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Rubber Recycling*

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Summary

The report summarizes the present situation on elastomer recycling with emphasis on tires. In the introduction it outlines the differences to other polymers and gives a global breakdown of present scrap tire volumes. It then specifies the various areas and possibilities of recycling, viz., reduction, reuse (retreading), rubber crumb manufacture and use, reclaim, recover, i.e. pyrolysis, hydrogenation and conversion to energy. Finally, landfills and biodegradation are touched on.

1. Introduction

Conventional rubbers (elastomers) are usually crosslinked materials. In that respect, they are comparable to thermosets. In some literature references, they are referred to as "thermoset rubbers" which is a contradictio in se since the essential difference between the two is that rubbers have their working/application range *above* T_G with the consequence that glass transition temperature must be as *low* as possible, <O°C, whereas thermosets are always used *below* their T_G and so, rather *high* glass transition temperatures are a prerequisite for them.

Rubbers are often subjected to dynamic forces, in compression or extension; this fosters aging and thus requires special compounding ingredients to keep it at minimum. Moreover, in order to obtain optimum properties which may vary between high elasticity and damping, a number of additives (fillers, fibers) constitute a significant part of the recipe. Often organic polymer content (natural and synthetic rubbers) is not more than 50% of the ingredients. However, one should keep in mind that overall in plastics, additives add up to ca. 25% [1].

Batchwise mixing of 10-20 different and largely incompatible components requires high energy, *i.e.* heavy machinery and affords high temperatures in order to lower viscosity and avoid excessive mixing times. Likewise, processing, *i.e.* shaping is energy-intensive due to high viscosities. Finally, crosslinking which frequently is synonymous to vulcanization (*viz.* if done in presence of accelerators and sulfur) has to be conducted discontinuously in molds for many applications..

Since ca. 30 years, competition to these classical rubbers has arisen from thermoplastic elastomers (TPE). Here, crosslinks/fix points in the matrix are composed of heterogeneities, *i.e.* disperse phases of high T_G; often they are covalently bonded on

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both sides to an elastic backbone with low T_G. They can, however, also be based on blends of various heterogeneous polymers. TPEs have cum grano salis a processing behavior akin to normal plastics and so they show great advantages over classical rubbers, not only in their ease of shaping, but also as regards recycling: Since their crosslinking sites are of physical rather than of chemical nature and depend only on the position of T_G (which must not be too high for processing restricions and elastic chain stability) there are certain limitations in the usefulness of this class of polymers. Such disadvantages can be: Lower wear due to lower filler content, enhanced swelling/solubility due to physical cohesion only, larger stress relaxation due to phase slippage; this, incidentally, also occurs with ionic/salt type crosslinking in so called ionomers as long as they are elastomeric.

2. General considerations

The topic is not at all new - recycling of elastomers has been an industrial research theme during the '60s when the Club of Rome had pointed to the limited availability of resources, and it was aggrevated 10 years later during the first oil crisis. There was a literature survey by the ACS Rubber Division in 1972 [2] and there are at least 2 review articles from 1974 [3, 4] which essentially characterize the situation as it still exists today (with a single exception, *v.i.*, section 4.4.3). There is an excellent more recent review [5] summarizing our present state of technology, confirming this.

In general, the situation has paralleled that of plastics - perhaps with the exception that over the years academic research has never picked up the topic to a substantial extent, most probably because a) in most aspects it is below scientific standards and b) there is the popular believe that it is up to the producer to care for the scrap he creates.

3. Volume, compostion

Elastomers comprise *ca.* 15-20% of world-wide plastics consumption, *i.e.* 15 mio t/a at present. There are *ca.* 35% natural rubber (NR) and 65% synthetics (SR), a distribution which has been rather constant over the last 10 years. The present TPE-share is at 5%, but is projected to grow at a faster pace than the other rubbers in view of their superior processing behavior and easier recyclability.

Fig. 1 shows a distribution of synthetic rubbers in their areas of utilization [6]. The share of elastomers in car weight is *ca.* 5%, tires excluded. [7]. This is further broken down for elastomer applications in a passenger car, Fig. 2, [8], showing that tires with 60-70% of total consumption greatly alter the distribution (for abbreviations, *cf.* [6]). As they are also the largest single, conspicuous, eye-catching item found in the environment, they will be in the center of this report. Likewise it is only too natural that the cry for recycling rubber has focussed on one of the most ingenious, but also complicated elastomeric articles [9]. Their overall composition can be given as shown in Table 1A. If one looks for the calculated elemental distribution, it can be broken down as in Table 1B.

