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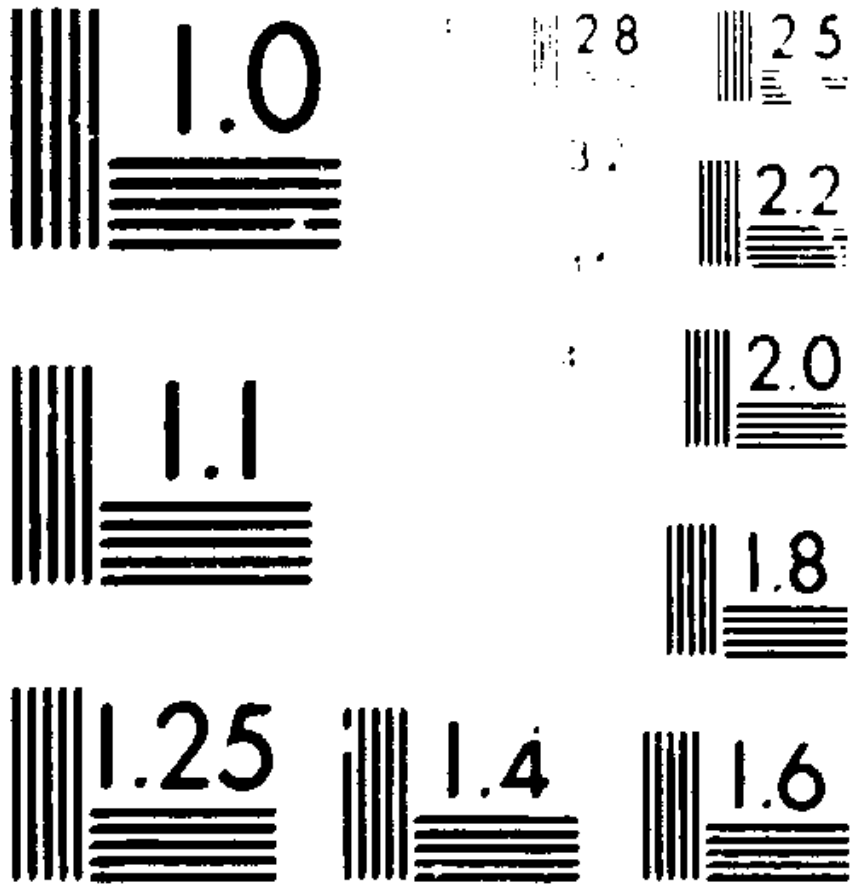
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PLASTICS WASTE AND ITS RECOVERY*

by

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Over hundred years have passed since the father of the plastics industry , the American John.W. Hyatt , developed the first plastics and only seventy-five years ago a real industrial growth was going to start with the inventions of Leo Baekeland(Belgian) in the field of phenol formaldehyde resins .

Initially the growth of the plastics industry was very slow and it was the post WWII period that made plastics popular . Its development was extremely explosive since plastics became cheap raw materials with a big range of flexible properties and high adaptability to low-cost manufacturing techniques.

But plastics industry is actually going too well . From several sides it has been approached as a material responsible for the damage to our environment . To a large extend the attitude of environmentalists towards plastics is unjustified and is a result of the failure of the plastics industry to develop proper communication channels with a public of non specialists .

When plastics are attacked as non-ecological materials , almost every time it refers to the non-destructive, not reclaimable , diseaseproducing or in general to the throw-away attitude of these materials. All this attacks have to be considered as not defendable since the amount of plastics waste is very, very few in regard to other traditional materials . For the USA it is about 2-3 % of the total amount of solid waste what means about 6 % in volume . And think, that whenever we replace plastic dishes or plastic bottles by stainless steel dishes or glass bottles, we only substitute by liquid waste !

It should also be remembered that very large proportions of waste generated by plastics industry is recycled directly in plant . Only a small amount is disposed or is without recovery value .
The rise of energy and materials costs , government regulations and norms , environmental awareness and consumer pressure groups, have changed a lot in the mentality versus waste . Not only industry became very interested , also the scientifical community did a lot of applied research . New separation and processing technologies became available and the recovery of energy and chemicals out of plastics become more and more widespread .
My objective in this lecture is to give a review of the actual state of art in the field of plastics recycling .

