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CONFIDENTIAL

TECHNICAL AND ECONOMICAL SURVEY OF RUBBER WASTE RECOVERY IN THE EUROPEAN ECONOMIC COMMUNITY

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A B S T R A C T

On the request of the C.R.E.S.T. Committee (Scientific and Technical Research Committee) of the E.E.C., a technical and economical survey of rubber waste recovery processes has been carried out, by B.R.G.M. (Bureau de Recherches Géologiques et Minières) in France, as the pilot (EEC contract 273-76-9 ECIF) with the agreement of D.E.M.P. (Délégation aux Economies de Matières Premières) and by KRITNO (Kunststoffen en rubber Institut TNO) in Holland, as the copilot (EEC contract 274-76-9 ECIN).

KRITNO has carried out a survey of literature and studied processes for recycling used tires in the rubber industry (retreading and reclaiming) ; B.R.G.M. studied all other processes to reuse scrap tires (pyrolysis, incineration, road and sportground surfacing, reefs building, water pollution control, and so on ...) and size reduction (traditionnal shredding and cryogenic grinding).

The report gathers technical and economical data on studied processes and a specific conclusion has been set out for each class of processes. It also contains a synthesis of information collected during a symposium on used tires disposal in june 1977 in Washington (U.S.A.) by Mr. GELUS (Compiègne University, France), on the request of B.R.G.M.

Four classes of recommendations in decreasing order of priority have been set out in the conclusion :

1. Retreading and size reduction are recommended fields for financial assistance regarding research and development.

2. Incentives for research and development are also recommended for some aspects of reclaiming, road surfacing, pyrolysis and fight against pollution.

3. Some fields are of interest but do not obviously need public help to research : incineration with heat recovery, playground surfacing, artificial reefs building.

4. Further research do not seem to justified on protein synthesis and agricultural uses.

Statistical and economical studies on production and collection of used tires are also recommended.

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RESUME

A la demande du comité C.R.E.S.T. (Comité de la Recherche Scientifique et Technique) de la C.E.E., une étude technique et économique des procédés de récupération des déchets de caoutchouc, a été réalisée, par le B.R.G.M. (Bureau de Recherches Géologiques et Minières) en France comme pilote (contrat CEE 273-76-9-ECIF) avec l'agrément de la D.E.M.P. (Délégation aux Economies de Matières Premières) et par le KRITNO (Kunststoffen en rubber institut TNO) aux Pays-Bas comme copilote (contrat CEE 274-76-9-ECIN).

Le KRITNO a fait une synthèse bibliographique et a étudié les procédés de recyclage des vieux pneus dans l'industrie caoutchoutière (rechappage et régénération) ; le BRGM a étudié tous les autres procédés de récupération (pyrolyse, incinération, recouvrement de routes et de terrains de jeux, récifs artificiels, lutte contre la pollution ... etc) et la fragmentation (dilacération classique et broyage cryogénique).

Le rapport rassemble les données techniques et économiques sur les procédés étudiés et des conclusions spécifiques sur chaque classe de procédés. Il contient également une synthèse des informations recueillies au cours d'un symposium sur l'élimintation des vieux pneus à Washington en juin 1977, par M. GELUS (Université de Compiègne, France) à la demande du B.R.G.M.

Quatre groupes de recommandations par ordre de priorité décroissante se dégagent dans la conclusion :

1. Deux domaines prioritaires pour l'aide publique sont le rechappage et la fragmentation.

2. Une aide à la recherche et au développement est aussi recommandée pour certains aspects de la régénération, la couverture des routes, la pyrolyse et la lutte contre la pollution.

3. Quelques domaines présentent un intérêt certain mais ne requièrent pas nécessairement d'aide à la recherche des pouvoirs publics : incinération avec récupération d'énergie, couverture d'aires de jeux, récifs artificiels.

4. Les recherches ne semblent pas mériter d'être poursuivie sur la synthèse des protéines et l'usage agricole.

Aucun jugement n'a pu être porté sur les autres procédés mentionnés.

Des études statistiques et économiques sur la production et la collecte de vieux papiers sont également recommandées.

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TECHNICAL AND ECONOMICAL SURVEY OF RUBBER WASTE RECOVERY IN THE EUROPEAN ECONOMIC COMMUNITY

GENERAL CONTENTS

PART 1. :

CONCLUSIONS AND RECOMMENDATIONS

PART 1.

CONCLUSIONS AND RECOMMENDATIONS

CONTENTS

PART 1. : CONCLUSIONS AND RECOMMENDATIONS

Each chapter in parts three to five include specific conclusions in which a judgement on the processes concerned is set out, and in which our recommendations on research programs required to develop the process are explained with some details. Moreover, information to compare processes which belong to the same class are also included in chapter 4.2, 4.3 and 5.3.

However, it is useful to briefly summarize and compare these specific conclusions here.

Table 1 gives a short comparison of the classes of processes according to induced raw materials savings, potential market, economics and obvious advantages and disadvantages.

Table 2 summarizes our recommendations on a research and development policy at EEC level, and very rough evaluations of time and cost needed for these research programmes.

CLASS OF PROCESSES	POTENTIAL RAW MATERIALS SAVINGS	POTENTIAL MARKET	ECONOMICS	ADVANTAGES	DISADVANTAGES OR BARRIERS TO DEVELOPMENT
RETREADING	Optimal retreading replaces 64,000 ton of new car tyres (rubber, chemicals, energy, steel wiring, etc...)	large	EUA 23,000,000 annual savings in total or EUA 350 per ton of additionally converted waste.	real recycling : mileage retreaded car tyre = mileage new tyre.	image of retreaded car tyre and marketing need improvement.
RECLAIMING	Optimal reclaiming saves 75,000 ton of waste, replacing raw materials. (raw rubber chemicals)	large	EUA 25,5000,000 annual savings in total or EUA 355 per ton of additionally converted waste.	improves rubber processing - replaces raw rubber in rubber articles.	image of reclaim and marketing need improvment.
PYROLYSIS	Energy (solid and liquid fuel) <u>or</u> compounds perhaps suitable for rubber industry.	unknown as market do not well defined.	good if use of products in rubber industry or similar is possible.	obvious if real recycling of char residue is possible.	market to be found.
INCINERATION	Energy.	large	very good if no new investment is needed ; medium in other cases	immediately possible and saves some fossil fuel.	high investment, low profit and low savings
ROAD SURFACING	Stone <u>or</u> bitumen (according to choosen process).	large	promising <u>for bitumen substitution</u> since generating long life surfacing.	high potential profit by making a good quality surfacing.	unknown for bitumen substitution. Technical and economical barriers for stone substitution.
SPORT GROUND SURFACING		about 50 000 t/year in EEC ?	very good	safety, confort, profit	
ARTIFICIAL REEFS BUILDING	Increase of available sea food.	unknown.	expensive disposal.	perhaps positive environmental impact.	environmental impact not perfectly known.
ABSORPTION OF POLLUTANTS	Positive environmental impact.	several 10 000 t/year in EEC ?	unknown.	efficiency.	technical research still needed before large scale applicatio[n]
PROTEIN SYNTHESIS	protein ?				difficulties of developing an efficient process.

TABLE 1 : COMPARISON OF THE CLASSES OF RECYCLING PROCESSES

CLASSES OF PROCESSES	RECOMMENDATION ON THE PROMOTION OF FURTHER RESEARCH ON THE PROCESS	JUSTIFICATION OF THE RECOMMENDATION	NATURE OF POSSIBLE RESEARCH	VERY ROUGH EVALUATION OF COST AND TIME REQUIRED FOR RESEARCH PROGRAM	POSSIBLE IMPACT OF RESEARCH PROGRAM ON EEC
RETREADING	First priority recommended.	Retreading is the most direct way of recycling tires. It is the best way to save raw materials and its economic balance is good.	1. Field research about the availability of sound casings in the EEC. 2. Laboratory research of the quality of retread rubber and precured treads in the EEC. 3. Research on quality tests of retreaded tyres.	COST — TIME 1. $ 60,000-$ 120.000 — 1-2 year 2. $ 62.000-$ 70.000 — 1 year 3. $ to be estimated — to be est.	See table 1, materials savings and economics.
SIZE REDUCTION (shredding and grinding)	First priority recommended.	Size reduction is the key of a lot of recycling processes.	1. All research able to decrease cost of grinding. For instance : - use of classical means to cool rubber materials before grinding. - reduction of energy requirement for shredding and grinding. - technological optimisation. 2. Influence of particles shape on their use by various processes. 3. Economical studies about cryogenic grinding.	1. At least 500 000 EUA (European Unit of Account) 2. 20 000 EUA 3. 30 000 EUA 4. to be estimated — to be est.	Improvement of the economics of all processes using ground rubber.
RECLAIMING and recycling of rubber powder in the rubber industry	Recommended.	Keeping alive an already existing recycling industry which uses tires rejected by the retreading industry.	1. Laboratory research on the quality of reclaim (grading system) 2. Laboratory research on the influence of reclaim on existing rubber compounds (and retread comp.). 3. Research on size reduction of steel braced radial car tyres. 4. Laboratory research on the influence of particle size of rubber powder on the mechanical properties of vulcanizates. 5. Research on mixtures of virgin rubber powder and scrap rubber powder. 6. Research on suitable binders in ground scrap.	COST — TIME 1. $ 44.000-$ 60.000 — 1 year 2. $ 60.000-$ 80.000 — 1-2 year 3. $ 60.000-$ 80.000 — 1-2 year 4. $ 52.000-$ 70.000 — 1-2 year 5. $ 70.000-$100.000 — 1-2 year	See table 1, materials savings and economics.
PYROLYSIS	Recommended, but only to investigate char residue market and not to study new processes.	Pyrolysis is only attractive if products can be recycled in part of rubber industry or in other industry with a high value.	Industrial scale experiment of use of pyrolysis char residue by rubber industry or other industry.	500 000 EUA (European Unit of Account) 2 years.	Knowledge of a market to develop pyrolysis as a real recycling process.
INCINERATION WITH HEAT RECOVERY	No research recommended, except perhaps for some experiments of reconversion of old fashioned coal boilers.	Incineration is already industrial but generates small profit and small materials savings, except if an existing old plant can be used.	Help to some projects of incineration of tires by transformation of an obsolete old fashioned grid coal boiler.		Savings of capital and useful reuse of old plants.
ROAD SURFACING	Research recommended to use rubber as a substitute for bitumen, but not to use it as substitute for stone.	Using rubber in bitumen provides longer life to roads and costs savings might be substancial. This is not true for processes in which stone is replaced by rubber.	Detailed examination of the economics in the EEC context. Technical evaluation of SRI process by field tests.	Economics : 6 months 30 000 EUA Technics : 500 000 EUA-1 000 000 EUA	Recycling large amounts of tires and considerably increasing life of roads.
SPORT GROUND SURFACING	Not recommended.	Processes are technically well developed and provide good profit to industry. So, no public research is urgent.			
ARTIFICIAL REEFS BUILDING	Reasonnable but not highly recommended.	The process is feasable, somewhat attractive, but very expensive.	- Improvement of knowledge of environmental impact. - Investigation about the fish productivity of the process, and its improvements.	200 000 EUA 2 or 3 years	Knowledge of a way to make safe and efficient reefs.
ABSORPTION OF POLLUANTS	Reasonnable.	The process seems efficient to fight hydrocarbons pollution in rivers, and perhaps in the sea.	- Economic studies. - Investigation on the way to handle crumb after absorption and to dispose it (incineration...).	200 000 EUA 2 years	Knowledge of a way to use several tens of thousands of tons of tires by fighting pollution. possible energy recovery.
PROTEIN SYNTHESIS	*Not at all recommended.*	Unrealistic process.	*no*	*no*	*no*
AGRICULTURAL USE	Not recommended, but the processes have not been deeply studied during the enquiry.	No positive results until now.			
OTHER	No recommendation.	No sufficient data.			

TABLE 2 : RECOMMENDATIONS ON A RESEARCH AND DEVELOPMENT POLICY AT EEC LEVEL

1.1. FIRST PRIORITY FIELDS.

First priority fields for public help are recommended for :

1.1.1. *Retreading.*

Retreading which is the best way to save raw materials, labour and even energy, and is almost a kind of repairing.

In most EEC countries retreads of truck tyres have a share of about 50 % in the repacement market as these tyres are retreaded 2 or 3 times. In the case of car tyres the situation is different and increased retreading to an optimal condition is possible. In chapter 3, the potential effects of increased car retread production are described and conclusions are given in chapter 3.2. as well as recommendations in chapter 3.3.

In optimal conditions an increase in car tyre retreading from 12,6 % to 22 % of the total tonnage of worn car tyres can be obtained (see chapter 3.2.2.).

1.1.2. *Size reduction.*

It is not a process to reuse scrap tire, but it is the key of many processes of incineration, pyrolysis, road and ground surfacing, reclaiming, absorption of pollutants .. Size reduction is expensive and several ways to decrease its cost should be investigated, a very promising one being perhaps cryogenic grinding without liquid nitrogen.

1.2. OTHER RECOMMENDED FIELDS.

Support of research and development programmes is recommended in other fields :

1.2.1. *Reclaiming.*

Reclaiming is one of the oldest classes of recycling, which will show a revival in times of increasing prices of raw rubber.

The potential effects of increased reclaim production are described in chapter 3, showing that substancial savings can be obtained in raw materials. (see conclusions in 3.2. and recommendations in 3.3.).

In optimal conditions, an increase in reclaim production from 22 % to 37 % of the total tonnage of worn car tyres can be obtained. (see chapter 3.2.2.).

1.2.2. *Road surfacing.*

The only kind of processes which seem promising consists of using ground scrap rubber as a modifier of asphalt properties. This kind of processes provides long life roads and very large savings. The economics should be further investigated and if our conclusion is confirmed, large scale applications must be promoted. On the other hand, it is not recommended now to support research about stone substitution.

1.2.3. *Pyrolysis.*

The main products of pyrolysis are a liquid fuel which looks like fuel oil and a carbonaceous residue (char). The carbonaceous residue can be used a a substitute for coal and probably as a semi-reinforcing charge in low quality rubber products. Unfortunately, it is not suitable for use in the tire industry. As the economics show that pyrolysis is attractive only if char can be recycled in the rubber industry or in other industry as a substitute for a high value raw materials, the only recommended field of research is the promotion of industrial scale tests of pyrolysis products, for instance by financing a production of oil and char, and by helping industrialists in trying to incorporate these products in their production.

1.2.4. *Absorption of pollutants.*

Absorption of polluants, mainly of liquid hydrocarbons in rivers and at sea, is an attractive field. Both economics and technology still need to be investigated. Problems of recovering solid particles after absorption, handling and disposing it for instance by incineration with heat recovery still have to be investigated.

1.3. POTENTIAL RESEARCH FIELDS.

Other fields for research are also reasonnable but not very recommended for public help, for various reasons :

1.3.1. *Incineration with heat recovery.*

Incineration with heat recovery raises no more technical or environmental problems with now available furnaces, but it requires expensive investments and its thermal efficiency is low. It can thus be considered as a short term solution and no public help is recommended except for some experiments which can help to maintain in use existing old fashioned grid coal boilers, which have a suitable design for tire incineration.

1.3.2. *Sports ground and play ground surfacing.*

Lots of processes are included in this class. Most of them are industrially applied and provide high profit. There is no need to help research in this field. The only recommendation is to open this market to recreational area (school yards ...) and some other public points in which safety, or silence might be required.

1.3.3. *Artificial reefs building.*

This might be a useful way to dispose several millions of tires with a positive environmental impact, and so some research in this field can reasonnably be carried out. But, it is an expensive disposal and moreover there are two main risks :

- First, environmental impact is not well enough known and it would be dangerous now to build quickly large reefs in Europe.
- Second, there is a risk that people would just put tires anywhere and anyhow in the sea and call it artificial reefs building.

1.4. NOT RECOMMENDED RESEARCH FIELDS.

There is a last group of fields about which it is actually recommended not to spend any public money.

1.4.1. *Protein synthesis.*

Protein synthesis by microbiological action on scrap tires is not a realistic project. The probability of solving problems related with toxicity and extremely low efficiency is very small and tire is not the suitable material for the research. So no public help is recommended.

1.4.2. *Agricultural use.*

No research is recommended since it does not seem a promising way according to the results of past experiments.

1.5. STATISTICS AND ECONOMICS.

Other recommendations deal with some problems which are out of the scope of this report.

1.5.1. *Statistics.*

Amounts of scrap tires available for recycling industries in EEC are far from being well known. Detailled statistics, as collected in Germany in 1974 should be obtained each year in all EEC countries to know the overall arising of used tyres, and the consumption of retreading, but also the amount of scrap tires used by other reuse industry (agriculture, incineration, sport ground surfacing...). Such figures are really needed to measure the actual importance of the problem and the impact of any governmental policy. It is a difficult task which can be drawn by an organisation such as BLIC.

1.5.2. *Collection and transport.*

The collection and transport of rubber scrap is a general problem in recycling and the resulting costs will remain important factors in the economics of all existing and new recycling processes. A technical, statistical and economical study on collection and transport of rubber scrap is really needed, to know how it would be feasible in practise and what would be its average costs.

PART 2. :

GENERAL REVIEW

PART 2.

GENERAL REVIEW

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PART 2. : GENERAL REVIEW

2.1. INTRODUCTION.

2.1.1. *Frame work and scope of the study.*

The CREST Committee (Scientific and Technical Research Committee) of the EEC has decided, in 1976, to implement a survey of rubber waste recovery technology, research and development, in the EEC and in other countries.

France has been chosen as the pilot country and the Netherlands as the copilot country. In France, B.R.G.M. (Bureau de Recherches Géologiques et Minières) has been chosen by the D.E.M.P. (Délégation aux Economies de Matières Premières) to carry out the study (EEC contract n° 273-76-9 ECIF). In the Netherlands, work has been done by KRITNO (Kunststoffen en rubber institute TNO - EEC contract N° 274-76-9 ECI N).

The study is essentially focused on tire recovery, and does not deal with collecting and gathering tires. Its main objective is to gather technical and economical data about all processes, whatever state of development they have reached, to identify the topics on which complementary research programs would be necessary for a further development of processes, and to set an economic judgment on the usefulness of these research programmes.

The study started in June 1976 and lasted until November 1977.

2.1.2. *Methodology and partition of the work.*

The survey has been planned in such a way that it can schematically be divided in five steps which are representated by the following table :

Step n°	Available material	Action	Output
1	- Governmental organizations. - Technical associations - Available literature.	- Visiting, writing phoning. - Surveying.	- List of companies, laboratories, ... etc involved in the field of rubber waste recycling. - Statistics.
2	- Adresses of companies laboratories, ... etc involved in the field	- Setting and sending a questionnaire with an accompanying letter.	- Answers : (filled questionnaires, letters, complementary literature).
3	- Filled questionnaires - Letters - Literature.	- Analysing these results.	- Hypothesis about research opportunities. - List of definite complementary data to collect. - List of people who can actually help.
4	- List of people who can actually help. - List of definite complementary data to collect.	- Visiting.	- More or less complete information.
5	- Collected information - Statistics (from step n°1).	- Analysing the information on a technical and an economical point of view.	- Classification of the processes - Economical judgment - Recommendations for a research program at Community level.