There are differences to plastics [10] in that for tires both carbon and nitrogen contents are lower, sulfur is higher and the C/H-ratio is quite different (6.8 *vs.* 12.2); this means that by comparison tires (and many elastomeric articles) are closer to coal

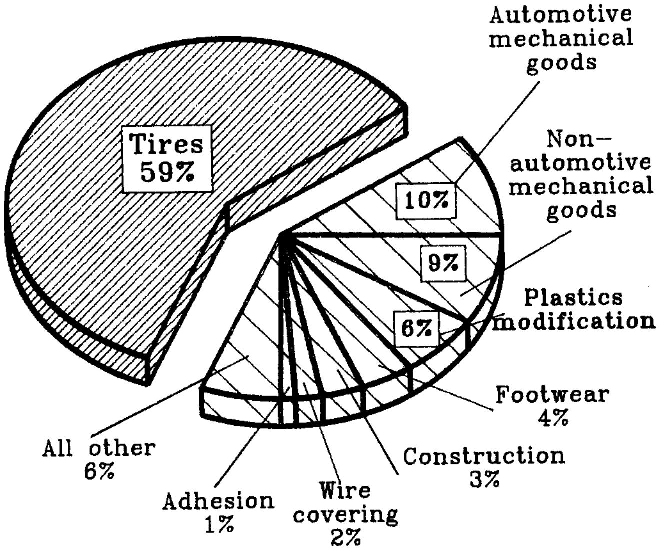

Fig. 1. Global synthetic rubber use [6]. Total 1990 consumption: 7.1 mio t
(Source: IISRP, C&EN, May 31, 1991)

in their caloric behavior whereas plastics by nature resemble hydrocarbons (oils). Obviously, this difference is due to the high filler, *i.e.* carbon black content in tires. In addition, it may be noted that the halogen content is very low as compared to overall plastics waste.

As a consequence of their importance, statistical data for scrap tires are available in many countries. One can estimate that the total figure for the western world (excluding Russia and China) amounts to *ca.* 10 mio t/a of tires at present. Table 2 [5, 9, 11-13] shows a split-up for few major consumer countries and todays situation concerning their disposal. This will be the topic of the report., together with possible routes for solutions. The EC-projection for the year 2000 is shown in Fig. 3 [9].

4. Types and possibilities of rubber recycling

Basically it has been recognized that the same priority scheme must be applied for elastomers as for plastics, *i.e.*,

*reduce
*reuse
*recycle
*recover (energy)
*landfill

maintaining the ladder principle, adopted by the EC [9] from the EPA [5, 11, 14].