Plastics waste or plastics ore !

What are we doing actually with our wastes ? Most of the pure industrial waste is recycled in-plant , the rests(generally mixed waste not able , as we think , to be recycled) are dumped or have been burned or buried in landfill , since the economics of complex mixed waste separation have not been right . Since a few years this mixed waste can be handled by special municipal or private waste treatment factories .
It became clear that the problem is the rests. To make these rests profitable several ways are actually proposed and currently working in several countries .

What are in the context of the available methods (see annex I) the alternative technologies for polymer reuse and what is likely to be their status in the next decennium .
Before answering this, let us stipulate some characteristics of polymer waste.

A first distinction has to be made whether the waste is refused after production, manufacturing or consumption .

I. Industrial plastics waste

Industrial plastics waste is plastics waste generated by various industrial sectors or all products and materials that the producers or processors cannot directly or indirectly valorize. Resin scrap , injection cores etc.. are generally recycled without difficulty in-plant, by passing them back into the processing machines. Care is taken not to pollute them, and if mixed or polluted with other material,they end on the rubbish dump or in plastics reclaim firms .
Where possible, with the help of modern technologies and if the amount is sufficient, hydrolysis and pyrolysis techniques can convert the waste into monomers and/of recover the energy produced during the incineration . So, the cycle is complete but costly and a maximum material utilisation has been achieved. Rests can also end together with the urban waste in a recycling factory where they after selection among other wastes , can be reused into special designed applications.

II. Postconsumer plastics waste

Postconsumer plastics waste or commercial waste is plastics waste generated by consumers and from the various circuits of distribution (pallets, sacs, packaging , etc.) .
Certain commercial waste can be more or less easily sorted and separated in well defined polymer families (PE covers used to wrap merchandise, household, PVC bottles etc.) Even without selective collection of household refuse, complete physical methods such as floatation, magnetizing , ballastic sorting makes it possible to separate plastics from other products .
In general, the commercial waste is less pure than manufacturing spoilage but suitable for floor coverings, pipes not subjected to stresses etc. Industrial and pilot scale experiments are conducted everywhere but we have to take in consideration the following economical aspects : price of collection, transport, sorting and washing, regularity of supply, homogeneity of the waste etc.

A special type of post consumer plastics waste is urban waste, which contains plastics waste of industrial and commercial origin = all waste products resulting from the consumption of household and collected by town services .
Here we have mainly plastics which cannot be sorted economically either because they are made of plastics materials diverse in nature or because they are spoilage materials in which plastics is only part of a complex (shoes, coated fabric etc.) .
Without considering their mechanical properties, there are certain processes which make it possible to obtain products. These valorization methods of waste products are only possible if large quantities are available and there are outlets for finished products. There is a condition however, involving regeneration and transportation costs before and after transformation, which should be economically feasible .

Note that a considerable amount of data is available regarding postconsumer plastics waste , very little is known about industrial waste . In the USA one estimates that the volume of industrial plastics waste is approx. 3 millions tons in 1980. This amount will triple by the year 2000.
From the total plastics production in the USA (15.10^6 T) about 4.7 % is recycled by reprocessors and over 8% is recycled in plant . Since there is currently a trend towards the development of scrapless plastics processing equipment, resulting in the decreasing generation of industrial waste, assumption of the estimated waste amount is only a very rough estimation . (annex II)

The technologies enabling the reinsertaion of recuperated products in an industrial cycle are :
... recuperation by recycling the raw materials + saving of energy input
... recuperation by recycling by saving the energy content of the materials .

The proposed technologies to fulfill these aims are : reuse of plastics products, recycling of plastics materials, regeneration of chemical products and recuperation of energy .

Reuse

The reuse of a material consists in using the object it constitutes again as such , after cleaning if necessary, without submitting it to a modification of form . The deposit packaging is a classic example together with bottle cases, pallets, jugs, tyres etc.

