion-proof material. Therefore it would not make sense to use bio-degradable plastics for machine parts, but they would prove valuable for packaging materials. In that branch of industry the duration of the application of plastics articles is usually short. A long lifetime is not necessary.

5.6.1 Definitions

Degradable plastics are plastics materials which deteriorate under the influence of light, water, heat to macromolecules which remain biodegradable.

There are a number of advantages connected with these materials:

(a) Separation of the plastics materials from the household refuse is not necessary;

(b) landfilling needs less space;

(c) the litter problem could be solved by using such materials;

(d) medical applications: the human body is able to decompose plastics materials; and

(e) films for special applications in agriculture and food packaging can be produced.

5.6.2 Psychological reasons

Bio-degradable plastics can be decomposed by bacteria or fungii. Plastics can be disposed of without difficulty or extra cost.

5.6.3 Problems

Although bio-degradable plastics materials have many advantages, the problems listed below should be taken into consideration:

1. Bio-degradable polymers lead to an uncertainty with packages. A too early decomposition causes contamination or even loss of the product. Test and safety measures would prove necessary. Stock-keeping of products would become complicated.

2. The polymer must not contain toxic components which may migrate into the product during decomposition.

3. New technologies for recycling have to be found.

5.6.4 Assumptions

The requirements listed below are essentia. for this type of material:

1. Only non-toxic additives may be used.
2. The additives should not discolour the article.
3. Coloured or imprinted plastics must also decompose.
4. There should be a possibility of controlling the rate of degradation.

One way to manufacture bio-degradable plastics is by the use of bio- additives, such as starch in PP, PS or PE instead of conventional fillers.

Starch is one of the most important carbohydrates. It is produced in huge quantities, second to cellulose. A special type of enzyme fluidizises the starch and destroys the links between the macromolcules. Normally about 20 per cent of starch can be added to the polymer.

Difficulties occur in the distribution of the starch in the plastics materials, because starch is hydrophilic and most plastics used in the packageing industry are hydrophobic. A chemical treatment,such as curing, etherification or esterification proves necessary, but on the other hand these pretreatments cause decomposition problems.

A second possibility was found by Imperial Chemical Industries (ICI). They developed the bio-degradable polymer "Biopol".

Biopol is a bio-degradable thermoplast, consisting of the alipatic polyesters polyhydroxybutyrate (PHB) and polyhydroxyvalerate (PHV). [10]

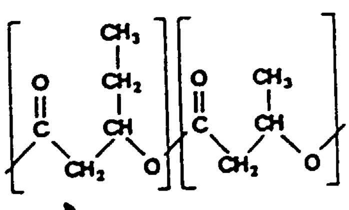


Figure:4

Polyhydroxybutyrate is manufactured by a chemical reaction caused by bacteria with sugar as basic material. The polymer can be processed by using conventional equipment. The performance of Biopol is determined by the portion of PHB and PHV and it can be reused several times.

5.6.5 Waste disposal

Biopol is manufactured from sugar and starch by a process of fermentation. It can be decomposed completely by bacteria and fungii which occur in soil. By means of hydrolysis an oligomer is formed, this acts as a food supply for the micro-organism and is decomposed. Biopol can be deposited at landfills or incinerated without causing any problems. Recycling of Biopol is possible, but not economic.

5.7 Direct reutilization of duromeric materials

Duromeric materials cannot be melted over and over again. Thus it is not possible to process them twice.

Nevertheless a technology to reutilize then has been developed based on milling and using them as filler in thermoplastic materials. The duroplastic material can substitute up to 20 per cent of the new material by improving the mechanical properties and reducing the costs. [12]

6. THE ECONOMICS OF DIFFERENT TRANSPORT SYSTEMS FOR REFUSE

6.1 Basics and problems

The major technical problems in transportation, refining, disintegration and treatment of waste, arise from differences between the mechanical, physical and chemical properties of the materials. Additional problems are caused by the collection of the waste, originating from the long distances between the waste producers and the recycling companies (landfills, power plants, etc.). Thus the waste transportation systems now used are becoming more and more uneconomic and new solutions for a wide area of waste disposition have to be found.

Instead of the dustcarts, economical and beneficial transportation systems could be used. Pneumatic tube transportation systems with suction pipes or pressure pipes could be built. For longer distances combined container traffic or other transportation systems, such as belt conveyors, could be used.

More careful planning of waste disposal systems and adoption of more purposeful and practical public cleansing systems would make it possible to use integrated refuse disposal systems. By this the entire method is meant by which refuse is transferred from the place where it originates to the place where it is finally returned to the industrial or ecological cycle. The figure below illustrates a number of different waste disposal systems.

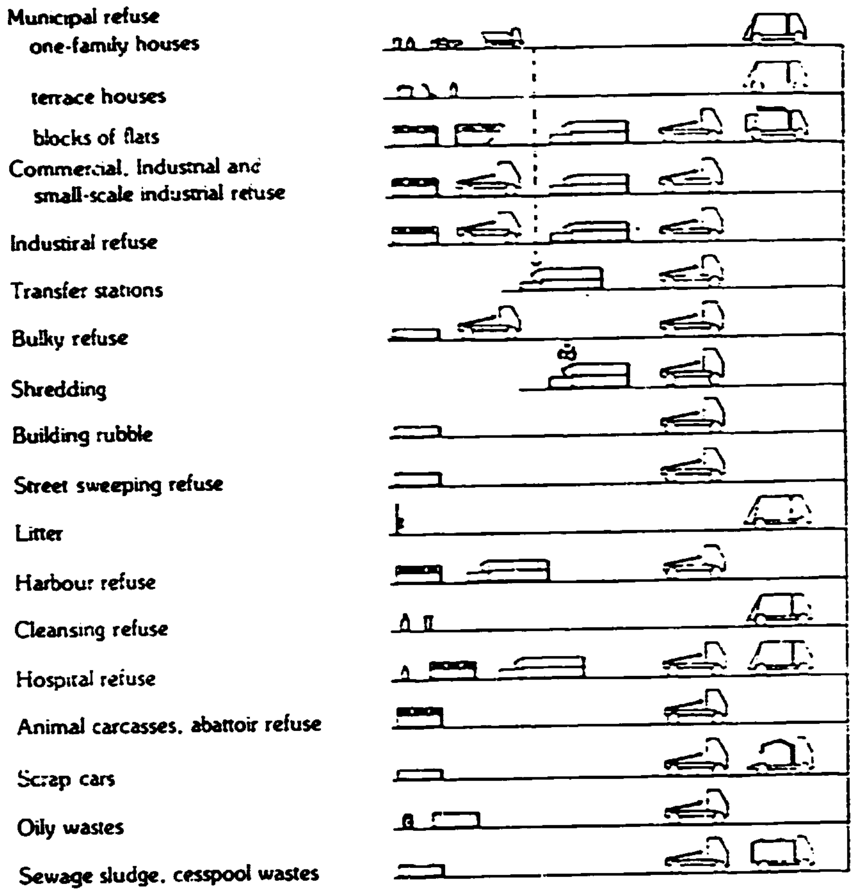


Figure:5

The refuse is taken from its place of origin to the local collection and transportation point near the house, where it is temporarily stored, then by way of the actual transport stage to the place where it is treated. Waste disposal systems can be devided into two sections, the collection (storage and transportation systems) and the treatment of the refuse. The points listed below should be considered:

1. The collection and transportation of refuse comprises a considerable part of the whole waste disposal process, since between 60 to 80 per cent of the total costs involved in waste disposal are spent on the collection and transport stages.

2. The development of refuse and collection systems and the smooth operation of these play an important part in the visible disposal of waste. The treatment of refuse and the ways in which it is finally disposed of on the other hand are not always seen as a part

of the overall urban picture. Nonetheless, they are reflected in the urban surroundings and in the total economic cost of waste disposal.

Although a waste disposal system can, in principle, be studied in two separate sectors it should nevertheless be borne in mind that the way in which refuse is treated may have a very significant effect on the choice of collection and transport methods.

6.2 Refuse collection and transport systems

Refuse collection and transport systems are integrated systems of equipment and methods by which refuse is transferred from the places where it originates to the sites where it is treated or pretreated. The ways in which refuse is collected and transported from a house or block of flats often form a separate stage from the stage where it is transported to the treatment site.

Household waste is mainly placed in bins or bags and carried from the kitchen to dustbins or refuse containers in the yards. Today newspapers and magazines are often collected separately. In large blocks there may be special chutes to facilitate the transport of refuse. Though very pleasant for the inhabitants, they are not very popular, partly for economic reasons and partly because of experiences, which have not been entirely positive with such chutes.

The collection of refuse and its transport away from homes is the most visible stage of waste disposal. Moreover, numerous systems have been developed for this stage of waste disposal.

Refuse collection and transport methods can be devided into four main classes:

1. Bin methods
2. Demountable container methods
3. Transfer loading methods
4. Pipeline methods.

Bin methods may involve the emptying of the bins or the exchange of full bins for empty ones, and the containers used may be of a permanent or disposable type. eg. sacks. Transfer loading methods are two-stage methods of transport and may be used with either bin methods or demountable container methods. Pipelines are also two-stage transport methods, the first stage being the actual pipeline system, and the second involving the use of a demountable container.

6.3 Bin methods

6.3.1 Refuse bin/truck equipped with boom crane

This method may be of the exchange type, where the full bin is exchanged for an empty bin by means of the truck crane, or it may be of the emptying method, in which the bin is hoisted onto the platform of the truck to be emptied and then returned to its original place.