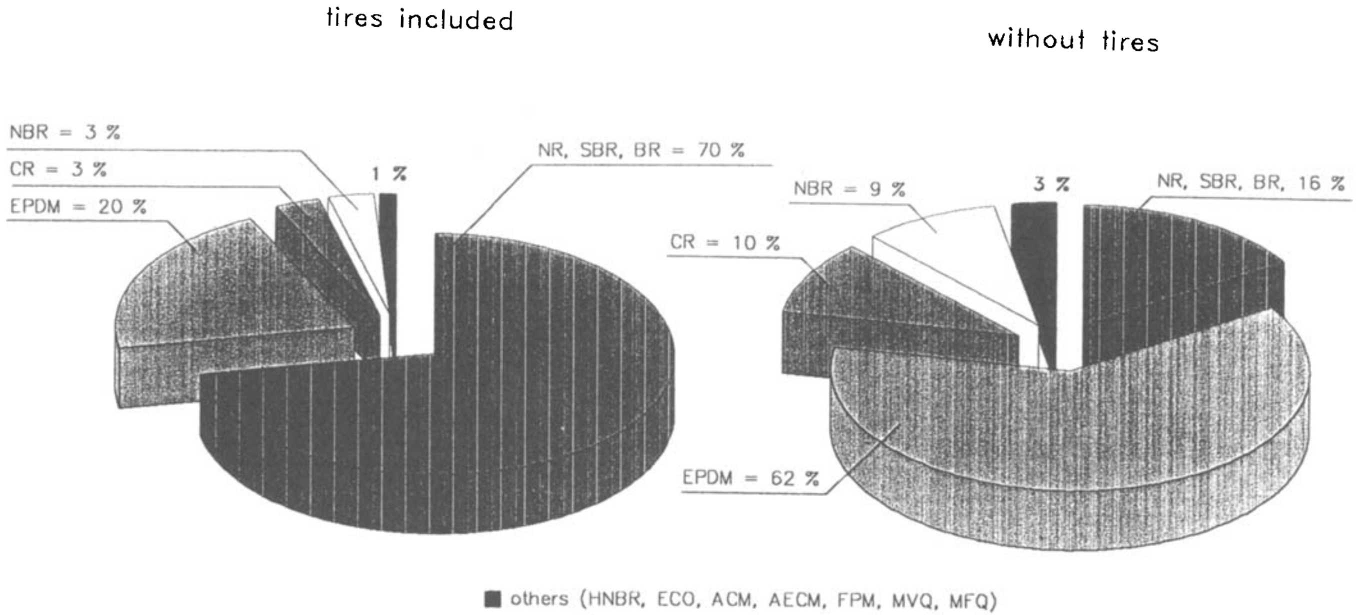

Fig. 2. Fraction of elastomers in Type 3 BMW [8]

TABLE 1. COMPOSITION OF TIRES (wt-%)

A. Materials	
Natural Rubber (NR)	23
Synthetic Rubber (SR)	24
Carbon black	25
Steel cord	14
Textile cord	4
Others	10

B. Elemental		Tires	Plastics
Carbon	C	73.0	65.0
Hydrogen	H	6.0	9.5
Oxygen	O	4.0	6.5
Nitrogen	N	1.4	2.5
Sulfur	S	1.3	.1
Chlorine	Cl	.07	5.9
Zink	Zn	1.5	
Iron	Fe	13.5	
Ash			10.5

Table 2. USED TIRES IN SELECTED AREAS

Area	Year	10^3 t	Disposal (%)							Lit.
			thermal	crumb	reclaim	retread	export	landfill	unknown	
USA	1992	2800	23	6	4		3	63	1	5
Japan	1992	840	43		12	9	25	8	3	11
Germany	1993	550	38	14	1	18	18	2	9	13
UK	1992	450	9	6		18		67		12
EC	1990	1975	30	20				50		9

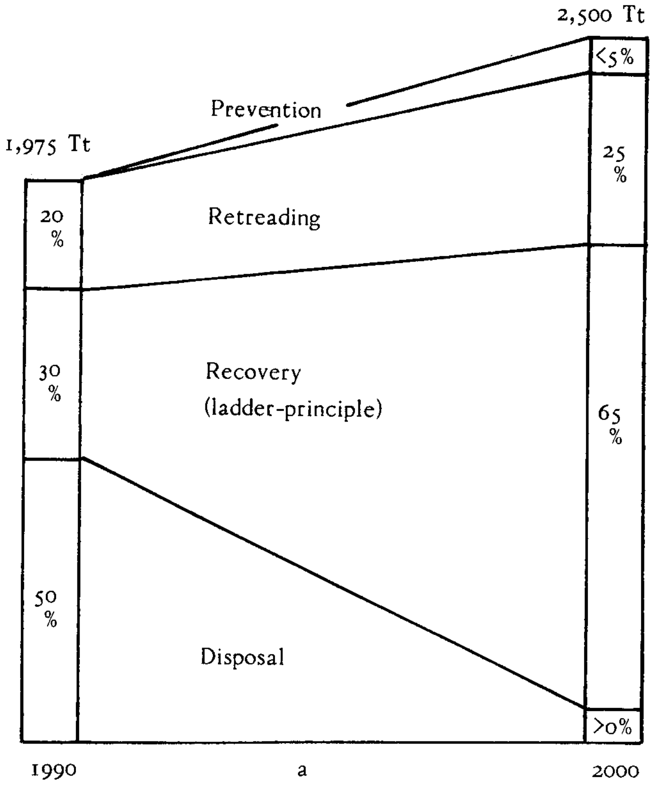

Fig. 3. Estimate of the amount of used tires disposed of in the EC in 1990 and final target to be achieved in 2000 [9]

4.1 Reduce

4.1.1. Production

As long as no crosslinking has taken place, the situation in a first approximation can again be compared to plastics - with additional complexities, *e.g.*:

a) problems of size reduction; in many cases, however, comminution is not required since off-spec compounds can be fed back into the last mixing step as rubber sheet in preweighed proportion or they can be cofed onto the pre-warm mixing mill or into the extruder as a small strip.

b) prefabricated composite structures like rubber sheets, coextrudates, calendered rubber/fabric complexes; their proportion augments with the degree of automatization.