The plastics bottle on the other hand is a typically wasted packaging, rarely reused, which eliminates having to resort, to use polluting operations such as washing, rinsing and transport . Since each new plastic bottle is intact and sterile , when filled all risks of microbian contaminators or chemical contamination are avoided for the user . In France it is prohibited to reuse plastics bottles for mineral water , for an identical use and it can seem preferable to extend this rule to other food industry packaging . On the other hand, there is no reason why recipients for other purposes cannot be reused .

Recycling

The main problem in plastics recycling is that we have to treat mixtures of different polymer families .

For the recycling of pure non-polluted industrial wastes (such as waste generated by the resin manufacturer, the fabricator, the converter) most manufacturers have already in-plant recycling methods utilizing special adapted cutting devices, mixers and extruders . But what with the mixtures such as they are generated by compounders , packagers, assemblers, distributors, consumers(= urban waste) . Separation of miscellaneous polymeric families is nearly utopic. Nevertheless some companies (Japanese) have developed methods to separate them by means of density, air flows, electro-static methods and hysteresis effects .

In most of the literature on plastics waste, the terminology of primary, secondary, tertiary and quarternary recycling is used .

PRIMARY RECYCLING

Primary recycling involves using uniform, uncontaminated plastics waste to manufacture plastics products . Only thermoplastics waste can be directly reprocessed : it can be used alone or , more often added to virgin resin at various ratios .Primary recycling can be performed by the processor in plant or through reprocessors.

The main technical problems are :

. degradation of the material due to repeated processing
. contamination
. handling of low-bulk density scrap
. degradtion of mechanical performances

The industrial practice of primary recycling is based on size reduction techniques done by various type of granulators, , cryogenic grinding , plastcompactors (CONDUX) etc.

SECONDARY RECYCLING

Secondary recycling utilizes plastics waste unsuitable for direct reprocessing through standard equipments . Despite the big publicity on this topic , still a lot of work is to be done . The main reasons for this slow development are :

. waste plastics tend to be contaminated
. most of the plastics are mutually incompatible
. a feedstock with a consistent & reproducible composition is not always available
. the economical viability is dangerous
. mass production is not possible actually

The waste received in secondary recycling factories can be classified in four ways :

* postconsumer waste recovered from municipal refuse
* postconsumer waste obtained from returnable packages
* industrial waste consisting of a single type or mixed

(see annex III)

With the steady increase in resin prices economics for recovering, most of the scrap materials are becoming more favorable and new reclaim technologies for each of these scrap materials (PET bottles, PP battery cases, ABS, urban waste ... etc) are evolving.

Since many years metallurgists and specialists in material science have been looking for new alloys and in the same context new ways have been developed for the reutilisation of plastics waste into composite materials . Since plastics waste is an ore with a high content of raw material (metalores are exploited at a content of mineral of less than 1%) reclaiming becomes economical .

We know that most of the polymers are not inter-compatible and do not show adherance between them after plasticising.By mixing them, a more or less heterogeneous product is obtained which is far from capable of offering the qualities found in the separate components .

Most plastics cannot be separated from impurities without a certain inconvenience using fusion as with metals . This is due to the fact that any thermal processing entails varying degrees of polymer degradation . The impurities - paper, labels, glue, textile, food etc - alter sometimes the qualities of the recycled product but they operate also as a filler, a reinforcement, they act also as a good method of compensating viscosity differences, since they act as an aid to homogenisation .

Regeneration therefore leads to a level of quality being obtained which is all the more acceptable as the raw materials can be sorted , separated, washed etc.

The essential factor in the recycling of mixed polymers is an efficient method of homogenizing the mixture. Two generations of plastics technologies have been brought up on the idea that PVC, PE, PS are mutually incompatible . So, new technologies transforming such mixtures in acceptable alloys with consistent and predictable properties came as something of a shock and arouses considerable scepticism . Now several machines are on the market .