This method has proven uneconomic, nonetheless, it is still in use in the Soviet Union, for example. [3]

6.3.2 Refuse bin/compacting refuse collection vehicle

The full bin, sack or small container (1 to 5 m^3) is emptied either manually or mechanically into the loading hopper of the vehicle. The refuse is then compressed by means of a compacting plate or screw device into the loading space of the vehicle. Such vehicles can transport about 50 to 80 m^3 of loose refuse at a time. This method is in general use throughout the developed world for the collection of household refuse and of industrial refuse similar to household waste.

6.3.3 Refuse sack/light collection vehicle

The full refuse sacks are collected by means of a mechanical loading device and a light vehicle equipped with a loading platform that can be tipped. Vehicles of this type can transport about 5 to 10 m^3 of loose refuse at a time. The method is used principally for the collection of household waste, mainly for transport to a nearby refuse dump or treatment site.

6.3.4 Container/compacting refuse collection vehicle with winch

The full container (usually 6 to 8 m^3) is emptied mechanically by means of a winch arrangement into the loading hopper of a compacting refuse vehicle and the refuse is compressed into the load carrying space of the vehicle. It can transport 50 to 80 m^3 of loose refuse. The method has become very widespread of late, since such a type of strong multipurpose vehicle can be used for transporting various types of refuse, even furniture and machines.

6.4 Demountable container methods

6.4.1 Refuse container/truck with demountable body equipment

The full refuse container is transported by means of a truck equipped with demountable body apparatus to the refuse treatment site or transfer station. The container is emptied by tipping. It can transport 5 to 20 m^3 of loose refuse. A very popular system is the Multilift demountable container system, even building refuse can be collected and transported with it. They are only used for household waste if 1 to 20 m^3 accumulates daily and the journey to the treatment site does not exceed 15 kms.

6.4.2 Compacting containers/truck with demountable body equipment

The refuse is collected directly or emptied from refuse containers into a certain compacting equipped apparatus. The full container is then transported by means of a truck with demountable body equipment to the refuse treatment site. Such a container can transport 40 to 80 m^3 of loose refuse. This method is widely used for collecting commercial and industrial refuse where the accumulation of refuse is 15 to 50 m^3 each day at least and the journey does not exceed 30 kms.

6.4.3 Refuse compactor/refuse container/truck with demountable body equipment

The refuse is collected directly or emptied from large containers into the loading hopper of a refuse compactor. The loose refuse is then compressed into a detachable refuse container attached to the compactor. The full container is then transported to a refuse treatment site. Such a container can transport 50 to 100 m^3 of loose refuse. The compactor/container system is mainly used for collecting commercial and industrial refuse and for collecting refuse from households producing 10 to 100 m^3 of refuse a day and where the distances are no more than 30 to 40 kms.

6.5 Transfer loading methods

Transfer loading methods involve two stages of transport where the refuse is transferred from one form of transport to another. Usually only transport by road is considered when talking of transfer loading. However, there are other methodes of transfer loading in use involving the transfer of refuse from road transport to rail or water transport. The principle of transfer loading methods is illustrated below. [3]

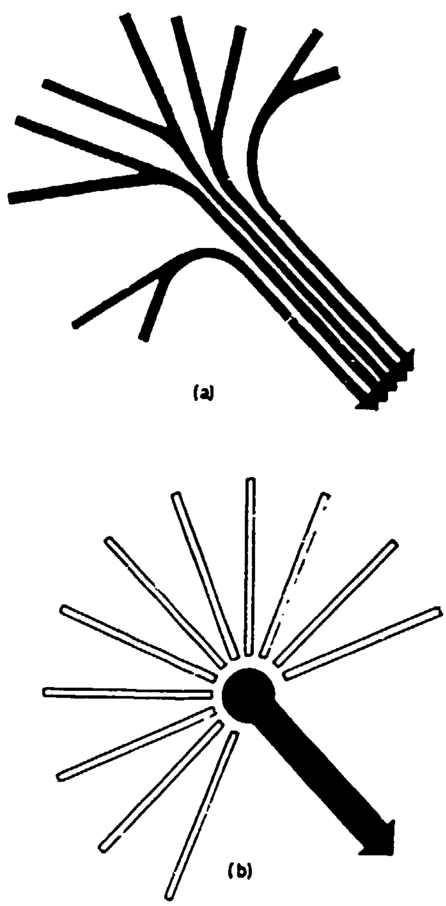


Figure:6 Diagram illustrating principle of transfer loading. (a) The refuse is transported straight to the treatment plant. (b) Refuse is taken first to the transfer station and then to the treatment plant.

Transfer stations do not, provided they are operated properly, pollute the environment, furthermore they can be operated at relatively low cost.

The waste can be transported to the transfer station with the methods described above. In the station the waste can be put through a refuse shredder or a refuse crusher and afterwards is usually compacted by a packer plate or a screw compactor.

The transport containers used in this method are capable of transporting 100 to 150 m^3 of loose refuse at a time.

A transfer station can also be built in the centre of a large town, for example underground, as has been done in central Stockholm. Finland especially shows an increasing interest in the transport of refuse from water to land and vice versa. [3]

6.6 Pipeline methods

Pneumatic and screw methods of transport are widely used in industry for carrying different kinds of powdery and fine-grained materials. Since the early 1960's, pneumatic transport systems have also been used for municipial refuse. In addition to various collection and transport systems for household refuse, pneumatic methods have also been used for district refuse handling in residential areas where the refuse is collected and transported by means of a pipeline to a central refuse collection centre. At the centre the refuse is separated from the transportion air stream and then usually compressed into transport containers and taken away by trucks.

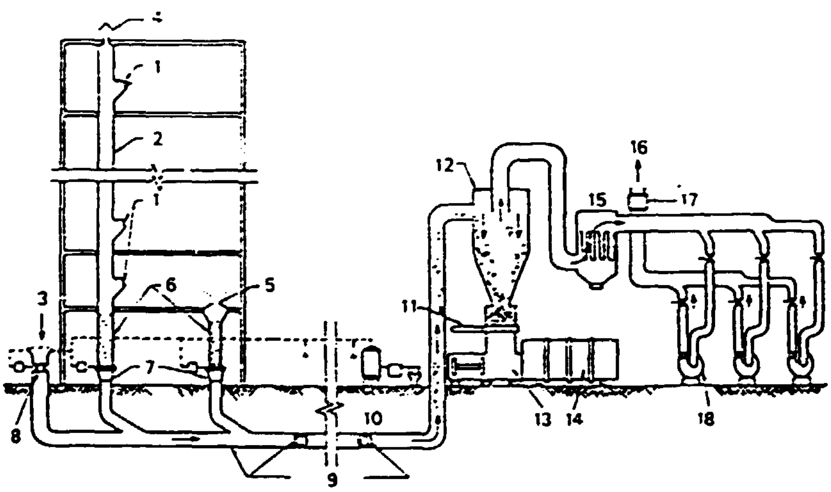


Figure:7 Pneumatic pipeline system for use in residential blocks[10]: (1) chute feed, (2) refuse chute, (3) air inlet, (4) relief inlet, (5) floor-mounted chute feed, (6) refuse storage section, (7) discharge valve, (8) air inlet control valve, (9) pipeline joints, (10) compressor, (11) slide gate, (12) cyclone separator, (13) compactor, (14) transport container, (15) air filter, (16) air outlet, (17) silencer, (18) exhaust blowers. (Reproduced from P.H. Luiten, in: *National Waste Processing Conference 1976*, by permission of The American Society of Mechanical Engineers).

The most important users of these methods are hospitals, government offices, industrial plants and heavily built-up residential areas. One considerable advantage, which has been increasingly stressed, is that the refuse does not have to be touched by human hand at any stage of the collecting process. Among the advantages of pipeline methods of transporting refuse are the absence of smells and noise, aesthetic and hygienic benefits and the reduction in traffic. Weighed against the ecological benefits are economic considerations and also technical difficulties, such as pipeline wear, and above all, the danger of blockages.

In the past years a new method, using a screw, has arisen alongside the pneumatic systems. Systems using water as a transport medium are also in use.

6.7 Transportation conditions for hazardous material

The number of transports of hazardous material has increased during the past years, up to 30 per cent of the European railway and road traffic. [2]. Industrial waste can often be classified according to several hazard classifications (eg. explosive materials, inflammable fluids, toxic, caustic or radioactive materials), thus precautionary measures have to be taken, a classification proves necessary.

6.7.1 Risk and transportation-safety

The problem in the transportation of hazardous material is mainly found in the following point: Ensuring the safety of the transport, of the transport devices and the people involved. Especially railway and road transports are performed in densely populated areas. Another important influence is pollution control. Safety measures must endure the whole lifetime of a hazardous material.

One of the most important points is the unification of the transport conditions.