Nevertheless, it is quite obvious that most of the production scrap unergoes rework processes. As an example, there are world-wide targets in Japanese tire companies to keep it <1% - figures unthinkable 10 years ago. - As for vulcanized scrap, *cf.* the following sections 4.2.

4.1.2. Products

Here, the target is reduction of products that could enter the waste line. The European Commission states targets (5% life extension of tires), *cf.* Table 3 [9]. With the advent of the steel-braced tire during the '60s and '70s, their mileage has almost doubled *vs.* the old cross-ply type (at the expense of comfort). There are great efforts now to reduce rolling resistance of tires by material improvements and by constructional measures for reduced weight (which intrinsically does not extend tire life, but it lowers vehicle energy demand, *i.e.* fuel consumption). It should be mentioned in passing that the energy consumption for making a tire has also been reduced by over 40% during the last 20 years.

TABLE 3

PRELIMINARY EC-RECOMMENDATIONS FOR SCRAP TIRES

EUROPEAN COMMISSION DG XI

General Directorate Environment, Nuclear Safety and
Catastophy Protection, Brussels

Proposals of the working party for the recommendation
of the commission as of 1993
on the prevention, utilization and disposal of scrap tires.

Summarized general targets:

1.1 Prevention	* 5% reduction of new tires' production through extended life cycle * Genuine maintenance of tires to be fostered by better instruction and enlightment of the drivers * Information and facilities for measuring tire pressure to be improved * Research into road surface improvements to minimize tire wear at equal safety and noise considerations
1.2 Collection	* In the year 2000, collection of almost 100% of scrap tires
1.3 Recapping	* to be increased to at least 25% of old tires in the year 2000
1.4 Utilization	* at least 65% of old tires in the year 2000 on top of retreading * Study utilization of large size old tires * Promote competition between retreaded and new tires (in original homologation?) * Incorporate scrap tires in asphalt roads * Provide legal frame and facilitate permissions for incineration of those scrap tires that cannot be used in other ways
1.5 Disposal	* Elimination of deposition or burning without energy conversion until 2000. Bicycle and large size tires (> 1.40m) are exempted from these targets

4.2. Reuse (Retreading of tires)

Looking at the cross-section of a new tire, Fig. 4, the largest single component is its tread and it is this part which is more or less severely worn-off during its life. Retreading therefore is an old topic and there exist established markets around the world for such products. In Germany, there are now shares of 12% for car and 48% for truck retreading with a total of *ca.* 10 000 t/a [13, 15].

The incentive for utilizing retread car tires is in inverse proportion to engine power and speed rating of the vehicle; it is clear that retreaded tires should only be mounted on low-speed rated cars (S-, T-range) [16]. There must be an age-restriction for the acceptance of worn tires (*e.g.* 6 years) and it goes without saying that careful inspection is required prior to start buffing and afterwards during the process. The EC-target here is for 25% in the year 2000, Table 3.

In addition it must be envisaged that lower weight or longer running tires (due to less annual mileage) are becoming less suitable for retreading operations [6]. There are, however, attempts to homologate retreaded winter tires as original equipment in Germany. Finally, there is competition pricewise for these lower cost sizes through cheap new tire imports. In countries with raw materials shortages and low-powered cars like the former East Germany a considerably higher car tire retread rate than mentioned above can be found, *viz.* 40% [17].