Partition of the work between KRITNO and B.R.G.M. during step 1 and 2 has been done on a geographic basis, except that literature survey has been carried out by TNO and that B.R.G.M. only supplied it with listings from an automatic search of "chemical abstracts" and french C.N.R.S. (Centre National de Recherche Scientifique). B.R.G.M. has carried out the enquiry in Belgium, France, Germany, Italy, Luxembourg and countries out of EEC (U.S.A., Japan, ...), while TNO was enquiring in Great Britain, Danemark, Ireland, the Netherlands.

Partition of work in the field of information analysis, visiting companies and laboratories, and writing the final report has been done according to the following table.

<table>
<tr><th>TOPIC</th><th>WORK of KRITNO</th><th>WORK of B.R.G.M.</th></tr>
<tr><td>Literature survey</td><td>Redaction of a synthesis report.</td><td>Providing KRITNO with "Chemical abstracts" and "CNRS" listing related to the topic</td></tr>
<tr><td>Study of EEC rubber waste mass flows.</td><td>Providing BRGM with already collected information.</td><td>Redaction of a synthetic chapter.</td></tr>
<tr><td>Retreading</td><td rowspan="2">Visits in EEC countries and redaction of technical and economical chapters.</td><td rowspan="2">Assistance and organisation for visits in France.</td></tr>
<tr><td>Reclaiming</td></tr>
<tr><td>Pyrolysis</td><td rowspan="9"></td><td rowspan="9">Visits in EEC countries and redaction of technical and economical chapters.</td></tr>
<tr><td>Incineration</td></tr>
<tr><td>Road surfacing</td></tr>
<tr><td>Traditional and cryogenic size reduction</td></tr>
<tr><td>Fight against pollution</td></tr>
<tr><td>Artificial reefs building</td></tr>
<tr><td>Protein synthesis</td></tr>
<tr><td>Public works, agriculture and miscellaneous.</td></tr>
<tr><td>CONCLUSION</td><td colspan="2">Redaction</td></tr>
</table>

2.1.3. *Contents of the report.*

The report has been divided in five parts, each part containing one or several chapters. At the end of each chapter is printed, on green pages, the appendix of the chapter. This presentation has been adopted since the report is mainly a juxtaposition of chapters, the form of which is not always homogeneous since they deal with different types of processes, and since some of them have been written by B.R.G.M. and others by TNO.

- *Part one* summarizes conclusions and recommendations on a research policy at the EEC level.
- *Part two*, called "general review" contains statistical information on rubber waste flows and recycling in the EEC, and a detailed survey of the literature made by TNO.
- *Part three* has been completely written by KRITNO and deals with two industrial ways to recycle tires in the industry : retreading and reclaiming. These are technics which have already been used on an industrial basis for tens of years. A summary of the KRITNO study is given in 3.1.
- *Part four* has been written by B.R.G.M. and deals with all other methods to reuse scrap tires and to save various kinds of raw materials : pyrolysis, incineration with heat recovery, road surfacing, sport ground and play ground surfacing, artificial reefs building, absorption of polluants, and other reuses. It has been divided in seven chapters, one per class of processes.
- *Part five* has also been written by B.R.G.M. and provides information and conclusion on size reduction (shredding, grinding, cryogenic grinding, ...). It is not really a way to reuse scrap tires, but size reduction is extremely important as the key of various processes for reclaiming, pyrolysis, incineration, road or sport ground surfacing, absorption of polluants, ...

Parts three, four and five contain in each chapter as detailled as possible technical and economical information and a specific conclusion.

For this purpose, B.R.G.M. has developed a definite methodology which has been as for as possible applied in parts four and five. This methodology is explained in part four, chapter 4.1.

2.2. MAIN FLOWS OF RUBBER MATERIALS IN THE EEC COUNTRIES.

A general view of the materials involved in this study on waste rubber is derived from several sources :

KRITNO survey of literature 121/77,
RAPRA report by G. Cheater c.s.,
De Nederlandse Rubberindustrie 10/76,
Frost and Sullivan Handbook,
Rubber Statistical Bulletin,
and others.

2.2.1. *Consumption of virgin rubbers (raw rubbers).*

In 1975, the world production of rubber amounted to about 10 millions ton, 33 % being natural rubber, from Asia and the balance synthetic rubber produced in the U.S.A. and Europe.

According to figure 1 the main consumption pattern is :

Japan	1 000 000 ton
EEC	2 000 000 ton
U.S.A.	3 000 000 ton

The production of goods in which these amounts are processed can be described as follows :

tyres	65 - 70 %
other transport uses	10 %
shoe soling	8 %
technical articles	15 - 20 %

More than half of the rubber production is required for the manufacture of tyres, that is mainly for the production of treads (about 70 % of the weight of the tyre).

The tread compound is composed of the following materials :

Natural rubber or SBR (or both)	100 parts by weight	50 % by weight
Carbon black	55- 60 parts by weight	30 % by weight
Process oils	20- 30 parts by weight	15 % by weight
Zinc oxide	3 parts by weight	2 % by weight
Others, as sulphur, accelerators anti-oxidants etc...	7 parts by weight	3 % by weight
	185-200 parts by weight	100 % by weight

Composition of tread compound

This means that the tread has a rubber content of 50 % ; truck treads are mainly made from natural rubber and car treads from SBR.

Furthermore the tread contains a considerable amount of carbon black as a reinforcing agent.

NR is a world commodity and market notations are available in Singapore, London and New York. The trend to increasing prices of NR (RSS) is indicated in figure 2.

2.2.2. *Production of rubber compounds.*

A rough estimation of the tonnage of compound produced in the EEC can be made by assuming a rubber content of 40 %. The total tonnage of compound processes is :

$$\frac{2\ 10^6}{0.4} = 5 \text{ millions t/a}$$

2.2.3. *Car populations.*

In figure 3, the population of cars in the different countries is indicated. It is expected that in 1985 the car population in the U.S.A. will reach 150 million units. This would mean a growth of 35 % in the next decade, probably with a trend to smaller cars with more efficient motors.

In the EEC, the car population is expected to grow from 70 million to about 100 million in the next 10 years with a rate of growth of 3,5-4 % per annum.

BRD had in 1975 the highest car population in the EEC of about 17 million units, Italy, England and France follow in with 14 million units on a average and Benelux with about 6 million units.

The production of cars is decreasing in the U.S.A. and EEC but it is expected that the upwards trend is returning soon.

2.2.4. *Production of tyres.*

The production of car tyres shows a decreasing tendency up to 1975 according to the figure 4 as a consequence of the energy crisis. However, U.S.A. figures indicate an upwards trend in the production to 187 million units in 1976.

The production of car tyres in 1975 in the EEC is about 110 million units, France leading with about 34 million units.

Regarding replacement sales of car tyres a smaller rate of growth is expected than in car sales. An increase of about 2,5 % per annum to 1980 is predicted with a slower rate in the period 1980-1985 of 1,5 % (see figure 5 and 6).

2.2.5. *Scrap tyres production in the EEC.*

Waste rubber is composed of used tyres for the greater part as can be noted from the following french data.

Year	Used car and truck tyres	Total rubber waste
1971	320 000 ton	400 000 ton
1975	350 000 ton	480 000 ton
1980	430 000 ton	600 000 ton

Rubber waste in France (Gummi Mayer)

About 70-80 % of the total waste is composed of tyres and in the next pages we will consider mainly this type of waste. The waste in the form of clippings, refuse articles, inner tyres, dumped rubber goods etc... cannot easily be quantified.

An investigation into scrap tyre arisings has been made in England some years ago. According to the report by G. Cheater c.s. the situation in 1974 could be described as follows :

	Cars	Trucks
Total worn tyres	23 467 588 units 159 580 ton	3 394 319 units 135 773 ton
Tyres in vehicle scrap yard	23 %	19 %
Tyres to reclaimers	22 %	0 %
Tyres exported	5 %	7 %
Tyres retreaded	16 % (50 % suitability)	28 % (65 % suitability)
Tyres rejected by retreaders	16 %	15 %
Unknown remainder	18 %	31 %
TOTAL	100 %	100 %

This table reveals that there are 3 sources of scrap tyres, being :

	Cars	Trucks
1. tyres in vehicle scrap yards	23 %	19 %
2. tyres rejected by retreaders	16 %	15 %
3. unknown remainder	18 %	31 %
sub total in %	57 %	65 %
sub total in tonnage	91 000 ton	88 000 ton

Though the number of truck tyres is much lower than that of car tyres the tonnage of waste is about the same.

In figure 3.1. page 108, these percentages are indicated in order to show the english methodology of estimating worn tyre arisings.

It is obvious that the home arisings of worn tyres and the amounts of retreadable tyres cannot be counted easily or roughly estimated. Instead the estimation of worn car tyres is based on the home replacement sales of new tyres and the amount of tyres on wrecked vehicles in scrap yards. Both amounts are often published. This method has been used in the report by G. Cheater and is demonstrated for England in figure 3.1. page 108.

About 7 to 8 % of the car population is scrapped per annum, however it is not known exactly what is happening with the tyres on these vehicles. Probably they are in bad condition for the greater part and not worth to be removed and inspected. According to figure 3.1. page 108, the home arising of used car tyres is mainly caracterized by the home replacement of new tyres and the amount of car tyres on wrecked vehicles in scrap yards. The outcome of the Cheater's method has been used in analogous way to make an estimation of arisings of used car tyres in the EEC.

The results are sketched in figure 7.

From figure 7, it can be seen that in 1980, the EEC will produce a total of about 100 million worn tyres.

Twice this amount is expected in the U.S.A.

Total weight of worn tyres (ton)	338 000	%
Dumped	185 000	55
Retreaded	90 000	27
Reclaimed	20 000	6
Powder	30 000	9
Incineration	7 000	2
Horticulture, reef	6 000	1
Total	338 000	100
Reference publication UHDE 1976		

Disposal of used tyres in BRD 1974

Total weight of worn tyres (ton)		317 900	%
"Dumped"		247 900	78
Retreaded	tourism	6 000	2
	truck	39 000	12
Reclaimed		11 600	4
Powder		11 000	3
others		2 400	1
Total		317 900	100
Reference Ministère de l'Environnement 07/73.			