An example

The essential characteristic of the FN machine, is that it shal subject the mixture for a very short period to a high rate of shear at high temperature . Short residence time is necessary to prevent decomposition of less stable polymers and high shear rate is necessary to get intensive mixture at a viscosity much lower than that of the normal plastic melt. The machine is working under constant viscosity since the different polymers in the mixture have different melting points.
The energy absorption in the mixture is proportional to the viscosity for each material and an autoregulation of the viscosity is inherent to the process. In order to keep the process in a good thermodynamic balance no heat is introduced from outside to regulate the temperature in the material . The machine is composed of a very short screw (4-5 D) that never contains liquid material and has only transportation and pressure build up functions .
The screw end is acting as a shear element, that melts in a very short time the material by inner friction. Between the two elements a thermal barrier prevent the heat to pass from the shearing zone to the transport and pressure zone . (see illustrations through slides and samples)

TERTIARY RECYCLING

Tertiary recycling or chemicals out of plastics waste .There is a solution possible to recuperate the chemical components of plastics waste, but it is delicate to handle and the economics of the system are not so evident .
The solution consist in considering the plastic portion of waste as crude oil, heating it to high temperature in a vacuum for example and recuperate the products of decomposition. These products are hydrocarbons which are partially usable in the chemical industry and partly hydrocarbons with no chemical value but which can be used as combustible to heat the pyrolysis kiln .
In fact two methods are used :
§ pyrolysis : it is the physical and chemical decomposition of organic materials caused by heating in an oxygen-free or oxygin deficient atmosphere.
Test are being conducted all over the world with difficulties to be overcome as follows :
. necessity to operate with large quantities in order to be profitable
. separation of gaseous mixtures is even complexer than those obtained by oil cracking .

The advantages that are claimed are :

. urban waste can be converted economically (?)
. reduction of volume by over 90 %
. no air pollution through pyrolysis (?)
. since the plant is quasi not polluting atmosphere and require a small space , units can be settled in cities(transport is lower)
. the process is a net energy producer
. the produced energy is in a convenient form
. valuable chemicals can be recovered
. little oxidation takes place during pyrolysis so that metals can be recovered.

In the future pyrolysis techniques could be extented to all urban waste and thereby enable the recuperation of a wide variety of chemical products and slag which can be valorized.

§ Chemical decomposition of plastics waste by hydrolysis , glycosis or other processes

Decomposition of plastics waste by chemical means has certain advantages over pyrolysis . The decomposition products are more uniform, control is easier, , lower capital investment and even small plants can work economically.

Although it is possible to decompose many polymers , the main interest today is in polyurethanes .

QUARTERNARY RECYCLING

Quarternary recycling or the recuperation of energy out of waste .

Energy recovery from municipal solid refuse can take the following routes :

- burning the waste in steam generated incinerators
- burning the refuse in heat exchangers
- pyrolysis
- Hydrogenation
- Anaerobic Digestion

At the present time, incineration is the most advanced waste energy utilized technology .

Incineration is only defendable if energy recuperation is considered . This technology is for the moment widely used in Europe for urban waste and some industrial waste such as tyres.

Outside of plastics (5000-9000 kcal/kg of 180-320MJ/kg) , urban refuse has a calorific power of 1500-2000kcal/kf or 54-72 MJ/kg. This contribution of plastics is important since it not only facilitates combustion but its energy can be recovered in the form of hot water (for urban heating systems, green houses) or in the form of electricity (one kg of plastics being equivalent under these conditions to 0.65 kg of fuel).

The production of one kg plastics consumes a total of 1,8 to 2,5 kg of fuel equivalent , so it can be considered that nearly 30% of this fuel can be recovered during incineration with energy recuperation .

It should be noted however, that the processing units with recuperation in the form of hot water or electricity are only profitable in the present state of technique when applied to urban centers of more than 100.000 inhabitants with a waste production of min 1 kg/day/inhabitant .

Conclusion

There exist for the moment a general trend to try and valorize plastics waste, however the variety of methods proposed demonstrates that the problem is complex .

Regeneration in which the product is recuperated in the form of high polymer, gains ground.It imposes not only the requirement of the processing not degrading the material but that of obtaining as pure as possible a product with acceptable qualities . In addition the costs of collecting , sorting , washing etc. as well as the discomforts implied by these operations must all be accurataly evaluated .

Generally we ascertain that a lot of recycling probleme can be solved easely and that recycling techniques can be much more improved if at their origing the products are better conceived and in such a way, that the recuperation becomes a child's play .