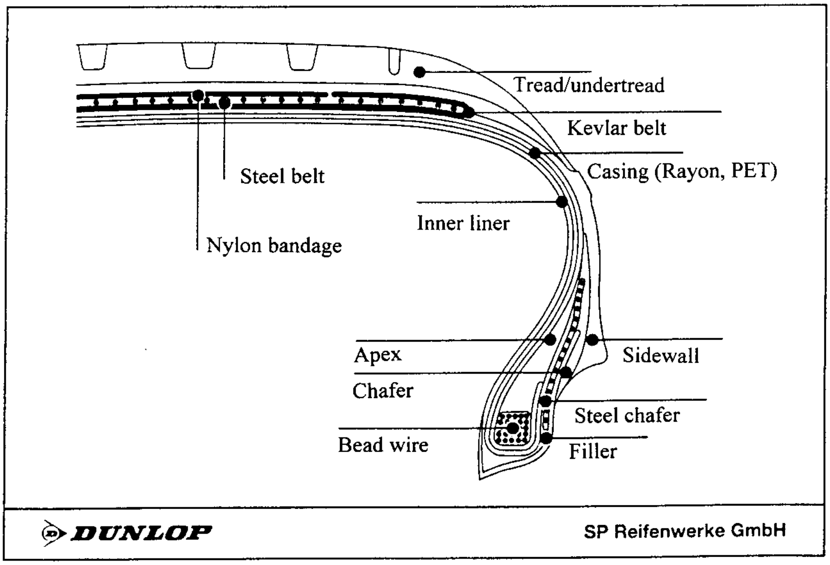

Fig. 4. Cross-section of a radial car tire

Life-time and mileage expectations for truck tires have also been tremendously increased over the years; nevertheless, retreading is rather high as seen from the above figure, in particular for rear twin or double axle tires where the safety aspect of a blow-out is less important. This also holds for aircraft tires which in view of their severe wear characterisitcs in short time are known to be retreadable for >10 times. - It might be added that although retreading extends the lifetime of a tire, it will eventually have to be scrapped and thus ends up in the waste cycle.

There are limited chances of utilization for whole or damaged tires as, *e.g.* on playgrounds, in agricultural covering, as fenders or road wall screens. Claims for their usefulness as fish farms and tire reefs are maintained [4, 5].

4.3. Recycling

4.3.1. Rubber crumb

Manufacture. It is obvious that size reduction is a must for reutilization of a crosslinked material since it cannot be reshaped. Cutting of elastomers even if they are isotropic presents problems and this is aggrevated for fiber/steelcord reinforced articles. Nevertheless, for producing rubber powder there are well-established techniques available and one can distinguish between

a) dry
b) wet (in presence of water)
c) cryogenic (with liquid nitrogen)

grinding. In case of the first 2 processes, *i.e.* at ambient temperature, sieving is required; nevertheless, a broader particle size distribution is obtained than in case of process c). However, the latter powder has a smoother, less active surface structure and a narrower size distribution which can have disadvantages for reuse [18]. Although there are always claims that *now* cryogenic grinding has become economic with approaching a wt.-ratio of 1/2 for N_2/rubber [15, 19] it appears to be the more expensive process [20].

A specific preparation has been described for heavy steel reinforced conveyor belts: removal of the wire by electrical resistance heating with consecutive cryogenic elastomer grinding and reincorporation into new compounds [21]. - An unusual and certainly not economic proposal is the preparation of crumb from whole waste rubber goods swollen in toluene; lower energy requirements are claimed [22].

For many years one has tried to incorporate rubber powders thus made into genuine articles [3, 4], but as a rule of thumb one loses 1% of a property/1% of crumb addition [5, 23], *i.e.* one moves along the cascade of property deterioration. It is obvious that there is a correlation to crumb size and there are recent claims for ultrafine powders made by ambient grinding (>80 mesh, <0.2 mm diameter) that provide for minimal property losses and viscosity increases up to 25 phr addition [24]. However, fineness/higher surface area must have its price. In addition, there is the question of compatibility, *e.g.* if crumb is prepared from a whole tire containing various compounds including butyl rubber and with hardness differences of 40 Shore A (Fig. 4) is put back into a tread compound. If on the other hand, crumb is made from individual, selected sections alone, the separation process itself is costly (and will only be restricted to the tread because of its volume and ease of separate removal).

Without doubt, high-cost speciality rubbers should be ground up and reused; there are recent claims for fluoro rubber (FKM) powder addition up to 100 phr with considerable compound cost reduction and tolerable property levels [25]; such crumb materials are commercially available [26].

Use. There are many well-known proposals for elastification of plastics by rubber crumb, the most prominent ones being PU sports grounds, floor mats, railroad crosssings *etc.* [4, 27], but it seems that the market can reach saturation here and it does not help repeating these as valuable outlets.