Disposal of used tyres in France 1971

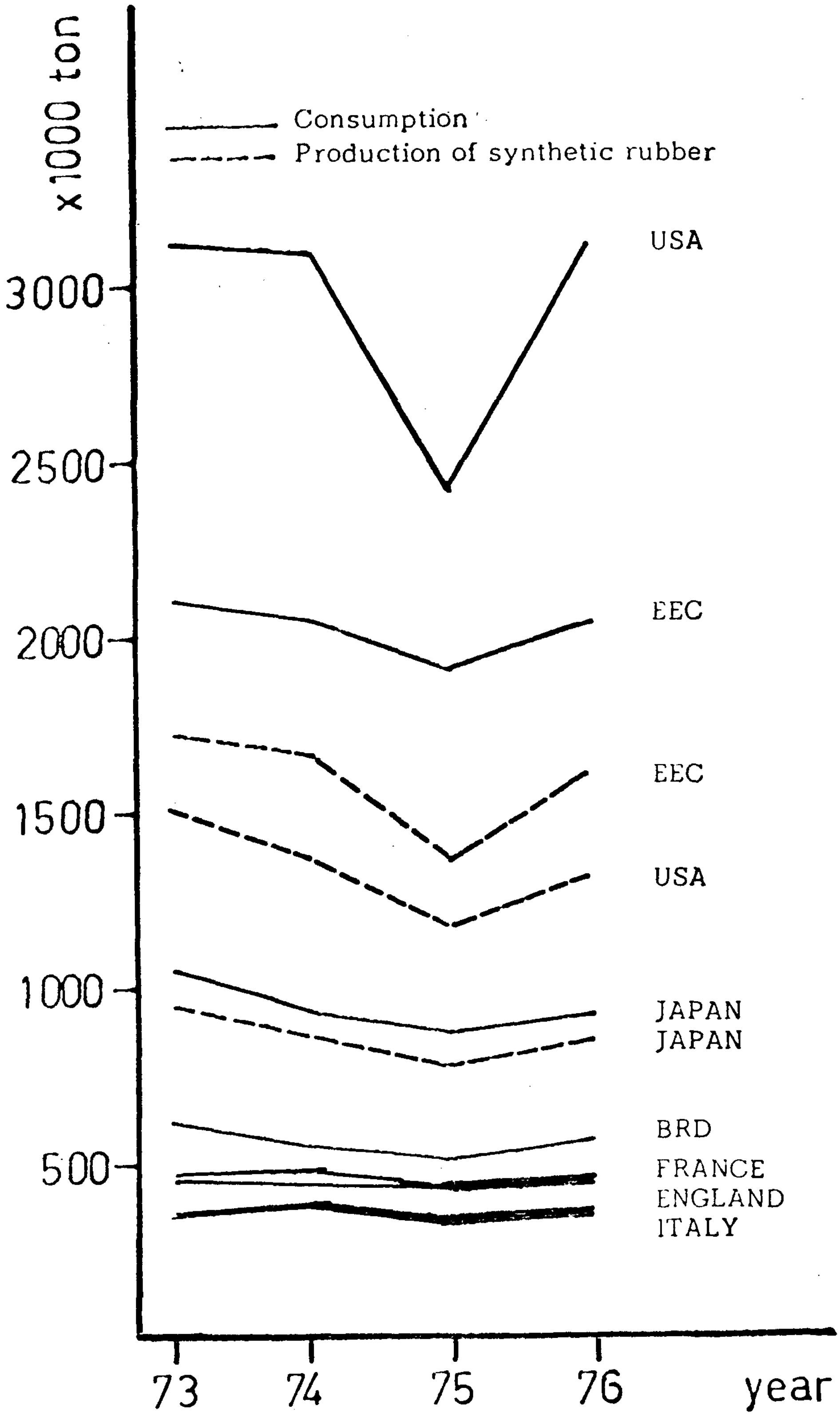

FIGURE 1 : VIRGIN RUBBER

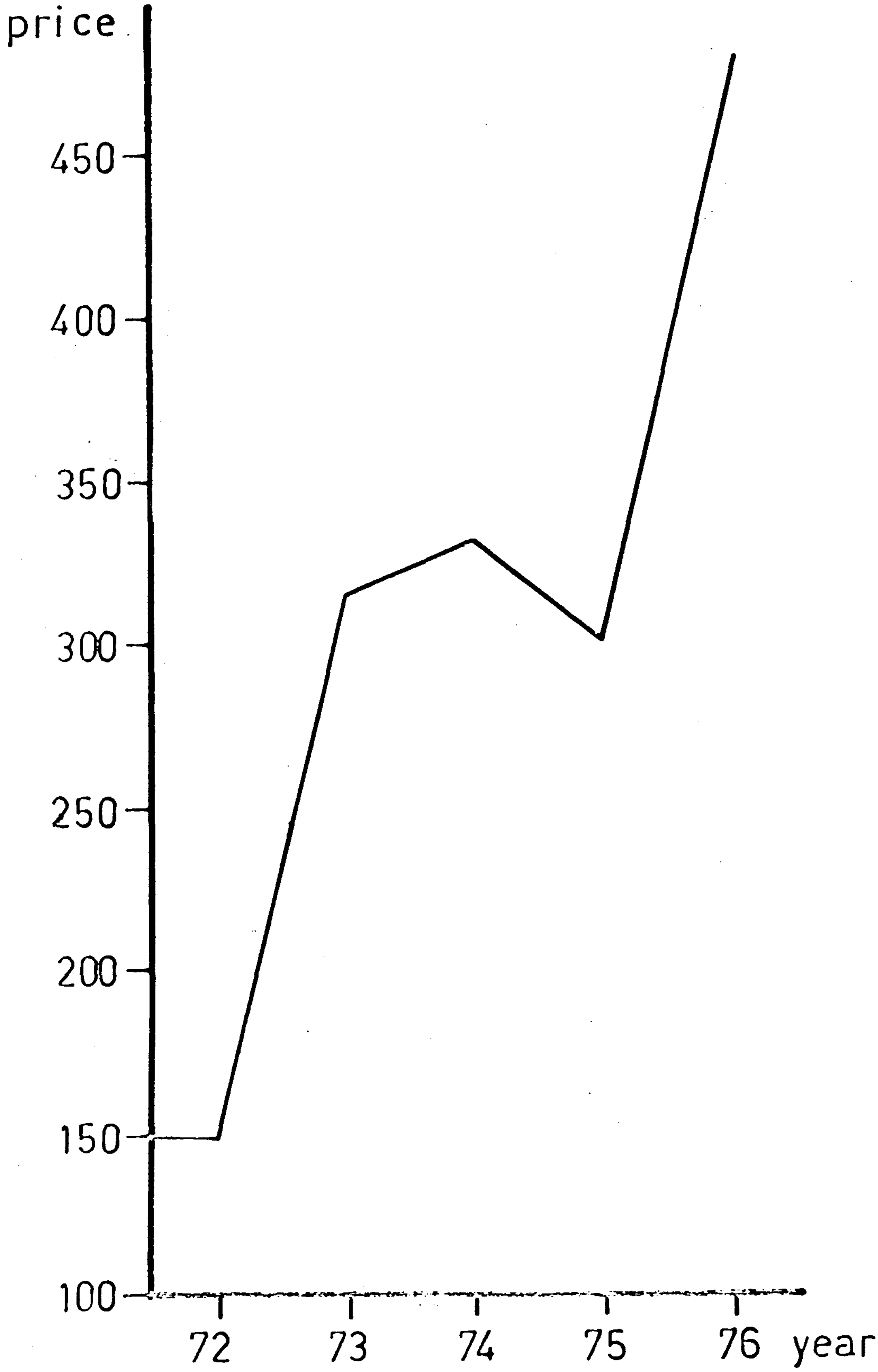

FIGURE 2 : MARKET PRICES OF NATURAL RUBBER (RSS) in Pound Sterling per ton

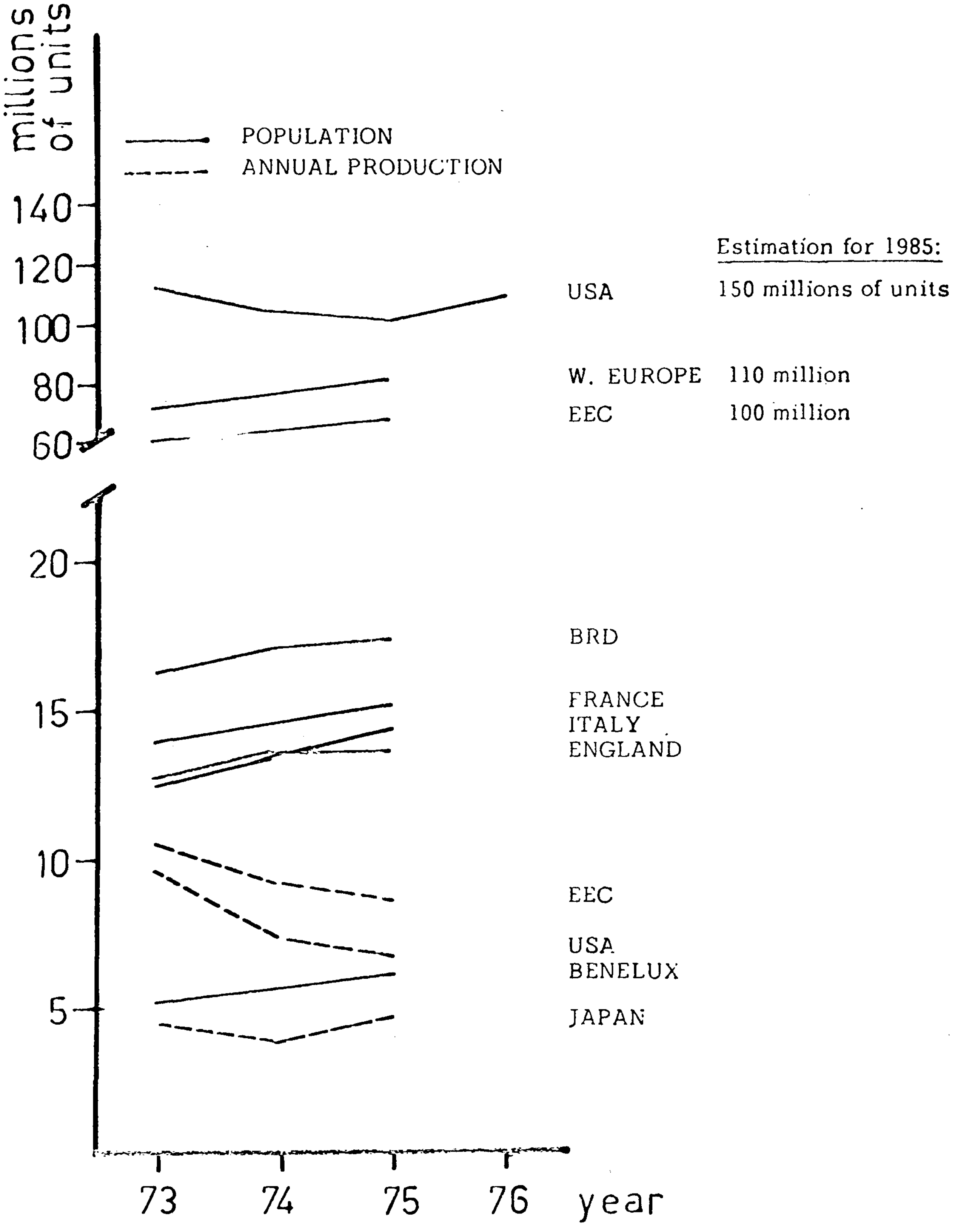

FIGURE 3 : NUMBER OF PASSENGER CARS

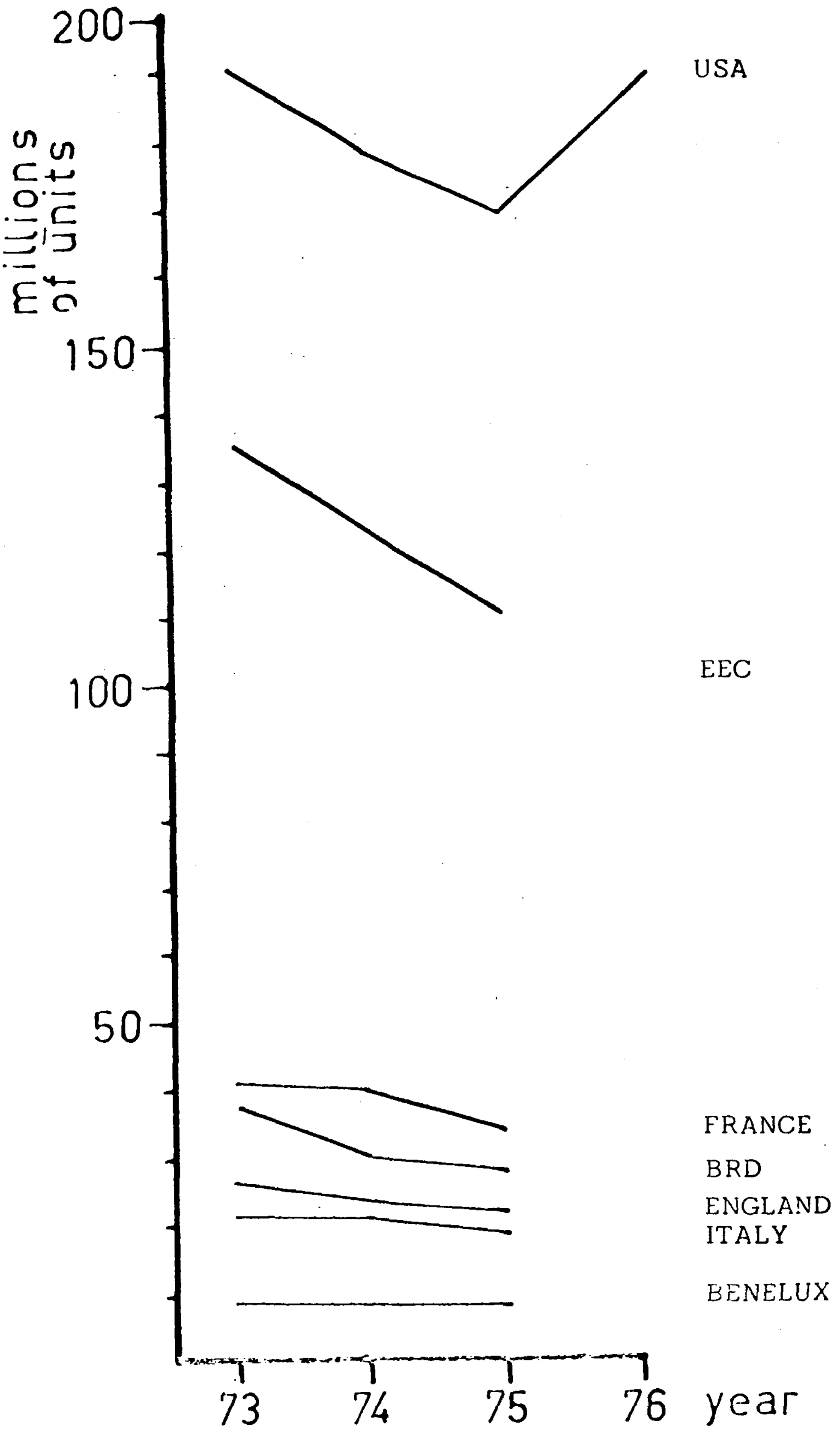

FIGURE 4 : PRODUCTION OF NEW CAR TYRES

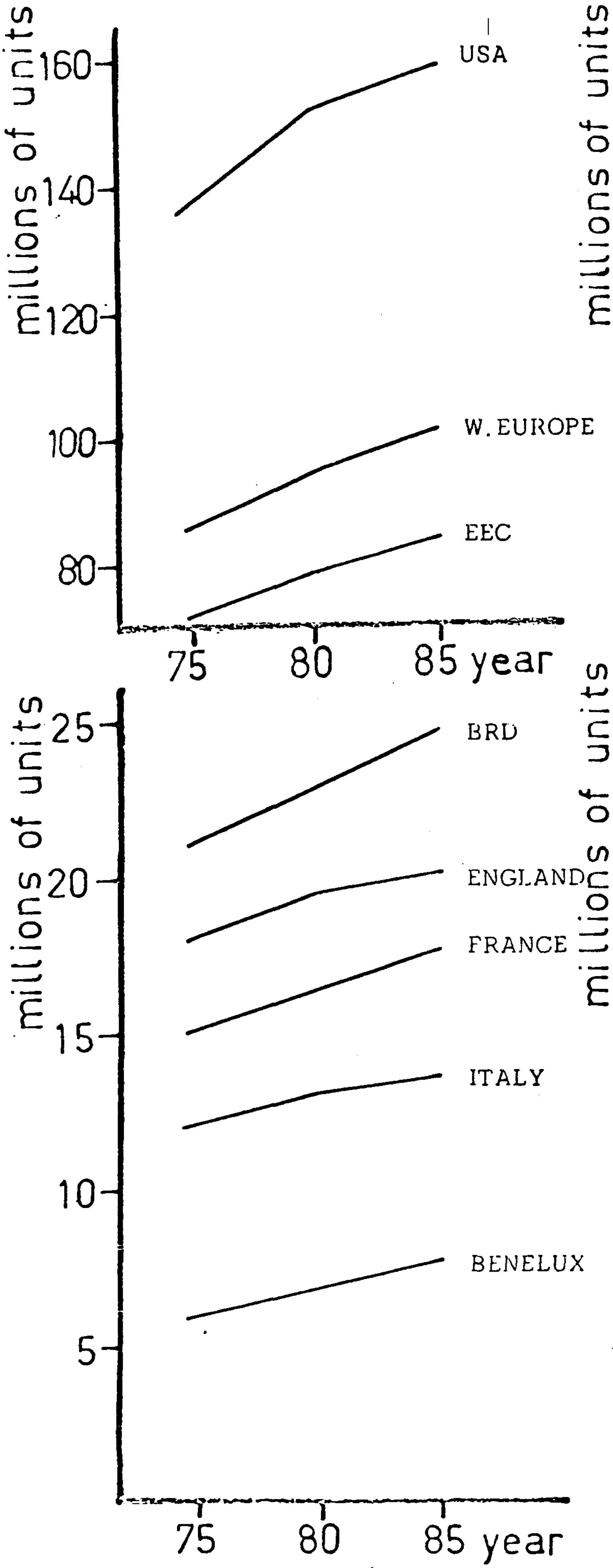

FIGURE 5 : ~~FIGURE~~ FUTURE REPLACEMENT MARKET CAR TYRES (Frost & Sullivan)

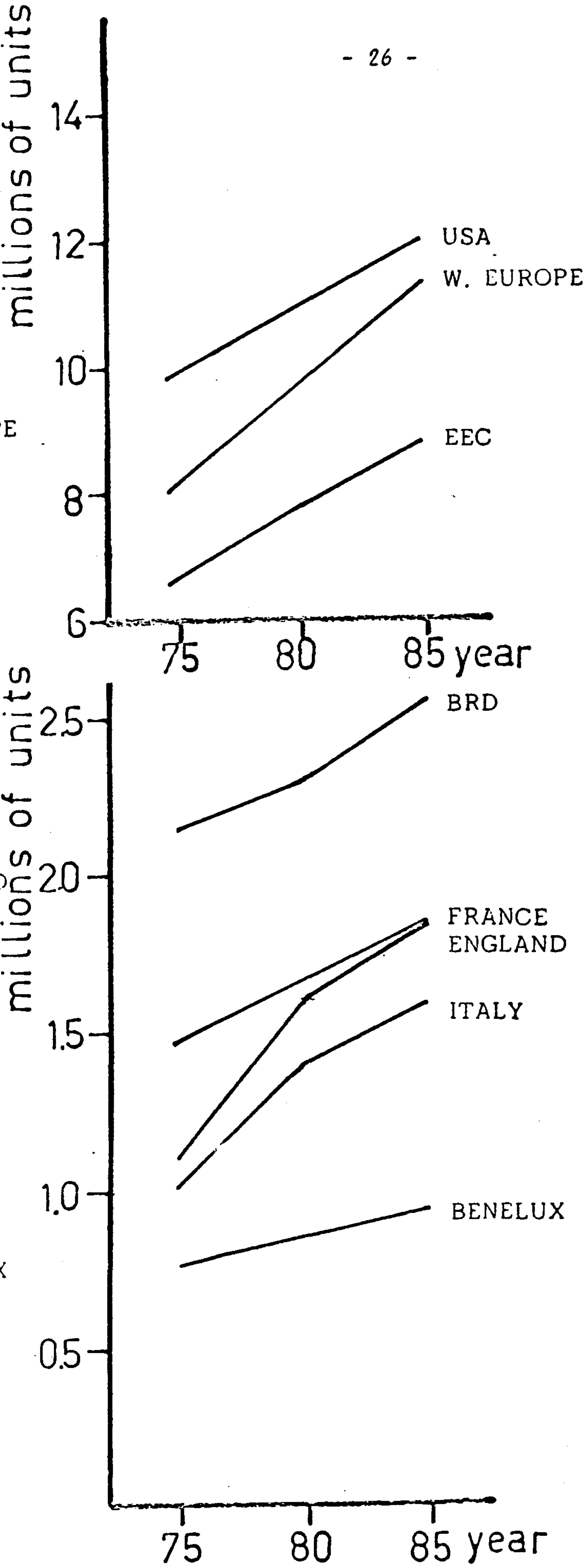

FIGURE 6 : FUTURE CAR SALES

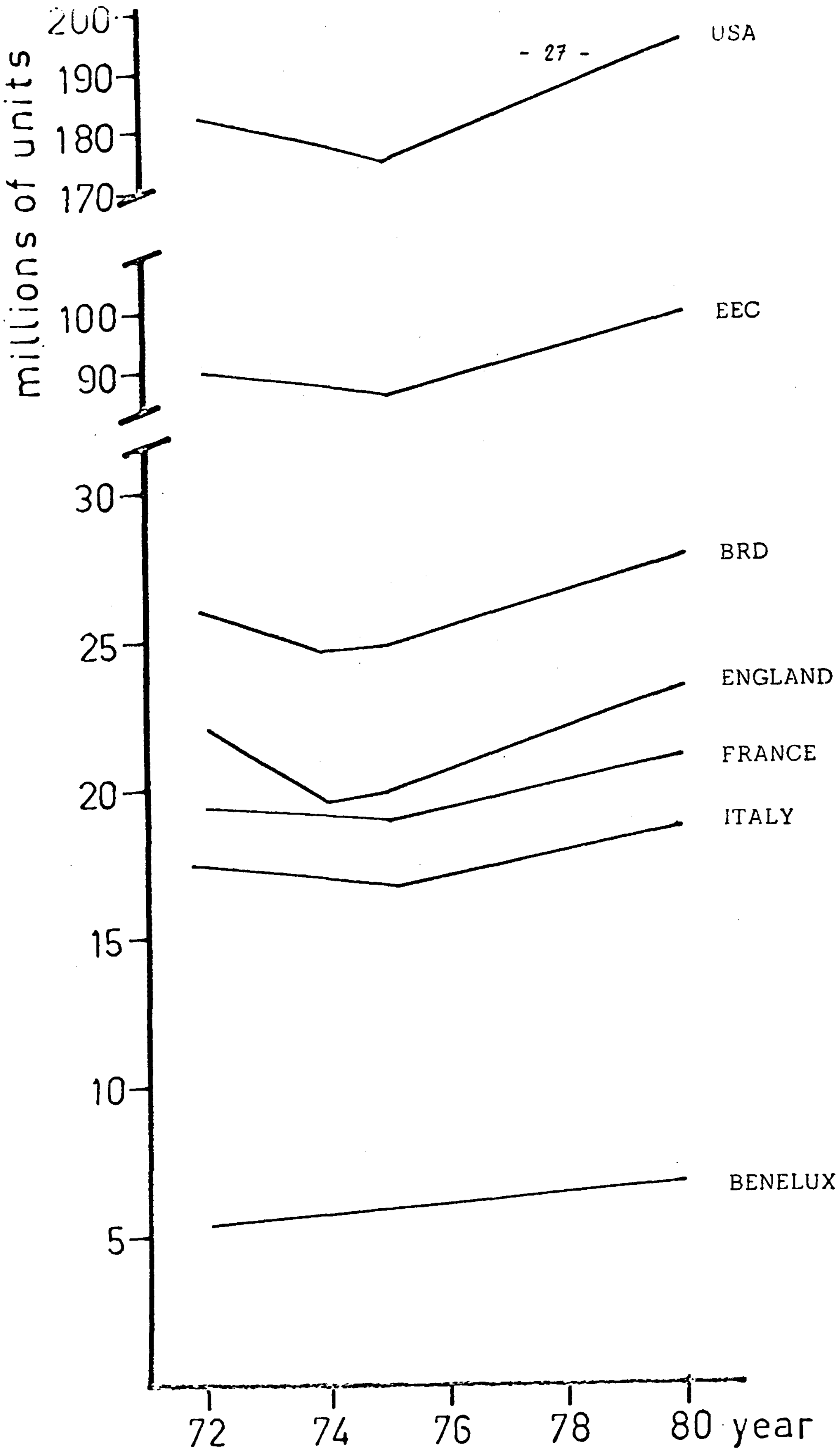

FIGURE 7 : ARISINGS OF USED CAR TYRES

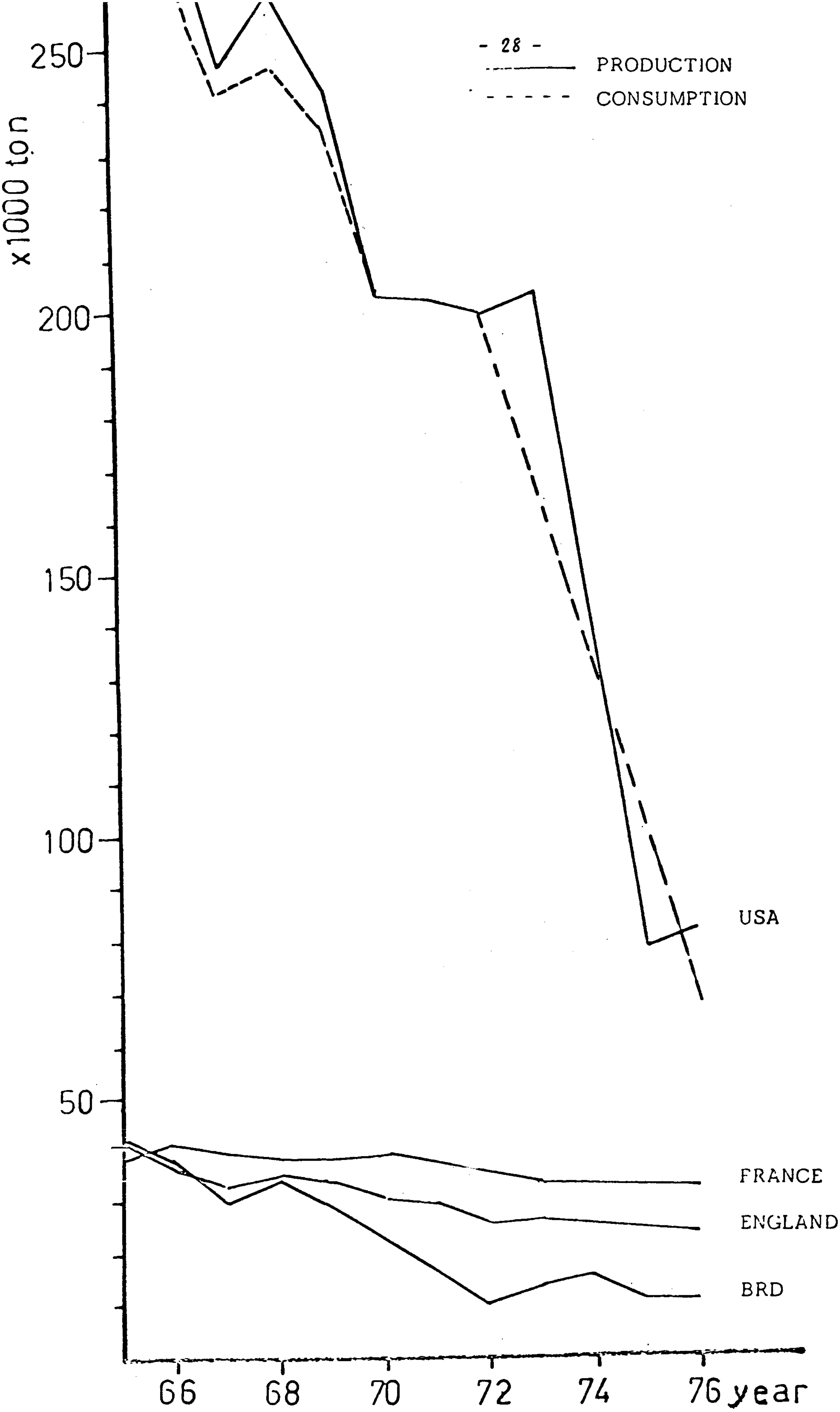

FIGURE 8 : REGENERATED RUBBER (RECLAIM)

2.3. CRITICAL SURVEY OF LITERATURE ON RECYCLING AND DISPOSAL OF WASTE RUBBER.

(*Report* n° TNO 121/'77)

2.3.1. Conclusions of the literature survey.

2.3.1.1. Retreading.

Intensification of tyre retreading will decrease the need for new tyres and thus lower the present scrap arisings.
Retreading of large tyres is close to its maximum in most countries and has been accepted as a reliable operation.
Car tyre retreading is below its potential maximum in most countries - particularly in France - and should be promoted by technical assistance and quality control.

