Small Scale Recycling of Plastics

by Jon Vogler

Published by:

Intermediate Technology Development Group (ITDG)

Available from:

Intermediate Technology Publications
9 King Street
London WC2E 8HN
ENGLAND

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INTERMEDIATE TECHNOLOGY PUBLICATIONS 1984

Acknowledgement

The author wishes to express his gratitude to the Overseas Development Administration of Her Majesty's Government for financial support for the preparation of this book but to stress that the views expressed are entirely his own and do not necessarily represent the views of O.D.A.

Printed by Printpower, London.

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Plastics Recycling in Kenya.
Project established by the Author

CHAPTER 1: WHY RECYCLE PLASTICS?

The subject of this book is how to create employment by recycling plastics. Although it is primarily intended for use in developing countries the principles are universal and may equally be applied in industrialised nations. Indeed, the quantity of plastic products which are thrown away after use is far higher where the whole population has a "consumer" life style, so opportunities may be greater in such countries.

It describes the collection of plastics waste that has been used once in the world outside and can be collected and processed for return to the factory and remoulded for a second service life.

The book does not cover recycling, by the plastics industry, of scrap produced within the factory, although much of what is included may be applicable. The techniques and equipment used and the skills available in the factory situation are more complex than the simple machines and procedures covered here.

In an age when worldwide unemployment has reached levels not previously expected, it is not necessary to justify any book that introduces employment creation opportunities. The opportunities offered by plastics recycling appear attractive and have not been developed fully. The reasons have been explained in "Remoulding the Future" (Ref.1). They are an important warning of the mistakes and failures of the past, but are too lengthy to repeat here. The reasons why recycling offers good job creation prospects have been discussed in "Work from Waste", (Ref. 14). Some further reasons, peculiar to plastics, must be presented here, if only to persuade the reader to continue. They are as follows:-

Economics

Some recycling activities are not profitable: they cost more than they earn. In general those are most profitable that deal in high value materials. For example the recycling of high grade waste paper, such as computer paper, is usually far more profitable and less problematic than that of newspaper and cardboard which have low value. Plastics, which are mainly derived from petroleum, are expensive materials, at least in terms of their weight. This means they can be recycled profitably; but caution!

One reason why high value is important is that transport costs normally dominate recycling economics - if the value is high compared with the transport cost then a profitable operation is frequently possible and vice versa. Transport costs depend not only upon weight but also on volume.

It is no use having a high value if the volume is so high that transport costs are excessive, even though the ratio of value to weight may be advantageous. This is why so much attention will be paid to volume reduction throughout this book.

Recyclability

Some materials are naturally recyclable, others are not. For example, scrap copper can be melted to produce ingots of the same quality as new copper, smelted from ore. Waste paper on the other hand can never be restored to its initial quality no matter what care is taken in refining and purifying. Plastics are near the better end of the recyclability scale. If they are properly cleaned and foreign matter is removed, the quality of some plastics can be almost as good on the second use as on the first. Not always however. PVC for example can suffer seriously during the recycling process unless care is taken. For explanation of "PVC" and other initials, see Table 1 (Page 10).

Labour intensity

The recycling process can be broken down into different stages, some of which are optional. The initial stages: collection, sorting and cleaning of material are all labour intensive and require little capital equipment. The work is suitable for those who have little skill and the sorting and cleaning may be done by people with certain sorts of disability.

Investment progression

The later stages do require investment in equipment, which may be bought using the profits of the earlier stages if outside finance is not available. This prevents complex developments before early stages have been learned and consolidated. For those lacking previous industrial experience, this may be essential to ultimate success. However this is a slow process and to have capital ready from the start may be more attractive to those who are impatient or ambitious, although it does increase the risk and scale of failure.

Environmental benefit

Because it degrades slowly under the effects of wind, sun and rain, plastics waste is one of the most objectionable kinds of litter. It lies around streets and open spaces for weeks or months after it has been dropped. It may become coated with other, objectionable wastes, provide a harbour for vermin and insects and block up drainage systems. Any process of recycling that places a value upon this material, so that there is a financial advantage in preserving it rather than discarding it, is to be welcomed.

The benefit is greater in poor urban areas, where even small earning opportunities will be seized, as these are the districts where municipal cleansing is frequently least thorough.

Foreign exchange improvements

Although the manufacturing of plastics products may be well developed, few developing countries make their own raw materials. These are therefore imported. If the products are not exported foreign debt is created. By recycling local scrap, these imports and hence the debt, can be reduced. Where plastics feedstock is produced locally recycling may still save energy and raw petroleum.

Low cost raw materials

With good quality, low cost, secondary material, plastics goods manufacturers can cheapen certain kinds of products, without loss of functional quality. Even a small margin may be the difference between profit or loss, competitive price or loss leader, or may enable plastics to be chosen in preference to metal or glass.

A chance for the urban poor

Finally, a vigorous plastics recycling industry can provide unique opportunities for the poorest to earn a small income by collecting waste materials for sale to a recycling plant. No capital is needed, skills may be passed from one to another with little difficulty, so this can provide a catchnet against the consequences of extreme poverty.

This chapter has mentioned benefits for the community, for the nation, for industry and for the individual. Involvement of so many may be one reason why few initiatives in plastics recycling are taken. Another reason is the mystery of the subject and, to remove this, Appendix I considers what plastics are, why they are used as they are and how products are made from them. Readers may prefer to study Appendix I before embarking on the next Chapter.

CHAPTER 2: THE PLASTICS INDUSTRY. PROCESSES, PRODUCTS AND STRUCTURE.

Manufacturing Processes

Although the recycler may never perform any plastics manufacturing operation, to know the processes used by the industry is essential. The industry is the recycler's principal market and only by understanding the uses of the material he produces, will marketable quality and best prices be obtained. A company that advertises "Manufacture of all types of plastics products" may actually perform mainly operations that cannot use recycled material. For example food and drink containers are produced by heat forming thin polystyrene or ABS sheet. This process cannot use raw material in any other form and although reclaim can be used to manufacture the sheet, its use for food packaging is ruled out on health grounds.

The following descriptions of the main manufacturing operations indicate which provide markets to the producer of recycled polymer.

Large volume processes

The four types of operation that follow use a greater volume of polymer than all other industrial processes and all can use recycled material (or "reclaim") if it is clean and pure. These descriptions are brief but processes that can be performed by the recycler will be described in greater detail in Chapter 6.

Injection moulding (Fig. 1)

Injection moulding and extrusion (below) are the processes that use the most raw material. Pellets or powder, are loaded into a hopper which feeds it (by gravity) into the cylindrical barrel of the moulding machine. It is forced down the barrel by rotation of the spiral screw and becomes heated and "plasticized" (softened) in the process. The temperature is controlled by electrical heaters or water (or air) coolers round the barrel and it is forced, under high pressure, through a specially shaped nozzle into a strong, split, steel mould. The mould is kept cool so that the object quickly solidifies, the mould opens, the object is removed and the mould closes for the next shot. There are also machines that use pistons or plungers instead of screws. The process is similar to the pressure die casting of non-ferrous metals, from which it was developed.

Extrusion (Fig. 2)

This is similar except that there is no mould. Instead the nozzle discharges through a die: a steel plate pierced with a

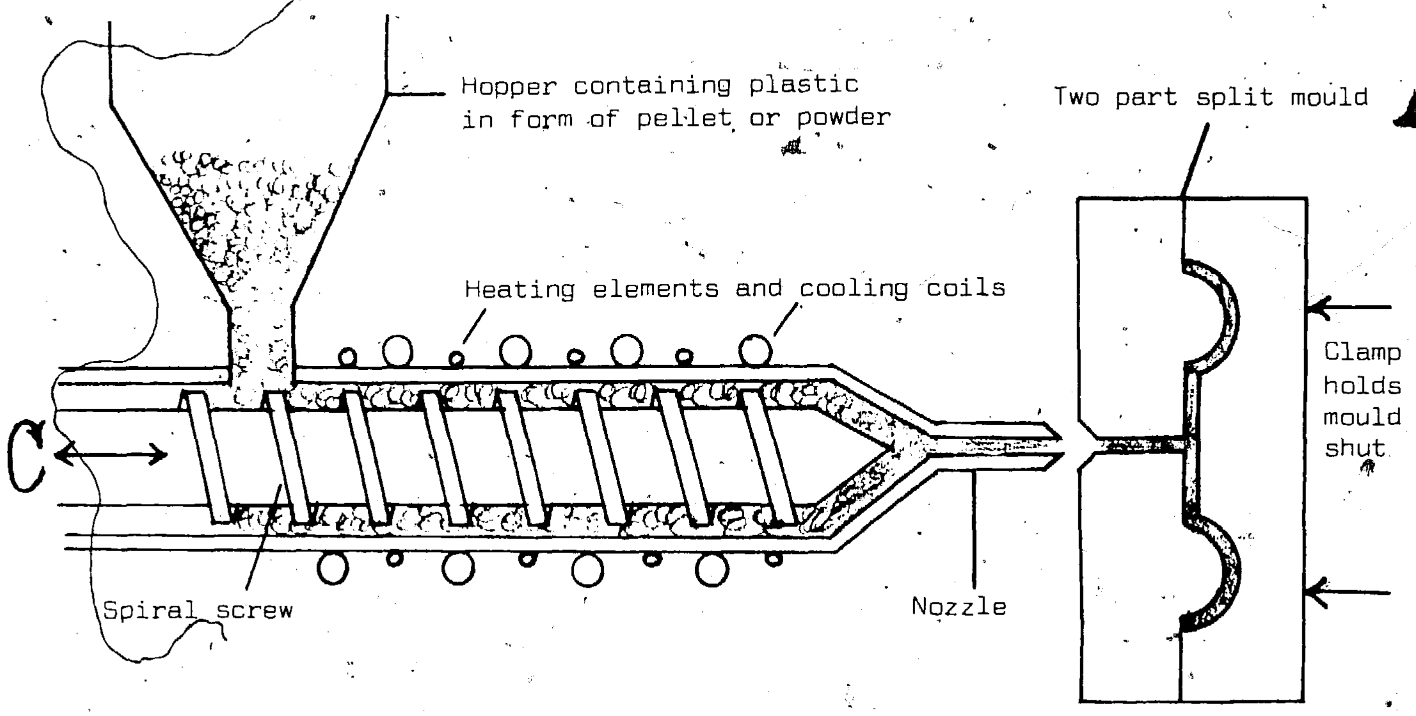


FIGURE 1: The principles of Injection moulding.

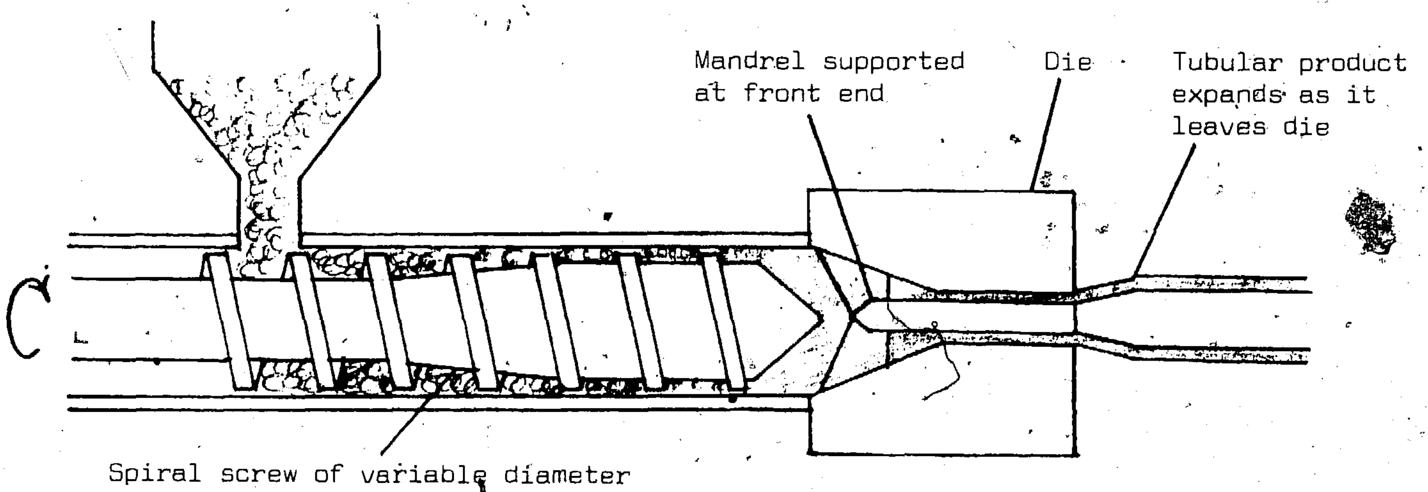


FIGURE 2: The principles of Extrusion.

hole which determines the shape of the continuous, parallel stream of plastic that emerges from it. The extruded material is cooled and solidified in air or a water bath or on a chilled drum, before being wound onto a reel or cut into straight lengths. Pressure in the cylinder is applied by one or more continuously rotating screws. The process, like the extrusion of metals, originated from the manufacture of spaghetti!

Blow moulding (Fig. 3)

Bottles and other hollow objects with a neck narrower than their body cannot be injection moulded without costly complications in the design of the mould. Blow moulding is used instead. It takes place in two stages similar to the blowing of glass. First a parallel walled tube, called a parison, is extruded. It is then transferred to a split mould which has been shaped for the final object, whose two halves nip the end of the parison to close it. Air is blown into the open end to expand it to the shape of the mould. The mould is kept cool and the finished article solidifies and is removed when the mould opens again. The overall thickness of the article may be varied.

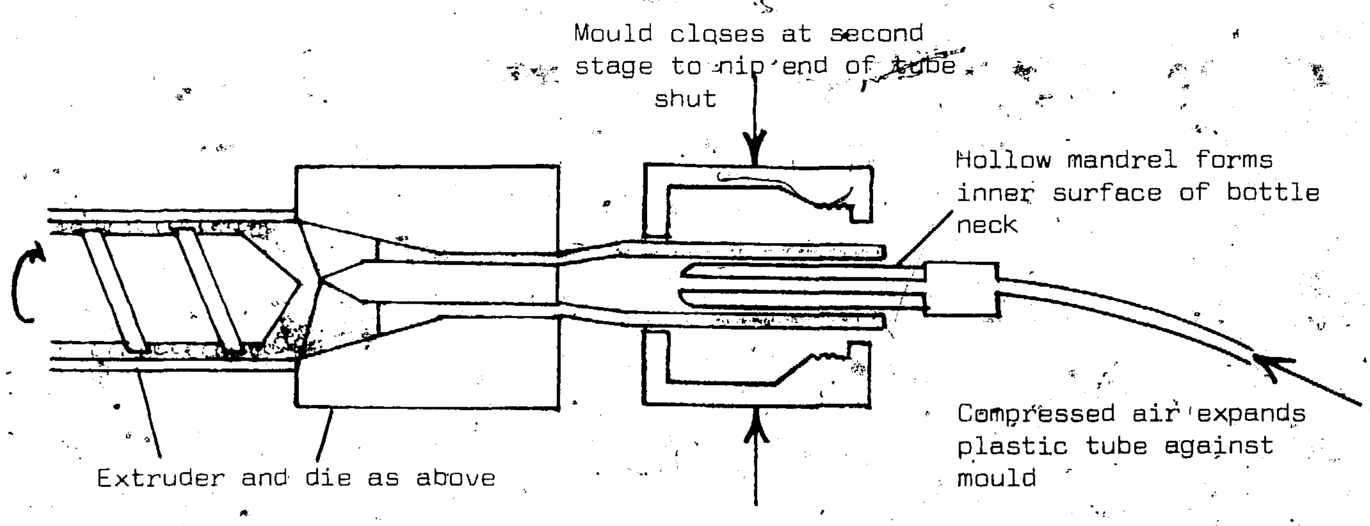


FIGURE 3: The principles of Blow moulding.

Blown film extrusion (Fig. 4)

This is a form of blow moulding but the parison is continuously extruded from a ring-shaped die, usually vertically upwards. Air is blown through the centre of the die to expand it to a tube of thin film. As the tube rises it is cooled and solidifies and at the top is folded over and flattened between chilled rollers, thus preventing air from escaping out of the "bubble". After further cooling the collapsed tube is wound onto reels. To produce sacks or bags, the coils are fed through a machine which seals the bottoms and chops them off in one operation. To produce flat sheet the tube is slit down one side.

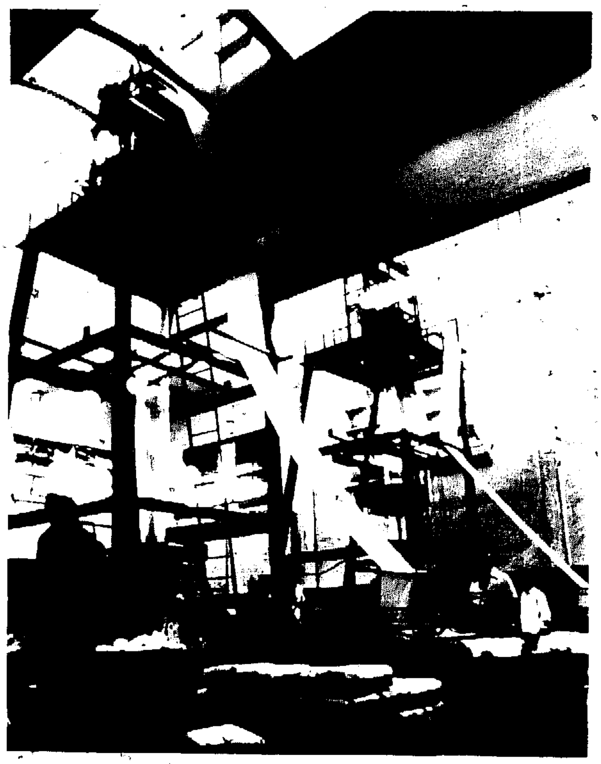


FIGURE 4: Blown film extrusion.

Less common processes

The plastics industry also employs the following less common operations, in which a percentage of reclaim can be mixed with the raw material.

Callendering

This is another way of producing wide sheets. A hot dough is made from the raw material in a heated mixing machine. The dough is squeezed through successive heated rollers to form a sheet of the desired thickness; then through cooled rollers and reeled up.

Slush moulding

Special grades of PVC can be mixed cold with liquid plasticisers to form a paste. This is formed into articles by pouring into a split mould which is rotated so that the paste covers the inside, it is then heated. After cooling the rubbery solid is peeled off the inside of the mould. The process is slow but can use cheap moulds and is suitable for production of small numbers of objects. The paste can also be used to coat cloth ("leather-cloth") or to make washable wallpaper.

Rotational moulding

Large hollow objects are made in small quantities by using a low-cost, low-strength mould, into which a predetermined quantity of thermoplastics in powder form is fed, followed by rotation (in two directions) in an oven. The powder plasticizes and covers the surface of the mould evenly. Rotation continues during cooling.

Coating

Plastics may be applied to the outside of other materials, particularly paper, textiles and metals, to protect them from moisture or chemical attack. Coating can be done by roller, by spraying or by dipping. Special forms of materials are available for these processes. Porous materials may be impregnated with plastics in similar ways.

THERMOPLASTIC PROCESSES THAT DO NOT USE RECLAIM WITHOUT PRIOR PROCESSING

Film Casting

Is used to produce very accurate, high quality films, for example those used for photography. The material is continuously cast onto a smooth, flat, moving belt to form a continuous layer of perfect smoothness and clarity and uniform thickness. Quality is more important than cost and reclaim from outside the plant is not used.

Thermoforming

Flat sheet is heated and formed, either by vacuum suction into a shaped mould or onto a shaped former or by squeezing between male and female dies. It is used to make cheap food and drink cups and trays from continuous coil and large parts, such as refrigerator linings, from single sheets. Reclaim can be used if it is first formed into sheets, but ONLY for products that do not come into contact with food.

Fabrication

Sheets, rods, extrusions and other material forms are cut, shaped and joined by screwing, welding or adhesives, to make a wide variety of products. Fabrication is mainly used when quantities are too small or the product too complex to justify the cost of a mould. Offcuts can be recycled into small fabrications.

Machining.

Plastics are used in engineering in the same way as metals and wood and can be turned, milled, drilled and planed to required shapes. The process is used where small numbers of parts only are required. Nylon is extensively machined in the engineering industry.

Heat sealing.

This is used to convert plastic film into bags and packages.

Shrinking

Special films are available for "shrink wrapping". The article is loosely wrapped in film and heat applied to a carefully controlled temperature. The film shrinks snugly around the object but is not melted.

Foam manufacture

This is described in Appendix 1. There is no fundamental reason why reclaimed polymer should not be used for foaming but the amount of polymer used in foam production is small and most producers buy the material ready prepared. Appendix III includes the name of one of many companies that recycle polyurethane foam into foam products and may be willing to licence the process elsewhere.

Thermoset manufacturing operations

These will be listed for completeness but are of little interest to the recycler:

Manufacture of laminates, compression moulding, transfer moulding, jet moulding, manufacture of reinforced plastic products.

Products of the Plastics Industry.

Table 1 and Figures 5 to 10 illustrate the products made from the most common polymers.