Then there is the old topic of rubber/tire crumb in roads with the target of elastifying and quieting the surface. Starting with concrete, this has been attempted with natural rubber (latex) addition around the beginning of the century [4]; for crumb, there is the advantage of no temperature stress on the elastic particle, but the disadvantage of complete incompatibility. It is just the other way for asphalt: there, one must ask what elastomeric property level is retained by the rubber crumb when maintainig it in the asphalt matrix heated at 175°C for 10 or 20 h. This important question has rarely been investigated, but it has been found recently that aging as a result of storage at elevated temperatures can affect performance of polymer-modified asphalts dramatically [28, 29]. Again, there are wet (pre-swelling in asphalt binder), dry and some other process variations [27]. It might be considered significant that rubber has been described to prevent coalescence of asphalt in case of addition of other plastics waste [30].

Since nowhere in the world the technique has gained large scale momentum, the US-government decided to make it going by law and since 1990, ISTEA (Intermodal Surface Transportation Act) has been around, demanding an increasing proportion of tire crumb in US federal highways and, according to schedule, culminating in 1997 with 20% [31]. However, the law did not pass US-congress and there may still be "a long road for rubberized asphalt" [32]; in spite of possible cost and viscosity increases there are claims for reduced cracking and detoriation, greater impermeability to water and better lifetime. The project seems to have been severely eroded after odors of burning rubber from tire chips smoldering underneath the surface have been reported [33]

There have been some other propositions for utilization of rubber powders [4], none of them reaching even semi-commercial stages, *e.g.* for ion-exchange material [34] where the question of leaching of ingredients has not been investigated.

4.3.2. Reclaim

In theory, bonding energies between C-C and C-S are different [35], but in reality there is no practical reversibility of S-vulcanization without attacking the main chain. Nevertheless, one has tried to activate the surface of rubber crumb for revulcanization by thermal and chemical degradation [26]; the product, reclaim, was once widely used in the rubber industry, *e.g.* in 1941, 32% of virgin NR consumption was reclaim [25]. In those days each tire factory had its own reclaim station. This has gone down to *ca.* 1% in Germany [36], *cf.* Table 2, and in other countries, due to cost consideration and environmental problems (*i.a.* smell). In those compounding areas where reclaim had been incorporated (*e.g.* carcass), technical disadvantages by omitting it were not of paramount importance although they existed [14].

In place of classical reclamation, special surface treatments of ground rubber have been recommended. A more recent approach uses (liquid?) polymers together with accelerators for surface compatibilization (Surcrum) and claims better property retainment at high loadings (>25 phr) [36]. Continuous production of rubber sheets has been reported [37]. The question of mono-materials ("sortenrein"), *e.g.* NR-crumb for NR-compounds of the same formulation has to be sorted out as in other cases.

In another process (De-Link), 7 phr of a masterbatch containing an undisclosed miracle chemical are mixed with rubber crumb on a mill or in an internal mixer, yielding a continuous sheet with slightly inferior properties in less than 10 min [38]. Unfortunately it has become very quiet on this enterprise during the last year. - A further approach by ultrasonic treatment with undisclosed temperature levels has been described for rubber crumb devulcanization in a laboratory extruding equipment affording properties of tire reclaim [39].

Proposals claim modifications by Cl_2- [25] or other propriatory reactive gases [40] to render a polar active surface in the hope of converting such crumb to a high-value-added filler. - Another recommended surface agent is TOR (trans polyoctenamer); it can be used in low concentrations (<5%) for various rubber compounds containing crumb to reduce loss of static and dynamic properties [41, 42]. - Finally, surface devulcanization by biological attack has been claimed, *cf.* section 4.5.

4.4. Recover

Here all thermal processes will be summarized; the discussion and some of the possibilities again are similar to the plastics scene.

4.4.1. Pyrolysis

It is quite clear that one cannot expect to recover hydrocarbon monomers or even oligomers from the complex rubber structures by pyrolysis. If a formulation contains 30% of carbon black or white filler plus other inorganic material, one must expect reduced yields anyway. In addition, there can be the size reduction neccessity for articles like tires or hose in order to facilitate heat transfer, *e.g.* by fluid bed energy.

Although many laboratory, pilot-plant and even commercial attempts have been made to establish economical units over the last 25 years [43] (*e.g.* Kobe Steel in Japan, Tosco in USA, Tyrolysis in UK, Ebenhausen in Germany and many more) none has survived. The product spectrum is well-known [44]; there are variations by vacuum or in presence of H_2, N_2 [45] or in molten salts like $NaAlCl_4$ [46]. Texaco had opened an experimental "liquifaction unit" for a mild cracking process below 370°C at atmospheric pressure resulting in light and heavy oil fractions [47]. Vacuum pyrolysis of ground up crossply tires yields a plasticizer oil that can be applied as extender for SBR [48].