There are several international regulations for:

road transport:	ADR	(Accord Europeen Relatif au Transport International des Merchandises Dangereuses en Route)
railway transportation:	RID	(Reglement International Concernant le Transport des Merchandises Dangereuses par Chemin de Fer)
shipping traffic:	IMDG	(International Maritime Dangerous Goods Code)
air traffic:	ICAO	(International Civil Aviation Organization)

These are accepted by most countries of the world. According to these regulations the classification of hazardous material is listed below:

Classification 1a:	Explosive substances and goods
Classification 1b:	Goods loaded with explosive substances
Classification 1c:	Pyrotechnics and the like
Classification 2:	Compressed, liquefied gases or gases solved under pressure
Classification 3:	Inflammable fluid substances
Classification 4a:	Inflammable solid substances
Classification 4b:	Self-igniting substances
Classification 4c:	Substances developing inflammable gases in contact with water
Classification 5a:	Flammable acting substances
Classification 5b:	Organic peroxids
Classification 6a:	Toxic substances
Classification 6b:	Disgusting substances or contagious matters
Classification 7:	Radio-active substances
Classification 8:	Caustic substances

The containers must resist against aggressive agents. Plastics materials are often used.

6.7.2 Unification of the hazard-classifications

In European rail and road traffic the international hazard classifications are valid.

For international traffic within Europe several transport conditions concerning tank cars transporting hazardous material listed in the regulations were added.

7. DISPOSAL OF WASTE-BASICS AND TECHNOLOGIES

Plastics refuse can be treated mechanically, thermally or chemically by various techniques. The goal of mechanical treatment is the recovery of a "regranulate", on the other hand chemical and thermal processes have been developed to provide the basic materials or to convert plastics refuse into energy.

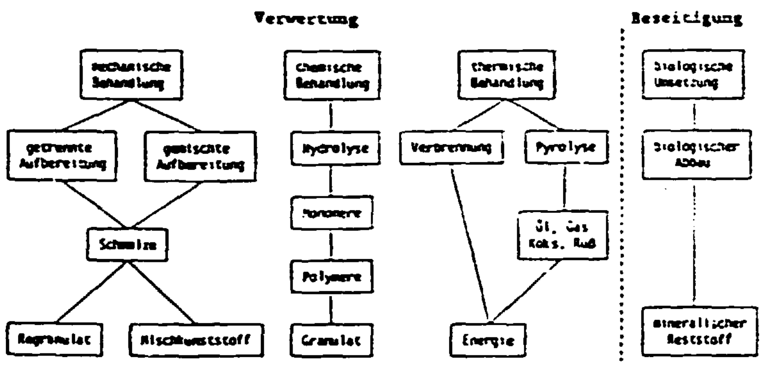


Figure:8

7.1 Material recovery by central sorting of household refuse

Material contained in household refuse can be recycled either after collection of source segregated materials or after centralized manual or automated sorting of refuse.

7.1.1 Basics and problems

The oldest simplest and most widely used sorting method is the hand-picking of valuable components from waste. Although most of these activities will meet criticism on hygienic, social and aesthetic grounds, it should also be stated that recovery on the dumpsite is an organised and basic part of developing economies all over the world. The capacity of sorting at a belt varies from a few hundred kg/h for light and bulky material to severals tonnes/h for dense material. Usually the belt moves at a speed of 10 m/min. [3]

Sorting methods can be subdivided into dry and wet methods. Dry methods are cheaper in investment and operating costs than wet methods, but they may create dust problems and explosion or fire hazards. Moreover, the recovered fractions are still contaminated with dirt or organic materials. Wet methods are more expensive, they yield a cleaner product, but give rise to a waste water treatment problem. The table shown below lists a number of dry and wet methods, with their size range of application.

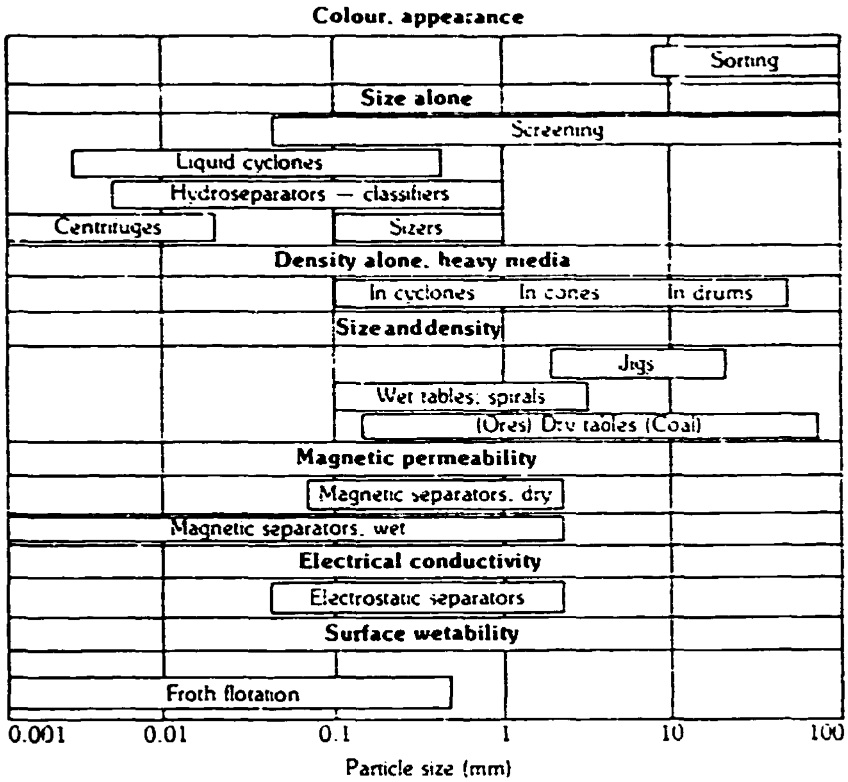


Figure:9

7.1.2 Yields and grades

Each sorting operation subdivides a feed stream into at least two fractions, between which the components of the original mixture are distributed. The performance of a sorting operation on a component can be characterized by a concentration ratio, a yield and a product grade. When a separator, for example, is used to extract plastics materials from a refuse layer, spread onto a conveyor belt, the previous factors can be defined as follows:

$$\text{Yield} = \frac{\text{Amount of plastics material in the concentrate}}{\text{Amount of plastics material in the feed stream}}$$

$$\text{Product Grade} = \frac{\text{Amount of plastics material in the concentrate}}{\text{Total amount of the concentrate}}$$

$$\text{Concentration Ratio} = \frac{\text{Flow rate of the feed material}}{\text{Flow rate of the concentrate}}$$

These factors should be as high as possible, but may be conflicting goals.

7.1.3 Size reduction

Size reduction is a basic operation for all separation methods. Hydrolysis and pyrolysis require only small size reduction, on the other hand there is a size reduction to small particles necessary for technologies such as screening and separation to remove non-plastics and separate the different types of plastics materials.

Size reduction in sorting systems can serve:

1. to make oversized materials more tractable;

2. to liberate entangled material;

3. to convert composite items to more homogenous materials; and

4. to give the feed stream an optimum, homogeneous size for a particular sorting process.

For all these reasons, shredding is the basic step for a large number of automatic refuse classification systems. But it can also be used as a selective classification method for specific feed streams:

1. Shredding of a mixture of paper and piastics films selectively tears the paper, expecially when this is moist;

2. Glass can be eliminated from plastics or metals by crushing it in an impact mill or a drum with filters. [3]

Hammer and flail mills operate on the basis of impaction and shredding.

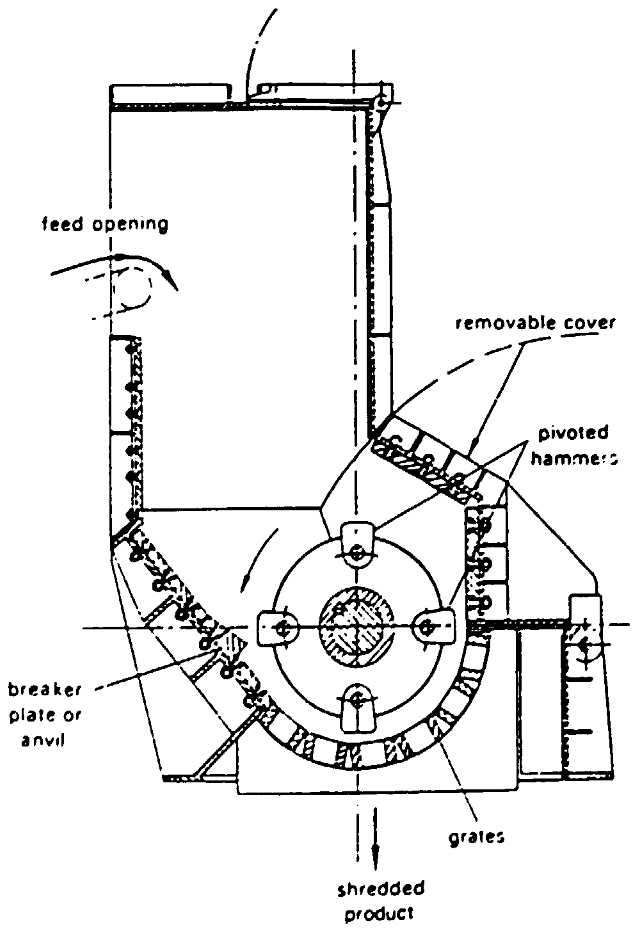


Figure:10

These consist of a heavy casing, with a single or double rotor, rotating at high speed (usually 1,000 to 2,000 rev./min.). Low speed knife or disc mills are used to reduce the size of the larger refuse components without extensive shattering of glass or cross contamination.

There are several problems forthcoming with size reduction. The equipment has higher operating and investment costs and during the shredding process the different components are cross contaminated.