2.3.1.2. Reclaim production.

Reclaiming should be promoted by decreasing its present costs and by the development of new markets.
Research will be necessary to find use for the main by-product (fibres) and to evaluate the technical merits of reclaim in special rubber and asphalt compositions.

2.3.1.3. Shore and off-shore applications.

The reuse and disposal of worn tyres in artificial reefs and in shore and bottom protection might be the most simple and fastest solution to dispose of large quantities of rubber scrap.
Little or no size reduction is needed and cost is mainly governed by collection and transport.
The feasability of these methods should be seriously considered in densily populated coastal EEC areas with large scrap arisings.

2.3.1.4. Road building and repair.

Some applications of reclaim and tyre crumb in asphalt pavements have been accepted by USA authorities or are being seriously considered.
Large potential scrap outlets have been calculated. The best American results should be evaluated under practical EEC conditions.

2.3.1.5. Reuse in rubber products.

Small amounts of reclaimed or powdered rubber scrap are traditionally recycled into the rubber industry and new markets are growing in sporting and sound damping applications.
Though it is not to be expected that scrap could ever replace most of the new rubber in compounding, there are strong indications from recent publications that by using very fine powdered scrap relatively large amounts could be recycled in high quality products including tyres.
More systematic research in this field will be needed to find the optimal combinations of scrap particle sizes, of types and amounts of new rubber and of other compounding ingredients.

2.3.1.6. *Incineration.*

Tyre combustion would have a very limited effect on the EEC fuel consumption.
The economy of large incinerators with tyres as a single feedstock is doubtful because of the high costs of transport and environmental protection.
The use of shredded tyres as an additive in coal and domestic refuse incineration will be a more practical approach.
Relatively small tyre incinerators for unretreadable tyres might be economic at the retreading plants because tyre cost are minimal there and the generated steam could be returned into the retreading proces.

2.3.1.7. *Pyrolysis.*

The pyrolysis of rubber scrap is still in the pilot-plant stage and its economy is mainly determined by the value of the solid residue.
Pyrolysis installations are rather complicated and are less attractive for small scale local operation.
Large scale installations for rubber pyrolysis will require high capital cost and - unlike in incineration - additional costs will arise from the grinding operations which are generally judged to be necessary.
The marketing value of the present products is insufficient. Moreover, only part of the products might be recycled to the rubber industry.
Like in combustion, the problem of proper location of pyrolysis plants is generally overlooked.
Tyre pyrolysis might be considered in combination with new or adapted installations for domestic and agricultural refuse.
In this relation the need and the extent of size reduction should be studied.

2.3.2. *Introduction.*

According to the contract 274-76-9 ECI-N between the European Economic Community and the Organization for Industrial Research TNO, the latter Organization was charged with a "Technical and economic study on the recycling and recovery of waste rubber within the Community". This study is being carried out by the Plastics and Rubber Research Institute TNO (KRITNO) of Delft, The Netherlands, belonging to the TNO Organization, in cooperation with the Bureau de Recherches Géologiques et Minières (BRGM) of Orléans, France.
In this cooperation BRGM is the pilot and KRITNO the co-pilot institute.
As a part of this work a critical survey of the relevant literature on the subject has been prepared now by KRITNO. The details of this survey are presented in the additional chapters of this report.
The state of the art as derived from literature and presented in this report will be combined in a final report with the experience of BRGM and KRITNO from the responce to their questionnaires and from personal visits to a number of factories.
In this final report definite conclusions and recommendations will be presented regarding the feasability and selection of methods for the recycling and disposal of waste rubber.

2.3.3. *Evaluation of methods for recycling or disposal of used rubber products.*

2.3.3.1. *Existing methods for rubber reuse.*

2.3.3.1.1. Retreading

In tyre retreading the worn tread is replaced by new rubber to recondition the tyre for a second or even more equal life-times [1, 2].
In fact it is the most direct road in rubber recycling because the complicated construction of the tyre is not destroyed and because the amount of rubber lost by road wear is relatively low. Estimates of this amount vary from 8-8½ [3] to 15-20% [4] of the original tyre weight.
As retreading prolongs the useful life of the tyre it decreases the number of scrapped tyres as well as the consumption of energy and raw materials for the production of new tyres.
The waste arisings from the retreading industry are relatively low. Of the original tyre weight 6-15% is removed by grinding the worn tread to prepare a fresh and uniform surface [3, 4]. Besides that about 3% of the retreaded tyres are rejected.
Large amounts of these "peelings" and "buffings" are reused in the production of reclaimed rubber, floorings and asphalt compositions. Exact information on these amounts is not available however.

A great number of retreading processes is mentioned in literature [5, 6, 3, 7, 4, 8].
In all processes the worn tyres are inspected for damage in carcass and beads and for absence of ply separation. After acceptance the treads are peeled and ground to the required dimensions, brushed to remove adhering dust and covered with new rubber as soon as possible to prevent contamination and surface oxidation and to assure good adhesion. Of large tyres only the tread section is generally renewed (top capping and recapping). "Bead-to-bead" remoulding is often used in car tyre retreading to give the sidewalls a more attractive appearance.

All retreading processes can roughly be divided into two main groups :
- processes using unvulcanized new rubber and
- processes using prevulcanized treads.

Unvulcanized rubber is mostly used in the form of "camel-back" which is an extruded strip of the required cross-section suitable to cover the area to be retreaded. The casing is coated with an adhesive, the camel-back is uniformly applied, the two ends are linked and the whole is carefully pressed onto the casing to remove entrapped air.

Instead of using camel-back it is also possible to apply the new rubber directly from the extruder onto the casing.
As the extruder presses the hot rubber onto the casing, a better adhesion is claimed and no adhesive is needed.

Other variations are mentioned but are of minor importance. In all these processes the new rubber is vulcanized and bonded to the casing in one single operation, using a patterned mould and an airbag inside to provide sufficient pressure.
The temperature of the mould has to be high enough to ensure good vulcanization of the tread in a reasonable time.

The use of the prevulcanized treads is of growing importance, especially for large tyres and radial tyres.
Because the tread is already cured and only a thin layer of adhesive has to be activated for bonding, the actual retreading operation can be performed at lower temperatures and in shorter times.
It is claimed that overcure of the carcass is minimized in this way. At the same time better mileage is claimed because the freedom in compounding the treadrubber is not limited by flow requirements during retreading.
Prevulcanized tread systems are operated under the names of Bandag, Kenprest, Duraband, Vacu-lug, Vulcap etc.

The importance of tyre retreading in the replacement market can be judged from figures given by BIPAVER (Bureau International des Associations des Vendeurs et Rechapeurs de Pneumatiques) and presented in table 1 below [4].

TABLE 1

Percentage of retreads in the replacement market of 1972

Country:	% of car tyres:	% of truck tyres:
France	5	49
Germany	27	49
Netherlands	15	49
Italy	27	50
Norway	31	40
Sweden	15	30
UK	28	35
USA	22	38

Obviously the retreading of large tyres is a considerably more accepted pratice compared to car tyres.

Roughly the same figures are still holding for the present situation as far as truck and bus tyres are concerned. For various reasons the relative share of retreaded car tyres has been further decreasing since. Aside from the price competition from new tyres, this decline can be ascribed to the marked change from cross ply to radial tyres. Many car tyre retreaders were not prepared to adapt their equipment or able to find enough suitable worn casings during this continuing switch [4].

In the UK figures have been published concerning the "retreadability" of worn casings [4]. These figures are given in table 2 below.
Retreadability is defined as the percentage of worn casings that are technically suitable for retreading.
It was found that car tyres could be retreaded only once, but that the larger tyres could be retreaded up to three times (a fourth retread could be neglected).

TABLE 2

Retreadability of worn tyres

Type:	1st., 2nd. and 3rd. retread:	Retreadability (%):
car	retreaded once	40 - 50 (45)
truck and bus	1st. retread	60 - 80 (70)
	2nd. retread	40 - 45 (42.5)
	3rd. retread	10 - 25 (17.5)

Taking the mean values (in parenthesis in table 2) valid for the whole EEC, the technical limits for the percentage of retreads in the replacement market can be calculated. These calculations are given in appendix 1.
For car tyres the maximum was found to be 31% and for truck and bus tyres it was found to be 51% of the replacement market.
Comparing these percentages with the share of retreads in the replacement market (table 1) the following can be concluded.

Truck and bus tyre retreading is very close to the calculated maximum in most of the EEC-countries mentioned, except for the UK.
Car tyre retreading is very intensive in Germany, Italy and the UK, but in some countries there is enough room for further intensification, especially in France.
Because of technical and economic reasons mentioned before, the actual gap between retreadability and the present share of retreaded car tyres in the replacement market is even greater than suggested by table 1.

The economic barriers to car tyre retreading will decline if the prices of new tyres continue to rise due to the increasing cost of energy and raw materials.
The retreading industry is studying means to improve its position. Several recommendations resulted from the BIPAVER conferences in Oslo and in Venice in 1975 and 1976 [9] with special attention to the retreading of the radial tyre and the running characteristics of retreaded tyres.
The retreading industry should be assisted in solving its technical problems and by the creation and acceptance of a system of quality control and guarantees that will convince the consumer that retreaded car tyres are as safe as new tyres.

2.3.3.1.2. Reclaim production

Reclaim * is produced from vulcanized rubber scrap by breaking down its vulcanized structure by the action of heat, chemicals and mechanical work. Though reclaim has the plasticity and appearance of a new unvulcanized rubber compound it is different in that the original sulphur network is only partly removed or modified and the molecular weight of the main chains is reduced. Moreover it may contain rests of the reclaiming chemicals and - if tyres have been used - of the fibre reinforcement.
As a result reclaim compounds have lower physical properties than compounded new rubber and the main reasons for its use are price and improved processing of rubber compounds [4, 10]. The following advantages in rubber processing can be listed:

1. Faster and more uniform fillerdispersion with less power;
2. Faster extruding and calendering with smaller variation in shape and thickness;
3. Faster mastication of new raw polymers;
4. Less tendency to deform prior or during vulcanisation;
5. Better resistance to overcure;
6. Less tendency to premature cure by cooler processing;
7. Improvement of building tack;
8. Fewer moulding defects.

* Note:
The meaning of the term reclaim, given here is in accordance with the existing practice within the rubber industry. It should not be confu sed in this report with the more general meaning of this word. to describe the products obtained by other conversion methods.

In many rubber products 20 - 40% of reclaim can be added to the new rubber content without serious effects on physical properties [4] and even much higher amounts are used in economy products like car mats.
Traditionally tire carcass compounds have been the main outlet for reclaim because of its processing advantages despite their relatively low reclaim tolerance in view of physical properties. It was estimated by the US Reclaiming Co. [11] that not more than 10% of the scrap rubber could ever be used in existing rubber products.

Many reclaiming processes have been developed. In all these processes the scrapped rubber has to be shredded and ground into crumb to permit a proper reaction of chemicals and swelling agents with the vulcanized structure, to promote good heat transfer and to remove the fibers by mechanical or chemical action.
Many chemicals are mentioned [4, 10] as reclaiming agents like phenol alkyl sulfides and disulfides and various unsaturated compounds and solvents like coal tar and petroleum naphtas and tall oil derivatives.
Sodium hydroxyde and metal chlorides are used to destroy the fibre fraction.
A number of well-known processes [4, 12] are listed below:

The heater or pan process

Finely ground, fibre-free scrap is blended with chemicals and submitted during 4-12 hours to steam of about 15 kg/cm^2 pressure. No drying is required.

The digester process

Coarsely ground scrap containing all fibres is mixed with chemicals and water and treated in a heated moving autoclave with an internal pressure of about 15 kg/cm2.
The charge has to be washed and dried.
The Rubber Regenerating Company Ltd. in Manchester is still using a modified version in which the scrap is finer ground and most of the fibres are separated.

The high pressure steam process

No chemicals are used and the scrap is coarsely ground.
The scrap is submitted to steam of about 60 kg/cm^2 for 1-10 minutes. After the treatment the scrap is fragmented by a quick release of the steam pressure and has to be dried.

The Engelke thermal process

Ground scrap is mixed with reclaiming chemicals and submitted to very high temperatures during 15 - 20 minutes. No defibering is needed because all fibres are completely carbonized. The product remains dry.

The Lancaster-Banbury process

Like the Engelke process this is also a thermal process using a Banbury mixer instead of an autoclave to provide mechanical work. It is less effective in destroying fibres.

The dispersion method

An aqueous emulsion is prepared of defibred scrap, emulsifiers, peptizers and an alkali and is mechanically treated at 50 - 60 °C. A high quality reclaim is produced but the process is time-consuming.

Of these batchwise processes most have been dropped because their economy is low. Continuous processes have been developed with equal or better quality, high speed and less environmental problems from smell or effluents.

One of the first in this new generation is the Palma-process, developed by the Heureka rubber factory near Budapest [4, 13, 14, 15]. This factory is now a part of Taurus Hungarian Rubber Works. Scrap tyres are transformed into textile-free rubber powder and rubber-free textile flock. In 1970 the basic unit to process about 1 ton per hour of tyres costed £ 57,000 with an energy consumption of 306 kwh per ton. Part of the crumb is converted into low cost reclaim of high quality. Information about the present state and further technical details of the process could not be obtained from the factory.
It has not been adopted in Western-Europe because the textile could not be reprocessed on normal modern equipment.
The Reclaimator process [4, 10, 16, 17] was originally developed in the USA and is applied in the UK by United Reclaim Ltd. of Liverpool.
Tyres are defibred during grinding in hammer mills and are further ground to 30 mesh powder. After mixing with peptizers and oil the powder is fed into an extruder, in which it is reclaimed by frictional heat in about 5 minutes. United Reclaim's annual production is 9000 tons of reclaim, 7000 tons of crumb and 4000 - 5000 ton of textile fibres. For these fibres no use could be found up to now.
The Lurgi-Ficker process [4, 18, 19] is a modification of the Reclaimator process. The two hollow screws and the body of the extruder are heated by a circulating liquid of 200-260 °C. The process is independent from frictional heat, the extruder merely transports and mixes the material during reclaiming. Factory trials at Dunlop's in Hanau, Germany have shown that the product is as good as that of the reclaimator even with 5-10% fibres left in the feedstock.

Investigations of other processes [20, 21, 22] have been reported, but did not lead to further substantial improvements.

The reclaiming industry both in Europe and in the USA is facing a lot of problems [10, 16, 17, 23] which are summarized below:

1. A decreasing market in the rubber industry.
   Tyre carcasses are a declining outlet because the number of plies is decreasing and less reclaim is tolerated in radial tyres.
2. Competition of low priced synthetics from COMECON countries.
3. The large investments needed for more economic installations.
4. Transport cost for scrapped tyres.
   Because the stronger companies are concentrating , the areas to be covered are increasing.
5. The financial burden of environmental restrictions.
6. The low value of recovered textile and wire.
   Copperplated wire is deleterious to rolling and drawing operations. Many patents exist on these subjects [24, 25] but practical solutions are still to be found.

The prospects for reclaim could be improved if new markets could be found, preferably outside the rubber industry.
According to the US Rubber Reclaimers Association [26] reclaim is a very useful additive in bituminous roads. By the addition of 1-2% of reclaim about 60% of all scrapped tyres could be recycled into roads.
Less room is present in the tradional rubber industry. However investigations in South-Africa have shown [27] that large amounts of reclaim can be incorporated into rubber roofing sheets of good quality.
Research on the reutilisation of textile and wire should be backed by the government. A relatively small charge on new tyres could be used to lower the transport costs of worn tyres.
Apart from these actions the position of reclaim will improve with further increasing prices of raw materials and energy.

2.3.3.2. *Other methods for disposal and reuse, not requiring chemical conversion or grinding operations.*

It is generally thought that it will be too expensive to remove all waste rubber by size reduction and other conversion processes. As a result a great number of ideas has been launched - and in some cases tried out - for using worn tyres completely or largely intact [28].

The most promising solution seems the building of artificial reefs in coastal sea-areas to promote fish-life.
Many tyre manufacturers have been supporting reef-building projects, particularly Goodyear [29].
Succesful experiments have been reported [2, 29, 30, 31, 32] from Florida, Australia (Adelaïde), New Sealand, Jamaica, Greece and Japan. According to the US Bureau of Sport Fisheries and Wildlife [2] no measurable water contamination was found in Florida and after 10 years of practical experience no deterioration of the tyres was established, while fish-life was strongly promoted.
Different methods are reported [33, 39] to make bundles of 6-10 tyres by connecting them with cords of polypropylene or nylon bolts. Cost estimates from the USA [34] run from $ 0.3 - 4.0 per tyre depending on methods and tyre transport.
The Osborne reef in Florida was reported to be constructed at $ 0.3 per tyre and was said to contain 75000 - 215000 tyres [4, 30, 39].
At the moment about 100 reefs are being built all over the world [11].
In the total USA Atlantic coastal area is a direct need for reefs composed of about 1500 million tyres [2, 4], equal to the US scrap arisings of about 8 years.
According to Goodrich [35] about 9 million tyres per annum could be used to promote fish-life around the British Isles.

Though all artificial reefs are reported to increase fish-life, it is too early to judge whether the costs of reef-building are counterbalanced by the profits. It might however be the fastest solution for densily populated coastal areas for the time that other methods for disposal or reuse are under development.

Protective systems at or below the waterlevel might also be of interest for coastal areas.
Succesful field tests are reported [11, 36, 37, 38] in the prevention of shore erosion by mats of interlinked tyres.
The tests have been carried out by Goodyear in cooperation with the universities of Rhode Island and Michigan.
The tyres were linked by nylon cords or by the edges of scrapped conveyor belts into mats of 150-300 feet length.
In the Bay of Narragansett near Rhode Island it was found that 70% of the wave energy could be absorbed by floating barriers of these mats. The mats are anchored to the sea bottom by means of cables and buoyancy is provided by filling part of the tyres with foam.
The same construction was also succesfully tested as a non-floating shore lining.
Similar results are reported from the New Hampshire Great Bay estuary, the Wingfoot Lake Park near Akron, Lake Erie and Lake Michigan.
One floating breakwater of 1000 feet length is said to contain 11000 worn tyres at a price of $ 7000,-- (about $ 0,64 per tyre).
More than 1000 miles of the US coastal line is reported to be unsufficiently protected and conventional protection systems would amount to 1000 million dollars [38].
An extrapolation from the 1000 feet figures will be flattered of course. Nevertheless it would lead for 1000 miles to an outlet for 58 million worn tyres at a total cost of 37 million dollars, being far less than the conventional cost.