In spite of claims to the contrary [49], it has been shown that the carbon black coming out of the reactor is of poor quality and has nothing in common with those types used in the recipes [45]. This might have been anticipated since a) there are different types of carbon black in different compounds and b) their sensitive surface structure is already changed by mixing, not to speak of pyrolysis.

4.4.2 Hydrogenation

Hydrogenation of coal is a well-known process (Bergius) to synthesize gasoline and oils. In Germany, a unit at Bottrop existing from the oil crisis which has been modified to accept oil refinery residues was charged in a 50 t trial partly with comminuted rubber crumb (5-20%). Conditions are 450 °C and *ca.* 300 bar H_2-pressure; a catalytic effect with yield increases of crude oil was observed [15, 50]. The plant is now fully booked for the recovery of plastics packaging waste.

In the US, experiments to coprocess tire material together with coal under similar conditions [51] have shown

- also large yield increases (with FeS-catalyst)
- conversion of ZnO to ZnS
- trace metals of coal are deposited preferentially in residue and can easier be removed

One should note that on the one side, rubber is more akin to hydrocarbons from its polymer composition and so it could be considered better compatible with oil residue in hydrogenation; on the other hand, there is also similarity to coal due to the 30% of carbon black in many compounds, *cf.* Table 1.

4.4.3. Conversion to energy

Although tire fires are terrible, long lasting accidents difficult to extinguish [52], ignition of rubber is not facile. Nevertheless, it is clear that elastomeric compositions possess high energy contents, comparable to those of other combustibles (*ca.* 33 MJ/kg [4, 5, 15]). Thus, instead of employing great efforts to break down the polymer structure into only partly useful substances (which may serve as fuel eventually) it has been recognized that direct utilization of the inherent energy content of complex rubber articles at the end of their life cycle should be the ultimate answer to the waste problem specifically when they contain textile or steel cord fibers. There are 3 possible routes:

- Mono-rubber energy plants (tires-to-energy)
- Cofiring with other waste
- Cement kilns

It should be noted in passing that recent trends towards a "green" tire with reduced rolling resistance [53] replace a larger part of the carbon black by incombustible silica, thus reducing the energy content of tire treads considerably.

Mono-rubber energy plants. The prototype for this is an incineration unit working for more than 20 years successfully in Germany (Gummi-Mayer) with a capacity of 40 t/d and emission levels below those required by German law [54-56]. With this technology (Fechter), larger power stations have been constructed in the US at Modesto, Cal. and Sterling, Conn. with a total nameplate capacity of 30 000 tires/d (*ca.* 270 t/d) [5]. Of even larger size (*ca.* 370 t/d) were plants (Elm) in England [12, 57] and there were other enterprises around the world under construction [58], Germany being sluggish due to environmental concerns [14]. The temperature range achieved is around 1250 °C. It must be said that many of them are no longer in operation [59, 60].

Microwave heating keeps to be mentioned [4, 59, 60]; it can reach much higher temperatures, around 2000 °C, but apparently it has never come to work in practical terms.

Cofiring. This version makes use of tires as partial feed together with other fuel sources; there are various boiler types and in some cases, cofiring of tires has given impressive improvements in emission reduction. [5]. Rather than starting from scratch, modification of existing power stations to adopt whole tires or sections of larger truck tires (>1.5 m diameter) appears a logical solution. Additionally, the wide-spread distribution of scrap tires can be easier matched by corresponding available power station facilities.

A speciality is incineration with O_2, a technique well-known from metal refining with advantages in

*high temperature levels (>2000 °C)
*composition of unwanted volatiles (reduced NO_x, no organics left)
*metals bound to slag [61]

An architecturally quite stylish approach to this technique has been realized in a Swiss-Italian pilot plant (Thermoselect) with a preconnected low temperature pyrolysis/de-gassing unit. Technical details are somewhat hard to come by. It is supposed to accept 45% of organic waste in combination with household refuse. For that reason there are various municipal projects underway in Germany.