TABLE 1 COMMON RECYCLABLE PLASTICS

POLYMER	CHARACTERISTICS	TYPICAL PRODUCTS - (Figs 5-10) (Not necessarily Recyclable. Note that the same product may be made from many materials).
Low density polyethylene (LDPE)	Soft, flexible Easy to heat seal. Only glass clear if very thin; thick sections are milky white (or coloured).	Film bags, sacks and sheeting. blow-moulded bottles, Food boxes Flexible piping and hoses, household buckets, bowls, etc. Cable coverings, usually telephone cables.
Medium density polyethylene (MDPE)	Intermediate between LDPE and HDPE.	Squeeze bottles.
High density polyethylene (HDPE)	Tough, stiffer than LD. Even thin film is milky (or coloured).	High strength film for sacks and bags. Larger bottles, buckets, crates, jerry cans, pallets, dustbins and other household objects.
Polypropylene (PP)	Like HDPE but harder and more rigid. Can be bent sharply without breaking. "Oriented" film is tough and very clear.	Chairs and other furniture. Best quality homewares and other strong mouldings such as car battery housings, other car and domestic appliance parts, jerry cans, wine barrels, crates, pipes and fittings. Rope, string, strapping, tape and woven sacking and carpet backings, netting. Heat sterilizable surgical goods.
Rigid polyvinyl chloride (PVC)	Hard and rigid in its unplasticized form.	Water and irrigation pipes and fittings. Gutters and rainwater pipes, window frames, building panels. Credit cards, records, transparent packaging, bottles, thin sheet and corrugated sheet.

TABLE 1 - cont.

POLYMER	CHARACTERISTICS	TYPICAL PRODUCTS
Plasticized PVC	Soft, flexible, rather weak. Can be highly transparent. Easily bonded to textiles, metals etc.	Sports and toy balls, inflatable toys and boats. Toys, dolls, novelties. Hose, cable coverings. Suitcases, handbags, other luggage. Shoes, flooring, raincoats, shower curtains, upholstery, automobile linings. Bottles, especially for oils and other chemically active liquids, clear film and pallet covers
Polystyrene (PS)	Easily moulded, but brittle. Can be crystal clear.	Cheap transparent kitchen ware, light fittings, bottles, lenses, jewellery. Toys, radio cases. Medical syringes and other sterilizable medical goods. Food containers and lids. Cheap baby-feeding bottles.
Impact modified PS	Less brittle but no longer clear.	Refrigerator interiors and other domestic appliance mouldings. Vending cups and take-away food trays. Shoe heels.
Expanded PS	Very lightweight, white, expanded foam - not economic to recycle.	Ceiling tiles, insulation, packings, padding.
Acrylonitrile Butadiene Styrene (ABS)	Tough, stiff, easily moulded to give shiny surface finish. Good resistance to food, oils etc.	Food (especially margarine) containers. Telephone hand-sets & other office equipment, camera housings. Domestic appliance parts. Electrical hand tools. Toys.
Polyamides (Nylons)	Strong, very tough, machinable. Slippery low friction surfaces.	Engineering uses such as gears, bearings. Domestic appliance parts, pipe fittings. Textile yarn, fishing line, netting, hose reinforcement brush bristles, surgical twine, tennis raquet strings.

TABLE 1 - cont.

The following occur in lesser quantities:

POLYMER	CHARACTERISTICS	TYPICAL PRODUCTS
Polymethyl Methacrylate (Persper or Acrylic)	Rigid, transparent, attractive when coloured. Excellent resistance to weather.	Illuminated display signs. Glazing, esp. of aircraft. Automobile, light and optical lenses. Telephones, furniture, piano keys.
Polyethylene Terephthalate (Polyester, Terylene, PET)	Tough, clear, a very strong. Excellent electrical properties Can be shrunk for packaging.	Polyester textile yarn. Magnetic recording tape. Transparent "oriented" film for packaging. Soft drink bottles. Photographic film base. Industrial strapping.
Polycarbonate (PC)	Very strong, rigid, heat resisting, tasteless, stain resistant, vandal resistant, can be crystal clear.	Lenses for strong electric lighting, Baby feed bottles, Tools, Glazing, Heat resistant kitchen ware.
Polyurethane (PU)	Flexible, rubbery, with good insulation properties.	As foam for furniture fillings, packaging, insulation, sponges. As solid for tyres, shock mounts, roller coverings, shoes. With textiles for clothing.

FIGURE 5: Objects made of LDPE.

FIGURE 6: Objects made of HDPE.

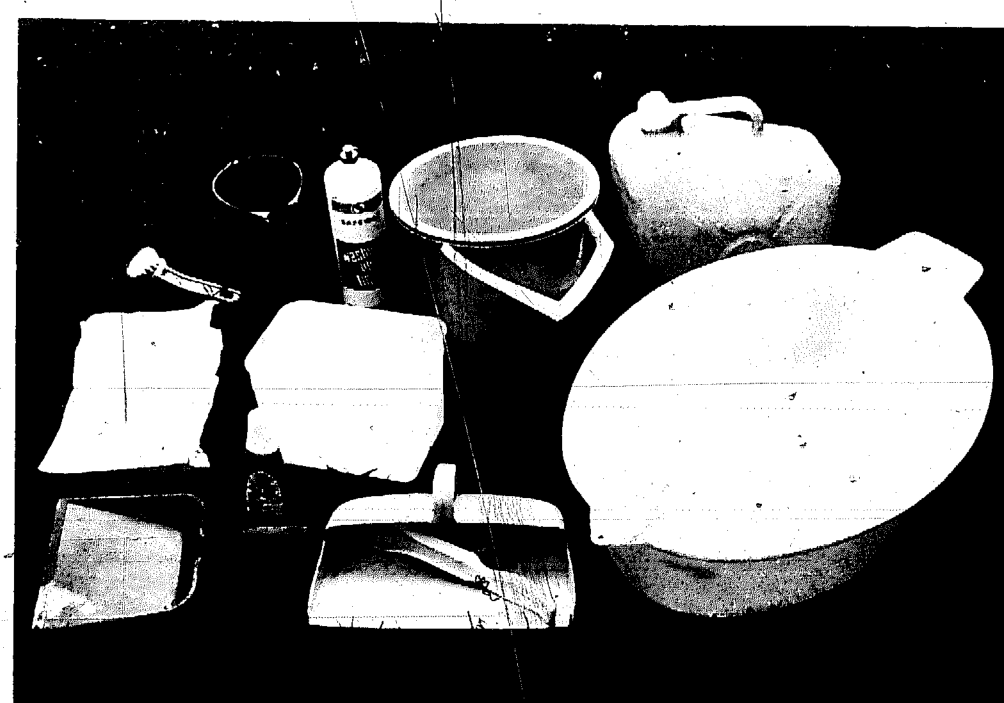
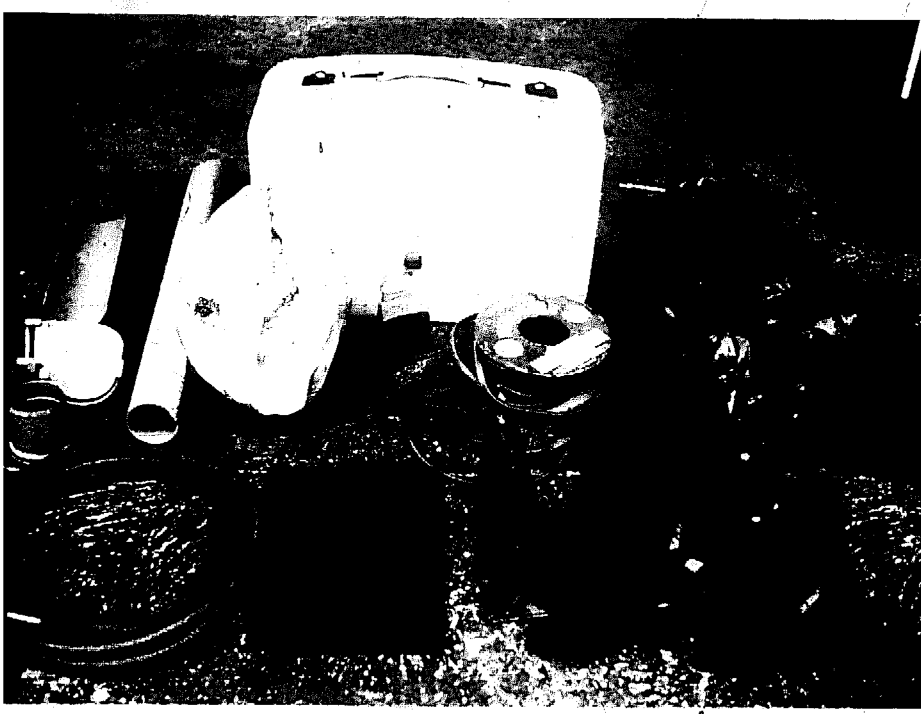


FIGURE 7: Objects made of PP.

FIGURE 8: Objects made of PVC.



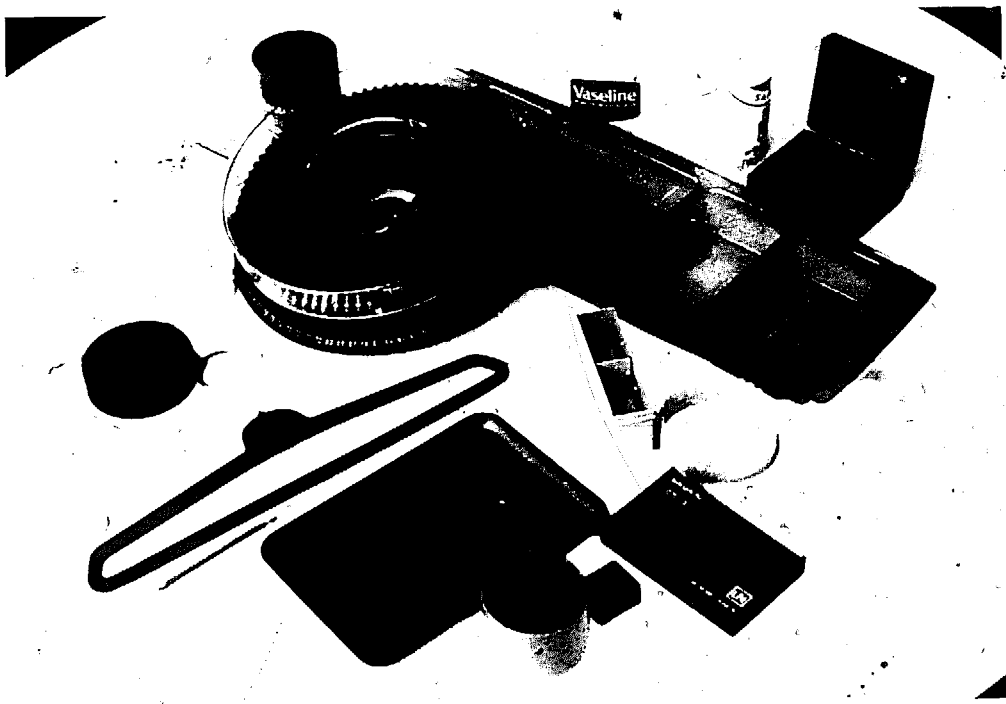
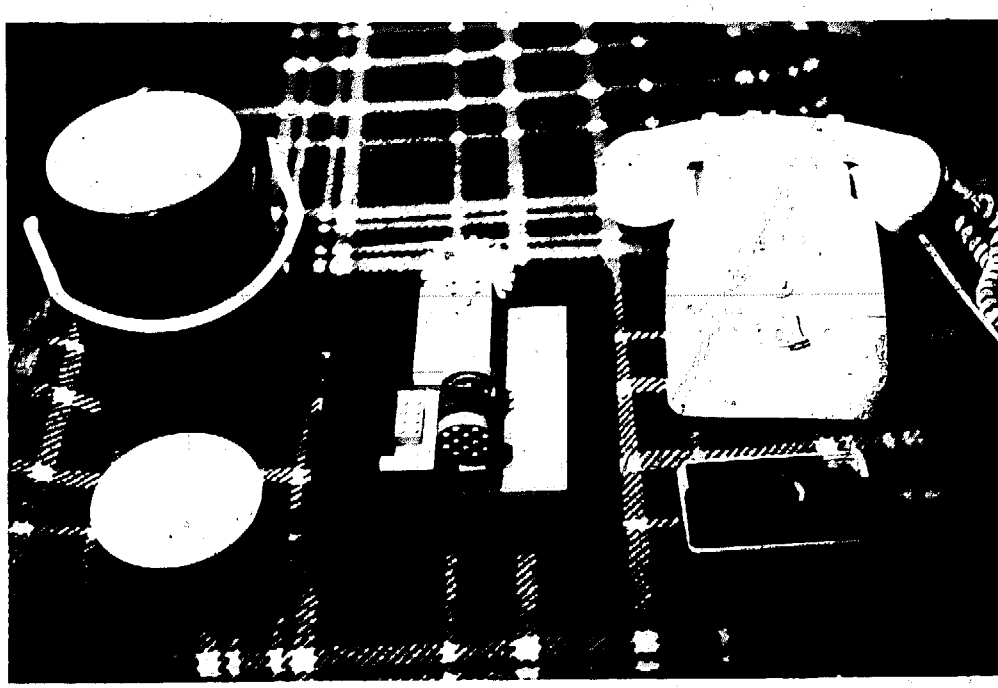


FIGURE 9: Objects made of PS.

FIGURE 10: Objects made of ABS.



STRUCTURE OF THE PLASTICS INDUSTRY

The would-be recycler also needs to understand the structure of the plastics industry. The following pattern is likely to be general but there will be some variation from country to country.

Raw Material Producers

These are (usually large) chemical and petroleum companies who produce "virgin" plastic feedstock, (sometimes called resin or polymer) in huge quantities. The main influence they have on the recycler is to fix prices and availability of virgin materials. It is these, not the costs of his operations, that determine the price a recycler can charge for "secondary" material. Virgin material is delivered in powder or pellet form, in plastic or paper sacks of around 20 kilos weight, in large cardboard drums that hold many times that quantity or even by road tanker.

Compounders

These specialist companies, usually small, stock various polymers and provide the manufacturers of plastic goods with technical advice and the most suitable materials or mixtures for each individual need. In addition to basic polymer, the compounder stocks plasticisers, anti-oxidants, stabilizers, accelerators, colouring, and other additives. The compounder is often the best market for the recycler because he possesses superior technical knowledge and has a large volume throughput of virgin material, in which small percentages of reclaim will reduce cost without seriously affecting the quality required by the moulder.

Stockists

These warehouses stock polymers and compounds but neither manufacture themselves, nor provide a compounding service. They may be agents or subsidiaries of the producer companies or departments of companies concerned with the supply of other materials such as chemicals, rubber or paper. They may be willing to stock reclaim alongside virgin materials, especially if these are in short supply.

Specialist Manufacturers or Moulders

These buy their raw materials from compounders. If they do their own compounding, or if the material is used as produced and does not need compounding, they may buy direct from stockists or producers. The term "moulder" is used generally to cover those that extrude, callender, cast or thermoform as well as injection moulders. They are specialists in plastics and do not perform other types of manufacturing.

Some companies produce rods, sheets and extruded sections to be used by fabricators. They may be an attractive market to the recycler because they operate at high volume, but rarely have as much flexibility to vary product quality as moulders who know, accurately, the final market for the product.

Other Manufacturers

Many companies are not plastics specialists but employ moulding operations in the manufacture of some other product. For example shoe and boot makers use plastics extensively and may carry out the various plastics moulding operations in the same production sequence as the work in leather, canvas, rubber etc. Many manufacturers use plastic packaging machinery at the end of a production operation.

Fabricators

These firms cut and join sheet, rod or extrusion to manufacture a variety of products. They have no opportunity to use reclaim.

Machinery and Tool Makers

One other sector of the plastics industry justifies mention although not customers for reclaim. The makers and suppliers of plastics manufacturing machinery, tools, moulds and dies are well informed about who does what, who makes what and who uses what within the local plastics industry. They may advise who is likely to buy material.

The plastics trade press

There are many magazines about plastics. Most accept advertising for the buying or sale of secondary material. Anyone considering entering the reclaimed plastics industry should read these (in the local library if a subscription is too expensive). If material cannot be sold through other methods, a small advert offering secondary polymer is a good investment. "Work from Waste" includes advice about the wording of such advertisements.

The Bibliography includes a list of plastics trade journals.

CHAPTER 3: GIVING THE CUSTOMER WHAT HE WANTS

Some business markets are "captive": whatever the price charged, the customer has to pay or go without. Public companies that supply gas, electricity or mains water are in that fortunate situation. In other businesses the reverse may be true; the customer has a satisfactory alternative product available and needs strong persuasion to buy yours. Recycled plastics are definitely of this kind. Only by offering a reclaim that is substantially more attractive than new or "virgin" polymer can the recycler hope to obtain and hold a market. This chapter considers the differences between virgin polymer and reclaim and what is needed to make the latter marketable.

Price

The main, often the only, reason why a customer buys reclaim is because it is cheaper. The use of reclaim in the manufacture of a product or material means he will either capture orders which he would otherwise have lost or will make more profit from the sale. The factors that determine the price of reclaim are therefore of the greatest importance.

The price can be set either by what the customer will pay or by what it costs to produce. The latter can only be used for captive markets; the former must be used by the recycler. It can be calculated as follows.

The amount of persuasion the customer will need to use reclaim can be expressed as the Reclaim Price Advantage Ratio:

$$\text{REPAR} = \frac{\text{Price paid for reclaim} \times 100\%}{\text{Price paid for equivalent virgin material}}$$

It is found by experience and by study of the market situation and of the quality of the reclaim. If, for example, the customer's process needs great purity and reclaim is likely to contain occasional particles of sand or dust, then the REPAR must be rather low. If however the reclaim is almost as satisfactory as virgin polymer a REPAR approaching 100% is possible. Indeed if the virgin material "cannot" be obtained at all then the REPAR may even exceed 100%: a situation not uncommon in developing countries with strict import controls. Normally the REPAR will vary between 40% and 80%.

The price that the customer would have to pay for virgin material can be found from stockists, or compounders.

The price that the recycler will ask from the customer will then be:

$$\text{Selling price} = \frac{\text{REPAR x price of virgin resin}}{100}$$

This is not dependent on the recycler's production costs and if these costs are greater the recycler is faced with a difficulty. He has a choice: either he can ask the customer for a higher price, knowing that it is not likely to be given (unless his estimate of the REPAR was too low,) or else he can decide not to collect and recycle this material for this customer. A third option, to sell at less than production cost, should not normally be accepted.

Example

A customer manufactures low cost polyethylene buckets on a large injection moulding machine. What price should the recycler ask if virgin material sells at $600 a tonne and the recycler's costs are $300 a tonne, to produce clean, reclaimed pellets.

Because the product is large and of low quality, with thick sections, the customer will not suffer technically by using a high proportion of reclaim and will make large savings in his material costs, which are substantial. Therefore a REPAR of 70% could be tried, giving a selling price of $600 x 70% = $420, well above the recycler's costs.

Example

A customer manufactures polyethylene shopping carrier bags on a blown film extrusion machine. What price should the recycler ask if virgin material sells at $700 a tonne and the recycler's costs are $350 a tonne to produce clean, reclaimed pellets.

Because the film blowing process is sensitive to the presence of tiny specks of dust or grit, and material costs are low compared with the very expensive machine costs, and because some of the film may be used for high quality, printed packaging, a REPAR as low as 25% will be needed to tempt the customer. The selling price will be

$$\frac{\$700 \times 25 = \$175}{100}$$

and this is so far below the recycler's costs that it is not worth dealing in this material to this customer. However the recycler may like to calculate what REPAR is necessary for such a deal to be profitable and it will be:

$$\text{Minimum REPAR} = \frac{\text{Cost of reclaim x 100}}{\text{Price of virgin}}$$

In this example: minimum REPAR = $\frac{350 \times 100}{700}$ = 50% which would

only be achievable under these conditions if virgin material were very difficult to obtain.

Availability

The situations in which virgin material is not available are:-

- Times of real or imaginary international oil crisis (as in 1973/4) due to war, oil producer price cartels, etc.

- Times of national import restriction due, usually, to foreign exchange pressures, war, etc.

- Where customers are remote from suppliers of material, transport is unreliable or delivery times lengthy.

- Where stockists or compounders are unreliable or simply run out of stocks.

- Where the customer gets unexpected, heavy demand for a product.

The reclaimer should be constantly alert to such situations and exploit them. In 1973/4, following the OPEC crisis, reclaim was selling in Britain at a REPAR greater than 100% for a short time and in the turbulent political situations common in certain countries such opportunities may occur frequently.

Availability, however, is a two edged weapon. It is also necessary for the recycler to prove to his customer that he can have material available in adequate quantities when it is needed. This may make it necessary to collect and produce more than can be sold at one time and stock the balance in order to offer rapid deliveries when these are called for. Be willing to deliver small quantities on a trial basis if a moulder or compounder temporarily runs out of virgin material. If he is satisfied with the quality of the reclaim he may then order it on a regular basis, initially using very small proportions in his compound but slowly increasing these to progressively cheapen his product. Only if he is making his own moulded products (see Chapter 6) should a recycler consider production of less than one tonne of reclaim per week.

Quality - Definition

The two previous matters have been essentially commercial. The remaining ones concern quality. The recycler's objective is to produce reclaim to satisfy the customer's needs, and thereafter maintain both quality and quantity, at an economic cost. To achieve this he will probably need to produce reclaim as near to the quality of virgin polymer as is consistent with low costs of production.