This objective can be made clear by the expression :
" Design for conservation" . To apply this concept many criteria can be taksn into account :

. economical use of raw materials
. life time and adapted (functional) use of products
. relationship between resource recycling and the environment
. the PPP principle (The polluter's pay principle) have to be considered
. the necessity to discover the limitations of a closed system
. consider correlations between waste recovery and free competition
. optimum efficiency of materials and energy

In spite of our endeavours in technical research and development, there is no way to escape the problem illustrated by the proverb " nothing comes of nothing ". Technology only provides us with ways of changing the physical form of materials. Accordingly , we can depend only upon our good sense as human beings.

My proposals for recycling plastics wastes are as outlined above . Hereafter I would like to introduce to you some slides and practical examples and once again express my sinc hope for the future development and recommendations of this congress . I hope that this meeting will be profitable to each of us from a world-wide viewpoint .

It comes clear that the problem is on the wastes . To make these wastes profitable , several ways are actually proposed and currently working in industrialised countries .

LANDFILLING : landfilling or dumping is in most countries the dominating method (70% in Belgium), largely under uncontrolled conditions.The present situation is that existing dumping sites will soon be fully utilised and that new suitable sites are difficult to find, due to ground conditions and ground deterioration,formation of gases, leaching water treatment, groundmovements, odours etc. after dumping.

COMPOSTING : Composting is the break down of refuse by micro organisms. Only suitable for organic materials attackable by such organisms. Equal parts of refuse and sewage are composted but it is difficult to find a demand for the final product .

INCINERATION: A large proportion of refuse is incinerated predominantly in major population centres where the energy content of the refuse is high (2.600 kcal/kg in Belgium).The equipment is subjected to difficult working conditions which involve high maintainance costs and a short time between overhauls.Due to the strict demands of authorities ,concerning the emission of solid and gaseous polluants,this form of treatment will be obliged to face growing operating costs . This methods permits to reduce the waste 80-85% and part of the residue can be used in road construction for example .But is it really necessary to burn all that valuable material in which we have put so many energy in producing it ?

RECOVERY : From the national economy aspect,recovery of materials from waste is profitable to society, since it reduces handling costs and conserves the resources. But it is also profitable to the individual since lower handling costs are reflected in the municipal taxes.In addition , significant energy savings can be made by separation methods of the materials , the volume of waste is reduced , recycling and new usability of various materials are some important considerations of the recovery process.

PYROLYSIS : Pyrolysis is one of the emerging alternative technologies , which although still in its infancy , is expected to occupy a major position in the field of waste treatment practice.Pyrolysis is literally a breakdown of the basic molecular structure of the material brought about by the action of heat -anaerobic or aerobic conditions- the chemical species arising from the degeneration forming the main pyrolysis products (char, gas & liquid organics). The process is still costly and in exploration.

Other methods such as Hydrolysis ,Refuse-Derived-Fuel , Compacting technologies a.o. are for the moment developed within research programs .

TABLE 1 Plastics Waste Generated by Resin Producer (USA)

Resin	% Waste plastics[a] NP	% Waste plastics[a] SP	Estimated amount of waste plastics (U.S.) (million tons)[b] NP 1978	NP 1980	NP 2000	SP 1978	SP 1980	SP 2000
PE	0.9	2.5	0.054	0.078	0.240	0.150	0.220	0.680
PP	2.2	4.0	0.035	0.059	0.275	0.064	0.110	0.500
PS	0.9	5.0	0.026	0.035	0.111	0.146	0.195	0.620
PVC	3.0	7.0	0.093	0.120	0.889	0.217	0.280	0.508
Total	1.5	4.0	0.208	0.292	1.515	0.577	0.805	2.308

TABLE 2. Plastics Waste Generated by Fabricator in Selected Processes (Commodity Resins Only) U.S.A.