For the EEC - and the low countries in particular - protection to water erosion is expected to be much more important than the often mentioned [2, 28] soil protection of the landscape.
It is roughly estimated that in The Netherlands 1 million m^2 of shoreline and underwater bottom has to be protected annually with conventional materials. If only part of this area could be protected by tyre constructions - assuming an average use of 1 tyre per m^2 - about 20% of the annual scrap tyre arisings in the Netherlands could be reused in this way and would replace tropical wood, asphalt, plastic sheetings and fabrics.

The rest of applications mentioned in literature seems less promising for large quantities of scrap.
The splitter industry transforms only 1% of the US scrap tyres to useful products [3, 28] though in some countries its contribution may be somewhat higher.
Worn tyres are debeaded and the remaining parts are punched to form gaskets, shims, solid tyres etc., or is cut into ribbons from which doormats or dockbumpers are fabricated [39].
Highway abutments from worn tyres have been tested by the University of Cincinnati. It was found that the severity of car collisions could be greatly reduced [28, 40, 41, 42] but the aesthetic drawbacks should also be considered [2].
Bynum [28] has suggested to use complete tyres or sidewalls as a road base material.
The flexibility of such foundations should protect the asphalt concrete to damage caused by shifts in the bottom.
The J&L Steel Company in Cleveland, Ohio [43] is using complete tyres as an additive in steel production to reduce foaming and slag formation. Worn tyres are replacing there wooden logs. It is not known whether this method has been adopted by other factories. The Dutch "Hoogovens" Steel Works has stated that their process does not allow for this method.

From the above it can be concluded that artificial reefs and protective systems at or below the water level can be useful outlets for large quantities of worn tyres, though the latter may have aesthetic drawbacks.
Their economic feasability should be further studied.
As the cost of these systems are greatly dependent on transport, their application should mainly be considered in countries with large coastal areas with high scrap arisings within a limited distance.

2.3.3.3. *Applications requiring size reduction without complete chemical conversion.*

2.3.3.3.1. Methods and equipment for size reduction of vulcanized rubber

For most applications and even for ultimate disposal it is necessary to reduce the size of worn tyres to various degrees [28, 44, 45] . Mechanical methods at normal temperatures are most frequently used and are still being improved.
The tyres are first broken into hand-sized fragments with specially developed punching, cutting and shredding machines.
The capacity of these machines is about 700 tyres per hour and special rotary knife cutters are being developed to reduce even 2000 tyres per hour [45].
The coarse fragments are further reduced in water-cooled toothed disc mills to powders and crumbs of 0,5 - 5 mm.
Fibres and metal parts are removed by pneumatic, electrostatic and magnetic means [25, 44, 46].

Gezolan in Switzerland is operating a modern grinding installation [47, 48, 49, 50] that processed 3000 tons of worn tyres in 1973 and 8500 tons in 1975.
Purely mechanical equipment has been developed by Condux and Schmalbuch-Lubeca in Germany, by J.P. Hennesy and Techniches Entwicklungsburo in the U.K., by Telecom Industries, Automotive Industrial Marketing, Tire Gator and Applied Power in the U.S.A. and by Inariyama Seizakusho and Kobe Steel in Japan [11, 46, 51, 52, 53, 54].
The Palma process in Hungary has already been mentioned in chapter 4. 1. 2. The grinding and classifying equipment of this process is specially directed to the production of very pure rubber, textile and metal fractions.
In the U.K. the Rubber and Plastics Research Association of Great Britain (RAPRA) is developing a grinding process for the production of 300 mesh powder to be recycled into high quality rubber products [4, 55, 56].
The rubber is first comminuted to a powder of about 40 mesh. After that a dispersion of swollen rubber particles is reduced to the required dimensions by the shearing action of a kind of colloid mill in which parallel discs are rotating in opposite directions with a very small clearance. After drying a powder is obtained.

A large number of publications is mentioning cryogenic grinding processes. These methods are making use of the fact that rubber becomes brittle when cooled below its glass transition temperature, after which it can be easily ground with less mechanical work, wear of equipment and noise.
Cryogenic processes are strongly advocated by producers of liquified gases and are mainly based on liquid nitrogen, though other cooling media like dry ice and methanol CO_2 are also mentioned. Powders down to 0, 1 mm can be prepared [45, 57, 58].
At very low temperatures no problems are encountered with the steel parts of the tyres, which are equally powdered and can be easily separated.
The very fine textile fibres are causing problems in air flotation. On the other hand the relatively high cost of liquid nitrogen is generally thought to be unacceptable. A more suitable way for using low temperatures could be found in the location of tyre grinding equipment at a liquid petroleum gas re-gasification plant [4].
The amount of liquid nitrogen to grind 1 kg of rubber is reported to be about 0, 9 kg. The figures however vary considerably between 0, 25 and 5 kg of nitrogen according to the nature of the scrap and the desired size of the end-product [58, 59].

In the U.K. low temperature grinding is applied by Cryogenic Services of Corby with a capacity of about 10000 tons per annum of tyres and various other materials [4, 59].
In Germany similar processes have been developed by Hazemag of Münster [60, 61], in Australia by Commonwealth Industrial Gas Ltd. of Sydney [11] and in Japan by Tokyo Gas Ltd. and Kanto Tar Products Co. Ltd. [62].
In Poland [63] a cryogenic method has been patented by the Ministry of Science, Education and Technology to process 4 million worn tyres using 2 million litres of liquid nitrogen. No technical details are mentioned and the reliability of the source should be doubted as it can be calculated from these figures that less than 0, 1 kg of liquid nitrogen should be needed per kg of tyre weight.

For the time being there are no indications that cryogenic grinding leads to better or cheaper products than conventional grinding techniques.
If the problems of cryogenic grinding can be solved and less expensive cooling media can be made available in wide areas its advantages will undoubtedly overrule in the future the conventional methods of size reduction.

2.3.3.3.2. Reuse in road building and repair

The application of rubber in bituminous roads dates back to about 1930. Originally the experiments were mainly directed to the addition of rubber as a latex and they were carried out all over the world.
There is no doubt that the addition of uncured rubber (like latex) improves the ductility and thermal stability of asphalt pavements. Though most reports on the benefits of latex addition are more than 20 years old, the results are confirmed by more recent publications [64, 65].
Because latex addition increased the cost of an asphalt mix by about $2, 00 per ton of mix [66] it had to be proved that the extra cost could be offset by lower maintenance cost or longer road life. The causes that the early experiments did not lead to a general acceptance of latex addition to asphalt have been broadly discussed at the Salt Lake City conference in 1971 on rubber in asphalt pavements [67] and can be summarized as follows:

1. Road builders were not interested in better durability.
2. Local authorities at that time would not even consider the extra cost of rubber addition.
3. Field testing for durability is time consuming and expensive. Most tests have failed to convince the authorities because they were carried out during too short periods, because of improper location and by lack of comparative data from conventional pavements under similar traffic conditions.

Since that time the incorporation of rubber in asphalt has been directed to reclaim and ground tyre scrap.
Mainly because of the lower initial cost of these materials, but also because of a changing attitude towards durability and conservation of raw materials.
As the costs of road maintenance are tremendously high, even savings of 10% or 5% would be interesting. This is illustrated by the fact that in 1970 the cost of road maintenance in the USA amounted to 5000 million dollars [67].

The addition of reclaim to asphalt has been studied in the USA by the Rubber Reclaimers Association and the University of Connecticut [26, 68].
The U.S. Rubber Reclaiming Co has been testing reclaim in asphalt for highway construction, patching, overlays and joint sealings. The compositions have been tested by 19 States and 6 States have adopted them for routine use [11]. It was found that reclaim prevented surface cracking and reinforced the road edges. It decreased the migration of certain asphalt constituents to the surface during hot summers and thus increased the skid resistance of the surface. Moreover the traffic could be admitted much earlier over the new surface.
The State of New York is using reclaim compositions for the sealing of cracks and joints and has found twice the normal life time [26]. Also the conference held by the Environmental Protection Agency in Akron in 1975 has reported good results with reclaim in road building and repair [10]. It was calculated that - out of several succesful applications - merely the introduction of skid resistant overlays might offer a reclaim outlet in the State of Mississippi equivalent to 6 million worn tyres.

Also tyre crumb was found succesful in road repair and particularly in stress-relieving-interlayers.
Stokely and Mc. Donald [28, 67, 69] developed a mixture of 20-35% tyre crumb (16-25 mesh) and 80-65% binder. The mixture was used over heavily cracked roads in Phoenix, Arizona. After 6 months of severe traffic none of the existing cracks had propagated to the new surface.
Even more interesting are the stress-relieving-interlayers (SRI) developed by Bynum and Galloway of the US Reclaiming Co. [2, 10, 67, 70, 71].
It was calculated [10] that 3000 scrap tyres would be consumed in each mile of highway in using this technique or [2] that the total USA scrap tyre arisings would be needed if the system would be applied to 15% of the annual USA road resurfacing.
The system consists of equal parts of 1/8"coarse tyre crumb, asphalt and aggregate . A layer of 1/4"-3/8" is applied between the road foundation and the actual surface layer.
It was found that a 1/4" SRI could prevent surface cracking at displacements in the underground being 5 times as large as the critical value without SRI [67]. The system is now under evaluation in several States by the Federal Highway Administration.

A similar composition has been developed by Skega in Sweden. This is however not used as a SRI, but for better low temperature and skid resistance of the road surface [72].

It may be concluded that the application in roads of worn tyres in the form of reclaim or crumb is accepted by several Local USA Authorities. Federal and other local authorities are seriously considering the application. Several applications seem to be very promising and are offering large potential outlets. In order to judge their value for the EEC a direct contact with the relevant USA authorities is recommended.

2.3.3.3.3. Reuse in existing and new rubber applications

Though it will be too optimistic to assume that all scrap rubber could ever be recycled into the rubber industry, it is generally known that this way of recycling has been applicated since long at a limited scale.
The scrap has been transformed into reclaim or into crumb and powder prior to recycling.
The advantages of reclaim are mentioned in chapter 4. 1. 2.
The main draw-backs of the present reclaim are its price and its adverse effect on the mechanical properties of rubber products as a result of impurities and main chain degradation of the original polymer.
Crumb or powder from scrap rubber are not chemically degraded and might offer therefor better potentials in new rubber compounds, which might be promoted by the advance of new grinding techniques producing purer and finer scrap rubber powders (chapter 4. 3. 1.).
Relatively coarse crumb from scrap rubber will be less expensive than reclaim. Fine powder may be more expensive but its incorporation in high quality products should be considered as far as its price does not increase the cost of the expensive compounds normally used for these applications.

Unpublished work of the Plastics and Rubber Research Institute TNO in the Netherlands has shown that scrap rubber particles can be firmly bound by new rubber compounds into an integrated structure. It could be concluded from these experiments that the properties of rubber compounds containing vulcanized scrap will be determined by the proper combination of scrap and new rubber compound and not by structural heterogenities caused by insufficient adhesion.
Keeping this in mind the possibilities of in-rubber recycling should not be overlooked, not even in high quality products like tyres.

Union Carbide [73] has investigated the addition of a very fine 325 mesh powdered scrap to a high quality styrene - butadiene rubber compound with an original tensile strength of 239 kg/cm^2.
20% of the new rubber content was substituted by 40% of powdered scrap. The results are presented in table 3 below. ASTM testing methods were used.

TABLE 3

Mechanical properties after vulcanization of a high quality SBR rubber compound with and without 325 mesh powdered scrap.

Mechanical properties	Original compound	Compound with powdered scrap
Tensile strength	239	227
Elongation at break	380	440
Tear strength	44	52
Fatigue properties in flexure:		
a. KC to first crack	23	48
b. KC to 20 mm crack growth	7.6	63

From table 3 it can be seen that the influence of the scrap rubber on tensile properties is insignificant: a slight decrease in tensile strength and some increase in elongation.
The tear strength is somewhat increased and the fatigue properties are clearly improved.
In a large number of other applications good results are mentioned about powdered scrap addition to rubber compounds.
The evaluation of most results is hampered however by the fact that the nature of the scrap and the reference compounds are not mentioned or because different mechanical properties have been considered.

One Soviet publication [74] could be found in which the same types of properties were investigated as in table 3, though the methods for fatique testing were not clearly defined.
In this investigation a medium quality polybutadiene compound with an original tensile strength of 172 kg/cm^2 was used in which 30% of the new rubber was substituted by an equal amount of powdered scrap that was approximately 10 times as coarse as in the work of Union Carbide (0, 25 mm sieve aperture).
In table 4 below the relative effects of the powdered scrap were compared with the results presented in table 3 to compensate for absolute differences introduced by different testing methods.

TABLE 4

Comparison of the change in mechanical properties after vulcanization and after incorporation of different powders in 2 different compounds.

Mechanical properties after scrap incorporation in relation to the values of the original compounds:	High quality compound of table 3, very fine scrap (ref. 73)	Medium quality compound. medium fine scrap (ref. 74)
Tensile strength	95 %	93 %
Elongation at break	116 %	93 %
Tear strength	118 %	128 %
Fatigue flexure method a	209 %	---
Fatigue flexure method b	829 %	---
Fatigue flexure method c	---	152 %
Fatigue in elongation method d	---	269 %

Methods a and b : see table 3
Method c : crack growth in KC, method not mentioned.
Method d : KC to break, repeated elongation to 150 %, method not mentioned.

Strong indications come from the results in table 4 that the improvements of tear strength and fatigue properties by scrap addition are consistent for this range of scrap types and compounds.
The tensile properties seem to be imparted somewhat by the coarser type of scrap.
It would be interesting to know more exactly the tolerance for fine, powdered scrap of some well defined rubber compounds.
Varying amounts of high quality tyre scrap in a number of well defined particle size distributions should be incorporated in some practical rubber compounds of known composition - particularly in tyre compounds - and the level of all relevant properties should be studied.

A large number of applications of crumb from scrap rubber in particle sizes from 0, 5 to about 5 mm have been mentioned in literature.
The Shoe and Allied Trades Research Organisation in the U.K. has reported succesful experiments with ground tyre scrap in soling materials [75].
Sporting surfaces have been developed from relatively coarse crumb by Bayer [62, 76], Avon Rubber [77, 78], Goodyear [28, 41, 42], Uniroyal [42], Minnesota Mining and Manufacturing Co. [79] and Berleburger Schaumstoffwerk [80].
The particles are generally bound with a poly-urethane but also with latex, tar, asphalt and epoxy-resins.
The Bayer proces is using very coarse tyre crumb without removal of textile or steel and a minimum amount of urethane binder.
The binder can be foamed to produce an even more open structure. All these systems can be equally used in sound damping applications. Special sound damping systems with ground rubber have been developed by Bayer [81], Japan National Railways [82], Malthe c. s. [83], Goodyear [41], Firestone [28] and Fibre-Metal Products Co [84].
Relatively fine crumb can be used in the production of foamed carpet underlay and carpet backing [4].
The Institute TNO for Building Materials and Constructions in the Netherlands has developed a composition containing coarse tyre crumb that enables the bonding of ceramic tiles onto wooden floors and other unstabile undergrounds.
Though reclaim is a chemically converted rubber crumb, the application of reclaim in roofing materials might be equally interesting. It was shown by the National Building Research Institute of South Africa that larger amounts of reclaim could be used in weather resistant rubber sheets for roof covering [27].

No quantitative data could be obtained from literature about the potential amount of ground or reclaimed scrap rubber in the existing and new rubber products as mentioned above. Much research and development work is still to be done, particularly in the field of extremely fine powders.
Even if it might be proved that - for technical or economic reasons - not more than 10% of the rubber now still being scrapped could be returned to its origin or to other rubber products, this amount would be a useful contribution to the problem of rubber scrap removal as well as an attractive and direct way of recycling.
From a grinding method producing a broad spectrum of particle sizes, the finest fraction might be recycled into high quality products like tyres and conveyor belts, a second and less fine fraction into medium quality rubber goods and a coarse fraction into sporting and sound damping applications.

2.3.3.4. *Thermal conversion of used rubber other than reclaim production.*

2.3.3.4.1. Incineration

Caloric values are reported for worn tyres varying from 8600 to 10200 Kcal/kg [4, 85]. The high values compared to coal (7000 Kcal/kg) make worn tyres potentially attractive as a replacement or additive for coal. At the same time the upgrading of the caloric value of domestic refuse with rubber scrap has to be considered.

Much work on tyre combustion has been done in the U. K. [4, 86]. The first tyre incinerators constructed by Redman, Heenan & Froude of Worcester were simple, hand-fired non-rotating furnaces [87] that could not cope with the general problems [4, 45, 86, 88] of the rubber combustion i. e. :

a. The slow initial burning rate, causing the rubber to melt. Molten rubber and ash easily cloggs the grates of the furnace.
b. The occurrence of very high local temperatures (hot spots) once burning, limiting the concentration of tyres in the furnace and the useful life of grates and refractories.
c. Incomplete combustion of carbon black and steel.

The manufacturer has left therefore the original conception and has developed a grateless cyclonic furnace [86] that operates at sufficiently high temperatures to destroy the tyres completely and melt the metal bead wire.
A furnace of that type was installated in 1972 at the Goodyear plant of Wolverhampton.
Its capacity is reported to be about 80 tyres (500 kg) per hour producing 4 tons per hour of steam which is recycled into the rubber factory [86, 89, 90]. So its output is about 8 tons of steam per ton of worn tyres.
According to other literature [4] it is being redesigned however.

Another improved construction is marketed by Lucas Furnace Developments Ltd of Wednesbury in the U. K. and Lucas American Recycling Inc in the USA [41, 88, 91, 92, 93, 94].

In the Lucas TD furnace tyres are automatically fed to the circumference of a horizontally rotating disc where burning starts at about 800°C. The tyres are gradually shifted to the central zone where final combustion occurs at temperatures of 1500-1700°C. The carbon black is completely burnt and liquid slag is easily drained at the centre.
The first Lucas furnaces were installed in 1971 at 2 retreading companies in the U.K.:
- the Standard Tyre Co of Leyton, London and
- the Homerton Tyre Co of Treforest, South Wales, both consuming 40 tyres per hour [4, 86].

The next two Lucas furnaces were placed in 1972. The furnace at the Avon Rubber Co of Melksham (U.K.) was started with 80 tyres per hour but even 180 - 190 tyres per hour have been achieved in the same furnace. It was reported that 10.000 lbs of steam were generated by 1500 lbs of worn tyres or about 7 tons of steam per ton of tyres. Tyre combustion is providing 10% of the factory's steam requirements [4, 86, 88]. The other furnace with about double capacity was built at Goodyear's Jackson plant in the U.S.A. [4, 88].

Pollution Technical Services Ltd has installed furnaces of another type in two retreading factories in the U.K.
In the furnace a "fire tornado" is created for clean and speedy combustion. The furnace was designed to burn tyres as well as other sorts of scrap.
The first of this type was erected at the Watts Tyre and Rubber Co of Lydney, Glos. and was reported to consume 300 - 350 kg of worn tyres per hour with an output of 1.5 - 1.6 tons of steam per hour. This leads to about 5 tons of steam per ton of tyres. The lower efficiency is attributed to the addition of other waste material.
The second incinerator was built at Ondura Ltd of Keighley [4, 86, 95].