The first essential is that the material be clearly defined, so that the customer quickly appreciates what uses it might have. The definition may be provided in a number of different ways:

a) Source

It may be sufficient to say what was the source of the secondary material. This should include:

What were the products and preferably who made them in the first place?

Where were they obtained?

How have they been subsequently processed?

Thus a satisfactory definition might be: "PVC cooking oil bottles, as sold in Supermarkets in Manila, Philippines, washed, granulated and free from caps or labels".

b) Material

It may be better to specify the material composition. This is not always possible but if regular quantities of a few standard wastes are collected it may be possible to trace them back to the moulder and obtain the information from him; indeed he may be pleased to buy the reclaim back. A satisfactory definition of this kind might be;

"PVC containing 30% nitrile rubber, 30% tritolyl phosphate, 2% dioctyl tin stabilizer and 2% titanium dioxide pigment".

c) Properties

Finally it may be possible to define a material by its properties and this is often what a compounder does. The basic resin is specified by name but the effects of other ingredients may be simply reported, for example:

"High density polyethylene of specific gravity 0.957, tensile strength 386 Kg/sq.cm., elasticity 9100 Kg./sq.cm and MFI (melt flow index) 0.5Gm/10 min. at 2.16Kg load".

To define a material in this way it is obviously necessary to have a good technical understanding and access to a testing laboratory.

The less experienced recycler will begin by using the definition by source and, as he gains confidence and expertise may venture into more scientific procedures later. It is worth remembering that many small moulders do not themselves know anything about the materials they are using but rely on a supplier or compounder to provide what is correct for their needs.

d) Trial and error — In many small factories reclaim will be defined by whether or not it produces an adequate product without trouble. Thereafter the only definition will be "the same as before".

Purity

The second essential is that reclaimed polymer needs to be "pure". One single type of thermoplastic free from other types or non-thermoplastics. This is because:

Impurities can spoil the properties of the product - strength and toughness, resistance to chemicals, leak resistance and, especially, visual appearance. The harm resulting is more than just one or two bad articles or even the inconvenience of having to replace the defective item. It is the damage to the moulder's reputation for quality, as a result of which he may fail to get future orders, may be subject to unduly stringent inspection of his goods when delivered, forced to reduce his prices etc.

Blockages can lose production time - The main problem is obstruction of nozzles and screens (fine wire mesh strainers) by non thermo plastic impurities such as grit, sand, paper, adhesive tape and paper labels. Labels, especially the tiny self adhesive variety used in supermarkets, are among the worst offenders, because they are so small that sorters may easily overlook them. Metal foil, for example tops of milk annd cream cups, is also troublesome. Although such blockages can be removed they play havoc with the economics of the production process.

Plastics moulding is a modern industry. It is aimed at exploiting the incredible advantages of plastics over other materials: lightness, thinness, ease of moulding complicated shapes, bright, varied colours, speed of production and low labour requirements. These are achieved by designing and building manufacturing equipment of enormous sophistication and complexity.

Such equipment is very expensive and can only "earn its keep" and produce at low cost if it is kept running continuously, often for twenty four hours a day, seven days a week. Thus an obstruction or breakdown destroys efficient operating economics and annoys the production manager. He would rather increase the product cost by 5%, by using a safe raw material that is 50% dearer, than increase the costs by 15% by having his machine out of operation for four hours a day while blockages are cleared.

Impurities can interrupt production in other ways than blockages: The most common occurs in the production of extruded, blown film. It has been explained how the film is developed upwards in a tall, continuous bubble. If a piece of grit or even dust punctures the bubble it may burst and the whole operation must be set up afresh. Thick film (e.g. fertilizer sacks) is less sensitive than thin (e.g. shop bags).

Permanent damage and wear to machines - Plastics machinery is designed to handle soft solids and fluids under high pressures and moderately high temperatures. In these conditions hard grit or metal can score or wear moving parts and have serious long term effects on the efficiency of the machine.

Cleanliness

In many ways cleanliness of a material is the same as purity. However the consequences of material being dirty may differ from those described above. For example oil or food residues may be absorbed into scrap plastic and, although they may not cause any of the problems described above they may spoil the appearance or create an unpleasant smell. Because it is impossible to know how they have been contaminated reclaimed materials from an unknown source should NEVER BE USED FOR food packaging, toys for children, kitchen utensils, drinking water piping and tanks or clothing.

Quality Reduction

When a recycler has supplied a customer with several quantities of reclaim and knows him and his needs well, it may be possible to reduce quality, purity or cleanliness of the reclaim (without harm to the customer's product) in order to save costs.

This should be done cautiously, a little at a time, paying close attention to the customer's reaction and whether he encounters any problems as a result.

If the customer is aware of reduced quality he will usually demand reduction in price.

Particle size and shape

Virgin polymer is normally sold either as pellet or as powder. The pellets are of uniform size and shape, about the size of maize grain. The powder is of consistent grain size. Consistency is important because it decides the density of the material in the moulding machine, which in turn determines the density and strength of the product. Particles of different sizes and shapes result in air spaces, gas bubbles or areas of incomplete fusion (due to unmelted material) in the product. Solid plastics scrap that has been passed through a granulator with a grid size of 4mm or 6mm will be equivalent to virgin pellet and will mix with it, even though the granules may be irregular in shape. The main problem comes with thin film or sheet. Granulating this produces a light flake which, because it is not dense enough to fall freely down the sloping sides of a moulding machine hopper, causes the machine intermittently to run out of material and feed air, often with problems of overheating. It is necessary to turn such material into crumb or even cylindrical pellets and these operations will be described in Chapter 5.

Small particle sizes are economical to pack. Large particle materials occupy more space and are expensive to transport and store.

Colour

When they are produced from raw materials, polymers are colourless or faintly yellow. Their final colour is obtained by mixing with heavily pigmented masterbatch which is expensive. By sorting plastic scrap into separate colours it is possible to produce a coloured reclaim whose use can save the moulder substantial colouring costs. This adds to the competitiveness of the recycled material, increases its REPAR and the price that can be asked for it. Such advantage is only gained if the recycler liaises carefully with his customer and adjusts his colour sorting to match the customer's needs. Products that are black, dark grey or dull green or brown are very likely to have been made from reclaim of mixed colours. Refuse sacks, garbage cans, buckets and jerry cans are common examples.

Packing

Having produced a clearly defined material, of good quality, at the right price and available in the necessary quantity at the right time, the recycler must not forget about the packing. Not only is it good commercial practice to make your product look good (the packaging industry, biggest user of plastics in the world - is based on that principle) but packing must:-

> Be strong, so that it does not break open during transport or storage.

Be leakproof, so that no product is lost and water, dirt or other contaminants are kept out.

Be of standard weight, so that the customer and the recycler have no argument about the quantity of material that has been delivered.

Be stackable, for ease of storage and transport. Sacks should be fairly flat so that they can be stacked ten or twenty high. Drums should have flat lids for stacking.

Carry the recycler's name. This is good commercial practice, makes the company look professional and businesslike.

Initially it may be sensible to use secondhand polymer sacks; often a customer will be able to supply them. These can either be stapled at the top to seal them securely or, better, heat sealed. Simple heat sealing machines are not expensive. Later it is worthwhile investing in new sacks, printed with the recycler's tradename and address, plus the weight and description of the material. The businesslike appearance is worth the extra cost.

WHICH PLASTICS TO COLLECT AND RECYCLE

Having studied the polymers, products, structure and processes of the local plastics industry and the conditions under which it will accept reclaim, the recycler should now be able to decide which plastics to collect and process. It is stressed that all rules are generalizations; local situations may change them. For example Rule 3 would not apply if local factories discarded plastic foam scrap (e.g. from furniture fillings) and local industries existed that could use it e.g. toy or cushion making.

Rule 1 Do not collect laminates, plastics bonded to fabric, paper or metal or reinforced with glass fibre etc., or thermosets. To test whether a plastic is a thermoset, see page 43.

Rule 2 Do not collect articles which:

a) Have the plastic mixed with, or joined to, non-plastics so that it is difficult to separate them: e.g. carpets, blister packaging.

b) Are made of plastics that are hard to identify - mainly expensive items such as those in the third column of Table 3 on page 32.

c) Are commonly soiled or unhygeinic - such as articles for babies and animals or hospital goods.

Rule 3 Do not collect foamed or expanded plastics. The costs of transporting these high volume materials will not be recovered by the value of sales. The only exceptions to this rule are where there is a clear market to use them in the foamed or expanded state e.g. as fillings for soft goods or as insulation. Even then, check carefully that the price offered is enough to cover all transport and collection costs and sell by volume (cubic feet or cubic metres) not by weight.

Rule 4 Do not collect film scrap unless you (or your customer) have the specialized equipment for crumbing or "agglomerating" it - see Chapter 5. Even then, remember that film has great surface area for little weight; this means that the area which can become dirty or contaminated, carry adhesive labels or tape, is very large so there may be more of these troublesome impurities per kg of polymer than is the case with solid scrap. Moreover, because film frequently takes the form of bags and sacks, there will commonly be residues of the former contents left inside.

All such impurities must be removed before sale, a time consuming and costly process (which, however may yield some small reward if the residues themselves can be reused or sold.)

Rule 5 Collect only those grades and polymers for which there is a market. The next stage is therefore to check out what markets exist. This, and the whole business of marketing wastes, is covered in some detail in "Work from Waste" and will only be outlined here. "Work from Waste" also contains a detailed case study of plastics recycling.

Find (from the telephone directory, Ministry of Industry, machinery suppliers or other sources) which companies in your district use plastics. Then assess whether they are likely customers. This may be possible without a visit, for example by conversation with a plastics machinery salesman who knows the territory. It may be necessary to visit one or more factories and discuss with the managers. The check list, Table 2 (p30) may be used to identify the kind of factory which is likely to be a good customer.

Rule 6 Collect materials that are abundant in your area. In particular consider:-

1. PVC for sale to manufacturers of flexible hose and plasticised pipe. These low grade, thick-walled products use a lot of polymer. Manufacturers are pleased to use a high percentage of reclaim for the lower price and quality range if they can overcome the technical difficulties. Common wastes that are suitable are:-

   Soft, flexible, plasticised PVC from footballs, ladies handbags, and other luggage. Suitable wastes are: cooking oil bottles - often a clear amber (yellow), shampoo and other pharmaceutical bottles (transparent bottles with sales appeal).

2. Unplasticized PVC for manufacture of rigid irrigation and drainage pipe, gutters etc. Again a high percentage of reclaim is often acceptable for the lower quality product.

3. High density and low density polythene from a wide range of housewares such as buckets, bowls, brushes, (cut out the bristles) laundry baskets etc. These are discarded by housewives when broken, contain good weights of polymer, free from adhesive labels, metal caps or other contaminants.

The manufacturer can reuse them to make similar thick products: low-cost, low-quality with a market among the poorer people of the community.

4. Low density polythene bottles, distinguished because they are a pearly white colour, translucent (not opaque but not transparent). Also opaque, white or coloured bottles, of the "squeeze" type.

5. Other bottles for household chemicals. These are made of high density polyethylene to give strength and rigidity despite the thin walls and are bright, opaque, white or coloured.

6. White polystyrene tubs, cups, plates and food containers, such as used by fast-food stores. These are thermoformed from polystyrene sheet and cannot be recycled for this purpose but can be used for other polystyrene products such as ladies shoe heels. They are very thin and occupy a large volume but can be stacked, one inside another or can be crushed or shredded by hand during collection to reduce volume and cheapen transport.

7. Crystal-clear, PET drink bottles, often large, usually with a base of black polythene or other material. These are widely used in Europe and U.S.A. and may be recyclable for manufacture of polyester fibre (e.g, fillings for sleeping bags) when the base, cap and labels are removed.

8. Some types of industrial scrap.

Recycling of mixed plastics waste

During the past ten years a significant technology has been developed in Europe and Japan for the recycling of mixed and dirty plastics waste into large products of low quality, such as fencing, building boards, cable drums and pallets (Fig. 11). In general it has not been commercially successful and further development is needed. A variant of this by a German company, Remaker, has been more successful but the machinery is very expensive by comparison with the equipment described here. A full description may be found in the Bibliography - Ref. 13.

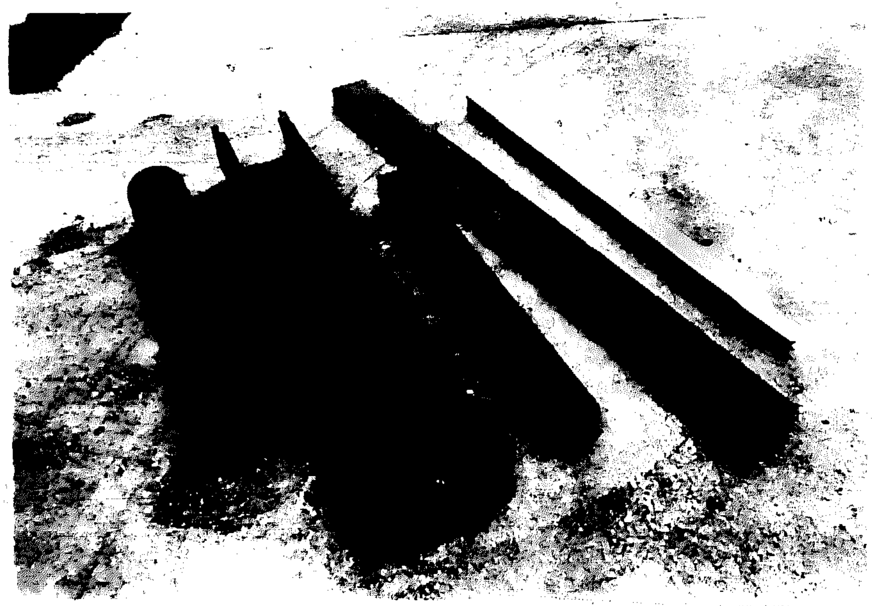


Figure 11: Large products of low quality made from mixed and dirty plastic waste by a Japanese process.

Other plastics recycling technologies

Ref. 15 describes many other plastics recycling technologies which have been developed but none has achieved such widespread application as the methods described in this book, which, are used to reprocess 400,000 tonnes of scrap plastic per annum.

TABLE 2 : CUSTOMER CHECK LIST

QUESTION	DEPENDING IN WHICH COLUMN THE ANSWER LIES: GOOD PROSPECT, ASK THE NEXT QUESTION	PROSPECT BUT TRY BETTER ONES FIRST	POOR PROSPECT
How close is their factory?	Close	Far	Very far
What kind of factory?	Compounders, Stockists, Moulders, Converters	-	Raw material producers, fabricators
What materials do they use?	Thermoplastic powders/pellets.		Thermosets, Thermo-plastic rod, coil, sheet, extrusion.
What polymers do they use?	Common thermo-plastics ie. HDPE LDPE,PS,Rigid PVC	Plasticised PVC Less common thermoplastics ie. PP,Nylon,PC Others on p12.	Other specialized polymers
What processes do they operate?	Injection moulding, Extrusion, Blow moulding	Blown film extrusion, Callendering Casting Others on p8.	Thermo-forming Heat sealing Fabricating Machining
What kind of products do they make?	Non-food contact and other products without health risks	-	Food Packaging Drug containers, Toys, Surgical goods hospital goods
What colour are products?	Black, dull green, brown or dark grey	-	Crystal clear
What quality of product?	Domestic or commercial quality IF STILL IN THIS COLUMN YOU HAVE A GOOD CHANCE TO SELL TO THEM	-	High quality or specialised

CHAPTER 4: COLLECTION OF PLASTIC WASTE

Almost every establishment used by people is a source of plastics scrap: homes, schools, factories, hospitals, shops, streets, parks, beaches and many more. Sometimes it lies loose as litter, sometimes it is collected together and stored in a container. This chapter will discuss the sources from which plastics waste can be obtained, the methods used for collection and transport and the cost of the collection process.
It is summarised in Table 3 (p32).

SOURCES OF PLASTIC SCRAP

Homes and Households

The main wastes are:-

- Broken housewares - See Figs. 5 to 10. Usually of HDPE or LDPE but top quality may be nylon or PP, lower quality PS.
- Bottles, usually of LDPE or HDPE, PVC or PET.
- Food containers, mainly HDPE, LDPE, PS, ABS.
- Film, sacks and bags, mainly of LDPE, HDPE, PVC, Polyester.
- Bottle caps - may be of HDPE, PS, PP, or even thermosets but if difficult to identify the polymer, leave them out.
- Damaged household appliances - fridges, telephone handsets, cooking utensils, etc. May contain many polymers.
- Damaged handbags and luggage, sports goods, especially footballs etc., and leather imitation clothing mainly of plasticised PVC.
- Shoes and sandals - often the sole is plastic, most commonly plasticised PVC but also polyurethane; sometimes the upper is plastic. If it looks like leather (but does not smell of leather) it is probably butadiene - styrene copolymer.
- Waterproof garments - may be of plasticised PVC and recyclable. If of plastic coated fabric they cannot be easily recycled.
- Toys - may be of any polymer.

TABLE 3 RECYCLABILITY OF PLASTIC PRODUCTS

The following list is neither complete nor unalterable but indicates sources of waste plastics:

Source	These products generally recyclable if clean.	These products not generally recycled because:	Obstacle to recycling
Packaging	- in Shrink wrap, home or store bags, food containers and tubs, drink and other bottles.	Blister packs	Plastic mixed with other materials.
In the home	Housewares - buckets, wastebins, bowls, brushes, pans, baskets.	Cameras, radio, T.V. and recorder cabinets	Small quantities of varied plastics mixed with other materials
	Tableware and cooking utensils. Telephones	Parts of domestic appliances	
	Fabrics, yarns and clothing (but these may be better re-cycled as textiles).	Jewellery	"
		Babywear - plastic pants diapers, bibs, cot sheets	Soiled material.
		Furniture, foam fillings, carpets, matting.	Mixed with other material
	Handbags, footwear, luggage.		
	Toys - building bricks, balls.	Toys - dolls, models, games	Wide variety of plastics used. Hard to identify, often mixed with other materials
	Gramophone records Photographic and audio-visual tapes and film,	Optics - spectacles, binoculars, telescopes	
Outside the home.	Rope, string and tape Office and school equipment.	Protective clothing - crash helmets, goggles, visors, gloves, boots.	"

TABLE 3 (cont.)

Source	These products generally recyclable if clean	These products not generally recycled because:	Obstacle to recycling
Outside the home.	Sports equipment - footballs, bats.	Sports equipment home- raquets, padding, skis, diving gear, surf boards	Wide variety of plastics used: hard to identify, often mixed with other materials
	Inflatable boats.	Boat gear - buoyancy aids, sails, masts & rigging, fittings.	"
	Hosepipe, plant pots,	Garden implements, furniture, netting, stakes.	"
		Workshop tools - handles, drill bodies.	"
		Automobile, train, bicycle, and aircraft parts.	"
Industry	Pipework, formers, packaging, cable.	Industrial equipment - tanks, vats, vessels,	"
	Containers and handling units - pallets, crates, stillages, bins, boxes drums, barrels, jerry cans.	Electrical fittings, Signs, advertising	Thermosets: Permanent.
		Adhesives, paints, metal coatings.	Bonded to non-plastics
Building	Water pipes, fittings and gutters, wall and roof panels, skylights, light fittings.	Reinforced structures.	Mixed with non-plastics.
		Laminates in furniture fittings and paneling.	Thermosets.
	Electrical cable. Sacks.	Electrical fittings, boxes.	Mainly thermosets
		Insulation foams.	Foams
Agriculture	Irrigation piping, hoses, sheeting, sacks, rope, string, Jerry cans, drums barrels.	Tanks, greenhouses.	Permanent structures

Hotels and Restaurants

These are often disappointing sources. The main wastes are:-

- Bottles and jerrycans - LDPE, HDPE, PVC, PET.
- Food containers - HDPE, LDPE, PS, ABS.
- Film sacks and bags - LDPE, HDPE, PVC.
- Drinking straws - LDPE, HDPE, PP or PS.
- Drinking tumblers - PS.

Factories and warehouses

These may be extremely fruitful. Never let anyone at the source of supply know what is done with their waste or they may try to recycle it themselves or charge you for it. The range of wastes can be very large but some principal ones are:-

- Process scrap from manufacturing operations that use plastics (in small quantities that are not worth the trouble to recycle). May be any polymer but the manufacturer usually knows which.

- Damaged crates (bottle containers) and pallets - usually HDPE or PP.

- Damaged or undamaged bottles, jerrycans, drums, barrels, etc., usually HDPE, LDPE, PP, PVC. There is often a good market for reuse of secondhand containers, so prices may be high. Watch out for poisons, acids and other nasty contents.

- Overwrap film - Many goods arrive at the factory over wrapped with polythene film to protect them. For example bricks may be transported, loose on a pallet with shrink cover. Small items are often mounted on a card then overwrapped with film which is shrunk on to make a firm package. Such material may be excellent for recycling: thick, free from impurities and of large quantity. PVC is sometimes used.

- Polyurethane foam or expanded polystyrene padding - do not collect unless an economic, profitable market has been identified.

- Rope or string - if it looks like plastic it will be PP. Nylon rope does not look like plastic, (except where the end may have been melted).

- Damaged or undamaged buckets, bowls, protective clothing etc.

Shops and Supermarkets

- Shrink wrap film - this may occur in huge quantities if it is used for packing cans and bottled goods - LDPE or PVC.