Costs:

Low speed knife mills:	mass specific energy consumption:	30 - 35 kWh/t
	costs for a plant with 1,000 t/a:	35 - 45 US$/t
hammer mills:	mass specific energy consumption:	150 kWh/t

[13]

7.1.4 Screens and sieves

Screens and sieves are basic equipment used to:

1. protect downstream equipment against oversized and tramp material;

2. remove fines, which are either valueless (e.g. ash), or interfere with subsequent operations, such as the formation of slimes; and

3. prepare the feed stream for a particular sorting process which requires material in a given size range.

Raw or shredded refuse can be subdivided into several size fractions with markedly different compositions:

1. Fines (usually below 2 cm), containing ash, dirt, earth or shattered glass.

2. Middle fraction (usually 1-2 to 5-10 cm), containing a large part of kitchen and garden waste, small pieces of paper, plastics or metals.

3. Large fractions (usually 5-10 to 15-30 cm), containing a large part of reuseable paper, plastics and bottles. 4. Oversized material, consisting of large films, magazines, and miscellanous objects. [3]

For some separation processes, such as the sink/float separation process and other processing technologies, sizes of particles above 1 mm are necessary. Tests with a 6 mm screen in a hammer mill have shown that more than 45 per cent of the product was reduced to sizes smaller than 1 mm. This portion cannot be recycled. [2]

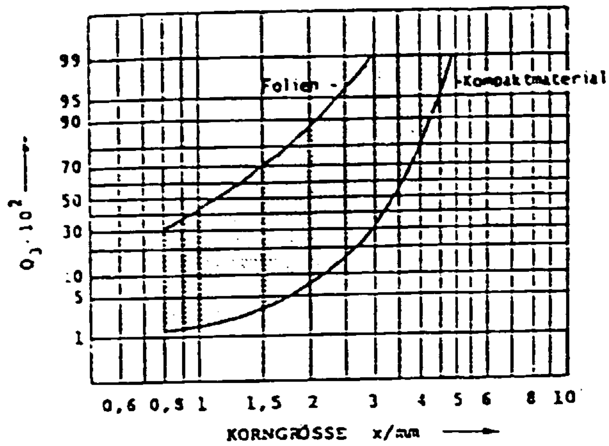


Figure:11

Drum screens, consisting of a slightly inclined, rotating cylindrical frame covered with a perforated plate, bars or wires, are mostly used in the screening of raw and shredded refuse. The most important operating problem with screens is their tendency to be blinded by wires, textiles etc..

7.1.5 Dry sorting

The success of the separation is basically determined by the particle size.

7.1.5.1 Ballistic separators

Ballistic separators are used to classify refuse according to the inertia of the individual components. The latter are dropped one by one onto a rotor and projected into a classifying chamber. The greater the mass of the particle, the greater is the travelling distance.

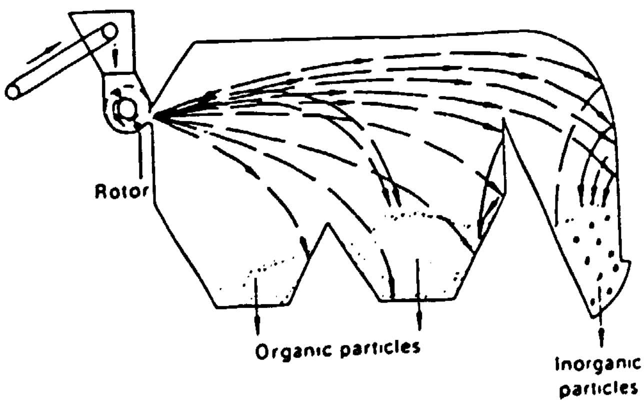


Figure:12 Ballistic separator. (Reproduced with permission from A. V. Bridgwater and C. J. Mumford *Waste Recycling and Pollution Control Handbook*. George Godwin/Van Nostrand Reinhold.)

In a sorting process developed by the Franklin Institute, refuse is shredded, screened and air classified. Material over 2.5 cm in diameter is hurled away by a rotating cogwheel in an almost horizontal direction and collected by one of three consecutive bins [3]

7.1.5.2 Secators

The secator is used to separate hard and elastic materials from softer and lighter ones.

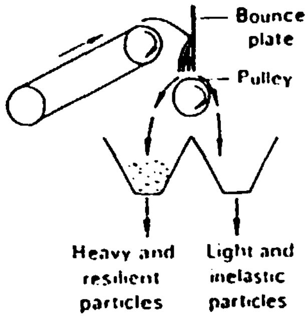


Figure:13 Secator. (Reproduced with permission from A. V. Bridgwater and C. J. Mumford *Waste Recycling and Pollution Control Handbook*, George Godwin/Van Nostrand Reinhold.)

The components to be separated are dropped onto an inclined band conveyor or onto a slowly revolving drum. The heavy, hard or elastic particles bounce up and move down by gravity, whereas the light and soft material adheres to the surface and is carried away.

7.1.5.3 Fluidized bed separators

Fluidizied bed separators have been invented for separating metal from cable sheath after chopping up electric cables.

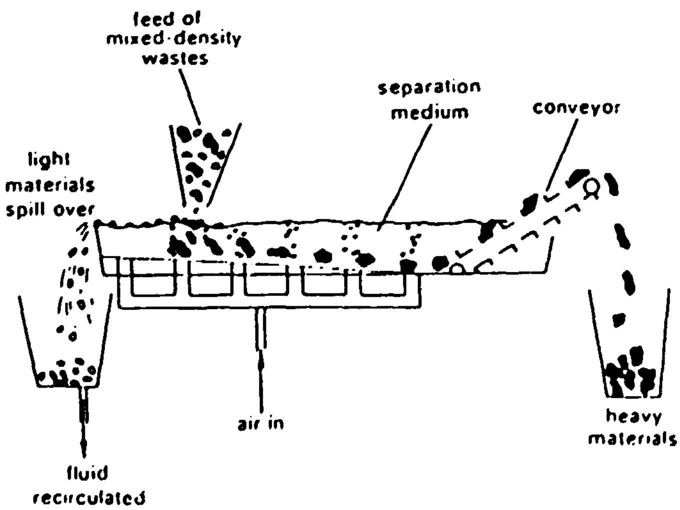


Figure:14 Fluidized bed separator. (Reproduced with permission from A. V. Bridgwater and C. J. Mumford *Waste Recycling and Pollution Control Handbook*, George Godwin/ Van Nostrand Reinhold.)

The separators are based on the sink/float principle, i.e. light particles flow atop and dense particles sink to the bottom of the bed. The separator handles material in sizes ranging from 0.2-10 cm and requires a miniumum difference of density of 0.2 g/cm^3.

7.1.5.4 Stoners

Stoners are slightly inclined perforated tables with a specific movement, so that dense particles climb faster than lighter ones. The latter are carried off downwards. An air current, rising through the perforations more or less fluidizes the mixture.

7.1.5.5 Air classifiers

Air classifiers separate waste components on the basis of falling velocity which is determined by weight and aerodynamic properties. They are major components of almost every dry sorting system.

Vertical classifiers give a sharper separation than horizontal ones. On the other hand their capacity is a factor 3-4 lower to allow the settling of particles without excessive mutual hindrance.

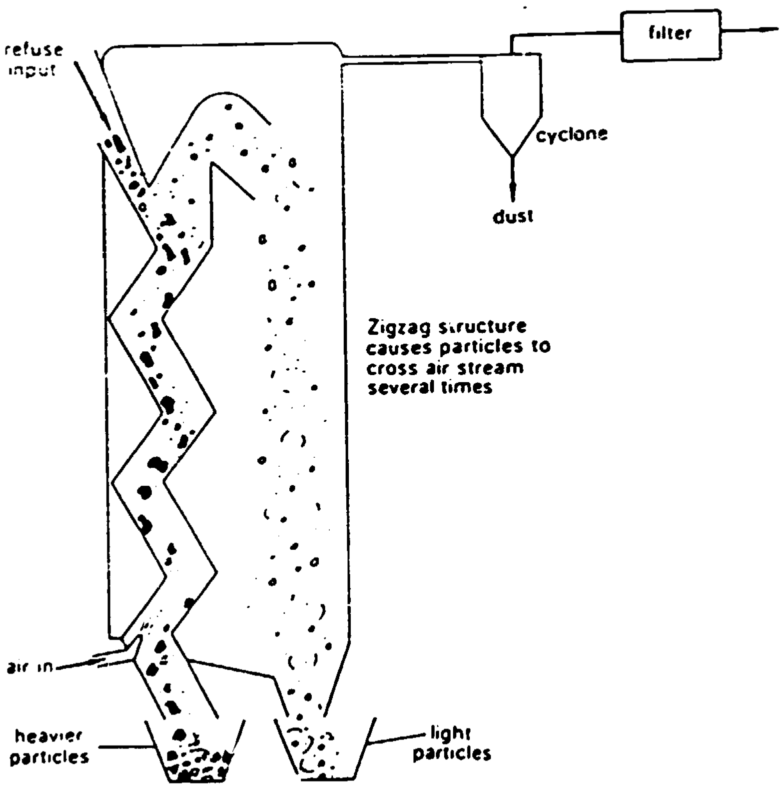


Figure: 15 Zig-zag air classifier. (Reproduced with permission from A. V. Bridgwater and C. J. Mumford *Waste Recycling and Pollution Control Handbook*, George Godwin/Van Nostrand Reinhold.)

The best classification is achieved by zig-zag air classifiers.