NP(Nuisance plastics) not reprocessable
SP(Scrap plastics) reprocessable)

Process	% Commodity[b] resins affected	% Waste plastics[a] NP	% Waste plastics[a] SP	Estimated amount of waste plastics[b] (U.S.) (million tons) NP 1978	NP 1980	NP 2000	SP 1978	SP 1980	SP 2000
Blow molding	8.9	1.4	3.0	0.020	0.024	0.081	0.042	0.052	0.172
Injection molding	25.7	2.0	10.0	0.080	0.100	0.332	0.410	0.496	1.660
Extrusion (film and sheet)	17.0	1.1	2.0	0.030	0.036	0.121	0.054	0.066	0.022
Extrusion coating	3.3	6.0	0.5	0.020	0.038	0.128	0.003	0.003	0.011
Extrusion (wire and cable)	6.5	5.2	3.0	0.054	0.065	0.218	0.031	0.038	0.126
Extrusion (profile and pipe)	10.3	2.2	3.0	0.036	0.044	0.146	0.049	0.060	0.200
Coextrusion	0.8	9.9	0.0	0.012	0.014	0.047	0.000	0.000	0.000
Calendering	5.0	1.0	2.0	0.008	0.010	0.032	0.016	0.019	0.065
Rotomolding	6.7	3.3	1.0	0.035	0.043	0.143	0.011	0.013	0.043
Total	84.2	2.4	4.7	0.277	0.331	1.248	0.605	0.747	2.299

TABLE Plastics Waste Generated by Converter in Selected Processes (Commodity Resins Only) U.S.A.

Operation	% Commodity[b] resins affected	% Waste plastics NP[a]	% Waste plastics SP[b]	Estimated amount of waste plastics (U.S.) (million tons)[b] NP 1978	NP 1980	NP 2000	SP 1978	SP 1980	SP 2000
Decorating 3-D products	5.6	0.3	0.3	0.003	0.004	0.122	0.003	0.004	0.012
Decorating film	6.7	4.0	2.0	0.043	0.052	0.175	0.022	0.026	0.089
Sealing bags	12.3	3.9	2.0	0.076	0.091	0.309	0.039	0.047	0.158
Cutting	8.5	10.0	10.0	0.135	0.162	0.548	0.135	0.162	0.548
Thermoforming	7.0	3.0	6.0	0.033	0.040	0.134	0.017	0.020	0.069
Total	40.1	4.8	5.0	0.290	0.348	1.288	0.216	0.259	0.876

a J. MILGROM " Incentives for recycling and reuse of plastics " report N) EPA SW 41C 72 Arthur D. Little Inc; Cambridge (MASS) 1972 .

b Estimations of J. Leidner - Ontario Research Foundation , Canada .

ANNEX III ref. Plastics waste by J.LEIDNER
ed. Marcel Dekker , 1981 New York.

Industrial Plastics Waste Consisting of a Single Type of Plastic. Usually plastic waste is too contaminated with nonplastic materials or too degraded to be used in primary recycling.

Since the products of secondary recycling are competing with other low-cost products (such as timber), secondary recycling has been developed primarily in countries where the competitive products are relatively expensive. Presently, Japan is probably the leader in secondary recycling technology, followed closely by the countries of Western Europe. Various technical approaches to secondary recycling are possible, including:

1. Reprocessing using slightly modified standard plastics processing equipment. This has the advantage of a ready availability of equipment but the disadvantages of frequent production problems and poor product properties.
2. Reprocessing using specialized processing equipment. The advantages are fast production rates and a product with reasonable mechanical properties, while a common disadvantage is high capital cost.
3. Chemical modification of mixed plastics waste. The advantage is a product with good mechanical properties; the disadvantage is that material costs are increased without solving the processing problems.
4. Use of plastic waste in combination with virgin plastic (i.e. as a core in sandwich structure). This has the advantage that good products can be manufactured at low material cost, and the disadvantage that only certain types of relatively uncontaminated plastic waste can be used.
5. Use of plastic waste filler in other plastic or nonplastic materials. This has an advantage in that waste material is used to extend a more expensive material and a disadvantage in that the applications and types of potential products are limited.
6. Use of plastic waste as a matrix in combination with low-cost filler. The advantage is that plastic waste acts only as a binder, the mechanical properties being contributed mainly by the filler. There is a disadvantage in that the applications and types of potential products are limited.

Out of the six approaches just listed, only numbers 2, reprocessing using specialized equipment, 4, the use of plastics waste as a core in sandwich structures, and 5, the use of pulverized wastes as fillers in plastics, have been commercialized.