- Beer and beverage can holders - the "Six pack" skeleton - HDPE, LDPE.

Hospitals and clinics

Hospital wastes must be approached with care as they may contain dangerous or unhygenic materials. However in many countries the dangerous wastes are collected separately for burning, so the remainder are typical of any large residential institution (see Homes) with the addition of:-

- X-ray film. In addition to the plastic this carries silver bearing emulsion whose value justifies separate reclamation. (See Work from Waste). The plastic that remains is usually PET but was formerly cellulose acetate. There may be an extra coating of other polymer.

- Autoclavable holloware - many items formerly of stainless steel, such as dishes, mugs, buckets, urine bottles, bedpans etc. are nowadays made of polypropylene. In the hospital procedure they are sterilized before reuse by washing and autoclaving (heating to high temperatures in a steam vessel). They may be collected for recycling (and PP fetches a higher price than many polymers) PROVIDED they are put through the washing and sterilization process for the last time, before collection by the recycler. Hospitals may calculate that the cost of this, less the scrap value will be no greater than the cost of safe disposal by other means. It is stressed that a recycler who collects such items without sterilization exposes his employees and the public to grave risk of disease.

Streets, parks, beaches etc.

Waste in such places is litter. How much and what kind will depend on the habits of the community and the municipal cleaning services. It will usually be dirtier than other wastes, having collected sand, soil and dust while lying, but these may be easy to remove. Collectors may prefer to avoid these materials or to wear gloves. Litter that has lain some time may have been degraded by the effects of sunlight. This is mainly a surface effect and does not prevent the product from being recycled. Where it goes deeper it may be necessary for the sorter to break off the affected, brittle, part and throw it away.

Special collection centres and schemes

To collect from the above sources needs transport to and from the location where the waste arises and this is costly in time and money. Some communities will bring their soiled wastes to a central place, such as a "skip" located in the car park of a supermarket. Often they will wash them beforehand, a double benefit. Such schemes have been fully dealt with in "Work from Waste". For plastics, with the problem of obtaining sufficient weight of material at acceptable cost and cleanliness, they can be good if correctly operated.

Refuse dumps and transfer stations

Great quantities of scrap plastic can usually be found at the refuse dump or garbage transfer station. It is not intended to discuss here the merits of refuse separation schemes, nor whether one should encourage the collection of materials from such unhygenic locations. These should be municipal decisions. In developing countries the public may not support collection centres but municipal dustmen often earn extra income by separating recyclables during their collection rounds. Armies of poor people live by scavenging, either in the streets or from the refuse dump, and purchase from them may be the cheapest source of plastic waste. They may be prepared to wash it for a small increase in price, but a second, careful wash will still be necessary.

It may be satisfactory for one scavenger to act as middle man with the help of a small cash float to start up. The price per unit of weight (lb or kg) that he will pay his fellows must be agreed by all and he receives a small extra sum (which may increase by steps with increase in the volume of material he is able to obtain). Such material may be purchased on a "weight produced" basis; collectors may work less hard if paid by time.

METHODS OF COLLECTION

These have been fully discussed in "Work from Waste".
In general:

a) House-to-house collection near the processing depot is cheapest with a handcart.

b) House-to-house collection far from the processing depot may need a vehicle or animal drawn cart.
Collectors work from it, carrying sacks and return to it when the sack is full.

Moulded or extruded plastic goods are very light for their volume, contain more air than plastic. Any container, (a sack, a cart or the back of a lorry), will have its volume used up before its weight limit is reached, which makes the cost per unit of weight very high. As the material is sold by weight, this becomes unprofitable. It is necessary to "densify" the material, to use the full weight capacity of the container at all times. This can be done by hand, with a chopper or other implement carried on the collection round. However, this may lead to difficulty in sorting - see page 46.

c) Travel by bus or minibus is practical for collectors carrying two or more sacks, (which must be large and tough). They should chop up large pieces and aim to collect not less than 40 lbs (20 kg) per day per collector.

d) Collection from the refuse dump, from factories or other concentrated sources should be not less than one tonne at a time, by high-sided lorry. A lorry fitted with a mesh cage will hold greater weight.

ECONOMICS OF COLLECTION

Profits to be made by recycling plastics are rarely large. To ensure that workers earn sufficient for their needs, costs of all activities (starting with collection) must be carefully checked, and compared with the value of sales. Methods used to calculate costs have been carefully explained in "Work from Waste", Chapter 18.

Yield

Because selling prices are per tonne (or per kg or per lb) all costs are converted to the same basis. However the weight delivered will be smaller than that collected because some material is discarded in the sorting process. The processing "yeild" is equal to

$$\frac{\text{Weight of material delivered to customer}}{\text{Weight collected to yield this quantity}}$$

Costs should be expressed as "per tonne delivered". Where costs are for tonnes collected they need to be divided by the yield.

Costs of collection

These may be calculated on a daily, weekly or monthly basis, for each collector individually or for the whole team together. The following should be included:

- Cost of labour (wages)
- Labour overheads (clothing, insurance, pension, supervision, etc.)
- Transport (bus fares, lorry fuel, animal fodder etc.)
- Publicity (advertising, leaflet printing and distribution etc.)
- Depreciation of equipment (cart, lorry, etc.)
- Interest on loans to buy equipment.

$$\text{Collection cost per tonne delivered} = \frac{\text{Total collection cost}}{\text{Weight collected} \times \text{Yield}}$$

CHAPTER 5: PROCESSING

This chapter discusses processing scrap plastic to obtain a granulate, crumb or pellet suitable for moulding or extrusion processes (which are explained later). The following operations are involved. The order must be decided locally:

Cleaning: If cleaning is done first, unwanted material may be cleaned.

Sorting: If sorting is done first it may be unnecessarily unpleasant for the sorters.

Size reduction

Granulation

Crumbing

Pelletization

Bagging and Delivery

Cleaning

Material delivered to the customer must be free from dirt so every piece should be cleaned but to achieve maximum production from a given number of workers keep washing (Fig. 12) to the minimum.

The following methods are listed in order of cleaning power: work down the list until the results are good enough.

a) Brushing with a soft brush to remove dry sand, grit etc.

b) Washing in plain cold water, with a brush

c) Washing in water with detergent. Powder detergents are cheaper than liquids. The cheapest way is to use the last few drops of liquid in each scrap detergent bottle and only add more if necessary.

d) Washing in hot caustic soda solution. This should be avoided if possible but may be necessary to remove oil or grease or heavy dirt. It is essential that stout, elbow length, rubber gloves, free from holes are worn. Buy these from suppliers of protective industrial clothing. Those sold by supermarkets or hardware stores are rarely strong or long enough. Caustic soda can normally be bought in a hardware store.

FIGURE 12: Washing scrap plastic.

FIGURE 13: Testing by floatation.

For all types of washing a mop, cloth or nylon bristled brush is useful. Cleaning baths or tanks should be placed at a comfortable height. Throw away objects that cannot be cleaned quickly and cheaply.

e) Cut off impurities that cannot be removed by washing, especially plastic and paper labels, rings of metal or other plastics around bottle necks etc. It is easier to cut away part of the plastic than to remove a label. Small amounts of glue that remain after a label is removed are usually acceptable.

To save time (that means cost) and water do not rinse after washing unless unavoidable. Place objects to drain on a sheet of polythene film, taking care that no sand or dust can blow onto them. When dry, store in a drum or carton.

Testing for Different Polymers

Although attempts have been made to develop automatic or mechanical ways or sorting plastic scrap, none has so far succeeded commercially; the only sure method is by eye and hand. As many different polymers look identical, considerable skill is needed to tell the difference. This is gained by practice and by testing when doubt exists. Even testing is not easy but the following system works reasonably in practice.

Workers are trained to carry out tests for different polymers, using locally collected material, and build up experience of what different products and different brands of the same product look like. After working for a few days in this way they will be able to distinguish 90% of all polymers by appearance. The remainder need testing. The rule is "If in doubt test. If still in doubt, throw it out".

The tests are tabulated in Table 4 but the following further explanation is needed.

a) Finger nail scratch and flexibility: PE that has been exposed to the weather may have hardened and become unscratchable, rigid and brittle. Very thin material of any polymer may seem flexible; very thick of any may seem rigid.

b) Flotation test: (Fig. 13) This is very useful to make the difficult distinction between high density polyethylene (especially if it has been hardened by exposure to weather) and polypropylene. Also between high and low density polyethylene. A mixture of water and alcohol is made up of exact density, so that one material will sink and the other float.

FIGURE 14: Testing by burning.

FIGURE 15: Cutting scrap on a circular saw.

If pure alcohol (ethyl alcohol - density about 0.79) is not available use iso-propyl alcohol (also called Propanol or Propan-2-OL - density about 0.78). Mix the two thoroughly and use a "hydrometer" (range 0.9 to 1.0) to test the density of the mixture. A density of 0.925 will ensure that poly-propylene floats and HDPE (or even a medium density PE) will sink. A density of 0.93 is better to distinguish HDPE from LDPE.

Flotation tests between polypropylene and LDPE cannot be done with certainty because their densities can overlap. Use the fingernail test and visual appearance instead.

Once made up the mixtures can be kept, provided they are securely capped to avoid evaporation or checked with a hydrometer before use. Flotation may be affected by surface tension; avoid by adding a couple of drops of washing up liquid to the water or mixture, or by carefully pushing the sample under the surface and swirling gently to remove any air bubbles.

c) For the flame test, (Fig. 14) cut a sliver 5cm long and 1 cm wide at one end, tapering to a point at the other end which is lit. Hold over a sink or stone, away from the body and clothing as samples may drip. The drips will only burn as they fall if they drop from within the flame.

d) PVC can be confirmed by touching the object with a red hot copper wire and returning the wire to the flame when it will burn green. Burn off <u>all</u> residue of material before repeating the test with the same wire. (Other polymers that contain chlorine or fluorine, such as PTFE or poly-vinlyidene chloride, also give a green flame in this test but they are rare).

e) Thermosets can be tested with a piece of wire just below red heat. If the wire penetrates it is a thermoplastic, if not it is a thermoset.

Readers requiring more complete tests to identify plastics are referred to Ref. 16 and 17.

TABLE 4 TESTS TO DISTINGUISH POLYMERS

Polymer	Flexibility	In Water	Relative Density	Burning	Smell on Burning	Scratches with finger nail	Can it be perfectly transparent.	Notes
Low Density Polyethylene LDPE	Very flexible	Floats	0.91-0.92	Blue flame with yellow tip: melts and drips burning droplets	Like candle wax	Yes Easily	No	Has a waxy feel. Intermediate densities between 0.92 and 0.96 also exist
High Density Polyethylene HDPE	Much less flexible than LDPE Film crackles when bent	Floats	0.96	ditto	ditto	Yes with difficulty, especially when cold or weathered	No	Very tough, hard to tear
Polypropylene PP	Hard to bend but does not break when bent	Floats	0.90-0.91	Yellow flame with blue base. Can drip burning droplets.	Ditto but less strong	No	No	Very strong Forms an almost unbreakable hinge if folded
Polyvinyl Chloride PVC	Rigid PVC is brittle Plasticized PVC can be very flexible	Sinks	1.2-1.6	Yellow, sooty smoke; does not continue to burn if removed from flame.	Pungent hydrochloric acid. DANGER do not inhale	Rigid PVC - No Flexible, plasticised PVC - Yes	Yes	Touch with a red hot copper wire and hold wire to flame. Green flame indicates PVC or other polymer containing chlorine.

Polystyrene PS	Very Rigid and brittle	Sinks	1.0-1.1	Burns strongly with yellow sooty flame. Leaves no ash	Sweet	No	Yes	Makes metalic ring when dropped on a hard surface
Acrylo-nitrile Butadiene Styrene ABS	Less rigid than PS	Sinks	1.0-1.1	Ditto but leaves some ash.	Rubbery	No	No	Often has silky surface finish No metalic ring when dropped
Celulose Acetate CA		Sinks	1.5	Like paper, not if flame is removed	Woody	No	Yes	Weak
Polymethyl Methacrylate (Perspex, Acrylic) PMMA	Brittle	Sinks	1.2	Yellow flame with blue base. No smoke Does not drip	Fruity, sweet like flowers	No	Yes	Strong but brittle but will break if bent. Does not ring
Nylon N	Very Flexible	Sinks	1.1	Blue flame. Melts & drips Does not continue to burn if removed from flame.	Like burning hair	No	No	Very tough and flexible
Polyethylene Terephthalate (Polyester) PET	Very Flexible	Sinks	1.4	Strong yellow flame with a little black smoke.	Little smell butter.	No-unless very thin	Yes	Tough and flexible. Shiny surface Crystal clear
Polycarbonate PC	Very Tough	Sinks			Sweet			Can be bent (with pliers) without breaking
Thermosets								Hot wire will not penetrate

Sorting

Sorting is easier if objects have not been chopped up as this destroys the familiar appearance. Organise sorters so that the least skilful sort into colours, and the best sorters sort each colour into different polymers.

In household waste there will be little material other than PVC, HDPE, LDPE, PS and ABS. These can be accurately sorted while all other polymers are thrown into an additional container for further sorting later when an adequate quantity has been collected.

Sort into labelled containers. Heaps on the floor get mixed up. Use the largest containers for the large volume materials.

Establish a foolproof system of quality control. The best sorter, or the supervisor, checks every container when full. If even one wrongly sorted item is found, the whole container should be emptied out and resorted.

It is easy to test sorters. Place twenty different examples of broken polymer around the room, number them and ask the sorters to list them. Only sorters who can correctly identify 19 out of 20 should be employed.

In addition to sorting by polymer, sort by colour as agreed with the customer. Not all colours need be sorted; perhaps five groups will be sufficient such as:-

- Clear
- White
- Red, yellow and orange
- Brown, black and green
- Blue

Size reduction

Size reduction during collecting reduces transportation volume but may make sorting difficult. Size reduction at the depot helps transportation to the customer and feeding of material to the granulator.

The easiest method is with a circular saw, such as is used in a woodwork shop - special blades for cutting plastics are available. Saws are difficult to guard and can take a finger off just as quickly as they can cut through a lump of plastic.

Operators should be trained, should have hair in a cap and loose clothing such as scarves or sleeves tucked in. Goggles should be worn to protect the eyes.

They should work where they cannot be disturbed or interrupted by other workers. This means working in isolation and is unpopular but essential for safety. Frequent breaks for a chat and relaxation will help the operator maintain concentration.

The object to be cut should be held in both hands which pass, well clear, either side of the blade (Fig 15). Feeding should be with a firm steady pressure; to force the object through the blade may result in "snatching" and the hands being drawn into the blade. Thick leather gloves offer protection but may not be acceptable in hot climates.

The saw operator should know exactly how small objects need to be. Cutting too small is costly and unnecessary.

If a saw is not available a hatchet and a solid tree trunk or block may be used. The object should not be held while striking. The hatchet swing should be from above the head in the direction exactly between the widely spaced legs so that a small deflection of the hatchet when it hits the object will not result in injury to the legs. Safety spectacles should be worn to protect the eyes from fragments.

A handsaw, with the object held in a bench vice can also be used.

The size for material which is to be sold without being granulated must be judged against the cost of transport. No rules can be laid down except to say that, if objects are made flat the best densification has been achieved; further size reduction will not yield the same benefit.

Preparation for Moulding

Before scrap can be fed into an injection moulder or extruder it must be converted into a "homogeneous", free flowing grain, powder, pellet or crumb. There are three ways of achieving this, depending on the cost and quality required:

Granulation: This chops solid material into regular sized, irregular shaped pieces.

Crumbing: After being chopped into flakes thin film is converted into a heavy crumb, dense enough to feed into a moulding or extrusion machine. This is sometimes called "agglomeration".

Pelletizing: Granulate or crumb is melted, screened to remove dirt, and made into pellets of a given size.

These important operations will be described in detail.

GRANULATION

This is performed by a simple machine called a granulator. One type comprises a rotating cutter mounted on a horizontal axle (not unlike the cutting cylinder of a grass mower, but with straight, not spiral, blades), which chops the material against fixed, stationary blades. (Figs 16 and 17). Usually there are three or four rotating blades and two fixed blades although other combinations are used. The blades are replaceable and can be reground. The rotating blades are bolted strongly to a solid rotor shaft, with a bearing at either end and a pulley, belt-driven from an electric motor. The fixed blades are bolted to the cutting chamber and have adjusting screws at either end, to move them in or out until the rotating blades just fail to touch them. Good quality blade steel is important.

Another kind of granulator has a vertical axis with flat blades rotating in a cutting chamber shaped like an upright drum. The flat circular base of the drum is drilled with holes to form the grid. The drive pulley is below the grid. See Figs. 18 and 19. This type is less efficient than the horizontal axis machine but much cheaper to make.

Material enters through a hopper, a steel box mounted above the cutting chamber. For safety, modern hopper design makes it impossible to touch the blades while the hopper is in position. The hopper is usually hinged to allow access to the blades for cleaning and resetting but a device should be fitted to prevent the blades turning when the hopper is open. It is extremely dangerous to interfere with this device or have the hopper open when the blades are turning. The hopper mouth is sometimes fitted with a rubber curtain to prevent fragments 'spitting' back at the operator.

Beneath the blades is the grid, a strong steel mesh of regular holes, often curved to fit the rotary blades. The hole size determines the size of the granulate. Small enough material can fall through, too large material stays in the path of the rotating cutters until cut smaller. A grid size of 6mm to 9mm (1/4" to 3/8") is common, but this should be agreed with the customer. Granulating costs increase for smaller hole sizes; if the customer is using large moulding machines he may be content to have a larger size of granulate.

A bin beneath the grid catches the falling granulate. Sometimes a mesh guard is set above the bin so that it is impossible to poke a finger through the grid into the moving blades, from below.

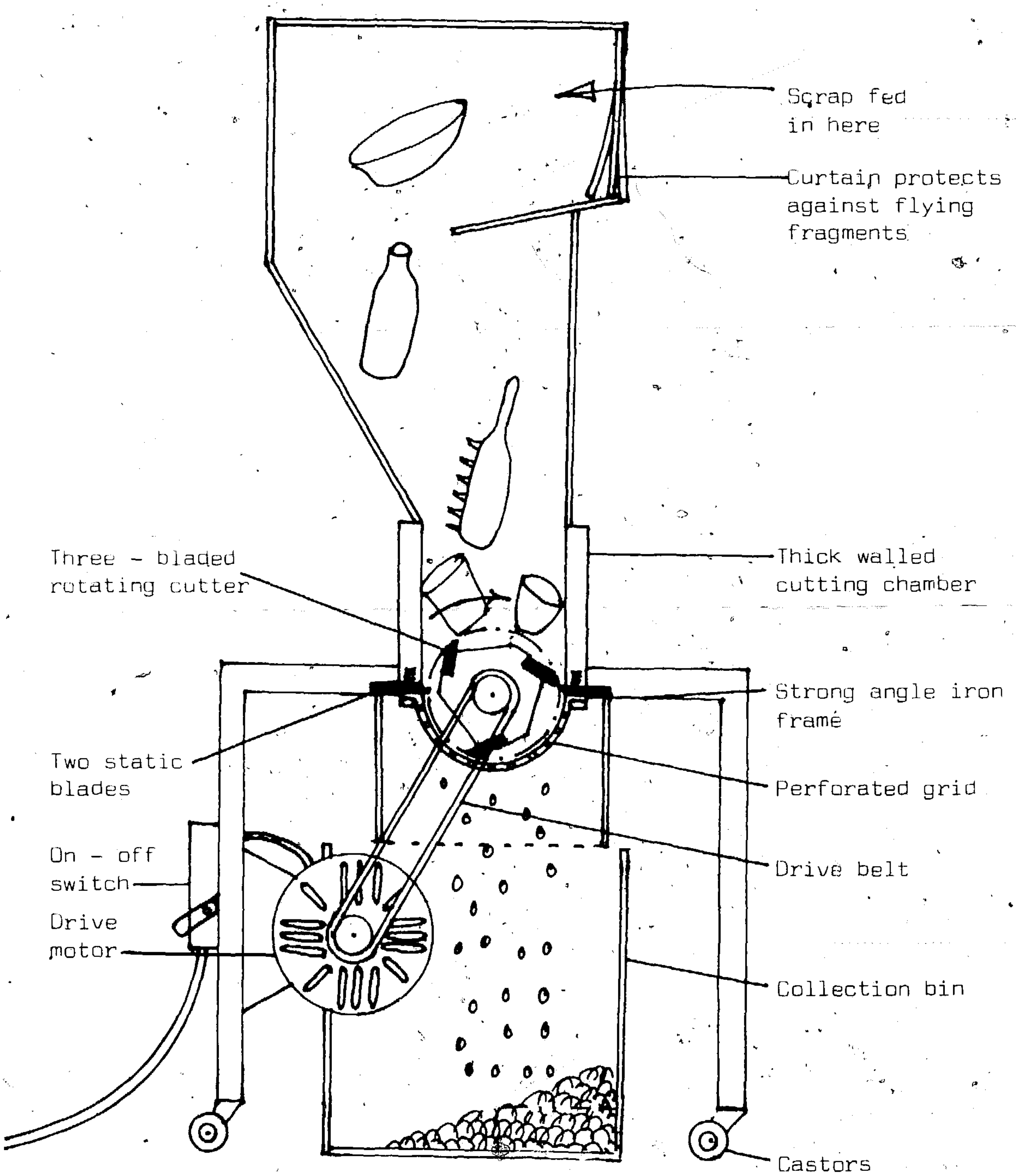


FIGURE 16: Granulator - (horizontal axis).