Air classifiers can be used to reduce the portion of fines, having a size below 1 mm. A combination of screening and air classification has proven useful for high throughputs.

7.1.5.6 Vortex classifiers

Particles falling through an air vortex change their radial position under the combinded influence of gravity and aerodynamic forces and approach their equilibrium radius in a manner depending on their density and drag coefficient. Such particles can eventually be collected at convenient points. Air is used as a classifying medium; when the density is lower than one water is used for denser materials.

7.1.5.7 Optical sorters

Optical sorters have been developed to separate colour sorted glass from a concentrate of mixed cullet. They can nor be used for sorting household refuse nor for separating different types of plastics materials.

7.1.5.8 Dry magnetic separators

Dry magnetic separators are extensively used in refuse sorting, either to recover ferrous metal from shredded refuse or to remove tramp iron from various streams. The overband separator consists of a stationary electromagnet around which a rapidly moving rubber belt is fitted to capture and carry off the material lifted from the refuse.

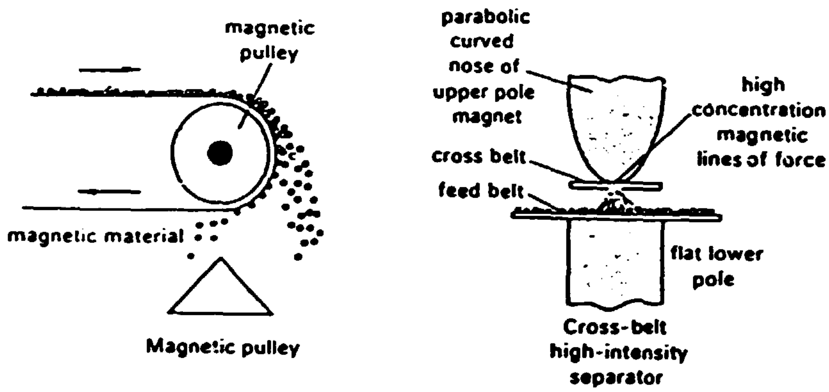


Figure:16 Magnetic separators. (Reproduced with permission from A. V. Bridgwater and C. J. Mumford *Waste Recycling and Pollution Control Handbook*. George Godwin/Van Nostrand Reinhold.)

On raw refuse, the yield of recovered material can be as low as 25 per cent; with shredded or sized refuse a yield of 50 per cent or more can be attained. The usual speed of a conveyor belt is about 1.5 m/s. The treatment cost is of the order of US$ 0.2 per tonne. [3]

This separation technique is often used after size reduction with a hammer mill, but before the knife mill in order to decrease wear.

7.1.5.9 Electrostatic separators

Electrostatic separators can be used to separate conducting from non- conducting particles, or even to separate non-conductors consisting of different materials. Typical applications include most paper/plastics, glass/aluminium, and different types of plastics.

In practice it is difficult to use electrostatic separators, because of the frequent occurance of short-circuiting.

The conductivities of polymers are very similar, therefore destaticisers have been developed to increase conductivity. This separation technology has proven uneconomic because of the lack of selective destaticisers. [2]

7.1.5.10 Metal detectors

These are used to detect small pieces of tramp metal. When a metallic particle passes through the detector, an impulse is generated. A deflection mechanism or an air jet is actuated by this signal and the metallic particle is ejected by one of these means.

7.1.5.11 Eddy current separators

Eddy current separators have been developed to separate metal particles from non-conducting ones. When a conducting particle is subjected to a variable magnetic field, an eddy current is generated which follows a closed circuit inside the particle. The induced current has its proper magnetic field which is opposed to the original field. The repellant force of the two fields can be used to deflect the metal particle from the feed stream.

7.1.6 Wet sorting

These methodes are mainly used for the purposes listed below:

1. to separate organics from inorganics by sink/float methods (e.g. for plastics recycling); and

2. to classify inorganic materials.

Wet processing virtually eliminates explosion hazards and dust problems. Fractions separated by wet classificators are generally cleaner than those obtained by dry methods. Unfortunately, they are generally more expensive in terms of both investment and operating cost.

7.1.6.1 Sink/float separation

A mixture can easily be separated into a light floating and a dense sinking fraction merely by immersing it in a fluid of intermediate density in which the individual components are insoluble. Water is a suitable fluid to separate floating organic from sinking inorganic material. Water/alcoholic mixtures of suitable density have been tested as a means for sorting plastics according to their various types (PE, PS, PVC, etc.). To separate materials denser than water, stable suspensions of very finely dispersed inorganic magnetic materials are used. The magnetism is necessary to separate them from the waste fraction later.

With the sink/float process plastics fractions with purities of over 98 per cent can be obtained. The separation of PVC-P (PVC Plasticised) is not possible. [15]

7.1.6.2 Wet classifiers

Wet classifiers are based on the differences in settling rates of dense and light particles of a constant dimension or between coarse and fine particles of a constant density. The driving force may be either gravity or centrifugal force, as in hydrocyclones and centrifuges.

7.1.6.3 Elutriators

Elutriators can be used to classify incinerator residue, car scrap, chopped electric cable or colliery waste. In an elutriator, the particles settle against a rising current (as in air classifiers), which increases the effective density of the liquid. The drag force on the particles is a complex function of size and form.

7.1.6.4 The hydrocyclone

A hydrocyclone is a vessel with a cylindrical conical shape and provided with a tangential inlet. The entering slurry whirls down along the wall of the vessel. Because of centrifugal forces, heavier particles are concentrated near the wall and are discharged through the apex. The rest of the slurry moves to the centre of the vortex and leaves the hydrocyclone through the overflow. Hydrocyclones are effective in separating solids from about 5 to 150 micrometers. [3]

The hydrocyclone has, compared with the sink/float process, a higher throughput and a simpler structure. The purity of the output can reach up to 97 or 98 per cent. The energy consumption is about 36 kWh/t. A plant with a capacity of 4,000 t/a causes costs of about US$ 20 per tonne of plastics material. [14]

7.1.6.5 The centrifuge

A centrifuge can also be used to classify solids. Since the entire body of liquid rotates at an almost uniform velocity, the shear forces between successive concentric layers of fluid are very small. Therefore the agglomeration of particles does not take place.

In nozzle bowl machines the feed enters near the axis of rotation and spreads radially between a number of closely spaced perforated disks.

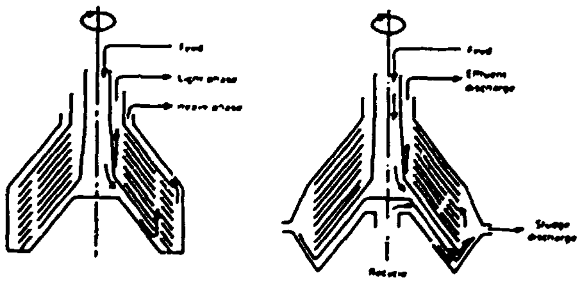


Figure: 17 Nozzle-bowl centrifuge. (From *Chemical Engineering Handbook*, by Perry and Chilton. Copyright © McGraw-Hill. Used with the permission of McGraw-Hill Book Company.)

The feed splits into a dense fraction which is collected by a discharge nozzle at the periphery of the bowl and into a light fraction which discharges near the axis of rotation. Sharp classifications are possible for particles below 10 micrometers.

7.1.6.6 Flotation

At the present flotation is probably the most important method for processing of complex ores, but can also be used for other materials such as plastics. The material is first slurried to a pulp. Chemicals are added which influence the surface properties of the material to be separated. Adsorption of collectors make particles water repellent (hydrophilic). Then a froth layer is created, either by mechanical means or by air agitation. The hydrophobic material collects in the froth and is scraped off, whereas the hydrohphilic material is retained in the pulp.

Flotation can be applied to all liberated particles that can be lifted by gas bubbles (5-800 micrometers).

The selective separation of plastics material is caused by chemical substances (5 to 150 mL/L) in the separation fluid. The purity can reach up to 99 per cent; the costs being about US$ 17 per tonne. [14]

With this technology the different PVC types can also be sorted.

7.1.7 Effects of collection

The collection method or frequency has a marked influence on the quality of the refuse to be sorted:

1. In compression vehicles the mixing and contamination of refuse components are minimal. Screw compacting systems open most refuse bags and cause a more intensive mixing. The tumbling action of rotary drum collection vehicles opens most bags and causes extensive moisture transfer and attrition.

2. The frequency of collection determines the amount of odour hindrance, flies and moisture transfer.

3. Where refuse is collected in paper or plastic bags, provisions should be made to open the bags and liberate the contents prior to or during the initial stages of sorting.

7.2 Recycling of plastics materials (material recycling)

The plastics fraction in household waste consists of more than 90 per cent of thermoplasts. These can be melted and processed over and over again (limit: decomposition). It is necessary to have at least an amount of 50 per cent of a certain type of a thermoplast to achieve sufficient mechanical strength. The compositions of thermoplastics in household waste is given in the table below: [2]

Plastics Type	weight per cent
Polyolefins	60 - 65
Polystyrene	15 - 20
Polyvinylchloride	10 - 15
Other plastics	about 5

Table:6

This way of recycling without separation into the different thermoplastics is of relatively low investment cost. It allows the manufacture of products with "new" properties, different from the "originating" thermoplasts and with mechanical strength lower than each of the mentioned commodity plastics. The processing techniques can be granuling, extrusion, foaming, injection moulding or compression moulding.