Cement kilns. As far as logistics are concerned, similar arguments as in the previous section apply for burning tires in cement kilns. Here, trials commenced with excellent success in Germany during the first oil crisis (in those days the cement company paid for the scrap tire!), so that it constituted an established process in 1980 [62, 63]. *Ca.* 20% of the primary energy (coal, lignite, oil) can be substituted by whole tires at the end of the rotary kiln; there is complete and slow degradation up to 2000 °C [15]. The steel is converted to iron oxides and S ends up as gypsum - both components of cement clinker [5]. Although there are legal problems of definition for "secondary" energy sources in Germany [14, 15], this type of recycling is a viable one - worldwide at the moment [5, 11].

4.4.4. Landfills

Clearly this is the most unwanted and no-future possibility. In the past, one has often justified mono-deposits of scrap rubber with

a) their environmental friendliness due to low/non-existing effluent content from leaching and
b) the possibility to store them until a potent solution for reuse crops up.

With the deceasing number of available sites and the corresponding cost explosion, cf. Fig. 5, [27] this is no longer valid and projections are consequently not bright, as also shown in Fig. 3.

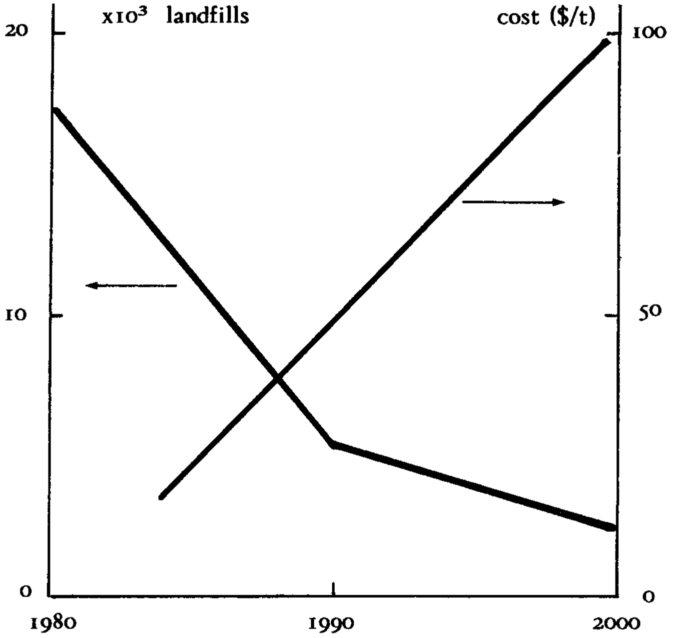

Fig. 5. Number of landfills and average landfill cost in USA [27]

4.5. Biodegradation

Keeping in mind that biological attack to NR-latex is quite facile [4], one has tried time and again to consider elastomeric articles as source for microbial attack [3]. Obviously, nature is able to take care of its own waste problems, but as soon as man becomes involved and converts the polymer NR into (high) tech materials by sulfur and numerous other ingredients, biological attack is minimized [64]. One could consider this fortunate since otherwise all the questions concerning the ecological fate of thousands of scission products would come up again; they were on the table when rubber crumb had been recommended as fertilizer [4].

Notwithstanding there has been an intersting recent approach. It claims [65, 66] to utilize a chemolithotrope bacterium in aqueous suspension for attacking powdered elastomers on the surface only, so that afterwards in mixing with virgin rubber, diffusion of soluble polmer chains is facilitated and bonding during vulcanization becomes again possible.

5. Conclusions

This report attempts to cover present aspects of elastomer recycling possibilities. Obviously many of them resemble routes of proposals for plastics, but with some diversification. The situation and the possibilities for plastics has been extensively treated [67]. Many processes have been attempted to be realized in the past without commercial success and thus one has to be suspicious to not encounter into a reinvention of the wheel. Above all, commercial and price changes could readily alter the scene, but one has to always keep in mind that all recycling techniques involving comminution bear a heavy cost penalty [5]. Consequently, clean conversion to energy should be progressed at the present time and in the near future. It is the logical answer, considering the fact that polymers have had a first life as useful materials made from fossile resources of which 90% are used for direct energy conversion *without* going through this intelligent step [61]. It appears as if even the political pressure [68] is slowly decreasing [59], for a number of reasons.

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Abbreviations: ERJ = European Rubber J.
KGK = Kautsch. Gummi Kunstst.
RCT = Rubber Chem.Techn.

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