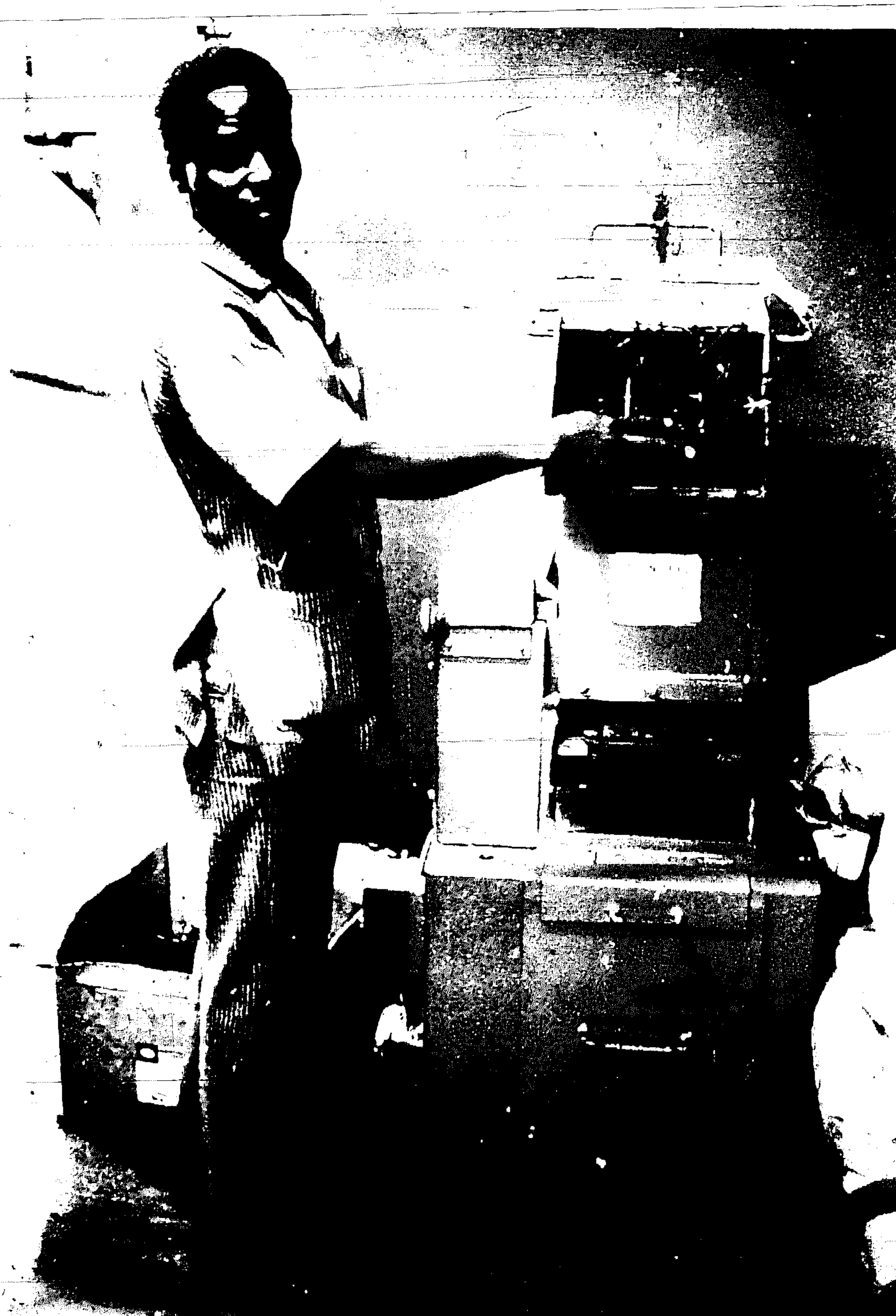


FIGURE 17: Granulator - (horizontal axis).

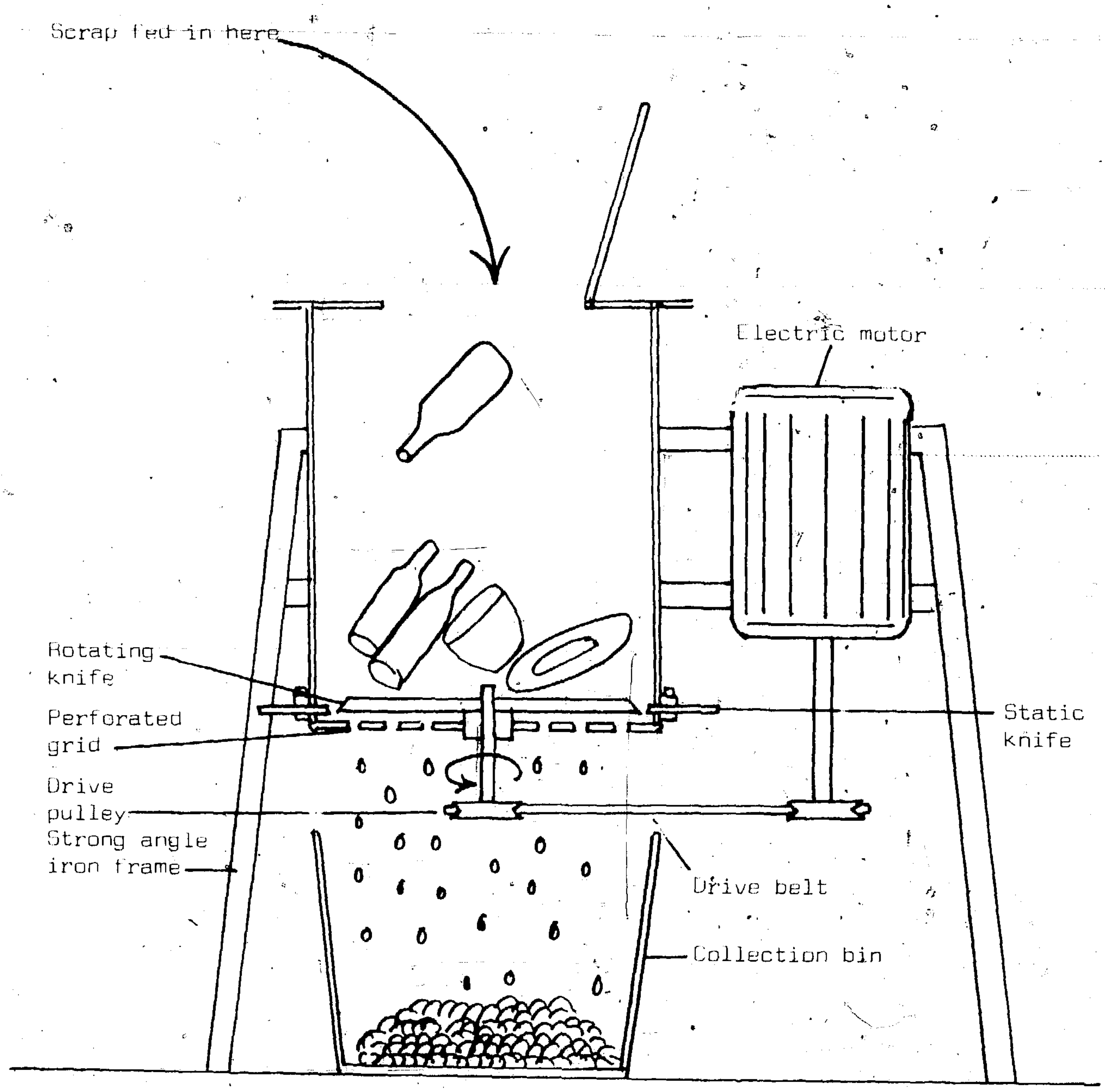


FIGURE 18: Granulator - (vertical axis).

The motor, belts and pulleys that drive the rotor are strongly mounted and should be guarded so that no article of clothing, hair etc., can be caught in them. The motor needs a switch fuse and large motors may need a starter. All granulators should have a large, red, mushroom-shaped stop button.

Granulators are noisy machines and in some countries, by law, they must be sound proofed or placed in a soundproof enclosure. Both are expensive but employers should be aware that prolonged exposure to loud noise can damage an operator's hearing. At least people working near such a machine should be given ear protectors.

Selection of a granulator

An important decision is the size and power required. This will depend on:

- How much money is available to buy the machine?

- What kind of plastics and products are going to be granulated? Tough polymers like nylon or polyester need more power than polystyrene or polyethylene.

- What rate of production is required?

- What size of piece is to be fed into the machine? The hopper mouth size decides this.

- How continuously will it operate? For continuous operation a larger motor is desirable. For inter-mittent operation a smaller motor can be used as it has time to cool.

- For the activities described in this book, 5 H.P. is an absolute minimum. A 10 or even 15 H.P. granulator should be obtained if possible. Manufacturers who can supply information are listed in Appendix III.

Buyers in Third World countries will find prices from European and U.S. manufacturers are far higher than those from India. This is for three reasons:

1) Indian machines have less sound proofing and safety features.

2) Indian machines are less expensively finished, but no less robust.

3) Indian manufacturing costs are cheaper.

For operation in the rough conditions of the Third World, with labour less used to operating and maintaining machines, Indian equipment may be more suitable than pricey machinery from the "North".

When purchasing a granulator, include:

- 1 or 2 spare sets of fixed and rotating blades, complete with fixing bolts.

- 1 or 2 spare sets of drive belts, motor bushes etc.

- Alternative sizes of grid if required for different customers.

When specifying the machine it is necessary to give the manufacturer full details of the electrical supply available. This involves:-

a) Mains frequency; is it 50 or 60 cycles per second?

b) Mains voltage; is it 110 volts, single phase?
220 volts, three phase?
240 volts, single phase?
440 volts, three phase?
Any other?

Other matters to check when selecting a granulator are:

- Will the machine be static in one place or should it be mobile? Does it need wheels?

- How easy is it to clean?

- What facilities exist for repairs and service if it goes wrong. Does the manufacturer have an agent in your district who will give it expert service?

To order machinery from overseas, an import licence and permission to send money overseas may be needed. First write to several manufacturers for quotations for the machine and spares. Ask for "CIF" the cargo seaport nearest to you. This means that the cost of packing, insuring and transporting the goods to that port is paid by the seller. You will still have to pay:

- The cost of clearing them through customs at your home port

- Any customs import duty

- Any tax

- The cost of transport from the port to where you want the machine

The cost of unloading it from the lorry

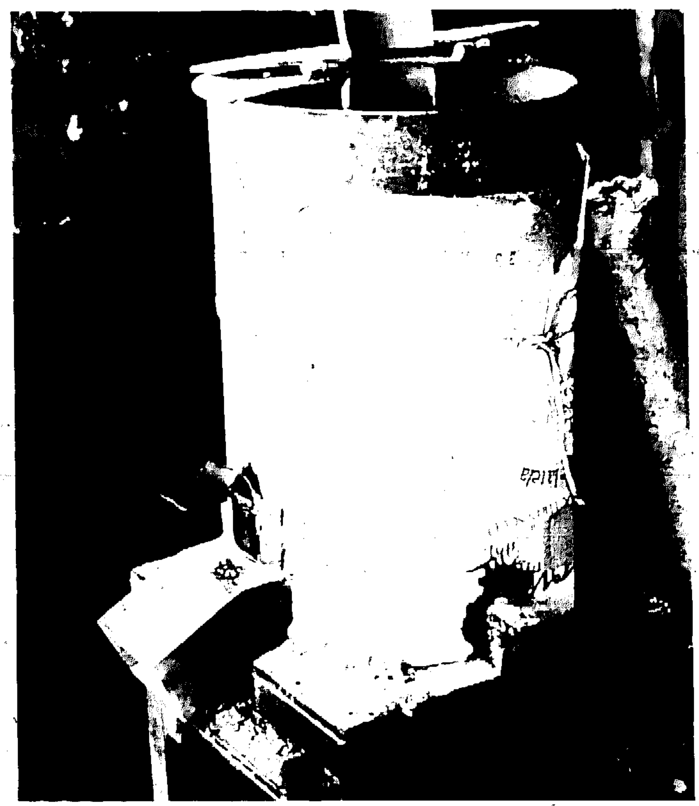
The cost of installing it

The cost of electrical connections

Allow for all these when planning purchase of such a machine. They may well come to 50 or 60% on top of the manufacturer's catalogue price.

Making your own granulator

It is neither uncommon nor difficult to make your own granulator, if you are a competent mechanic. In such a case the simplest design may be a vertical axis machine as shown (home-made) in Fig.19.



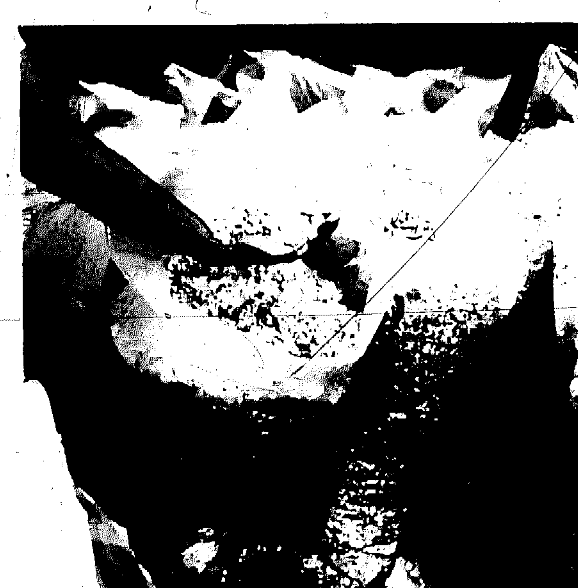


FIGURE 19: Home-made Granulator (vertical axis).

FIGURE 20: Bags of flake from granulated film.

The advantages of making your own granulator are:-

a) Far lower capital cost.

b) No problem with spares: you will always be able to make your own.

c) No problems of importing.

The disadvantages are:-

a) Home made machines are less efficient. This means that the cost of electric power will be higher.

b) Home made machiines are not likely to be so robust or to have such a long life.

c) Home made machines are not likely to be as safe; if you make your own machine, decide that it will have every possible safety feature; your health determines your ability to earn, so dangerous money-saving makes poor economics.

d) Time will be spent making the machine which could be spent on other things.

The decision whether to make or buy is a local one; it will depend on your own skill, or that of local workshops and the distance and price of commercial machines. A good policy for a group working in a developing country, where such machines are not manufactured, might be to home-make the first granulator, a small one with a 5 kW motor, and use profits earned with it to purchase a larger, more powerful, imported, factory-made machine at a later date.

Crumbers

Granulated film (Fig. 20) is too light and bulky to feed to an extruder or injection moulder. It does not feed freely in the hopper or down the screw. It can be converted to freeflowing material in a machine called a crumber (Fig. 21). This is like a vertical axis granulator but there is no perforated grid; the material stays in the path of the rotating knives and, while being chopped, is heated to melting point. The volume of the material decreases and, at the right moment, water is admitted to the cutting chamber. The molten plastic explodes into a hard, dense, beady crumb, (Figure 22) irregular in shape and size but suitable for feeding down the barrel of an extruder. Large amounts of water vapour are produced and sucked out by a fan.

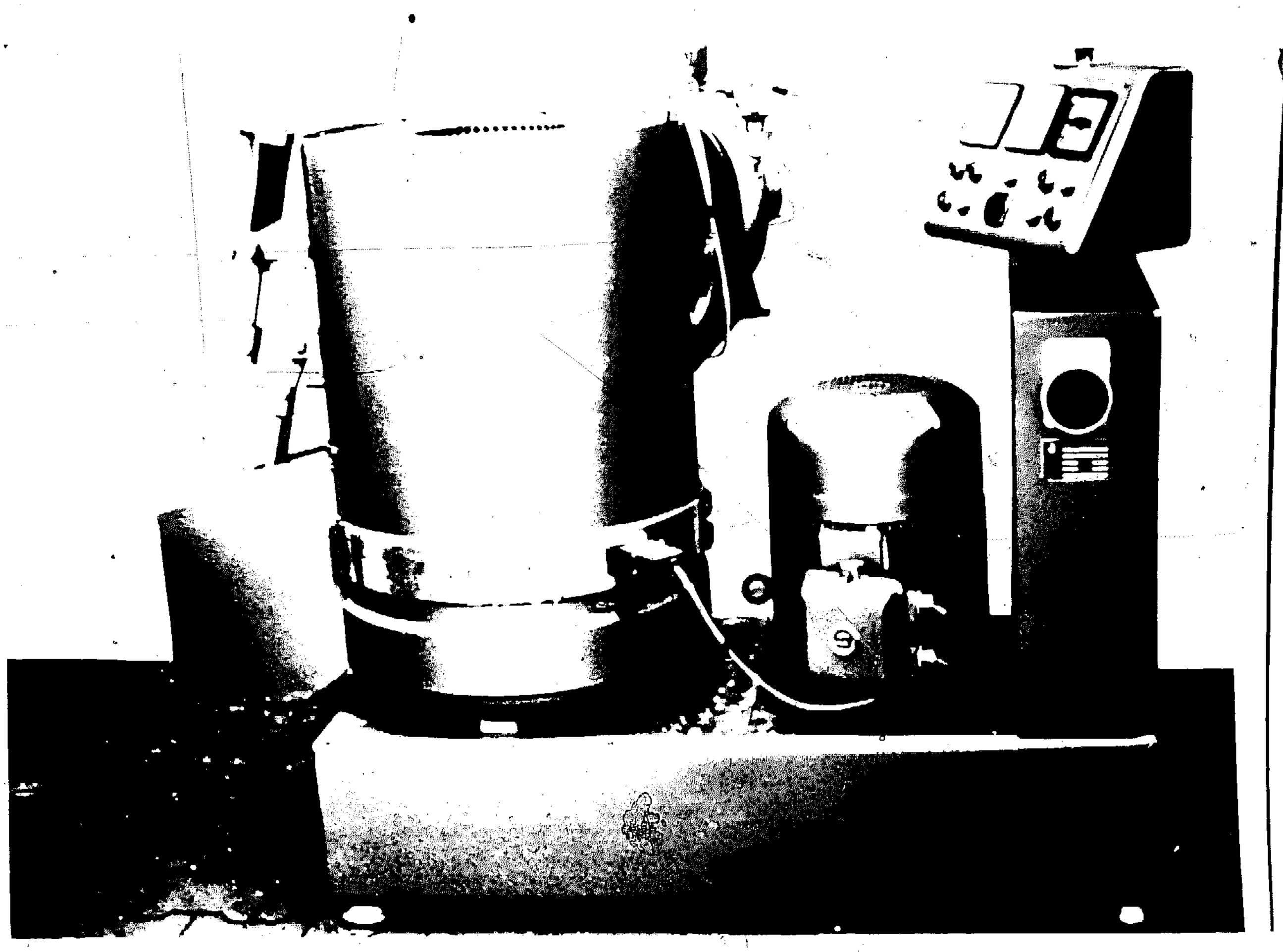


FIGURE 21: The Foliolux Crumber.

Starting from cold it takes about five minutes to plastify a load of film; half this once the machine has warmed up. Some machines further shred the crumb to improve its uniformity.

Crumbers are not cheap; the smallest Italian machine sells at about US$20,000 for an output of 60 to 70 kg per hour, but so far no other method has been developed for such effective reclamation of film scrap. The Foliolux machine shown in Figure 21 is the cheapest available, made by Plastmachines of W. Germany.

One type of crumber incorporates a washing plant that will clean soiled wastes, but is extremely expensive and complex. To date, no Indian companies appear to be producing film crumbers. Some instead use granulators and add water in measured quantities by hand.

Like granulators, crumbers can be home made; a pipe and valve to introduce water and a fan to exhaust the vapour are simple to fit. Vital parts need to be suitably treated against rust, by galvanizing or paint. Rubber seals need to be fitted where the rotor shaft enters the cutting chamber.

Drying

Some polymers are "hygroscopic" they absorb moisture slowly, and need to be dried before they can be successfully extruded and pelletized. Drying can be done by blowing warm air through a rotating drum of material, by stirring in a shallow trough in an oven, or by spreading out on a clean polythene sheet in the sun

FIGURE 22: Crumb - a hard, beady material.

the sun, provided dust and grit are kept out. Drying normally requires between 2 and 3 hours at between 70°C and 90°C but lower temperatures and a longer time can be used for sun drying, especially if there is a slight wind.

Polymers that particularly need drying are nylons, polycarbonate, ABS and high impact polystyrene and cellulose plastics.