To obtain a sufficient homogeneity, the material should be processed above the melting temperature of the most stable plastics fraction.

Kunststoffart	Erweichung [°C]	Verflüssigung [°C]
PVC	100 - 150	130 - 190
PE	105 - 130	140 - 200
PS	80 - 90	140 - 160

Table:7

Because of the differences between the melting points of the various types of plastics, a partial decomposition of several fractions may occur. The crack products must be sucked off and treated properly.

Recycling has always been the desired method, when compared with the thermal disposition of plastics waste. Without the requirement of using virgin material new plastics articles can be manufactured quite economically.

Although the quality of the recycled products is poorer than of those made of virgin material, they are still valuable for applications together with new material or for parts having to meet lower requirements and quality standards. The amount of recycled material in the virgin material is determined by the mechanical properties required. As a matter of fact recycled products are predominantly of dark colours, they are usually pigmented grey, black or brown.

In spite of these disadvantages mentioned above, recycling of plastics materials should be practiced in order to save resources and energy.

Generally spoken there are two philosophies existing in the recycling of Municipal Solid Waste:

1. Recycling of waste plastics consisting of pure polyolefins or polystyrenes providing a high quality "regranulate";

2. Recycling of the plastics mixture more or less as it occurs in the household waste bins without mechanical separation and sorting.

The recycling of industrial waste, consisting mainly of one type of polymer with little contamination is in practical operation since a long time, but is not to be dealt with in this report.

7.2.1 Recycling of plastics films and sheets consisting mainly of polyolefins

To achieve pure polyolefine waste complicated and expensive separation and cleansing technologies are necessary, resulting in high - quality products, showing excellent performance (tensile stress, MFI, etc.).

In the following the recycling process by ANDRITZ-technology will be described, similar process-techniques have been developed by AKW, WAVIN and LANCE.

7.2.2 The ANDRITZ technology-recycling plant

The plant for treating waste plastics with Andritz Technology, producing roughly 1 tonne polyethylene granulate per hour, is able to process mixed plastic films and sheets (mainly LDPE and HDPE-a low amount of PP) with a maximum contamination of 20 per cent.

Foreign matters and other types of plastics, such as PVC, PS, PET etc., are separated and removed in the cleaning and separating stages.

WASTE PLASTIC TREATMENT
PLANT USING
ANDRITZ TECHNOLOGY

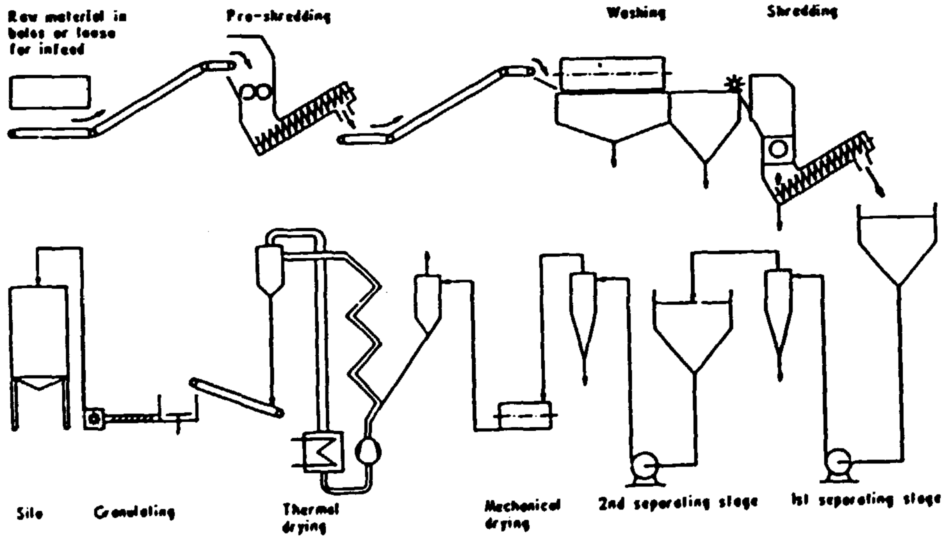


Figure:18

The process is carried out as follows:

The raw material is brought from the storage pile on a stacker truck and deposited on a belt conveyor, which brings it to the preliminary shredder.

The material coming from this shredder is transported to the preliminary washing stage on a second belt conveyor. Following this washing stage, there is a wet shredder, with rotating knives, which reduces the size of the films to pieces of about one cm in diameter.

After this second shredding stage, the plastics material enters a multi- stage separating and washing unit via a dewatering screw.

The multi-stage separating and washing unit has two highly efficient hydrocyclone stages, which remove foreign matter. The upper stream of washed material from the second stage then is put through a vibration dewatering stage.

In the low-concentration section after the separation stage, the shredded sheets are properly divided into two streams.

Since all subsequent units are in duplicate, the entire system's operating reliability is raised.

After the vibration dewatering stage, the material undergoes mechanical drying.

Now the raw material is more or less free of water, it is put through a thermal drying stage. From here it is conveyed on a specially designed storage conveyor to the granulator. Finally, the granulated material is blown into a mixing silo and filleo into bags from there.

The water needed in the wet section of the plant is circulated in two loops and cleaned efficiently by mechanical means in order to keep consumption of fresh water as low as possible.

The total electric energy consumption is approximately 0.6-0.8 kWh/kg granulate and around 0.15 KWh/kg granulate for thermal drying energy in the form of hot water.

The fresh water consumption, which depends on the grade of contamination of the waste films, is about 8 kg/kg granulate.

The resulting product is high-grade PE granulate, which can be used again for processing of plastics films. [28]

7.2.3 Remoulding of mixed plastics waste

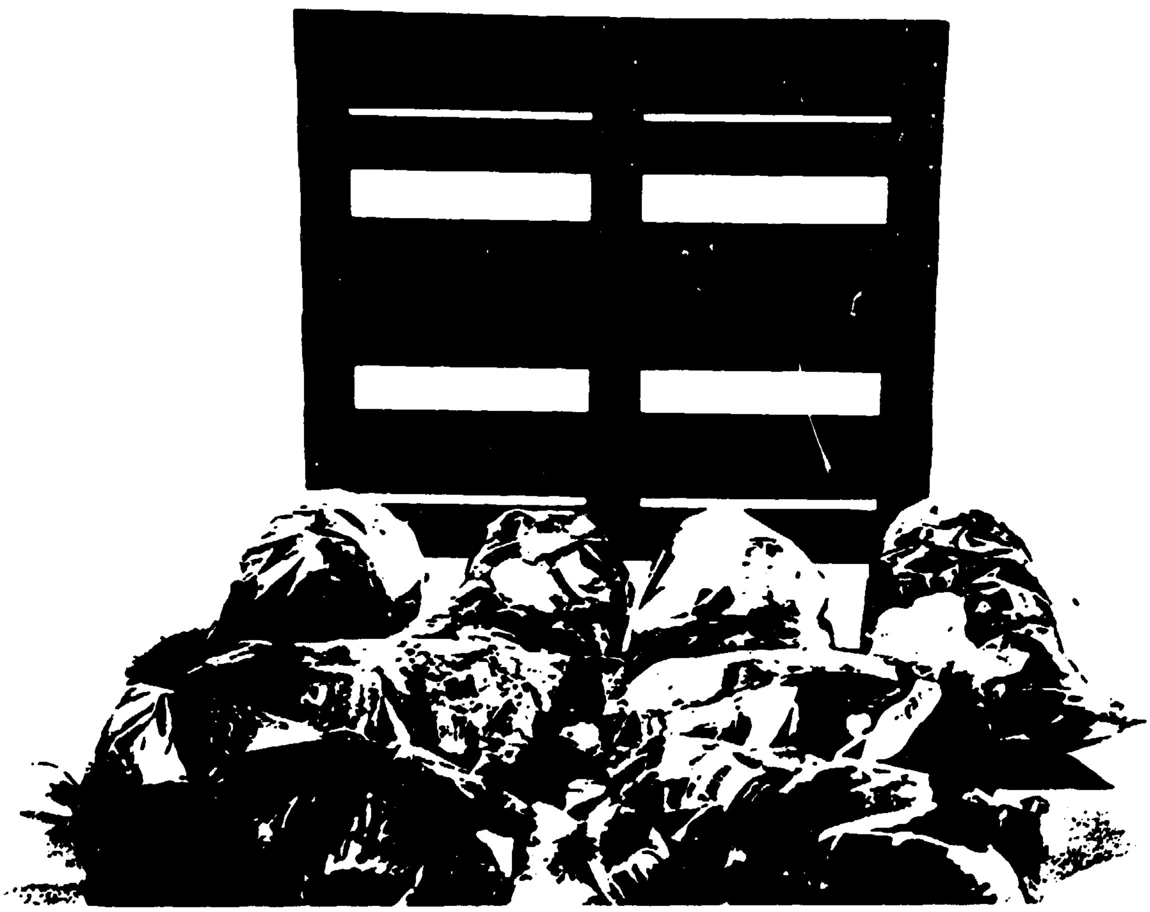
Using these technologies a great variety of waste, even copper-strands of cables, yoghourt-cups, all types of packaging materials and the like, can be recycled. A remarkable decrease in quality in comparison to the recycled products made of pure polyolefine waste, must be considered.

The determined development of energy and cost effective solutions to the re-processing of mixed (comingled) plastics waste has resulted in introducing "new" raw materials to the industrial market, which makes savings upon the use of basic energy resources and furthermore improves the environment.