In the U.S.A. the Fluor Utah Inc. of San Mateo, California [28] is producing incinerators of a design much alike to the Lucas-type. In Japan [54] a tyre incinerator has been developed by Riken Piston Ring Industry Co Ltd.
Inclined kiln rotary furnaces for tyre incineration are marketed by Bartlett-Snow Products Inc. of Cleveland, Ohio [28] and by Soc. Industrielle de Lillers in France [96].

Several systems for mixed refuse are mentioned in literature. In the U.S.A. the Foster Wheeler Corporation of Livington N.J. is producing an installation for the incineration of a mixture of 15% chopped tyres and 85% domestic refuse. Its capacity is 600 tons of mixed refuse a day giving 75 tons of steam per hour [28].
In Germany the retreading company of Gummi- Mayer K.G. at Landau, Pfalz is operating a furnace consuming 900 kg of tyres per hour and additional refuse that is covering up to 40% of the factory's energy requirements [1, 97].
In Gislaved, Sweden the Gislaved Gummifabrik is using an incinerator for domestic refuse and scrap tyres.
Its thermal energy production is equivalent to 25% of the oil consumption of the factory [98].
Furthermore it was reported that furnaces are available in the U.S.A. for the combustion of 3.5 tons/hour of chopped tyres combined with domestic refuse. General Motors has been operating an installation in which coal is fired mixed with 10% worn tyres, while Uniroyal is working on a similar project [4, 11, 34, 99].

From the above it can be concluded that well-designed furnaces are able to convert complete worn tyres into energy at an efficiency of 7 - 8 tons of steam per ton of worn tyres.
Size reduction is generally not required, which is an advantage compared to other conversion processes.
Tyres can also be used to upgrade the caloric value of other refuse, but in that case some size reduction is recommended. On the other hand Goodyear has stated [2, 26, 42] that its Jackson installation was not a "money saver" and calculated that the combustion of tyres is about 40% more expensive than the use of coal.

The contribution of tyre combustion to energy is small. It was calculated that the energy content of the total U.K. scrap tyre arisings would be less than 0.1 % of the national energy consumption [95]. Various authors [14, 34] are regarding therefor scrap tyre burning as a mere emergency-solution for situations where more useful methods cannot be applied.

The problems of optimal location of tyre incinerators have been considered insufficiently in literature. As the cost of collection and transport are important factors in worn tyre conversion, tyre combustion should be located in densily populated areas where most of the scrap is generated.
In these areas however the environmental stress on clean burning is most severe and the environmental cost of special personel and equipment will be an additional burden on the economy of the process.
The feasability of tyre incineration might be linked with the future development of retreading operations.
If more tyres would be collected for retreading, more unretreadable casings would be concentrated at the retreading plants and less would be scattered over wide areas.
Burning these casings in these locations would minimize the transport cost of the incineration and promote its economy.

2.3.3.4.2. Pyrolysis

A large number of publications, mainly from the U.S.A. and Japan, are available on the pyrolysis of rubber scrap. Most studies are concentrated on worn tyres, because of all types of rubber scrap, tyre scrap arisings are largest in volume and comparatively constant in composition. The present average tyre consists of more than 90% of organic materials that can be converted into a great number of chemicals.
If these chemicals could be recycled, scarce petrochemicals would be saved. Inorganic materials like iron, zinc and glass might be recovered at the same time.

The first practical experiments in the U.S.A. were carried out by Firestone in cooperation with the U.S. Bureau of Mines of Pittsburgh, Pa. [11, 28, 66, 100, 101, 102, 103]. Batchwise pyrolysis was carried out in the B.M.-A.G.A.-tester with 20-35 mesh tyre crumb at 500-900°C and yielded 40-50% of solid residue (char), 20-50% of oil and some gas. A reducing atmosphere resulted from the generation of hydrogen and carbon monoxide. It was found that the yield and the composition of the various fractions was strongly dependent on temperature.
Most char was obtained at the highest temperatures.
After these first experiments continuous pyrolysis was carried out in Firestone's own facilities at Akron, yielding 30-40% of char and 30-50% of oil.
The char was tested as a carbon black replacement in rubber compounds. From the results it can be concluded that it might replace some semi-reinforcing blacks of the SRF or GPF type but that its possibilities in the bulk of rubber products are very limited. Its quality could be improved by chemical treatment but the extra cost are not mentioned. By steam treatment the char could be transformed into anabsorbent carbon.
Various uses for the liquid fractions were suggested: as a processing aid for rubber and as a carbon black or petrochemical feedstock.
The gas is converted into heat.
It has been stated [42] that the economy of the process is not determined by the value of oil and gas but that it stands or falls with the carbon black value of the char.
The high capital cost is said to be an impediment to the construction of commercial scale facilities [34].
Despite considerable effort the process is still under development.

The Marathon Oil Company of Findley, Ohio has decribed the pyrolysis of tyres in a test unit similar to the AGA-tester of the US Bureau of Mines [104].
A char was produced at a temperature of 600-900^{o}C that could be effectively ground in a steam operated fluid energy mill.
The char could be used in a tyre carcass compound as a semi-reinforcing filler.

Another Firestone approach that is still under development is the DSR process [105, 106, 107, 108].
Scrap tyres are ground to 35 mesh, though coarser particles will be needed for better economy [106]. The scrap is depolymerized (DSR = depolymerized scrap rubber) by heating it at 250-275^{o}C during 12-24 hours with an aromatic process oil and pentachloorthiophenol as a catalyst.
The scrap is completely conversed into a viscous dispersion of carbon black in depolymerized rubber.
The DSR can replace equal amounts of rubber processing oils and part of the carbon black in new rubber compounds of medium quality. It was also found that the DSR showed some antioxidant activity and improved the tack of the compounds during processing.
As the possibilities for reuse in rubber are limited, other applications are being investigated like a fuel oil replacement, an asphalt additive for road resurfacing, adhesives, sealants, coatings and concrete reinforcements.

Goodyear has been equally involved in the pyrolysis of tyres into carbon, oil and gas [11, 109, 110, 111]. The situation is obscured by the absence of direct Goodyear publications and by the fact that the available literature is not quite consistent with respect to the present achievements.
In some articles it is stated that Goodyear is already converting 77000 tons of tyres per annum [109, 112], according to others [111] Goodyear is awaiting results from a 15 ton tyres per day pilot plant in 1977 and might start in 1978 a commercial plant for 11 million tyres per annum, while it was stated in a report of the International Research and Technology Corporation [2] that technological barriers have caused Goodyear (and also Uniroyal) to abandon the idea.

The 15 tons per day pilot plant was planned at Rocky Flats, Colo. after cooperative research with The Oil Shale Corp. Tyres are shredded to rather coarse 2" chunks. The pyrolysis is performed at 500-600^{o}C and heat transfer is promoted by heated ceramic balls. It was stated that a plant for 11 million tyres per annum producing 25000 tons of carbon black, 50000 tons of fuel oil and 4500 tons of steel would be considered if the pilot plant will prove to be reliable and sufficiently economic and if sufficient tyres can be collected at minimum cost [11, 111].

In another development by Goodyear in cooperation with the Columbian Division of the Cities Service Co tyres are ground to 3/8"-1/4" particle size and 10-30% scrap is mixed with a liquid hydrocarbon [11, 113, 114, 115] After digestion during 1-8 hours at 250-300^{o}C a solution is obtained that can be used as a carbon black feedstock in conventional equipment [11, 113].
The slurry can also be digested at 50 - 200^{o}C with free radical initiators such as cobalt napthenate or acetate to produce coatings or asphalt additives.
This process seems much alike the Firestone DSR-process but commercial realization is not mentioned so far.

Hydrocarbon Research Inc. of Trenton, N.J. has developed a continuous method for tyre pyrolysis in a hydrogen atmosphere, the H-Process [66, 116, 117, 118, 119, 120].
Ground tyres of 24 mesh are slurried in oil made in the process and containing a cobalt or nickel molybdate catalyst.
The slurry and hydrogen at a pressure of 70 kg/cm^2 are continuously fed into a reactor with a volume of 400 cm^3.
The scrap is converted into 37% of carbon black, 60% of highly aromatic oil and 3% of gas. The properties of the black were found to be comparable to semi-reinforcing rubber fillers.
The oil could be used as a rubber processing aid or as a low-sulphur fuel (less than 0.1% of sulphur).
It was calculated that about 10 kg of hydrogen would be consumed per ton of scrap and that the process will be profitable provided that the tyre costs (collection, transport and grinding) can be kept below 25% of the value of the carbon black produced.
The process has not been commercialized as yet.

The University of Tennessee, Knoxville, Tennessee has been experimenting with tyre pyrolysis in molten salts (chlorides) for optimal heat transfer [121, 122].
The char could be used as an absorptive carbon or as a smokeless fuel. Many problems are still to be solved with respect to the separation of the solid residue (char, steel, glass) from the liquid salts, the corrosive action of the salts and the chlorine content of the liquid hydrocarbons.

From Japan a large number of experiments regarding pyrolysis have been reported. It is difficult however to judge from literature whether an installation should be considered to be a test unit or a commercial plant. Moreover the consumption of 10000 tons of tyres per annum of Nippon Zeon, mentioned by Schnecko [109, 112] should be considerd as a prognosis.
Kobe Steel Ltd [62, 123, 124] is running a pilot plant with a rotary kiln having a capacity of 2.4 - 5 tons of tyres a day. It converts 10 mm scrap into 30% carbon, 40% oil and 30% gas within 10-20 minutes at 500-800°C. An installation is planned to convert pieces as large as 1/8 of a tyre at a rate of 25 tons a day.
A fluid bed process using sand or recirculated char as a heat medium has been developed by Nippon Zeon Co Ltd and the Japan Gasoline Co Ltd in cooperation with the Hokkaido Institute of Industrial Development of the MITI (Ministry of International Trade and Industry) in Hokkaido [54, 125, 126].

A pilot plant has been erected in Tokuyama in south-western Japan with a capacity of 1 ton of tyres per hour. Tyres are crushed to 20-30 mm and pyrolyzed at about 500°C.
The char is treated for use as an activated carbon or as a semi-reinforcing rubber filler.
Similar processes have been developed by the Hyogo Institute of Industrial Development of MITI near Kobe (9 mesh powder at 500-600°C), by the Bridgestone Tyre Co of Tokyo in cooperation with the BS-Asahi Carbon Co and the Osaka Institute of Industrial Development of MITI (activated carbon by steam treatment at 800 - 1000°C of the char) and by the Yokohama Rubber Co of Tokyo [54, 127].

The information concerning European activities was found to be less abundant.
Since 1970 the University of Hamburg (Institut für Anorganische und Angewandte Chemie, Abteilung Angewandte Chemie) has been involved in the pyrolysis of various waste materials including tyres [124, 128, 129, 130].
A test unit has been developed for fluid bed pyrolysis with sand as a heating medium. Using 40 kg of sand 15 kg of tyres could be converted at temperatures of 640-840°C into about 40% of char, 12-17% of gas and 26-40% of oil.
It was found that large tyre segments of about 1 kg could be used and it was predicted that it would be possible to convert complete tyres in a larger reactor at a rate of 1,3 tons per hour per m3 of fluid bed.

The same Institute has also been experimenting with salt bath pyrolysis. Difficulties were encountered however in separating the solid residue from the molten salts.

Tyre pyrolysis was also reported from Herbold-Pyrolyse GmbH of Karlsruhe [109, 112, 131].
A total capacity was mentioned of 2000 tons per annum but it is not sure whether this figure should be considered as an achievement or as a prognosis.
The Herbold installations are processing 100-600 kg per hour of scrap of 30-40 mm size at temperatures of 400 - 800°C.
It was stated that coarser scrap would be unfavourable for the quality of the solid residue. In a unit for 7.2 tons per day scrap tyres could be converted into 40% of fuel oil, 50% of carbon black, 4.9% of steel and 5.1% of gas. Part of the gas is used to heat the process.
In France, Albert Miclo of Mulhouse has been licensed by Herbold.

Investigations in the U.K. are mainly directed to the fuel value of pyrolysis products and little details are available on processes being tested and their value.
Batchelor Robinson [132] is operating a pilot plant for tyre pyrolysis and is considering a commercial plant for 10000 - 20000 tons of tyres per annum that will provide about 3600 tons of low sulphur fuel oil, gas to heat the retorts and char from the ash of which zinc oxide will be extracted.
The Warren Springs Laboratory of Stevenage, Herts [133] has been investigating the pyrolysis of various types of waste including scrap tyres and analyzed the products obtained. Pilot plant scale tyre pyrolysis was not mentioned.

From the various experiments in the U.S.A., Japan and Europe the present situation can be depicted as follows:
Technologically it is possible by pyrolysis to convert scrap rubber - and particularly tyres - into a wide range of solid, liquid and gaseous products.
The marketing value of these products however is doubtful at present and the economy of tyre pyrolysis is considered to be determined by local situations in view of the value of the solid residue and the cost of tyre collection, transport and size reduction.
Size reduction is a draw-back of pyrolysis compared to incineration. Probably for this reason the University of Hamburg is evaluating systems requiring little or no size reduction.
The complexity of the liquid fractions of tyre pyrolysis and the variability of their composition is another problem that has deterred potential consumers [4].

Pyrolysis of tyres is requiring complicated and expensive installations and tyres as a single feedstock might be considered only in densily populated areas with very large and concentrated scrap arisings.
Even there its economy is doubtful because the quality-price-relation of the residue is low and its market will be relatively small.
The facts that the efforts of large companies like Goodyear and Firestone have not resulted in practical plants up-to-now and that Dunlop in Hanau, Germany [112] has recently preferred incineration over pyrolysis both into this picture.

Tyre pyrolysis might have better chances in combination with the much larger volumes of other waste.
At the moment that the pyrolysis of domestic and agricultural waste will grow under environmental stress and will be considered as a useful method for the production of raw materials, these installations should be designed or adapted to the addition of worn tyres as a - relatively small - part of their feedstock.
In this relation the need and the extent of tyre size reduction should be investigated.

2.3.4. Appendices.

APPENDIX 1

Some calculations about the maximum share of retreaded tyres in the replacement market.

Assumptions:

1. The total capacity of the tyre replacement market is constant.
2. Each retreading operation will add to the tyre a new life-time that is equally long as the first life-time.
3. After each useful life-time every 100 worn tyres are replaced by x units of new tyres and (100-x) units of retreaded tyres.

If r_1, r_2, r_3 etc. are retreadabilities of worn tyres for the first, the second, the third etc. reconditioning operation, it can be easily seen that after a number of useful life-times a stabile situation will be generated in which:

$x + r_1x + r_1r_2x + r_1r_2r_3x + \ldots\ldots = 100$

Car tyres

$r_1 = 0.45$
$r_2 = r_3$ etc. are zero (chapter 4.1.1. table 2)

$x + 0.45x = 100 \qquad x = 69\%$

Maximum replacement share of retreads: 31%

Truck and bus tyres

$r_1 = 0.70 \qquad r_2 = 0.425 \qquad r_3 = 0.175$
r_4 etc. are zero (chapter 4.1.1. table 2)

$x + 0.7x + 0.7.\ 0.425x + 0.7.\ 0.425.\ 0.175x = 100$

$x = 48.8$

Maximum replacement share of retreads: 51%.

It can be shown that the maximum reuse of worn truck and bus tyres by retreading cannot be reached in one or two life-times (1LT = about 1½ year) Starting completely with new tyres this point will be reached after 5 life-times. (see example below).
Starting with an existing share of retreads the point of maximum recycling will be reached earlier.

EXAMPLE

Successive life-times	Units available 1)	Units replaced 1)
1	all new	100 N
2	48.8 new R_1 (potentially) 0.7 x100 = 70 Not retreaded 70 -51.2 = 18.8	48.8 N 51.2 R_1 + 100.0
3	48.8 new R_1 0.7 x48.8 = 34.2 R_2 (potentially) 0.425x51.2 = 21.2 Not retreaded 21.2 -17.0 = 4.8	48.8 N 34.2 R_1 17.0 R_2 + 100.0
4	48.8 new R_1 0.7 x48.8 = 34.2 R_2 0.425x34.2 = 14.5 R_3 (potentially) 0.175x17.0 = 3.0 Not retreaded 3.0 - 2.5 = 0.5	48.8 N 34.2 R_1 14.5 R_2 2.5 R_3 + 100.0
5	48.8 new R_1 0.7 x48.8 = 34.2 R_2 0.425x34.2 = 14.5 R_3 0.175x14.5 = 2.5 all retreadable tyres are retreaded	48.8 N 34.2 R_1 14.5 R_2 2.5 R_3 + 100.0
6 etc.	Situation stabile.	

1). N = new tyres
R_1 = first retreads
R_2 = second retreads
R_3 = third retreads

APPENDIX 2

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201 U.S.P. 3.726.944 April 10 (1973)	Phillips Petr. Co.	: Resilient Material.
202 GB 1.368.772 October 2 (1974)	G.O. Ewart	: Highway crash barrier.
203 GB 1.334.718 October 24 (1973)	Union Carbide	: Recovery of rubber.
204 DOS 2.159.735 June 14 (1973)	Dunlop AG	: Ion-exchangers prepared from rubber tyre scrap.

205 DOS 2.036.905 December 1 (1971)	Dunlop Holding Ltd	:	Mixed casting material consisting of elastomer particles dispersed in etc.
206 DOS 2.229.169 January 10 (1974)	Dunlop AG	:	Verfahren zur Nutzbarmachung von Abfällen aus Gummi und Polyaethylen etc.
207 DOS 2.137.891 February 15 (1973)	E. Schieling	:	Altgummimehl enthaltende Kautschukvulkanisate hoher Rissbeständigkeit.
208 Ned. Octrooiaanvrage 7.214.628 May 2 (1973)	N. Hemmings	:	Snijmachine.

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PART 3. :

RECYCLING TIRES IN THE RUBBER INDUSTRY

PART 3.

RECYCLING TIRES IN THE RUBBER INDUSTRY

CONTENTS

PART 3. : RECYCLING TIRES IN RUBBER INDUSTRY

3.1. SUMMARY.

In the rubber industry two recycling processes are being applied for the reuse of waste rubber since a long time :

- RETREADING or the reconditioning of worn tyres
- RECLAIMING or the conversion of waste into regenerated rubber.

As the production costs of these two processes could not be properly estimated, a comparison has been made between an optimal expansion of these processes and the existing situation in the EEC.

In this context optimal expansion is defined as a condition inwhich all suitable car tyres are being retreaded and the remaining available worn car tyres are being reclaimed.

The existing situation has been calculated as an average from figures available from the various EEC countries.

It was calculated in this report that the optimal production of retreaded car tyres could lead to a saving on present production costs of rubber articles amounting to 350 EUA* per ton of additionally converted waste and furthermore to a waste reduction of about 13 % of the present tonnage of waste.

About the same figures are found for the increased production of reclaim.

On the other hand it is evident that the success of recycling methods like retreading and reclaiming is dependent on costs of the processes and market conditions.

The image of car tyre retreads and reclaim (regenerated rubber) needs improvement. Both processes have to be promoted by means of marketing assistance and the establishing of suitable quality control methods.

Governmental aid will be necessary to speed up this promotion ; technically by means of suitable specifications (cahiers de charge) and economically by sponsoring research as outlined in the appendices 2, 3 and 4 of this report.