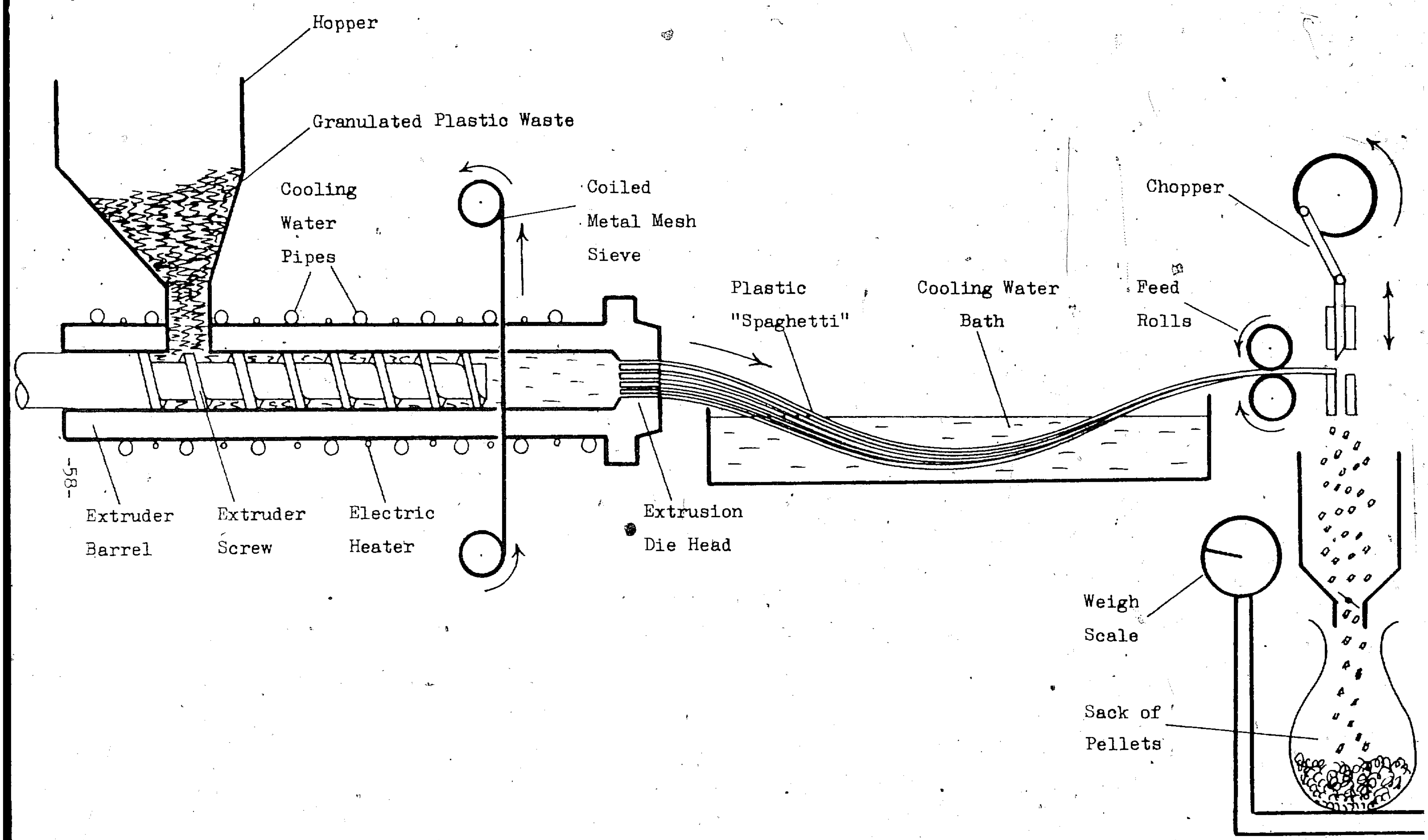


FIGURE 23: Extruder - pelletizer.

EXTRUDER - PELLETIZERS

An extruder is a machine normally used for producing plastic material in long, continuous rods, sheets, shaped sections or pipes. It can also be used to produce pellets and comprises (Figs 23 & 24).

a) A hopper into which crumb or granulate may be fed.

b) A strong steel barrel, able to contain the high pressures applied.

c) One or more screws, designed to force the plastic down the barrel and heat it at the same time. The design of the screw profiles is critical and they cannot be home-made for this reason.

d) Electric heaters and air or water cooling pipes around the barrel to enable the temperature of the material entering the nozzle to be precisely adjusted.

e) A nozzle through which the plastic is forced into:

f) The die - a steel plate, containing a hole whose profile is the desired cross section of the material to be extruded. For pelletizing, a "spaghetti" die is used; it comprises small circular holes, about 3mm diameter, arranged in one or two horizontal lines to extrude multiple strands of polymer simultaneously: as many as forty or fifty on a powerful extruder; a dozen on small machines.

g) A system to clamp the die to the nozzle against the pressure generated by the screw.

h) A motor and gearbox to drive the screw.

j) A mesh screen to strain out non-plastic impurities. This is fitted between the barrel and the nozzle and the melt is forced through it under high pressures, so its design must be robust. The screen must be changed when it becomes clogged with impurities; this is done in one of two ways. A continuous coil of screen on a reel at either end (like a typewriter ribbon) passes through a holding frame and is wound on (by an amount equal to the diameter of the barrel) at intervals. Alternatively unit screens can be fitted in a double screen changer that can be flipped from side to side (like the slide holder in an old fashioned photographic slide projector). This system is cheaper than the continuous type but less effective and takes time. Passage through a screen, to ensure that there are no impurities in the reclaim, is the main purpose of extruding and pelletizing plastic waste granulate or crumb.

k) A cooling trough - into which the extruded strands drop as they leave the die. It is long enough to ensure complete cooling. The strands leave it through a:

l) Haul off system. A pair of simple rollers or "tractors" whose speed matches that of the extruder feeds the strands to the next stage without over-stretching (leading to breakage) or holding back (leading to tangling).

m) Chopper. Finally the strands feed into a rotating chopper, are cut into short pellets and drop into a bin below. Alternatively the chopper can be mounted on the front face of the die, which requires less power to chop the hot, soft plastic. The length of pellet is determined by the speed of extrusion and speed of the chopper.

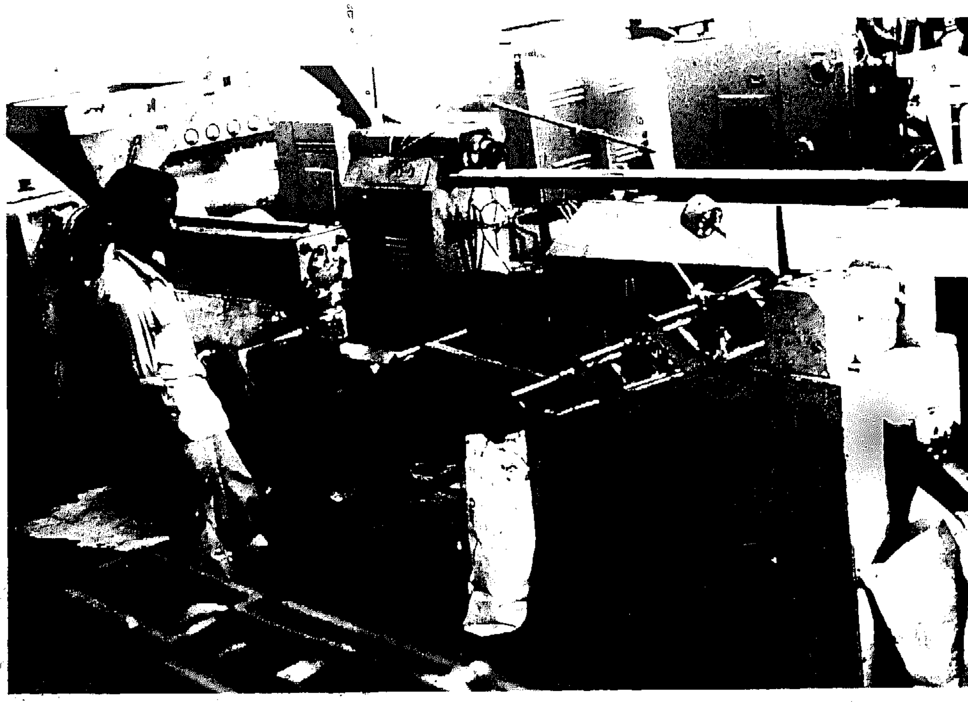


FIGURE 24: Extruder - pelletizer.

Selection of an Extruder - Pelletizer

There are many possible variations. It may be worth-while consulting your customer or another producer who is operating plastics machinery, before committing a large sum of money for an extruder-pelletizer system. The following points need particular attention.

a) The output of the complete line must match your intended production rate, with a margin for breakdowns, screen changes etc.

b) Each component: extruder, take-off, chopper, must be matched for speed.

c) Motors and other electrical parts must be rated to the electrical supply available; see page 53.

d) The screw must be suited to the polymer you are proposing to handle and the form in which it will be received (e.g. crumb, granulate etc.) The manufacturer will advise on this.

Extruders can be very complex machines but the complexity lies in the controls; to achieve high output and good control of product quality every feature may be electronically controlled. For reclamation extruders this is not necessary.

It is essential to see the machine demonstrated, on the application you have in mind. A machine built to extrude PVC hose-pipe may not be suitable for pelletizing high density polyethylene.

Your order purchasing the machine should lay down performance criteria that must be met by the machine before full and final payment is made. For example:-

"Shall receive polyethylene waste granulated to a 6mm mesh and shall extrude and chop into 3mm long pellets of 3mm diameter at the rate of 100 kg per hour and continue to operate under these conditions for a continuous two-hour trial without interruption."

Bagging

Having taken trouble to produce reclaim of high quality and reliability it is worth the cost of packing in a professional fashion. This needs a small scale, capable of weighing at least 20 and preferably 50 kilos. Fill every sack to the same weight and take care never to go under weight.

Secondhand sacks are suitable for granulate but pelletized material justifies a new sack or at least a new label stuck over the old one. Label every bag with precise details of the contents. Printed self-adhesive labels look professional and justify a higher price than scribbling with a felt pen. The sack can be folded two or three times at the top and stapled firmly. Use a rugged stapler and strong wire staples or obtain a heat sealing machine for polythene (or polythene coated paper) sacks. This applies pressure and heat to weld the sack closed in a neat straight line across the top and totally prevents entry of dirt or moisture.

From time to time check with your customer that the packaging is satisfactory, and that no bags have burst or split.

OPERATING PROBLEMS THAT MAY BE ENCOUNTED DURING PROCESSING

DANGER! In each of the following, switch off the machine and disconnect from electrical supply before opening machine, cleaning or making adjustments.

Circular Saw

Machine cuts too slowly	- Saw teeth broken: resharpen or replace.
	- Motor lacks power: have motor cleaned or, if necessary, serviced.
	- Saw clogged with plastic swarf: clean motor and blade.

Granulator

Motor overheats or cuts out	- Cutting chamber clogged with plastic: open machine and remove. Restart and feed more slowly.
Machine cuts slowly	- Knives blunt or chipped: resharpen fixed or rotating knives.
	- Clearances wrong: slacken off fixing bolts, adjust stationary blades using adjustment bolts, so there is only a paper thickness between rotating and fixed blades. Re-tighten fixed blade securing bolts.

Smell of rubber burning	- Drive belts damaged or slipping: check that blades are not clogged. Check no drive belts are broken or stretched.
Machine stalls	- Knives blunt or material too thick or tough for power of machine.

Crumber

Any of the faults of the granulator may apply to the crumber. In addition:-

Some material not crumbed, remains flakey	- Water added too soon.
Material comes out wet	- Too much water added.
Crumbs adhere to each other in large mass	- Insufficient water added.

EFFECT OF RECYCLING ON POLYMERS

In Appendix 1 it is explained how certain polymers degrade at temperatures at or near those required for moulding. The operations of recycling, especially of crumbing and pelletizing, involve actual melting and the possibility of degradation and certain other changes must be watched with care. The following notes cover the common polymers:

Polyethylene

The only problem is possible change in melt flow index - recycled polyethylene may have lower melt viscosity than new material. Material should be reprocessed at the lowest possible temperatures and held at these temperatures for as short a time as possible. Reclaim should be tested for melt flow index after processing (see Appendix II) and differences allowed for when blending with virgin material.

Polystyrene

Slight yellow discolouring can be reduced by keeping recycling temperatures and times down. High impact polystyrene should be dried before reprocessing as it absorbs water in service.

Polypropylene

Melt flow changes may be greater than with polyethylene, so testing of melt flow after processing is recommended. It is less stable than polyethylene and, in the event of degradation occuring, a thermal stabilizer would need to be mixed with the granulate prior to crumbing or pelletizing.

ABS

Drying before recycling may be necessary. Melt flow and other properties of reclaim may differ from virgin material.

PVC

Both plasticized and rigid PVC are sensitive to heat and may have poor stability at moulding temperatures, depending on the kind of stabiliser present. Keep temperatures as low as possible, for as short a time as possible.

A further problem with recycling PVC is the presence of a wide variety of stabilizers, plasticizers, fillers etc in large and (usually) unknown quantity in different products. Normally such materials can only be used to manufacture low grade products. However, if scrap can be sorted into similar categories (cooking oil bottles, footballs, flexible piping, cable sheathing etc.) then the material is likely to be suitable for blending in the manufacture of similar products. A sample should be tested to check heat stability and, if decomposition occurs, advice on a suitable stabiliser should be sought. The other properties needed for the proposed use can also be checked.

Polymethyl methacrylate

The colour and clarity of reclaimed material is slightly less than that of virgin. Contamination by other polymers will reduce weather resistance and spoil appearance.

Polycarbonate

This material must be dried before recycling, as it absorbs water in service.

Polyamides

Nylons require drying before processing. The different types of nylon have different melting points and other characteristics and should be kept separate. As most sources of nylon scrap are industrial this is possible.

Polyesters

High purity is essential; contamination reduces clarity and strength. Reprocessing is difficult and requires high and carefully controlled temperatures. Material should be dried before processing.

Cellulose acetate and other cellulose plastics

These materials need drying before recycling.

COSTS OF PROCESSING

The following factors will need to be included when calculating the total cost of processing. If material passes through a sequence of processes then costs of each must be added.

- Total labour cost
- Total overhead for that labour
- Cost of all consumables involved in washing or cleaning; soda, gloves, brushes etc.
- Cost of electric power to machines.
- Cost of any stabilizers or other additives.
- Depreciation of machines.
- Interest on loans to purchase machines.
- Rent and rates on premises.

Where different materials are collected and processed on the same premises it is useful to calculate the costs separately so that the profitability of each can be calculated. (See "Work from Waste", Chaper 18).

SAFETY IN PROCESSING

The importance of safe working methods and how to achieve them in a recycling operation have been fully described in "Work from Waste". Some of the main hazards of plastics recyling must be pinpointed here as well:

- Almost all plastics will burn. Every possible care to prevent fire should be taken. Smoking should not be allowed. Electrical machines should be unplugged or isolated at the end of each day's work. Fire extinguishers or buckets of water or sand should be kept available.

- Granulators and crumbers are powerful rotating machines which can cause serious injury. They should be treated with respect and never cleaned or repaired until the electric supply has been cut off and cannot be accidentally restored. The same applies to saws, extruders, in fact all electrical machines.

- All electric machines are potential sources of electric shock, especially in the presence of water. Care should be taken to ensure they are correctly installed and earthed and never repaired unless electrically isolated. Workshop floors should be kept dry.

- Injection moulders and extruders generate temperatures high enough to cause severe burns. Hot plastics will stick to the skin and burn horribly. Suitable protective clothing must be worn by operators.

- Scrap plastics can carry dirt or chemicals that may cause disease. Hands should be washed before eating or returning home after work.

- Plastics can give off poisonous fumes when burnt. Avoid breathing such fumes during tests (p.43). Leave the building quickly (closing doors and windows to slow spread of fire if possible) if an accidental fire occurs. Do not dispose of plastic waste by burning. Ensure good room ventilation wherever plastics are processed.

CHAPTER 6: MANUFACTURE AND SALE OF SMALL ARTICLES FROM RECLAIM

Recycling in the manner described in the last chapter can convert worthless scrap into material worth between US$400 and US$600 per tonne (1982 prices). If this material is moulded into a tiny product weighing perhaps 5 gms., it may wholesale at perhaps £20, equivalent to US$40,000 per tonne! There will of course be additional costs, some of them quite high, which are listed at the end of this chapter. None of them is large compared with the extra income to be derived from moulding operations. This chapter describes the equipment and skills needed to enter the moulding industry on the smallest possible scale and make far greater profit.

It is not intended to deal with any of the industrial machines described in Chapter 3 with their expensive, complicated electronic controls: many books are available for this. Cheaper alternatives are available. The kind of extruder described in Chapter 5 is available from India at about US$8,000 at the very cheapest. A range of hand-operated injection moulding and blow moulding machines exists that cost less than US$2,000 (or less than US$1,000 from India) and are therefore within the price range of a small project that has spent a year collecting and granulating scrap plastic and has managed to save some cash for further investment.

Small Injection Moulders - (Fig. 25)

These machines have an electric heater around the barrel. Pressure is applied not by a screw but by a plunger, forced down by turning a capstan handle. Heating time is controlled by a simple timer and a single cycle (charge, heat, inject, cool, eject) takes between 30 and 45 seconds. Production is thus limited to not more than a thousand items in an eight hour day.

These machines are very small which limits the size and weight of the product. For example the SP1 made by the Small Power Machine Company can plasticize up to 1 kg of polymer per hour, making 120 shots in that time, the maximum area of the mould (and hence of the product) is just under 40 sq cm and the maximum dimensions of the mould are 10cm x 10cm x 7.5cm.

Most companies offer a range of dies off the shelf and a service for making those not included in the catalogue. Moulds are made in aluminium and are expected to have a life of at least 20,000 components. They cost about US$200 each but could be made cheaper in local workshops.

A range of components suitable for moulding on a machine of this size is given in Table 5, and illustrated in Fig. 26.

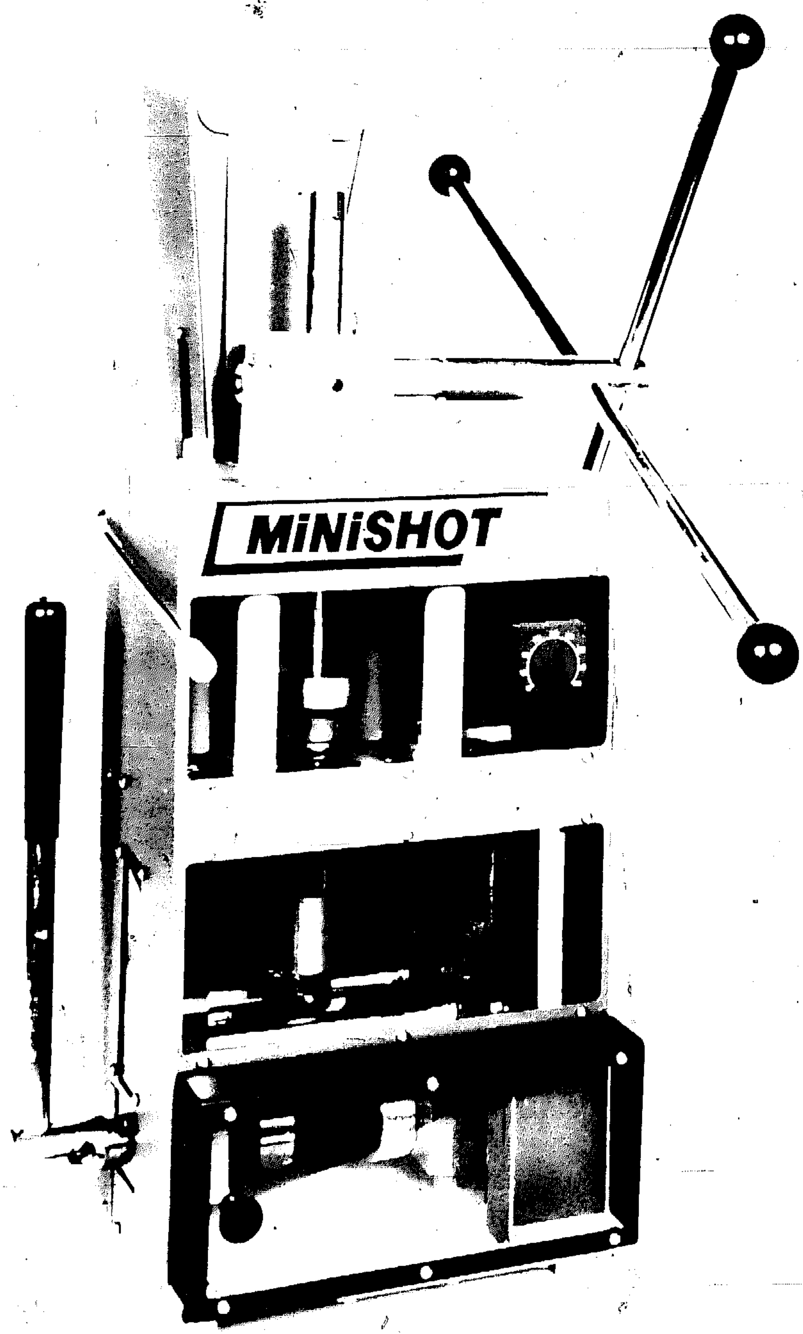


FIGURE 25: Small injection moulder.

Small scale blow moulding

Blow moulding is reported to be possible with a machine of this type by coupling a simple foot pump to the die.

Selection of Products for Small Scale Injection Moulding

The following technical matters must be taken into account when selecting products for small scale injection moulding:

- The weight of the product must not exceed the maximum shot weight of the machine.
- The size of the product, both area facing the nozzle and maximum dimensions, must not exceed those specified for the machine.
- The material must be a thermoplastic of suitable properties for injection moulding. Most of the materials listed in Table 1 are suitable.
- The shape of the product must be such that it can be withdrawn from the mould. Thus hollow objects with a neck narrower than their base are not suitable.
- Items with a screw, such as bottle caps, can be moulded but will need to be withdrawn with an unscrewing motion.
- Items with holes through them, or with metal inserts (eg. a screwdriver with a plastic handle on a steel blade) need special methods but these are not necessarily difficult if the mouldmaker knows his job.