The products are used for wood-replacement, EURO-palettes, palisades, fences, flower pots, noise control screens, drainage channels, marina supports and plant control constructions.

A frequently used technology was developed by GREINER, other companies with similar techniques are SUPERWOOD, ART and several Italian, Dutch and Swedish Companies all based on the basic development of the Japanese Reverzer-process which has been introduced to European countries by REHSIF SA. and modified and further developed by E. Klobbie.

7.2.4 DEKOPLAST-plastics recycling from GREINER EXTRUSIONSTECHNOLOGY COMPANY, AUSTRIA



Picture: 1

(Hollow Chamber Plastics Profiles from Mixed (Comingled) Plastics Waste)

7.2.4.1 Basic research

To establish this recycling technique several assumptions had to be met.

It was found that the most promising methods of collection and sorting were using the "Green Bin" system; in this system each household has two waste disposal bins, one "Black" for inorganic materials such as glass, paper, metals and plastics and a "Green" bin for organic materials such as food remains, wood and compostible remains. The second system involves the establishment of collection centers organised by local government. Households would be encouraged to bring their own inorganic waste and hazardous waste to the centres where this could be sorted and further transported to those recycling companies involved.

Using material gained from each method of collection trials were made with the plastics waste exactly as it was delivered. This meant that all soiling, dust, dirt and remains in plastics containers, is be attempted to be reprocessed with the plastics without further washing or sorting.

Analysis of this waste showed that this mixture was composed of the following:

weight per cent	Plastics Type
50 - 65	Polyolefines (PE, PP, Polyolefine laminates etc.)
15 - 20	Styrene polymers (PS)
8 - 14	Vinyl polymers (PVC)
0 - 5	Polyethylene terephthalate (PET)
1 - 4	Other materials, including dirt paper, aluminium etc.

Table:8

7.2.4.2 Preparation of the plastics waste

This phase involves the most appropriate methods of preparing the plastics waste into a form where this material can be processed into hollow chamber extruded profiles.

It must be realised, that the collected material can be divided into two basic types:

1. Formed parts (injection mouldings, vacuum formed mouldings, blow mouldings and injection - blow mouldings), know as hard plastics;

2. Items directly produced from plastics films (plastics sacks or bags and film wrapping), known as soft plastics.

By using conventional shredding and grinding machinery it is possible to size reduce both types of material, however the resultant granulate has obviously a relatively low bulk density. There are two reasons: The film products can only be chopped into small pieces which do not not flow easily in transport equipment and their intrinsic shapes give an uncontrolled low bulk density.

Size reduction of the hard plastics alone results in a regular granulate with a bulk density of approximately 0.35 g/cm^3, furthermore this granulate has a good flow.

Soft plastics and film products can be size reduced and densified using an agglomerator, where the film waste is processed into basically round (ball-like) granules with a regular bulk density of approximately 0.35 g/cm^3. This material also shows a good flow behaviour, which means, that the soft plastics granules and the hard plastics granulate can be remixed together and be processed in this way.

7.2.4.3 Machinery

This phase involves the development of the best suited extruder to plastify and homogenize the mixed (comingled) plastics and the design characteristics of dies and calibrators to produce extruded hollow chamber profiles.

The first trials were made with single screw, medium length machines, however the moulding material showed too much inclusion of gas. Further trials showed, that this gas comes from moisture inclusion in the waste and reaction gases from the plastifying of mixed plastics.

Experiments using relatively compact twin-screw extruders with medium length plastifying units and de-gassing units gave better results. A melt being 99 per cent free from gas inclusions can be formed.

Increased through-put (kg/hour) was further improved with the incorporation of a special agitator, compression device in the raw material hopper above the extruder barrel material inlet.

Processing temperatures range between 170 and 195 centigrades. Materials having higher melt temperature remain as "non-plasticated" fillers.

Die designs were optimized with the emphasis on providing more compression of the melt through the die flow channels.

Calibration and cooling of the formed plastics mass was achieved using a single dry cooling vacuum calibrator externly and wet calibrators under vacuum in a spray tank.

7.2.4.4 Products

The granulate size, approximately 5 mm, dictates the minimum wall thickness of profiles, 4-5 mm. Comparatively simple hollow planks, posts, pipes and single wall profiles have been produced and are now successfully competing with conventional products including items for the transport, construction and agricultural industries, such as noise control screens, drainage channels, marina supports and plant control constructions.

7.2.4.5 Cost analysis

(based upon Austrian conditions, maximum 4000 tonnes per year = 4 extrusion lines with Austrian costs, US Dollar converted at 13 ATS = 1 US$).

A. Investment:			US$ * 1000
a)	Land $5000\ m^2$ at US$ $23,00/m^2$	115.000.-- US$	
	(approx. 54000 SQFT) development cost	15.385.-- US$	

		130.385.-- US$	
on 20 year loan with 9 per cent interest			12.46
b)	Production building $2500\ m^2$ a US$ $460/m^2$	1.150.000.-- US$	
	(approx. 27000 SQFT) on 15 year loan with 9 per cent interest		128.23
c)	Administration building 300 m2 a US$ $1154/m^2$	346.200.-- US$	
	(approx. 3230 SQFT) on 15 year loan with 9 per cent interest		38.46
d)	Office funiture + equipment	46.154.-- US$	
	on 5 year loan with 9 per cent interest		11.31
e)	Vehicles 1 car, 2 trucks, 2 fortrucks	38.462.-- US$	
	on 5 year loan with 9 per cent interest		94.24
f)	Accessory production equipment	115.385.-- US$	
	on 5 year loan with 9 per cent interest		28.23
g)	Production plant		
	on 5 year loan with 9 per cent interest		640.77

			953.70

B. Overheads and Maintainance Costs		US$ * 1000
a) Building and land		19.23
b) Machinery		
1 barrel and screw set	34.61	
grinder knives	19.23	
accessories	23.08	
		76.92
c) Vehicles		
taxes/maintainance	6.92	
fuel	13.85	
		20.77
d) Overheads		
travel	23.08	
advertising	15.38	
service personnel	15.38	
insurance	11.54	
post, telephone, fax	26.92	
office and computer	26.92	
taxes and contrib.	15.38	
extras (not defined)	30.77	
working capital loan costs	15.38	
		180.75
e) Raw material		free of charge
C. Personnel		
18 people a US$ 29.23		526.15
D. Power		
2200 Megawatt/year at 0.1 US$/kWh	US$ 220.000.--	

1200 m^3 water
at 0.65 US$/m^3 US$ 7.800.--

227.80

2005.32

E. Cost

without selling costs, profit, freight, additives and margin at 90 per cent efficiency = 3600.000 kg (approx. 7.637.28 thousand pounds)

manufacturing cost per pound = 0.2526 US$/LB

[29]

7.2.5 Conclusion

In the last two years several recycling plants for plastics films have been installed in Europe and the real cost per tonne of regranulate including investment, operating and maintainance costs vary between US$ 300 and 400.

7.3 Pyrolysis

Pyrolysis is the thermal decomposition of organic materials under exclusion of oxygen, air, CO_2 and the like. Fugitive substances are emitted in a temperature range between 150 and 900 centigrades.

Products obtained in this process are:

- Pyrolysis soot or coke
- Pyrolysis oil
- Pyrolysis gas

The products are either used as fuel or to process basic materials for the chemical industry.

7.3.1 Products and their properties

Plastics are cracked in C_{25}-C_{40} aliphatic materials in a temperature range between 300 and 350 centigrades. Increasing the temperature up to 700 to 800 centigrades result in a C_2-C_4-olefinic fraction. The olefinic materials combine under high temperatures to aromatics under emission of methane and hydrogen. [17]

7.3.1.1 Pyrolysis soot or coke

The solid products provided by pyrolysis of plastics materials are:

- fillers
- soot
- coke

Depending on the material cracked the solid portion can range from 1 to 43 per cent of the input material. [2]

7.3.1.2 Pyrolysis oil

The portion of the pyrolysis oil is about 40 to 60 per cent of the input material. It is a mixture of light fractions und coal tar and consists to 95 per cent of aromatics. By means of destillation, the oil can be separated into a high and a low boiling fraction.

Benzol-, Toluol-, Xylol-Aromaten	Gew.-%	60 - 70
Naphthalin + Methylnaphthaline	Gew.-%	10 - 15
Siedeverlauf:		
Siedebeginn	°C	30 - 70
Siedeende	°C	200 - 250
Dichte:	kg/m³	800 - 900
Mischoktanzahl:		80 - 100 95 - 110
Organisches Chlor:	mg/kg	0,3
Anorganisches Chlor:	mg/l	30

Table:9

Benzol, Toluol, Xylol-Aromaten	Gew.-%	5
Naphthalin + Methylnaphthaline	Gew.-%	20 - 30
Gaschromat. erfaßbare Anteile	Gew.-%	70
Extraktionsrückstand:	Gew.-%	6 - 10
Dichte:	kg/m³	1000 - 1200
Asche:	Gew.-%	10
Organisches Chlor:	mg/kg	5
Anorganisches Chlor:	mg/l	1000 - 2000

Table:10

In the low boiling fraction benzene is the main component and has a portion of 30 to 50 per cent. The high boiling fraction could be used to produce naphthalene. Pyrolysis gas is mainly used in the petrol sector to increase the Octane Number. The refinement of chemical substances such as toluene and benzene has been proven to be uneconomic. [17,18]

7.3.1.3 Pyrolysis gas

Refering to the input material 35 to 60 per cent gas is developed. Pyrolysis gas mainly consists of methane, ethane, ethylene, propane. Its calorific value is about 35,000 kJ/m^3.