* 1 EUA : 1 European Unit of Account : Hfl. 2.81 (october 1977)

3.2. CONCLUSIONS ABOUT RECLAIMING AND RETREADING.

3.2.1. *Present situation in the retreading and reclaiming industry*

Tyre retreading and production of reclaim results in useful products. At the same time the contribution of these industries to the waste rubber recycling cannot be neglected.
Further expansion is hampered by technical problems caused by the limitations of existing equipment, the changing tyre constructions and by marketing problems caused by lack of generally accepted quality standards, inproper presentation and image of the recycled products and materials.
The existance of a wide variety of production methods, the confrontation with new machinery - presented for better economy but requiring high capital investments - and the relatively small price differences with competitive materials during the last decades are factors that make it difficult to get a clear picture of the development of retreading and reclaiming in the near future. No doubt the limited response on questionnaires and visits was influenced by the same factors.
On the other hand the great activity of manufacturers of machinery is an indication that the retreading and reclaim producing industries are still being considered as an important future market.

3.2.2. *The potential effects of increased retread and reclaim production*

A further expansion of both retreading and reclaim production will be possible provided the existing industries will be assisted with technical and marketing research.
A conservative calculation was carried out, disregarding all worn tyres on wrecked cars, tyres dumped at locations difficult to access at the present time and considering half of the remaining available worn car tyres to be retreadable.
It was calculated that the amount of waste car tyres in the EEC could be reduced by 139 000 tons annually of which 64 000 tons could be recycled by additional retreading and 75 000 tons by the production of additional reclaim.

At the same time the increased retreading and reclaim production would lead to annual savings on raw materials and energy of about :

- EUA 23,000,000 or Hfl. 65,000,000 on RETREADING
- EUA 26,500,000 or Hfl. 74,000,000 on RECLAIMING.

The potential effects of both processes have been condensed in the table and the diagram below.

TABLE 3.1.

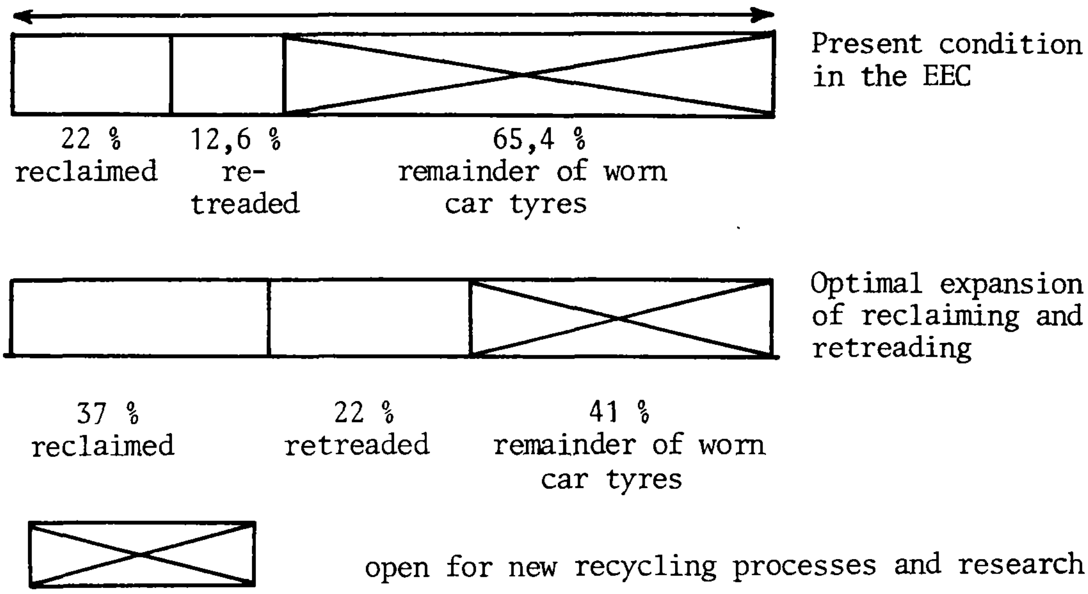
Economical and ecological effects of increased reclaim and retread production.

	Production of additional reclaim	Production of additional retreads
Savings on present production costs of rubberarticles in the EEC. EUA per ton of additionally converted waste	355	350
Waste reduction in the EEC in % of the total tonnage of worn car tyres	11	9
Waste reduction in the EEC in % of the present tonnage of waste	15	13

The effects of conventional recycling processes on the remainder of worn car tyres.

Comparison of present and optimal situation (see appendix 1).

100 % = total tonnage of worn car tyres (680,000 ton)



3.2.3. Policy

Both the retreading industry and the production of reclaim are not expected to lead to complete recycling of rubber waste. Additional methods as mentioned in the literature survey (2.3) should be evaluated or developed to fill the gap between total recycling and the capacity of existing methods.
Nevertheless retreading and reclaim production should be further assisted and equally promoted and other recycling methods should not work out at the expense of the existing industry.

3.3. RECOMMENDATIONS.

3.3.1. Distribution pattern of rubber scrap

A clear picture is needed of the distribution pattern of rubber scrap in the EEC.
Key factors in this pattern are local retreaders, reclaimers, scrap dealers and the tyre servicing trade.
A combined effort of these disciplines should be encouraged and should be coordinated by a qualified organization.

3.3.2. Presentation and quality standards of car tyres retreads and reclaim

Better presentation and quality standardization of retreaded tyres and reclaimed rubber should be promoted and should be assisted by research. Related proposals are presented in the appendices 2 and 3.

3.3.3. Rubber powder

An expanding market is expected for crumb and powder from worn tyres.
The present requirements of this market (sporting applications and sound insulation) are fulfilled with by - products and intermediate products of the retreading and reclaim production processes, but additional and better grinding facilities will be needed in the future.
High quality applications for tread buffings of the retreading industry should be investigated as well as methods for the production of very fine powder.

Unretreadable tyres should not be scrapped but converted to reclaim or powder for instance.

Related proposals are presented in appendix 4.

3.4. *VISITS TO THE RECYCLING INDUSTRIES.*

The results of the questionnaires have been discussed at the meeting of February 2nd. 1977 in Paris between BRGM, KRITNO and DEMP delegates. The minutes of this meeting are laid down in our interim reportnumber 59/'77 of February 11th. 1977.
It was decided to split up the work into subjects rather than into countries. Retreading and reclaiming were allocated to KRITNO and incineration, pyrolysis, cryogrinding and road surfacing to BRGM.

The response of the retreaders to the enquiry being insufficient, visits were planned to the centre of the rubber industry in France: Clermont Ferrand. Unfortunately there was no admission to the Michelin works, ⁂ centre of retreading, reclaiming, grinding and incineration (Michelin is holder of the patent of the radial tyre dating from June 4th. 1946). Therefore, it was decided to visit the Tyre and Equipment Exhibition in London of March 22-24th. 1977 in order to be informed about the latest developments in this field (see chapter 3.5).

Furthermore United Reclaim in Liverpool and UMAC Antwerp were visited in view of their specific comments in the questionnaires.

In France visits were paid to Wattelez Paris as their products (rubber powder) were presented in a good documentation and also to SOGECAP in Clermont Ferrand an important waste converter.
In London APEX rubber company was interviewed about the scrap market.

3.4.1. *Visits to the reclaiming industry*

During the past 10 years the reclaim consumption in England has fallen from 46 000 t/a to 20 000 t/a.
United Reclaim processes two million car tyres a year with a yield of about 80% or 13 000 t/a of reclaim by means of the Reclaymator process. In addition 7000 t/a of rubber powder is grinded.
UMAC stopped the reclaim production some years ago due to economical reasons like low prices of other rubber compounding materials.
Though the rising crude oil prices may change the market, a drawback will be the radial tyre with steel wire reinforcement. New equipment has to be installed to handle these tyres. The yield per radial tyre will also decrease.
Discussing marketing problems, it was concluded that the presentation of reclaim needed improvement.
Comparisons were made with the marketing of SMR virgin rubbers.
Masterbatches of reclaim with carbon black, oil, rubber powder should equally be considered.

⁂ BRGM was allowed to visit the works at a later date after a special request.

Furthermore it was advocated that new outlets should be explored in the building industry and in road surfacing.
However, governmental support is required for the development of these activities (research, investments etc.).

3.4.2. *Visits to the manufacturers of rubber powder*

Two firms were visited, which were active in the rubber powder market, having large stockyards with all sorts of waste rubber and also plastic waste.
Discussions revealed that in France rubber goods manufacturers do not produce as much rubber powder as in other countries. This job is left in France to some specialized firms like "Wattelez" which have the necessary equipment as discgrinders working with a greater efficiency than fluted rolls. At present the market for "contract grinding" is flourishing and an average production of 700 t/a of special powder can be made with a moderate sized installation.
Transport costs are reasonable within a circle of 500 km.
Besides contract grinding, rubber powder is sold, however the market is limited and the marketing of powder has to be improved to eliminate barriers in "cahiers des charges" of the road building and housing societies, the Government included.
Research is necessary on the surface activity of rubber powder, as some mechanical properties of rubber compounds may be influenced by the addition of crumb. Similar comments were made by Sogecap in Clermont Ferrand, a firm also active on the recuperation of metals and plastics.

3.4.3. *Visits to Apex Rubber Company, scrap dealer*

Rising market prices of virgin rubbers will favour the scrap market. The conversion of scrap into reclaim is preferred as reclaim has more applications than rubber powder. The market for powder will be limited also as a consequence of the high prices of powder.

3.5. VISIT TO THE TYRE AND EQUIPMENT EXHIBITION IN LONDON.

This exhibition was visited on March 22-24th. 1977 in order to obtain additional information about retreading processes and costs.

The major technical problems in retreading are related to the complexity of tyre sizes, tread widths and the variable expansion of the tyre casing during its original use. This forces the retreader to maintain a large inventory of moulds. Increasing costs of labour and energy are leading to smaller profits.

At the exhibition demonstrations were given of the two main methods of retreading, viz. "hot cap" and "cold cap".

3.5.1. Hot cap method

The unvulcanized treadrubber compound is applied on the casing by hand or it is extruded directly on to the casing without the use of cement or cushion gum.
This latter method has been developed by Barwell in England.

The Orbitread method automatically builds up a tyre by extruding parallel rubber strips on the casing.

Both methods allow savings in building time and in costs regarding the stocking of camelbacks.
A variety of sectional moulding equipment was shown for the vulcanization of the tread at temperatures as high as 180 C.

3.5.2. Cold cap method

This method is applied for retreading an increasing number of truck tyres, using pre-cured treads in the form of strips, fabricated by many rubber factories (Avon, Bandag, etc) or rings (Marangoni, RTS ltd, Kenprest etc).

Curing is carried out at lower temperatures, for instance in hot water of 95 C. Interviews revealed that this method will be used for the reconditioning of car tyres as well. However, material costs will be higher than those of conventional camelbacks.

3.5.3. *Retreading costs*

Talks with the delegates of the firms, mentioned above showed that a cost analysis of cold- and hot cap methods is difficult because of the large number of variable costs involved, for instance, stocking of camelbacks or precured treads, different leasing systems of machines or whole processes etc.

In the USA the American Retreading Association (ARA) has spent considerable effort in making some estimations. The following data were presented by Mr. Wagner:

TABLE 3.2.

Average USA processing costs in pence per pound of tread rubber

Year	1974	1975	1976	1977	Mass of rubber used:
Car tyre	38	42	45	49	9 lbs
Truck tyre (conventional)	47	52	56	61	25 lbs
Truck tyre (precure)	76	84	90	97	25 lbs

TABLE 3.3.

USA material and labour costs per pound of tread rubber also in pence (1976)

	Conventional		Precure
	Car	Truck	Truck
Material	24	35	64
Labour	10	10	14
Overhead	11	11	12
Total	45	56	90

The material costs of precured treads compared to ordinary camelbacks are about 80% higher, however, the mileage of the precured tread is said to be twice as much.

3.5.4. *Future trends*

The technical future of the retreading industry is difficult to predict as it will be influenced by several factors like : changes in tyre design, the development of other retreading systems and the availability of worn casings.

Tyre design

Tyre design is related to wear resistance, safety, comfort and vehicle construction: tyres are not designed for the purpose of retreading.
At present there is a change to radial tyres with a trend to lower section heights and wider treads. The changes are facing the retreaders with problems as diagonal casings will become absolete and radial casings need adapted equipment.
After this turn-over a more stabile situation is expected and the related problems can be overcome.
It is not to be expected that the number of rim sizes and tread widths will be greatly reduced by standardization. However, adaption of one general code system in view of tolerated speeds and loads as proposed by ISO for new tyres as well as for retreaded tyres might take retreaded tyres out of their isolated position and promote their acceptance by the consumers.

Other retreading systems

Simple retreading systems like the ring-tread-system will be of special interest to car owners making a high mileage and may have a positive effect on car tyre retreading.

Availability of worn casings

Worn casings are the feedstock for retreading.
No clear picture is available about the availability of worn casings in the EEC and their retreadability. Moreover the situation seems quite variable in different countries.
Research on this subject will be necessary and is proposed in appendix 2.

3.6. RECYCLING METHODS FOR TYRES.

Some important ways for real recycling can be described as follows:

Reuse of the worn tyre provided with a new tread.
The retreaded tyre has the same milleage as a new one. In the case of truck retreads second and third retreads are possible.

Reuse of the worn tyres in the form of a rubbery substance by chemical means (regenerated rubber or reclaim) or mechanical means (rubber powder).

Conversion of the worn tyre by means of incineration or pyrolysis into steam and chemical products.

In our literature survey (2.3.) these methods are already described.

It is evident that retreading cannot be the ultimate solution for reuse of worn tyres as sooner or later each casing will not be retreadable any more. However, without retreading, the amount of scrap tyres would be 16% higher according to the figure 3.1.

3.6.1. *The retreading industry in the EEC*

3.6.1.1. *Present situation*

Several sources had to be used to trace the numbers of retreads of car tyres, such as publications of Retreader Organizations (BIPAVER, ARA, VACO, Zentral verband des Deutschen Vulkaniseurhandwerks) and the report by G. Cheater c.s.
Some indications on the situation in France are reported in Revue Générale de Caoutchouc et Plastiques (October 1974, nr. 10, page 691 - 695).
The Italian situation in retreading is outlined in Pneurama (3, 1974, etc.).

It appears that the situation in the retreading industry is different in the various EEC countries.
Examples are the size of the installations, the links with tyre manufacturers, processes used, etc. In BIPAVER conferences it has been stressed that retreading contributes to economical vehicle operation and leads to savings in raw materials and energy. This contribution should be more firmly recognised and supported in the EEC by the relevant governmental institutions.

In chapter 3.5 it is reported that manufacturers of equipment in England, Italy, BRD and France are constantly developing better methods in order to improve and increase the production of retreads. The extruder-builder and the precured tread are examples in this respect.
Furthermore BIPAVER is concerned about the condition of retreadable casings, which are feedstocks for the process. For this reason and for safety reasons a pattern depht of at least 2 mm is advocated.

Calculations about the influence of retreading on the disposal of used tyres are difficult as a stable condition in the tyre market does not always exist. As the production of cars slowed down due to the energy crisis, part of the tyres for "original equipment" were put in the replacement market disturbing to a certain amount the car retreads/scraptyres ratio.

3.6.1.2. *Retreading data about car and truck tyres*

BIPAVER published the following data for the year 1974.

TABLE 3.4

Retreads in percents of replacement sales

	France	BRD	Holland	Italy	England	USA
Car tyres (new)	95	73	85	73	72	78
Car tyres (retreaded)	5	27	15	27	28	22
Truck tyres (new)	51	51	51	50	65	62
Truck tyres (retreaded)	49	49	49	50	35	38

This table shows that in most countries of the EEC retreads of truck tyres have a share of 50% in the replacement market due to the fact that they are retreaded two or three times and even more. These tyres are handled with care by truckers as considerable savings can be obtained.

For car tyre retreading, however, the situation is different. In the first place the relative price difference between new and retreaded tyres is much lower. Furthermore the casing is more vulnerable to damage and therefore will require more inspection prior to retreading.
At last the market for retreaded car tyres is influenced by the fact that these tyres are often considered to be second quality. According to table 3.4 the market for car retreads is on the same level in BRD, Italy and England, having a share of 28% of the replacement market.
In France the share of car retreads is low. If an increase to the same level would be possible, a capacity increase of about 4 times would be required. Also in Holland some increase would be possible.

In the report by G. Cheater it is shown that the maximum share of retreads sold could be 1/3 of the total sales of replacement tyres if half of the used tyres are accepted as suitable for retreading and a stable market is assumed.
It is, however, questionable whether this maximum could be reached under the present conditions of the market.
In the case of truck tyre retreads a higher replacement share than about 50% seems to be impossible: (see literature survey (2.3.)).
This figure is already realised to a great extent in the EEC due to a more stable condition of the market.

Considering the car tyre replacement market it can be assumed that the mean present share of retreaded car tyres in the total EEC replacement market is mainly determined by the 4 largest consuming countries. This leads to an average value of 22% of car retreads in the EEC replacement market (France 5%, BRD and Italy 27%, England 28%).
As no retreads are used as original equipment of new cars, the share of retreads in the total consuming market of the EEC (replacement and original equipment) should be lower than 22%.
In order to calculate this figure it was assumed that the ratio between total market and replacement market will be equal in all EEC countries and can be derived from the situation in England.

From the figures in table 3.5. it can be seen 16 % of the total English market for car tyres consisted of retreads.

TABLE 3.5.

Disposal of used tyres in England 1974.

	Car	Truck
Total worn tyres	23 467 588 units 159 580 ton	3 394 319 units 135 773 ton
Tyres in vehicle scrap yards	23 %	19 %
Tyres to reclaimers	22 %	0 %
Tyres exported	5 %	7 %
Tyres retreaded	16 % (50% suitability)	28 % (65% suitability)
Tyres rejected by retreaders	16 %	15 %
Unknown remainer	18 %	31 %
Total	100 %	100 %

In the table 3.4. it is shown that 28 % of the English replacement market for car tyres consisted of retreads.

So the above mentioned ratio for the EEC is estimated at $\frac{16}{28} = 0.57$ and the present share of retreads in the EEC car tyre consumption will amount to 0.57 x 22 % = 12.6 %.

The share of new tyres is 87.4 % which is equal to about 110 million new tyres in the EEC in 1975. So the number of car retreads produced in the EEC is about
$\frac{12.6}{87.4}$ 110 million = 16 million units.
From data in retreader's journals this amount could be roughly divided as follows (in millions) :

BRD 5, Italy 4, England 3.7, France 2, Benelux 1.3 (millions of retreaded car tyres).

3.6.1.3. *Possibilities for increased retreading of car tyres*
In appendix 1 it is calculated that a maximum of 22 % of the EEC car tyre consuption might be covered by retreaded tyres. For that calculation worn tyres on wrecked cars in scrap yards and at unknown locations were considered not to be usefull or not available for retreading. The net effect of imports and exports of worn casings and retreaded tyres was neglected. Furthermore was assumed that 50 % of the remaining worn tyres would be retreadable.

It was found in that way that optimal retreading of car tyres would lead in the EEC to a decrease in tyre disposal of 64 000 ton annually and to a saving in cost of Hfl. 65,000,000 annually.

3.6.1.4. *Research activities on retreading*

The distribution pattern of used and retreaded tyres has been studied in the Netherlands by SVA (Stichting Verwerking Afval). According to this study tyre servicing centres play an important part in the distribution of new and retreaded car tyres whereas the share of casings handled by scrap dealers cannot be traced with sufficient accuracy.