In addition the following commercial factors need to be considered:-

- What price do such items fetch in the shops?
- Are they already made in the country? Are they imported in which case you may get a big advantage?
- Can you achieve a quality as good as other producers?
- Is there a public demand for these items?
- How should you package them to obtain widest sales and the best price? Mount them on printed card? Blister pack? Pack in a polythene bag? Sell in small boxes? An attractive pack can easily double the price you will be able to charge - and will provide additional employment.

- What price will you charge? Study the prices of similar items in the shops and ask retailers what they pay for them, before you offer them supplies. You can aim to charge a price just below what wholesalers pay at present if your quality is just as good, charge less if your quality is inferior. If there is a shortage of these items in the country you may be able to charge even more than the current price.

- Try and sell to two or three different outlets, not to just one. Then you can chop and change or drop a bad payer without difficulty. For details of the selling of waste materials see "Work from Waste", Chapter 15.

- An important decision is whether to sell through wholesalers or retailers. If you sell through retailers you will get a better price; through wholesalers you will find it easier (less work) to sell large quantities. Wholesalers may not buy from you if you also sell direct to retailers in their area. Probably the decision rests on the matter of quantity. If the number of items you can produce will only satisfy the needs of two or three retailers then sell through them; if it will feed twelve or more then sell through a wholesaler.

  Work out the difference in price between the two and calculate whether it is worth the trouble and cost of distribution to the retailer in return for the extra price you receive.

Operation of a Small Injection Moulder

The machine is switched on to heat up, 10 to 15 minutes before it is required.

The mould is closed and clamped.

Material is placed in the hopper and a measured amount dropped into the barrel, where it is heated.

After a specified pause the operating handle is turned, forcing plastified material through the nozzle and into the die. The pressure is held for a short "dwell time", to ensure additional material flows into the mould to compensate for shrinkage, then released. After a further pause the mould clamps are released and steel pins used to eject the moulding which is now solid but still hot!

The next cycle can take place immediately.

A More Ambitious Machine

A more ambitious small scale injection moulding machine is widely used in Egypt. Although the material is injected using a hydraulic ram, powered by a 5h.p. electric motor and hydraulic pump, and the barrel has a 3kw electric heater, the die clamping is done by hand, using an ingenious system of links and levers moved by a long handle. The cost is around US$1,000 and production rates can be achieved that are not much less than those of fully automatic machines.

Problems that may be encountered during injection moulding:

Moulding is short or has holes in it or a rough surface - Mould is not totally filled - press harder on capstan, operate capstan faster or hold pressure longer. If the trouble persists it may be necessary to increase the size of the gate - the opening in the mould that allows the plastic to enter.

Flash - a thin layer of plastic escapes around the mould - Check mould is tightly clamped to nozzle, mould halves are securely joined, if mould is worn or damaged. If flash only occurs on one batch of material, its melt flow index may be too high.

Discolouration of the moulding - may be due to burning. Place thin paper between the two mould halves to allow air to escape as plastic enters. With PVC it may be due to decomposition of material - reduce amount of heat, or duration of heating or add a stabilizer to the polymer.

Misshapen product - product ejected from mould before cool enough. Material not homogeneous. Too short dwell time fails to 'top up' heat shrinkage.

Cracks or defects in moulding - heating period too short, polymer did not all melt.

TABLE 5 Small Mouldable Plastic Objects (See Fig 26)

Air freshener holders	Key tags
Badges	Magnifying glasses
Bangles and rings	Mobiles
Basin and bath plugs and other plumbing	Office equipment and sundries
Battery filler caps	Pencil sharpeners
Beer mats	Plastic flowers and fruit
Bobbles	Plastic wall plugs
Bottle lids and caps	Plugs and caps for tubular steel furniture
Bra buckles/clasps and stiffeners	Pop-on necklaces
Buckles	Replacement petrol filler caps
Buttons	School rulers and set squares
Cable joints	Screw-driver handles
Clothes pegs - without springs	Self-adhesive coat hooks
Collar stiffeners	Shoe heels and insoles
Combs	Soap dishes and boxes
Cosmetic boxes	Spools
Cotton reels	Spinning tops
Crucifixes, medallions	Statuettes and models
Cupboard knobs/drawer handles	Suitcase and briefcase feet
Curtain hooks, rings and runners	Tap washers and hose fittings
Cycle handlegrips, pedal rubbers	Tap spouts and hose nozzles
Desk pencil stands	Thimbles, darning mushrooms
Doorstops and door wedges	Tips for crutches, artificial limbs, blind sticks
Draughts or Jacks	Toothbrush holders
Electrical components - simple plugs	Tyre valve caps
	Wall ornaments - fridge ornaments with magnets:

X-mas tree ornaments etc

Yoyos

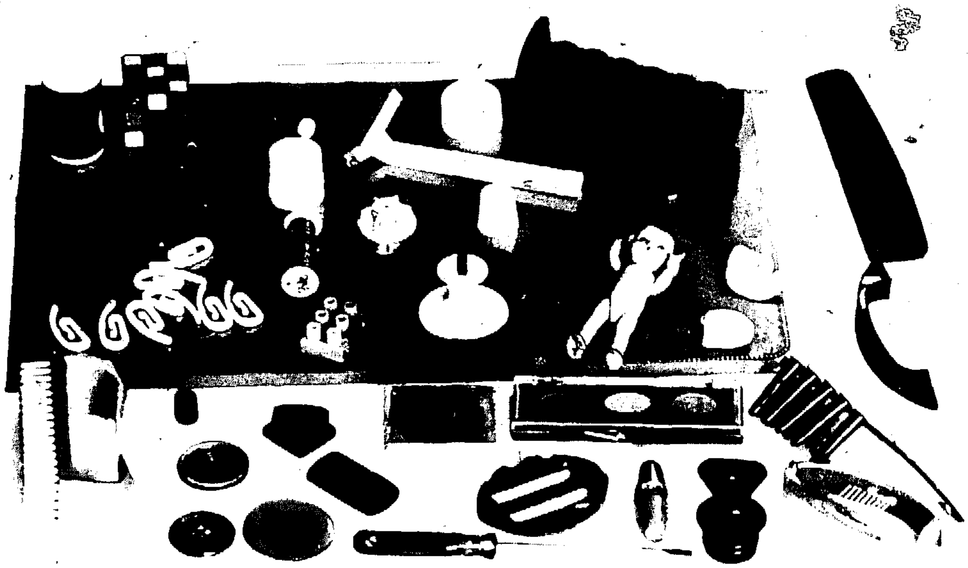


FIGURE 26: Small mouldable objects.

APPENDIX I ABOUT PLASTICS - THEIR CHEMISTRY AND STRUCTURE

The meaning of "plastic"

"Plastic" means "can be moulded into any form". Plastics do not possess this quality (called "plasticity") at all times; most are only truly plastic when hot; at room temperatures they are solid and either break or spring back if bent or stretched greatly.

Monomers and polymers

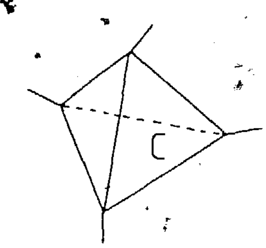
Plastics are mainly man-made, by chemical processes that start with various raw materials: frequently petroleum oil but also non-minerals such as cellulose (the basic material of plant cells) and even milk.

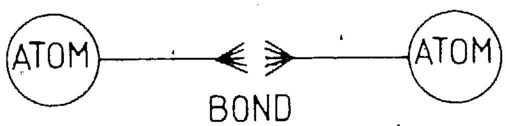
Their nature and behaviour is most easily understood by considering their detailed structure: the "atoms" and "molecules" of which they are made.

The plastics in common use are based on "polymers" which are either formed from simple organic compounds known as "monomers" or by combinations of chemical compounds which on their own do not make polymers. An example of a monomer is the gas ethylene, obtained from crude petroleum oil. Each polymer molecule, is made by joining thousands of monomer molecules together in a long chain by a chemical process called "polymerization" Each polymer is quite different from the monomer from which it is made: for example polyethylene, made by the polymerization of ethylene, is a flexible solid at room temperature, quite unlike the gas from which it is formed.

Carbon atoms and bonds

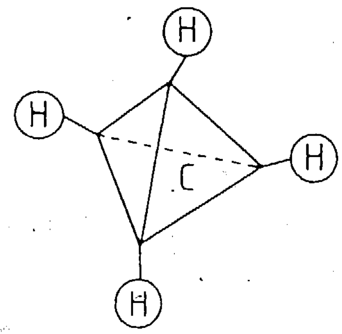
Carbon (symbol C) is an "element" found in nature in different forms: as coal, as graphite (pencil lead) and even as diamond. Although too small to be seen, an atom of carbon has a structure like a four-faced pyramid with one arm sticking out from each corner. The arms can be imagined as having hands with which they can join onto any other atom that has a free hand.



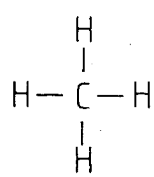


The joint between two atoms is called a bond. It can be thought of as the two arms and the clasped hands where they meet. Because they have four arms each, carbon atoms join readily with other atoms in a vast number of different ways.

Hydrogen (symbol H) is an element which exists in nature as a light gas (explosive when in contact with the oxygen in air). An atom of hydrogen has only one arm so four hydrogen atoms can join onto one carbon atom to make the simplest of all organic compounds: the gas methane, which is well known as the main ingredient of biogas or natural gas.



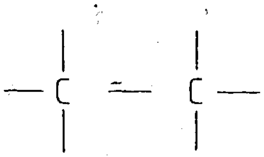
For simplicity it is drawn on flat paper like this:



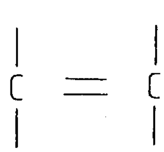
It should not be forgotten that it is three dimensional and some of the bonds should actually be pointing out of the paper.

As well as joining onto different atoms, a carbon atom can join onto another atom of carbon, either with each atom using only one of its four arms, which is called

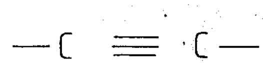
a single bond:



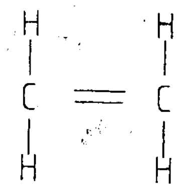
or with two arms each (a double bond)



or with a triple bond.



An example of a compound in which two carbon atoms are joined by a double bond is ethylene (chemical formula C_2H_4) whose molecule can be represented as:

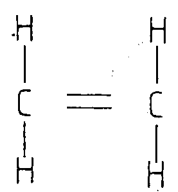


The simplest addition polymer - polyethylene

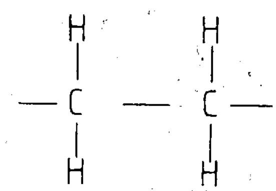
A molecule whose carbon atoms are joined by a double bond can still be joined to other molecules if the double bond is replaced by a single bond, leaving two arms free.

Such a molecule is called "unsaturated".

In the case of ethylene:

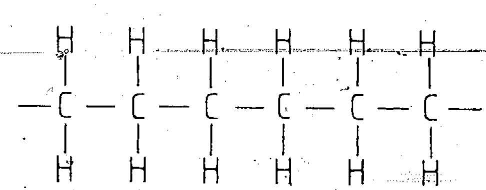


becomes



Consider a container that holds a monomer gas or liquid. For any single molecule with two free arms, the nearest available atoms to which to join are those of other, identical, unsaturated molecules. So, provided certain conditions exist to start the process, the monomer molecules join together to form a chain molecule. It may be extremely long, often several thousand atoms, and not every molecule in a polymer has exactly the same length; when speaking of the length or weight of a polymer molecule it is the average that is considered.

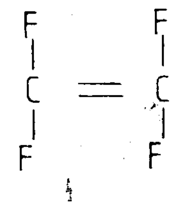
For example, ethylene polymerizes into a chain molecule of polyethylene (also called polythene) in this way. The process, of simply adding one monomer molecule onto another, is called addition polymerization.



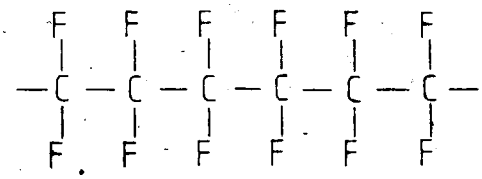
Because its structure is light, with no large groups or heavy atoms, polyethylene is a lightweight plastic, of specific gravity between 0.91 and 0.96, which floats on water.

An addition polymer without hydrogen - PTFE

Although hydrogen is one of the most common elements to which carbon joins, it is not the only one. For example, the monomer tetrafluoroethylene, which is like ethylene in structure:

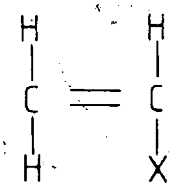


but with fluorine atoms (symbol F) in place of hydrogen, can be polymerized into polytetrafluoroethylene better known as PTFE, a plastic whose extremely low friction has many uses besides the familiar coatings for non-stick saucepans.



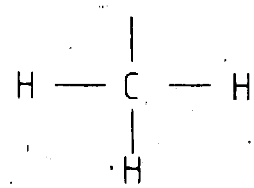
Other polyvinyls - polypropylene and PVC

Any monomer whose molecule has the form

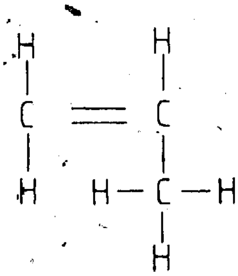


is called a vinyl. Its polymer is a polyvinyl. The X can represent either a single atom (such as hydrogen, as in ethylene) or a group of atoms.

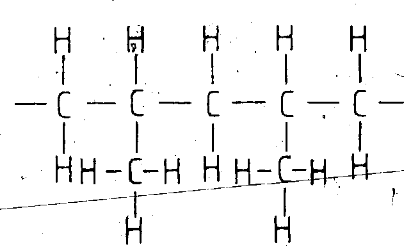
There are many such groups. For example the methyl group (C H_3) has one carbon and three hydrogen atoms leaving one arm free to join the vinyl structure



to form the monomer propylene



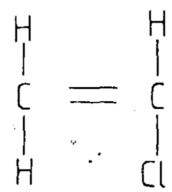
which polymerizes to polypropylene: an important plastic.



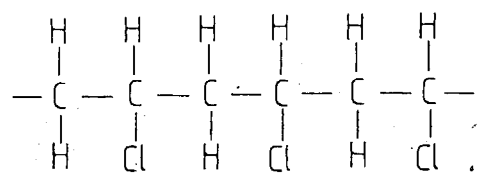
Because the CH_3 side groups are spacious but not heavy, the chain molecules will not pack so tightly together as will those of polyethylene, so polypropylene is less dense (specific gravity (s.g.) 0.90 - 0.91) The recycler uses this property to distinguish it from high density polyethylene, which it otherwise resembles.

When the X is an atom of the poisonous gas chlorine (symbol Cl), used to sterilize drinking and swimming pool water, the monomer is a gas called

vinyl chloride



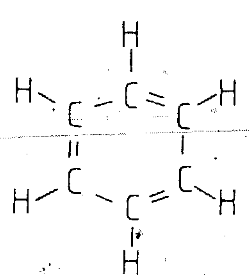
and the polymer is polyvinyl chloride or PVC, one of the most widely used plastics.



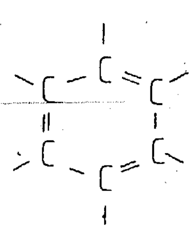
The chlorine atoms are much heavier than those of hydrogen, so that the pure polymer is much denser than polyethylene, with an s.g. of about 1.4, and sinks in water.

Polymers with benzene rings - polystyrene

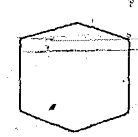
One special arrangement that carbon atoms take up very easily is a ring shape, called the "benzene ring"



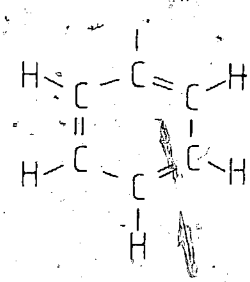
or



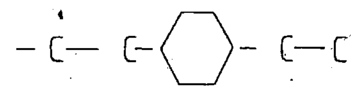
or just



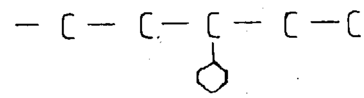
If one atom of hydrogen is removed from the ring a "free" arm is available to join onto other atoms. This structure is known as phenyl (C_6H_5)



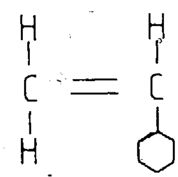
In some polymers benzene rings can be regarded as links in the carbon chain



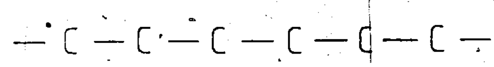
but phenyl groups may best be thought of as hanging from it.



For example, styrene
a vinyl with a phenyl group,



polymerizes into one of the most widely used plastics: polystyrene.



The phenyl ring, with its six carbon atoms, is heavy so that polystyrene is dense (s.g. about 1.05) and sinks in water. It is also very brittle, for reasons that will be explained later.

Copolymers - ABS

As well as the addition of identical monomers it is possible to polymerize different ones together. An important example is the "co-polymerization" of styrene with butadiene, a monomer whose presence in rubber gives toughness and resilience, and acrylonitrile which raises the melting point. The resulting co-polymer: acrylonitrile butadiene styrene or ABS, has the easy mouldability of polystyrene without its weakness and brittleness.

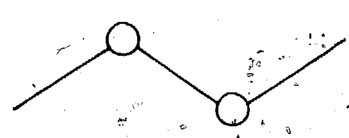
Condensation polymerization - polyester

Some polymers cannot be made by simple addition of monomers but require the chemical combination of two different compounds to form a monomer which is polymerized in the process. The chemistry may be complicated but one important material will be mentioned by way of illustration: Ethylene glycol and terephthalic acid combine to make water and ethylene terephthalate which polymerizes into polyethylene terephthalate otherwise known as polyester, (Terylene, Crimplene, Dacron, or Trevira) when it is a textile fibre, or as PET when used for packaging or for soft drink bottles.

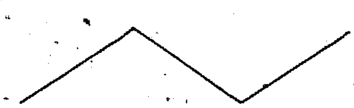
Other important condensation polymers are the polyamides, of which various types of nylon are the best known examples, and the polyurethanes, used as foam fillings in furniture.

Arrangement of the chain molecules in thermoplastics

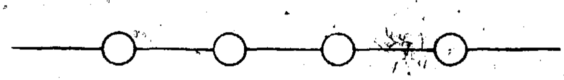
The above is but a glimpse of the chemistry of polymers, covering some of the materials that are mentioned in the text. It will also help to discuss how the chain molecules are arranged and the effect on the properties of various plastics. The kinds of molecules in the chains can now be forgotten and represented simply like this:-



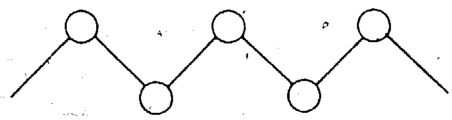
or even more simply by just indicating the main bonds, like this:-



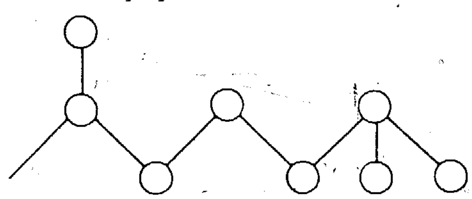
Because the carbon atom is three dimensional and can rotate about its bonding arms, which are angled to one another, it is not accurate to represent a polymer chain like this:



A nearer approximation would be to draw it like this:



Even then it must be remembered that it will be three dimensional and come out of the paper, and may have side chains:



Effect of heat on thermoplastics

When any material is heated the molecules vibrate. In a metal, once a certain temperature (the melting point) is reached, the molecules can move freely and the metal immediately becomes liquid. The long chains of most polymers however are intertwined with one another and separate only gradually as the temperature rises. This is seen first as slight softening then, as the chains become free to slide past one another, the material becomes plastic and will flow under pressure; then it may become a stiff liquid and perhaps, finally, a runny liquid. Plastics that soften when heated are called "thermoplastics". They can be easily moulded: shaped when hot and then cooled in the new shape. In some cases the plastic will burn, char or decompose in some other way before the liquid state is reached. Exactly how the material responds to heat is very important for recycling and later moulding operations. It can be measured in different ways, of which the most important are:-

Softening point - the temperature at which the plastic first softens.

Processing temperature - the best temperature at which to carry out moulding operations.

Decomposition temperature - the temperature at which chemical damage occurs in the plastic and it "decomposes"

Melt flow index - a measure of how fast plastic, at a given temperature, will flow under pressure.

Expansion and shrinkage - the change in length or volume as the temperature rises or falls.

Although a recycler will not need to know them until he progresses to the stage of melting material, for making pellets for example, they are mentioned here to stress how they are affected by the arrangement of the chain molecules.

Thermosets

Another kind of plastic behaves quite differently with heat. At the time of polymerization, some monomers form "unsaturated chains" whose atoms have "spare" banding arms, not joined to other atoms. The increased molecular activity, due to heat (or the action of certain chemicals called "catalysts"), causes these atoms to "cross link" between the chains. Cross linkages prevent the chains sliding, even when heat is applied, so no softening occurs. Such materials, known as "thermosets" can only be moulded once; at the time of the polymerization process. They cannot be remelted and reformed so they are not recyclable. They will only be mentioned elsewhere to list and identify them. Examples of thermosetting plastics are: phenol formaldehyde or Bakelite, one of the earliest plastics to be made and still used widely for electrical plugs and switches; melamine formaldehyde, used to make kitchen laminates such as Formica and crockery such as Melaware; and the epoxy resins, widely used in electrical equipment and composition floors.