Parameter	Anteil in [Gew.-%]	Anteil in [Vol.-%]
Wasserstoff	2,2	18,8
Kohlendioxid	4,3	1,9
Kohlenmonoxid	9,4	5,7
Methan	54,5	58,2
Ethan	5,2	3,0
Ethen	16,7	10,2
Propan	0,2	0,1
Propen	2,9	1,2
Butadien	1,2	0,4
Benzol-, Toluol-, Xylol-Aromaten	2,7	0,5
Mittlere Dichte:	0,764 kg/m^3	
Mittlerer Heizwert:	34 554 kJ/m^3 = 9,6 kWh/m^3	

Table:11

The gas can be used to replace natural gas.

7.3.2 Partial oxidation

The pyrolysis of plastics materials between 600 and 850 centigrades provides a mixture containing carbohydrates such as methane up to higher aromatics. A part of the input polymers is oxidized, thus the temperature is increased to 1500 centigrades. At this temperature mainly unsaturated C_2 carbohydrates and methane are formed. Synthesis gas is also developed. Unsaturated C_2 carbohydrates (ethylene) are basic materials for the plastics industry.

7.3.3 Economic considerations

7.3.3.1 Pyrolysis gas

A basic assumption is the short distance between the waste producers and the pyrolysis plant. This should not exceed 50 kms. This range would provide an annual volume of waste of about 10,000 tonnes. A cracking plant for household waste with 5,000 t/a, compared with industrial cracking plants (usually 500,000 t/a) is not economic, but can be used in combination. A price between US$ 350 and 600 per tonne pyrolysis gas could be obtained. [19,20,21]

7.3.3.2 Pyrolysis oil

The price depends on the price of crude oil. Pyrolysis oil usually costs about US$ 350 per tonne. [2]

7.3.3.3 Pyrolysis soot

Soot can be activated and used as active coal, or as pigment in varnishes and paints.

7.4 Hydrolysis

The goal of hydrolysis is to obtain monomeric basic materials from plastics refuse. A re-reaction of all plastics produced by means of polycondensation or polyaddition, such as the polyamides, polyesters and polyurethanes etc. is possible. The hydrolysis can be performed either in water or in higher alcohols.

The fluid or gaseous monomeric products can be used after special treatment to produce the respective plastics material again.

7.4.1 Hydrolysis of expanded materials

The most important material to hydrolyse is polyurethane. During the past years polyurethanes have become more and more popular and are today much in use. PUR is usually used as a foam, is expensive (US$ 15-18 per kg) and needs large transport containers.

At temperatures of 200 centigrades approximately two hours are needed for a quantitative chemical reaction. Increasing the temperature by 10 to 15 centigrades reduces the duration of the reaction by 50 per cent. [22]

By means of a twin screw extruder (reaction temperature 200-230 centigrades, pressure of hydrogen/steam: 15-30 bar) a continuous hydrolysis technique could be developed. [22]

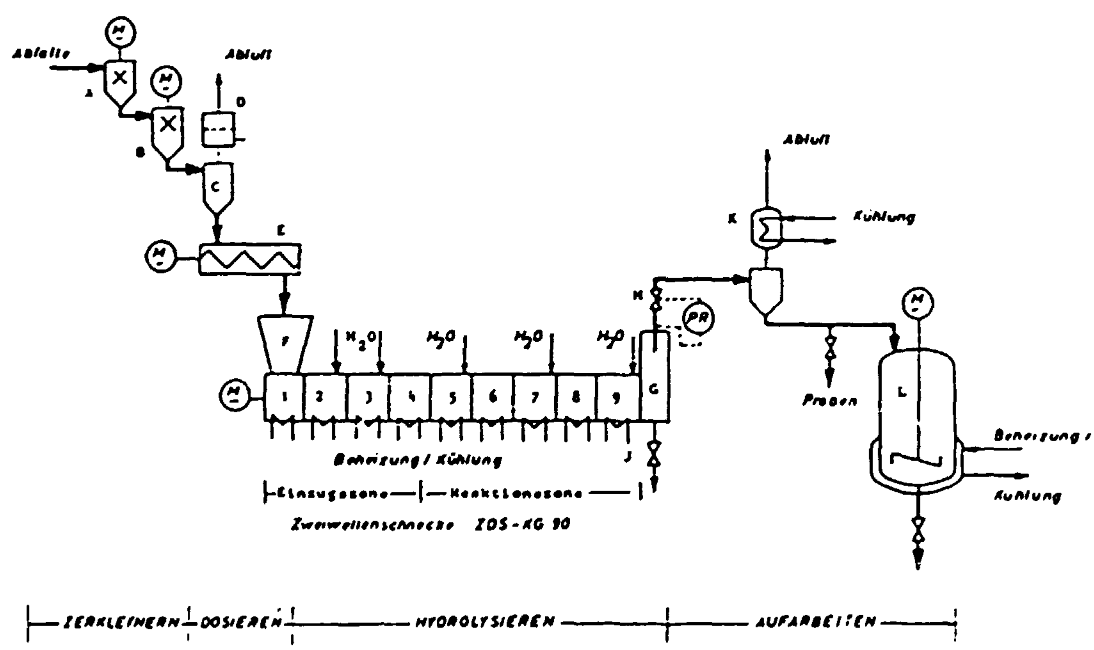


Figure: 19

The expanded PUR materials are first reduced in size to flocks or powder and then fed continuously into the hydrolysis screw. In the compression section the material is compacted. The water, essential to the hydrolysis process, is pressed into the screw by dosing pumps. It vaporizes under heat and pressure. The mixture of fluid and gas is continuously carried out by the screw.

7.4.2 Products and their properties

PUR foams are usually manufactored by means of a reaction between toluylendiisocyanate and polyether. Under special conditions polyurethane can be hydrolysed to the exact preproducts. The amine is used to produce the isocyanate.

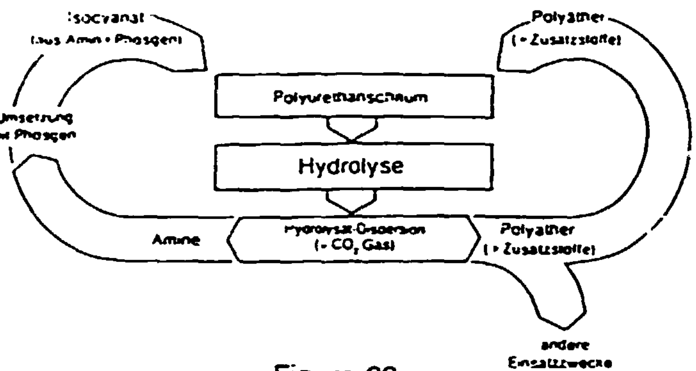


Figure:20

The amine (TDA) can be distilled. By means of a chemical reaction the amine is converted to the isocyanate. The polyether is not modified by the hydrolysis and can, after a purification, therefore be used without pretreatment.

This technology can be applied to all plastics materials which are hydrolysable. The performance of PUR produced from hydrolysed PUR foams and that of new PUR foams is similar.

7.5 Incineration

The calorific value of the plastics fraction in household refuse is about 30,300 kJ/kg. Thus polymers contribute about 15 to 20 per cent to the energy contents of the waste and a separate plastics disposal would lead to a decrease in thermal power.

Older incineration plants are designed for a calorific power of household waste without plastics (8,500 kJ/kg). These plants can only be operated with a reduced throughput, so a separate disposal of waste would prove economic for these plants. [23]

It must be considered that several types of plastics, e.g. PVC, emit HCl, heavy metals and organic substances. About 50 per cent of the HCl emissons are caused by plastics incineration. Ecologists talk of dioxins and furanes in the emissions, but this has not yet been proven.

7.6 Deposition at landfills

Plastics materials do not cause any fluid or gaseous emissions. They are completely inert and are therefore no-toxic.

Unordered disposition of household waste or industrial refuse leads to:

1.Contaminaton of subsoil water and water on the surface by extraction of toxic substances;

2.danger of contagious diseases;

3.contamination of the air in cases of uncontrolled fires; and

4.decreasing value of the nearby landscape.

Thus, an ordered deposition at landfills is required. The costs depend on the geographical position of the landfill, about USS 10-20 per tonne, but will increase strikingly in the future. [23]

Recyicling techniques, incineration, hydrolysis and pyrolysis need an ordered landfill for the deposition of non-usable remains.

7.7 Composting

Polymers in compost behave like glass or metals, i.e. they cannot be decomposed and must be separated. The problem is not physiological, but compost made out of waste, contaminated with plastics is hard to sell.

8. CONCLUSION

The economic value of recovered plastic material depends on the quality of the products that may be made from such a material.

For replacement of relatively cheap construction material separation and cleaning need not go very far. But for more sophisticated applications the recovered material has to meet agreed specifications.

Over the past few years, consciousness in society has undergone a decisive change with regard to environmental problems. A great number of technical research and development programs in the environmental protection area, as well as numerous legal regulations, have been the manifestation of this changes. Recycling of plastics is a relatively young industry which has been developing lately, and the trend is to continue at an increased rate. Thus also applies to reclamation of plastics from discarded industrial and consumer products containing plastic components.

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