All common thermoplastics are formed of saturated molecules (every bond is used). Some molecules, such as polyurethane, can exist in both the saturated and unsaturated states, so can be either thermoplastic (and possibly recyclable) or thermoset (not recyclable).

Amorphous thermoplastics - polystyrene, PVC and ABS

When thousands of chains, each made up of thousands of monomer molecules, grow, close to one another, during polymerization, they may end up totally entangled. Entanglement will be greater if the chains not only grow end to end, but also branch into side chains, or if they contain large or complex groups, especially rings hanging from the chain, such as the phenyl groups in polystyrene. Plastics whose chain molecules are arranged in a random, tangled fashion are called "amorphous" and have particular properties.

If a force is applied to try and stretch the material the chains will not smoothly slide over one another but bunch up. Such material is "brittle" and unyielding. It stretches little and breaks suddenly, especially under impact. In the early days objects made cheaply out of polystyrene soon cracked and broke to give all plastics a bad reputation.

Amorphous polymers are less dense than might be expected from the mass of the atoms that make up the chain. The chains cannot fit closely side by side but are held somewhat apart. Were it not for this separation the brittleness due to entanglement would be even worse.

Amorphous polymers soften more gradually and shrink less on cooling and this is the reason why PVC, polystyrene and ABS are very satisfactory for moulding complex shapes.

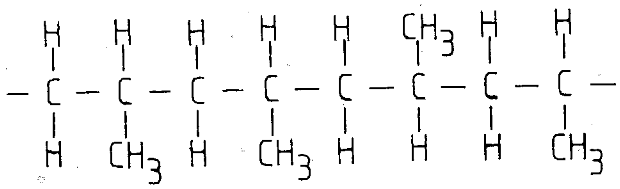
Crystalline polymers - high density polyethylene

Polyethylene normally has most of its molecules arranged in an amorphous structure with chains well separated. For this reason, and because the regularly shaped molecules have few side chains and no large atoms or groups so they do not become entangled, it is a soft, flexible, rather slippery material, even at normal room temperatures. However a few of the molecules are arranged in neat, orderly rows, similar to those of metals: such a structure is called "crystalline". By certain production methods it is possible to increase the proportion of molecules arranged in this way with many benefits. The chains pack closely together giving higher density. (s.g. between 0.95 and 0.96 so it still floats on water). The material is known as high density polythene, while the normal, mainly amorphous, material is called low density polyethylene. (s.g. 0.91 to 0.92). Intermediate grades, known as medium density, have an s.g. of about 0.93.

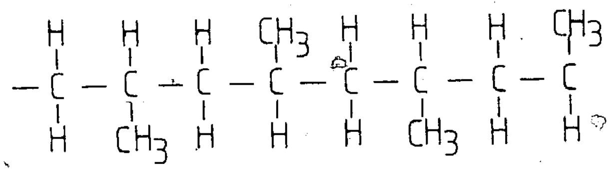
Because they are so intimately packed together, more force is needed to make the chains slide over one another, so strength and rigidity of high density polyethylene are high but the sliding takes place smoothly, without entanglement, so considerable yielding or stretching takes place before any breakage occurs. Material that behaves in this way is "tough", the opposite of brittle. More heat is needed to separate the chains sufficiently for softening to occur, so softening and melting temperatures are higher than those of low density polyethylene. High density polyethylene is increasingly being used for products, such as large buckets and thin film sacks and bags, for which its stiffness and strength are an advantage.

Polypropylene

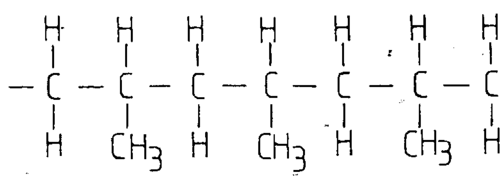
These useful crystalline properties are even more developed in polypropylene. Because of the structure of the vinyl monomer described overleaf, three different polymer chain structures are possible although all have the same chemical composition. Either the monomer molecules can be arranged randomly:



or alternating different ways:



or all the same way; (described as "oriented")



The last of these arrangements, coupled with absence of branching, results in packing of the chains as close as is permitted by the methyl groups, to produce a strong, tough, hard, high-softening-point plastic despite its light weight.

An example of these exceptional qualities is that hinges can be moulded into polypropylene articles simply by reducing the thickness to a fraction of a millimetre. The hinge only becomes effective when the material in the joint is caused to stretch and become oriented. Other materials also allow hinges to be moulded but, if orientation does not occur, these soon fail.

The size of the polymer chain

Addition polymerization can partially be controlled to determine the length to which the polymer chains are allowed to grow. Long molecules, with a high molecular weight, are stronger and tougher. They resist sliding more and can slide further before large numbers of chain ends come into line to create a weak place for breakage to occur. Higher temperature is needed to make the polymer sufficiently plastic to flow under pressure, so the melt flow index decreases as molecular weight increases. The ability of the polymer to stand up to attack by harsh chemicals is also increased because there are fewer vulnerable chain ends exposed.

Conversely, whatever damages the molecules and breaks the chains to reduce the molecular weight, reduces strength and toughness. Recycling, which may involve either mechanical battering or heat treatment of the polymer, may have some effect of this kind. Possibly more important is the environment to which the polymer may have been subjected before recycling. In general "process scrap" (plastic waste from the factory moulding process, recycled on the spot) will be little degraded. However, the ultra violet light in sunlight breaks polymer chains so "post consumer" waste, especially if it has been out in the weather, may have far less strength and toughness after recycling than when first moulded unless special corrective steps are taken.

Additives

One final aspect of polymers needs mention: the addition of other materials, which may or may not themselves be polymers, to modify their properties. It is not essential to know what these additives are, but it is necessary for the recycler to be aware of their possible presence and that he can use them to improve the quality of the reclaimed product. By far the greatest amount of additives (other than colouring) are used with PVC.

Plasticizers

Certain liquids, when mixed with a plastic, penetrate between the polymer chains, act as a lubricant and allow them to slide more readily, producing a more plastic material. The degree of plasticity depends upon the proportion of plasticizer that is used: as high as fifty per cent is possible. Plasticizers are principally used with PVC which is normally a hard, rigid polymer, to produce the familiar flexible material known as plasticized PVC, used for luggage, upholstery, footballs, etc. Because of their presence plasticized PVC is technically more difficult to recycle than rigid PVC.

Stabilizers

All plastics change chemically if subjected to a high enough temperature. Some burn, others char or decompose without burning. If the temperature at which this occurs is below, or close to, the softening point, then the material cannot be satisfactorily moulded. PVC is the particular example of this: although it does not burn easily it decomposes, giving off fumes of hydrochloric acid gas, which speed up the decomposition, damage processing machinery and discolour and spoil the finished product. Processing temperatures for PVC range between 150°C and 210°C but decomposition may occur as low as 180°C so the difficulties are great. They are overcome by ensuring that the period at moulding temperature is very short, and by the addition of a stabilizer: a chemical compound that raises the temperature at which decomposition takes place. Even stabilized PVC may not recycle more than two or three times without decomposition occurring. Stabilizers are not widely used with polymers other than PVC.

Antioxidants

Even at normal room temperatures, some polymers can be degraded by oxygen in the air. This is accelerated by ultraviolet light, present in sunlight. Temperatures above normal, even though below decomposition temperature, can make the situation worse. These attacks may have one of two effects. They may break the polymer chains, which happens to polystyrene and polypropylene, giving lower molecular weight and loss of toughness. Alternatively they may cross link them, which happens to polyethylenes, to give higher molecular weight, and loss of toughness in the finished product. This brittleness is found in polyethylene sacks and other containers that have been left out in the weather for a period.

These harmful effects are countered by the use of antioxidants. Low density polyethylene requires very little; other polymers, such as high density polyethylene, polystyrene, and polypropylene are more sensitive both during moulding and in use and more antioxidant is required.

Other additives

Inflammability can be reduced by addition of "flame retardants". Brittleness may be reduced by the use of "impact modifiers", rubbery materials which are physically mixed with the polymer. An example is high impact polystyrene, (which should not be confused with ABS, a genuine co-polymer developed for the same reasons.) "Fillers" are non polymer materials used to alter the properties or reduce the cost of the polymer with which they are mixed. For example glass fibres are used to reinforce thermoplastics like nylon, polyacetals and polypropylene. The result is called "g.r.p." or "f.r.p.". Such materials are in general, not recyclable. Of the many other additives mention need only be made of the huge range of "colourants" and "pigments" that convert the natural white or transparent appearance of nearly all pure polymers into the infinite range of bright and attractive colours that give plastics so much sales appeal.

Masterbatch

Additives are often mixed with the polymer in the form of a masterbatch - a quantity of the polymer containing a heavy concentration of additives. Cost of masterbatch may represent a high proportion of the total cost of the compound.

Foams and expanded polymers

Plastic foams are familiar in furniture fillings, where the foam, usually polyurethane, is flexible, and in packing where rigid foam, particularly expanded polystyrene, is commonly used. Foams are made by liberation of a gas within the molten polymer, followed by rapid setting before the foam has had time to collapse. The gas may be released during the process of condensation polymerization, as with polyurethane. Alternatively the foaming agent is combined with the polymer and can be released when required. For example polystyrene granules are available which can be heated in a mould to both plasticize the polymer and release the foaming agent. The shaped foam object is released from the mould when cool and set.

The gases are usually inert: carbon dioxide or nitrogen are common; and need cause the recycler no problem. However the weight of polymer in a huge volume of foam is very small so that the economics of recycling foams are usually very poor.

APPENDIX I[illegible] TEST FOR MELT FLOW INDEX

This test is designed for polyethylene and polypropylene. Place 4 or 5 gms of sample in an open topped cylinder as shown in Fig.27. The jacket is electrically heated and kept at a fixed temperature: 190°C for polyethylenes, 230°C for polypropylene. Weights (either 2.16kg, 5 kg or 21.6kg) are placed on the piston. The molten plastic is extruded through the nozzle and, at measured time intervals, the amount of material that has extruded through the nozzle is cut off and weighed.

$$\text{Melt flow index} = \frac{600 \times \text{Average weight of cut-off in gms.}}{\text{Time interval between cut-offs in seconds.}}$$

The nozzle is 8mm long and 2mm in diameter.

When quoting the M.F.I. the weight should be specified.

A full definition of the test is found in British Standard BS. 2782 Part 1.

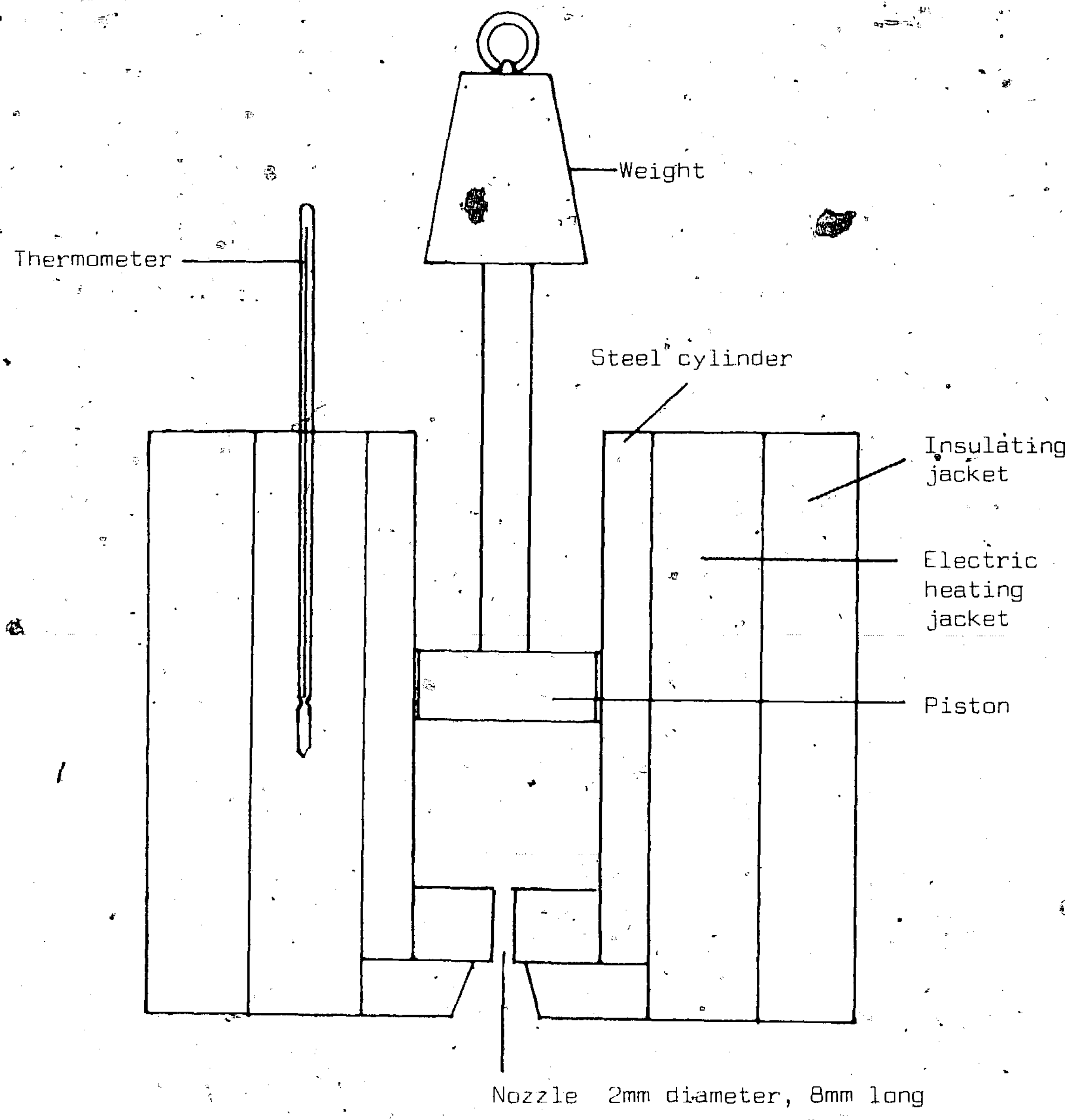


FIGURE. 27: Rig for measuring melt flow index.

APPENDIX III - MANUFACTURERS OF PLASTICS RECYCLING EQUIPMENT

SMALL EXTRUDERS

- Axsello Ltd., Unit 21, Chalford Industrial Estate, Chalford, Stroud, Gloucs., GL6 8NT, U.K.
- Leistritz, Marhyrapenstrasse 29-39, Postfach 1640, West Germany.
- Leistritz, 369, San Miguel Drive, Newport Beach, California, 92660/U.S.A.
- Axon, Håharegatan 2, Nyrang, S26500 Astorp, Sweden.
- R.H. Windsor (India) Ltd., E-6, U. Road, Thana Industrial Estate, Thana 400 604, India.
- Kobite Industries, 31 Shah Industrial Estate off Veera Desai Road, Andheri (W), P.O. Box 7368, Bombay 400 058 India.
- And the companies listed under VARIOUS below.

SMALL INJECTION MOULDERS

- Small Power Machine Co.Ltd., Bath Road Industrial Estate, Chippenham, SN14 OBR, Wilts, U.K.
- Griffin and George Ltd., P.O. Box 14, 285 Ealing Road, Alperton, Wembley, Middlesex HAO 1HJ, U.K.
- Boolani Engineering Corp., Prabhadevi Industrial Estate, 402 Veer Savarkas Marg, Bombay 400026/India.
- Florin Ltd., Manumold Division, 457-463 Caledonian Road, London N7 9BB, United Kingdom.
- Fon and Offord Ltd., Alma Street, Aston, Birmingham B19 2RP, United Kingdom

GRANULATORS

- Condux-Werk, D645, Hanan 11, Wolfgang, West Germany.
- Blackfriars Engineering Co.Ltd., 18-20 Holmethorpe Ave., Redhill, Surrey RH1 2NL, U.K.
- Kabran Engineering Ltd., Baxters Lane, St. Helens, Lancs, U.K.

- Leesona Cumberland, P.O. Box 6065, Providence, Rhode Island, 02940 U.S.A. or Daniels Engineering Ltd., Bath Road, Stroud, Gloucestershire GL5 3TL, U.K. (who also supply complete recovery systems).

- And the companies listed under VARIOUS below.

Granulator Knives

- A.F. Whiteley & Co.Ltd., Bingswood Road, Whaley Bridge, Stockport, Cheshire SK12 7NB, U.K.

FOAM RECYCLING PLANT

- Ryburn Foam, Springwood Mills, Holywell Green, Halifax, HX4 9BL, U.K.

CRUMBERS AND RECYCLING PLANT

- Kraus Maffei Aktiengesellschaft, Kraus Maffei Strasse 2, D-8000, Munich, 50, Austria. (Manufacture Condor Machines).

- Buchau-Wolf, Postfach 69, 4048 Grevenbroich.

- Fbm di F. Falzoni, 44012 Bondeno, Ferrara, Italy.

- Plastmachines, Gelderland G & D.H. Deutschland, Grobenzeller Straze 5, D-8031 Puchheim, Munchen, W. Germany.

- Kween B Plastics Ltd., The Old Manse, 2 Compton Road, Erdington, Birmingham B24 8QA, U.K.

- ESA (Yewtree) Ltd., Unit No 3, Chelmsley Wood Industrial Estate, Waterloo Avenue, Birmingham, B37 6QQ, U.K.

- Extrudaids Ltd., 7 Rose Industrial Estate, Bourne End, Buckinghamshire, U.K.

- And the companies listed under VARIOUS below.

VARIOUS

- S.T.D. Plastics Machinery Ltd., Yate, Bristol BS17 4AX, U.K.

- Plasplant Machinery Ltd., Bordon Trading Estate, Oakhanger Road, Bordon, Hants GU35 9HH, U.K.

- Brimco Plastic Machinery Prt.Ltd., 55, Gort Industrial Estate, Kandirli (West) Bombay 400 067, India.

- Boolani Engineering Corp., Prabhadevi Industrial Estate, 402, Veer Savarkas Marg, Bombay 400 025, India.

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Some popular plastics journals and magazines

U.K.

Plastics and Rubber Weekly (includes advertisements for new and secondhand machinery and for reclaimed plastic).

British Plastics and Rubber

Europe

Modern Plastics International

European Plastics News (incorporating British Plastics).

Kunstoffe German Plastics

Industrial des Plastiques Moderns et Elastomers

U.S.A.

Modern Plastics International

Plastics Technology

The Intermediate Technology Development Group was founded in 1965 by the late Dr. E.F. Schumacher. ITDG, an independent charity, gathers and disseminates information, and advises on the choice of technologies appropriate for developing countries. In addition, the Group is also involved in an expanding programme of work on technology choice for Britain.

SOME OTHER INTERMEDIATE TECHNOLOGY PUBLICATIONS

Work from Waste: Recycling wastes to create employment
J Vogler
'Practical, authoritative, detailed handbook that shows how employment can be created by recycling all kinds of refuse': David Astor.

This book deals with wastes, their origins, uses and methods of processing, which stimulate new activities and create employment. The book is divided into two main parts. Part I contains details of the wide range of materials that can be recycled and the processes involved. Part II describes how to set up and run a small business recycling wastes.
396pp. Illus. February 1982. ISBN 0 903031 79 5. £6.50.

The Low-cost wooden duplicator. How to make it. How to use it

The low-cost wooden stencil duplicator is a cheap printing machine which can be made for use in schools, colleges and small organizations. The duplicator is made mostly from wood and you need only simple woodwork tools to build. It is very easy to use and maintain. Broken or damaged parts are simple to replace because you can probably make them yourself.
Illus. £1.95.

Micro-Hydro: A Technical Brief
by Ray Holland

A summary of the present state of the art in micro-hydro with a section on the economics of micro-hydro installation and operation. This is the first of a series which will be invaluable to engineers, consultants and field workers in the developing world. This first publication will also be of great interest to smallholders, homesteaders and others interested in practising self-sufficiency.
Price: £2.50.

The Sten-screen
Making and using a low-cost printing process

The combination of stencil duplicating with screen process printing enables one to build a press for approximately £10. No sophisticated components are required for either construction or implementation. The process is capable of printing a wide range of formats; one can also print upon a variety of materials including paper, textiles and plastics. No electrical supply is required.
Illus. 20pp. £1.95.

How to make a Foot-Operated Pillar Drill
by Paul Smith

This is the latest in a series of workshop equipment manuals demonstrating methods of constructing your own machinery. Full illustrations and detailed building instructions are provided for the manufacture of a foot-operated vertical drill for use with either metal or wood. The book will be useful to rural workshops and training centres throughout the world as well as to commercial manufacturers of workshop tools.
Price: £1.95.

The Harnessing of Draught Animals
by Ian Barwell and Michael Ayre

This study concentrates specifically on draught harnesses for bovines and equines. It is intended to complement the many publications available on other aspects of draught animal power and to:
a) increase awareness of the role of harnesses in the effective use of animal-drawn implements and the potential for the use of improved harnesses; and
b) provide 'state of the art' information on available harness technologies that might be applied in developing countries.
Illus. £5.00 net.