A research proposal on the availability of sound casings and distribution patterns is outlined in the appendix 2 sub. 1.

In the period 1950-1960 KRITNO tested a great number of camelbacks made from NR or SBR, taken from the market. Quality control has been the subject of various BIPAVER meetings, but so far no research has been carried out. The existing requirements established in above period by KRITNO have to be updated.

A research proposal for quality control of tread rubber is indicated in the appendix 2 sub. 2.

In the USA a start was made with quality control systems aiming at labelling of complete retreaded tyres and regulations about product liability.

Up till now these attempts have not been succesful mainly because of differences in opinion about the severity of testing. Nevertheless a quality control system will be needed and related research is proposed in appendix 2 sub. 3.

3.6.2. *The reclaiming industry in the EEC*

3.6.2.1. *Present situation*

As reported in chapter 3.4. of this report, the reclaiming industry is facing many difficulties regarding production and sales. Many specifications do not allow the incorporation of reclaim in rubber coumpounds. During the past 10 years consumption of reclaim in England has fallen from 46 000 t/a to 20 000 t/a. The drop in consumption is largely accounted for by the reduction in the number of plies in tyres casings. In the USA reclaim consumption has decreased rapidly as well and consequently the production has fallen from 280 000 ton to about 80 000 t/a in the last 10 years (figure 3.2.).

In France only 12 000 t/a of reclaim is produced from the 400 000 t/a of waste rubber (about 3 %). The use of reclaim in non-tyre goods, especially cheap articles as matting, soling etc. is influenced by prices of virgin rubber, cheap fillers as clays, whiting, extenders like aromatic and naphtenic oils and further more the prices of carbon blacks. The market price of whole tyre reclaim is now about £ 150 - £ 200 per ton in England.

In the Comecon countries like Poland and Hungary reclaiming is furthered ; see our survey of literature (2.3.)
The present market in EEC and EFTA is estimated at 100 000 t/a increasing to 120 000 t/a in the next 5 years.

The future may well see a recovery in consumption due to rises of prices of above materials. There are processing and energy benefits to be gained.
Moreover savings in imports of virgin rubber can be obtained.

3.6.2.2. *Possibilities for increased reclaim production*

In appendix 1 the effect is calculated of "optimal" reclaiming. If the present reclaim production in the EEC is assumed to be 22 % of the total arisings of worn tyres an increase would be possible to 37 % using the reject tyres from optimal retreading and all other worn car tyres except those on scrapped vehicles and at unknown locations.

This extra reclaim production is 75 000 ton, which could lead to the substitution of 1.5 % of the existing compounds.

The savings which can be obtained at 1.5 % substitution of the existing compounds will be Hfl. 74,000 000 ($ 30,000,000). After optimal retreading and reclaiming there still will be left 41 % of waste tyres, being 23 % worn tyres on vehicles in scrap-yards and 18 % at unknown locations.

3.6.2.3. *Research activities*

The main drawbacks of the present reclaim are its price and its adverse effects on some mechanical properties of rubber products as a result of impurities and main chain degradation of the original polymer (see our survey of literature page 47). Research on the improvement of the process has not been carried out to a large extent, with the exception of Hungary, where the Palma process has been developed (see p. 39).

It is known that high energy radiation is causing break-down of rubber. This phenomenon is studied in France by CAPRI. The results may lead to a new process for the production of reclaimed rubber.
In the USA much research has been carried out on the application of reclaim in the innerliners of tubeless tyres and as an addition in binders, adhesives etc. Many patents exist about these subjects.

In the appendix 3 three research proposals are given on the quality control, on the influence of reclaim on existing rubber compounds and on the new machinery needed for shredding steel braced radial tyres.

3.6.3. *The manufacture of ground scrap*

3.6.3.1. *Present situation*

Methods and equipment for the reduction of vulcanized rubber are described in our literature survey (see part 2).
At the monent rubber powder is preferably made from waste rubber not containing fibres.

However, retreaders are producing raspings from treads as a by-product amounting to about 1 kg per car tyre and 10 kg per truck tyre.
In England the amount of raspings is about 17 500 t/a which at the present time is applied in matting and sporting applications. After grinding this amount could be used as a more valuable additive in rubber compounding. The advantages claimed for powder are better mould release, better control in extrusion and stiffening of the compound.

As the total retreading capacity of the EEC is about 4 times as large as in England (chapter 3.6.1.2.) total EEC production of raspings can be estimated at about 70 000 t/a. The total EEC production of rubber compounds is estimated at 5 million ton (chapter 2.2.2.).
Powder from raspings would amount to 1.4% of total EEC rubber compounds. This amount could be easily absorbed.

3.6.3.2. *Possibilities for increased ground scrap production*

When large markets will be developed for ground scrap in road surfacing, sporting and flooring applications (literature survey 2.3.)page 50 and part of the treading raspings will be used for powder production, additional grinding of worn tyres will be needed.

3.6.3.3. *Research activities*

In England SATRA has studied the influence of ground waste on soling compounds. In the Netherlands KRITNO has also carried out experiments with the incorporation of coursely ground scrap in rubber compounds. CAPRI in France is studying the effect of radiation on the surface of rubber particles.

In appendix 4 research proposals are mentioned on the influence of particle size of rubber powder on rubber compounds, on powder technology of masterbatches with virgin rubber powder, on suitable binders and on the use of rubber powders as an additive to plastics to improve the impact strength.

3.7. APPENDICES.

APPENDIX 1

The effects of optimal car tyre retreading and reclaiming on waste disposal in the EEC and on economy of production

1. General principles

All retreadable worn tyres will be retreaded.
The remainder of worn tyres will be converted into reclaim.
Tyre disposal will be limited to worn tyres that - for technical or logistic reasons - cannot be retreaded or converted into reclaim.

2. Basic considerations in marking the calculation

Tyre consumption = new tyre consumption + retreaded tyre consumption
Annual EEC tyre consumption = annual worn tyres in the EEC = 100 million units

The retreadability of worn new tyres = 50% (chapter 3.6.1.2.).

The average weight of a worn tyre = 6.8 kg.

Worn retreaded tyres cannot be reused for further retreading.

Worn retreaded tyres are equally useful for reclaiming as worn new tyres.

The part of worn tyres transferred in the EEC into reclaim at the present time is supposed to be equal to the UK figure presented in table 5 = 22%.

Worn tyres at unknown locations and on wrecked cars in scrap yards are not available and will never be available both for retreading and for reclaiming operations.
The related figures of both categories as mentioned for the UK in table 3.5. (18% and 23% respectively) are supposed to be equally valid and constant for the whole community.

3. Present situation in the EEC per 100 units of tyres

Consumption:

Retreaded tyres	: 12.6 units ($\frac{16}{28}$ x 22, chapter 3.6.1.2. and fig. 3.1.)
New tyres	: 87.4 units + (remainder)
Total consumption	: 100.0 units

Destination of worn tyres:

Worn tyres		100.0 units
Retreaded tyres	12.6 units	
Reclaimed tyres	22.0 units +	
Recycled tyres		34.6 units -
Disposed tyres (by difference)		65.4 units

4. Situation in the EEC per 100 units of tyres at optimal retreading and reclaim production

Retreaded tyres consumed= worn retreaded tyres = x units.
Worn new tyres = (100 - x) units.
Worn tyres on vehicles in scrap yards : 23 units (damaged)
Worn tyres , location unknown : 18 units + (vanished)

Worn tyres not considered for retreading 41 units

Worn new tyres in this category : $\frac{(100 - x)}{100}$ 41 = (41 - 0.41 x) units.

Worn new tyres available to retreaders:

100 - x - (41 - 0.41 x) = (59 - 0.59 x) units.

Retreaded tyres at 50% retreadability:

0.5 (59 - 0.59 x) = x x= 22 units.

Out of the worn new tyres 2x22 = 44 units are transported to the retreaders.

Retreaded out of 44 units : 22 units
Rejected = reclaimed : 22 units

Out of the remaining worn tyres (100 - 44 = 56 units) the worn tyres on scrapped vehicles and those of unknown location cannot be reclaimed = 18 + 23 = 41 units.

Available for reclaimers : 56 - 41 = 15 units.

Total available for reclaimers : 22 + 15 = 37 units.

Consumption:

Retreaded tyres : 22 units
New tyres : 78 units +

Total consumption : 100 units

Destination of worn tyres

Worn tyres		100 units
Retreaded tyres	22 units	
Reclaimed tyres	37 units +	
Recycled tyres		59 units -
Disposed tyres (by difference)		41 units

5. Decreased waste disposal in the EEC by optimal retreading and reclaiming of car tyres

Present disposal per 100 units of worn car tyres:

Worn tyres 65.4 units = 65.4 x 6.8 kg = 445 kg.

The reclaiming of a worn tyre of 6.8 kg produces 5 kg of reclaim and 1.8 kg of waste.
Waste from reclaim production 22.0 x 1.8 kg = 40 kg
Total waste per 100 units : 445 + 40 = 485 kg.

Optimal disposal per 100 units of worn car tyres :

Disposed tyres 41 units = 41 x 6,8 kg = 279 kg.
Waste from reclaim production 37 x 1.8 kg = 67 kg.
Total waste per 100 units : 279 + 67 = 346 kg.

Waste reduction at 100 million worn tyres annually:

$$\frac{10^8}{10^2} \times (485 - 346) \times 10^{-3} \text{ ton} = 139\,000 \text{ ton}$$

Contribution of optimal retreading to waste reduction:

$$\frac{10^8}{10^2} (22.0 - 12.6) \times 6.8 \times 10^{-3} \text{ ton} = 64\,000 \text{ ton}$$

Contribution of optimal reclaiming to waste reduction:

139 000 - 64 000 = 75 000 ton

6. Economic savings in the EEC by optimal retreading and reclaiming

The oil equivalents of new and retreaded tyres are 22.5 and 8.5 litres of oil respectively. *

* Personal communication.

Present situation in litres of oil per 100 units of worn tyres:

New tyres	87.4 x 22.5	= 1966 l.
Retreaded tyres	12.6 x 8.5	= 107 l. +
		2073 l.

Optimal situation in liters of oil per 100 units of worn tyres:

New tyres	78 x 22.5	= 1755 l.
Retreaded tyres	22 x 8.5	= 187 l. +
		1942 l.

Savings at 100 million units of worn tyres (= tyre consumption) =

$\frac{10^8}{10^2} \times (2073 - 1942) = 131 \times 10^6$ liters of oil.

As 1 litre of oil is about Hfl. 0,50 the total EEC savings by optimal car tyre retreading amount to roughly Hfl. 65,000,000. = EUA 23.000.000 ($ 26.000.000)

Extra reclaim production per 100 units of worn tyres:
(37 - 22) x 5 kg = 75 kg.

Total extra EEC reclaim production:

$\frac{10^8}{10^2} \times 75$ kg = 75 000 ton

EEC consumption of virgin rubber	: 2 million ton
Mean rubber content of rubber products	: 40 %
EEC production of rubber compounds	: $\frac{2 \times 10^6}{0.4}$ = 5 million ton.

If the extra reclaim production will be completely used as a substitute for existing rubber compounds (containing already some reclaim) this would lead to the substitution of

$\frac{0.075 \times 10^6}{(5-0.075) \times 10^6} \times 100\% = 1.5\ \%$ by weight of existing compounds.

This relatively small amount could be absorbed by the rubber industry. For relating remarks is referred to chapter 3.6.2.2.
For the sake of practical calculation it is assumed to be completely recycled to the existing rubber industry.

The cost of virgin rubber is about Hfl. 2,100 per ton.

The cost of rubber compounds compared to virgin rubber is decreased by the dilution with fillers, plasticizers etc.
On the other hand it is increased by the work for incorporation into the virgin portion.
Therefore the prices per unit weight of compounded and of virgin rubber are generally considered to be equal on average. The mean price of reclaim (containing) fillers, plasticizers etc. like existing rubber compounds) is about Hfl. 1,100 per ton.

Present annual value of EEC rubber compounds:

$5 \times 10^6 \times$ Hfl. 2, 100 $= 10^6 \times$ Hfl. 10, 500

1. 5% substitution by reclaim would lead to annual value of original compounds

$0.985 \times 10^6 \times$ Hfl. 10, 500 $= 10^6 \times$ Hfl. 10, 343

annual value of extra reclaim

75 000 x Hfl. 1, 100 $= 10^6 \times$ Hfl. 83

Total optimal value 10^6 (Hfl. 10, 343 + Hfl. 83) = $\underline{10^6 \times \text{Hfl. } 10,426}$

Annual savings by extra reclaim production

$10^6 \times$ (Hfl. 10, 500 - Hfl. 10, 426) = Hfl. 74, 000, 000 = EUA 26.500.000($ 30.000.000)

Total annual savings by optimal retreading and reclaiming:

Hfl. 65, 000, 000 + Hfl. 74, 000, 000 = Hfl. 139, 000, 000 = EUA 49.500.000($ 56.000.000)

APPENDIX 2

RESEARCH PROPOSALS ON RETREADING

1. Field research in the EEC about the availability of sound casings.

Scope of work
To trace the locations, the types, the numbers of worn casings and the costs for the collection and the selection of casings in the EEC.
To examine the possibilites of efficient transport to collection centres.

Aim of the research.
To further optimal retreading especially in the field of car retreads (see chapter 3.6.1.3. about savings in costs).

Time : about 1-2 year

Costs * : $ 60,000 - $ 120,000.

2. Laboratory research on the quality of camelback compounds and precured treads in the EEC.

Scope of work
To examine the quality of tread rubber on the basis of samples taken from the market in the EEC.
To determine the divergence in the levels of quality.

Aim of the research
To establish requirements for tread rubber.

Time : about 1 year

Costs * : $ 62,000 - $ 70,000

3. Research on the organization and the type of quality tests necessary for the evaluation of (car) retreads

Scope of the work
To establish a suitable plan for sampling retreads produced by small and big retreaders.
To carry out non-destructive and destructive testing.
To make a list of unacceptable defects.
To design a simulated service test.
Comparative testing with new tyres.

Aim of the research
To improve the image of retreads.
To further labelling as proposed by ISO
To develop simple and cheap equipment for the inspection (non-destructive) of worn casings and retreaded tyres.

* estimated

Time : to be estimated

Costs : to be estimated.

This is an ambitious program, which requires a lot of further preparation and organization.

APPENDIX 3

RESEARCH PROPOSALS ON RECLAIMING.

1. Laboratory research on the quality of reclaim.

   Scope of the work.
   To examine the quality of reclaim of known origin on the basis of samples taken from the market in the EEC. To determine the divergence in the levels of quality by repeated sampling.

   Aim of the research
   To develop a grading system by means of standard compounds.

   Time : about 1 year

   Costs : $ 44,000 - $ 60,000

2. Laboratory research on the influence of reclaim on existing rubber compounds.

   Scope of the work
   To examine the influence of reclaim on the processing of rubber compounds and on the mechanical properties of the vulcanizates in different fields (soling, basin and roofsheeting, matting, solid rims on wheels, tread rubber etc.). To make a marketing study of the usefulness of masterbatches of reclaim with powder and (or) oils.

   Aim of the research
   To improve the marketing of reclaim.

   Time : about 1-2 year

   Costs : $ 60,000 - $ 80,000

3. Research on the efficiency of equipment for the size reduction of steel braced radial tyres.

   Scope of the work
   To carry out tests on equipment with scrap radial tyres wire reinforcement. To make cost estimations for size reduction.

   Aims of research
   To promote economic size reduction.
   To recuperate steel wiring.

   Time and costs to be estimated.

APPENDIX 4

RESEARCH PROPOSALS ON THE RECYCLING OF RUBBER POWDER IN THE RUBBER INDUSTRY.

1. Laboratory research on the influence of particle size of rubber powder on the mechanical properties of vulcanizates.

   Scope of the work
   To sample rubber powder with varying particles sizes.
   To makes standard compounds with increasing content of powder of various particle sizes.
   To examine the processing and mechanical properties of these compounds.

   Aim of the research
   To promote the application of scrap powder in rubber compounds.

   Time : about 1-2 year

   Costs* : $ 60,000 - $ 80,000

2. Laboratory research on powder technology of mixtures of virgin rubber powder and scrap rubber powder.

   Scope of the work
   To examine dry blending techniques of compounds.

   Aims of the research
   To promote the use of ground scrap by the rubberindustry.
   To make savings in production costs.

   Time : about 1-2 year

   Costs* : $ 52,000 - $ 70,000

3. Laboratory research on suitable binders in order to produce sheetings and flooring of ground scrap.

   Scope of the work
   To examine existent and new materials to be used as a binding agent of ground scrap.

   Aim of the research
   To promote applications of ground scrap in flooring and sheeting.

   Time : about 1-2 year

   Costs : $ 70,000 - $ 100,000

* estimated

4. Laboratory research on the incorporation of ground scrap in plastics.

Scope of the work
To add rubber powder to polystyrene or PVC compounds.
To examine processing properties and mechanical properties.

Aim of the research
To improve the quality and to reduce the costs of high impact strength plastics.

Time : about 1-2 year

Costs : $ 80,000 - $ 100,000

APPENDIX 5

DEFINITIONS

Used or worn tyre	- A tyre which has been removed from a vehicle after use.
Scrap tyre	- A worn tyre which is unsuitable for reuse.
Retreading	- A method for reconditioning tyres by means of the replacement of the tread rubber on the casing.
Casing (carcass is an obsolete term)	- Laminated ply and bead structure of a tyre, consisting of reinforcing materials, interconnected by rubber compounds.
Bead	- That part of a tyre which is shaped to fit the rim, consisting of a steel wire reinforcement protected by wrappings.
Reclaim	- A sheeted, devulcanized polymeric material obtained by subjecting vulcanized rubber to a chemical process.
Crumb and powder	- Finely granulated vulcanized rubber scrap. The term powder is used for particles finer than 1 mm.
Tread raspings	- A by-product of the retreading process resulting from the partial removal of the tread of a worn casing.
Cushion	- Thin intermediate rubber layer between the tread and the casing.

APPENDIX 6

List of abbreviations

EEC	European Economic Community.
DEMP	Délégation aux Economies de Matières Premières, Paris, France.
BRGM	Bureau de Recherches Géologiques et Minières, Orléans, France.
KRITNO	Plastic and Rubber Research Institute TNO, Delft, the Netherlands (a subdivision of TNO).
TNO	Toegepast Natuurwetenschappelijk Onderzoek (Applied Scientific Research), The Hague, the Netherlands.
SATRA	Shoe and Allied Trade Research Association.
ARA	American Retreading Association.
RAPRA	Rubber and Plastic Research Association of Great Britain, England.
BRD	Bundes Republik Deutschland.
BIPAVER	Bureau International Permanent des Acheteurs et Vendeurs des Pneus Rechapés.
EFTA	Economic Free Trade Association.
ISO	International Standards Organisation.
CAPRI	A group of : Centre d'Etudes Nucléaires de SACLAY, France.
SMR	Standard Malayan Rubber.
RTS	Ring Tread System.
RSS	Ribbed Smoked Sheets.
NR	Natural rubber.
SBR	Styrene butadiene rubber (synthetic rubber)

vdV/RBM

FIGURE 3.1.

DISPOSAL OF USED CAR TYRES IN ENGLAND (reported by G.Cheater c.s. 1974).

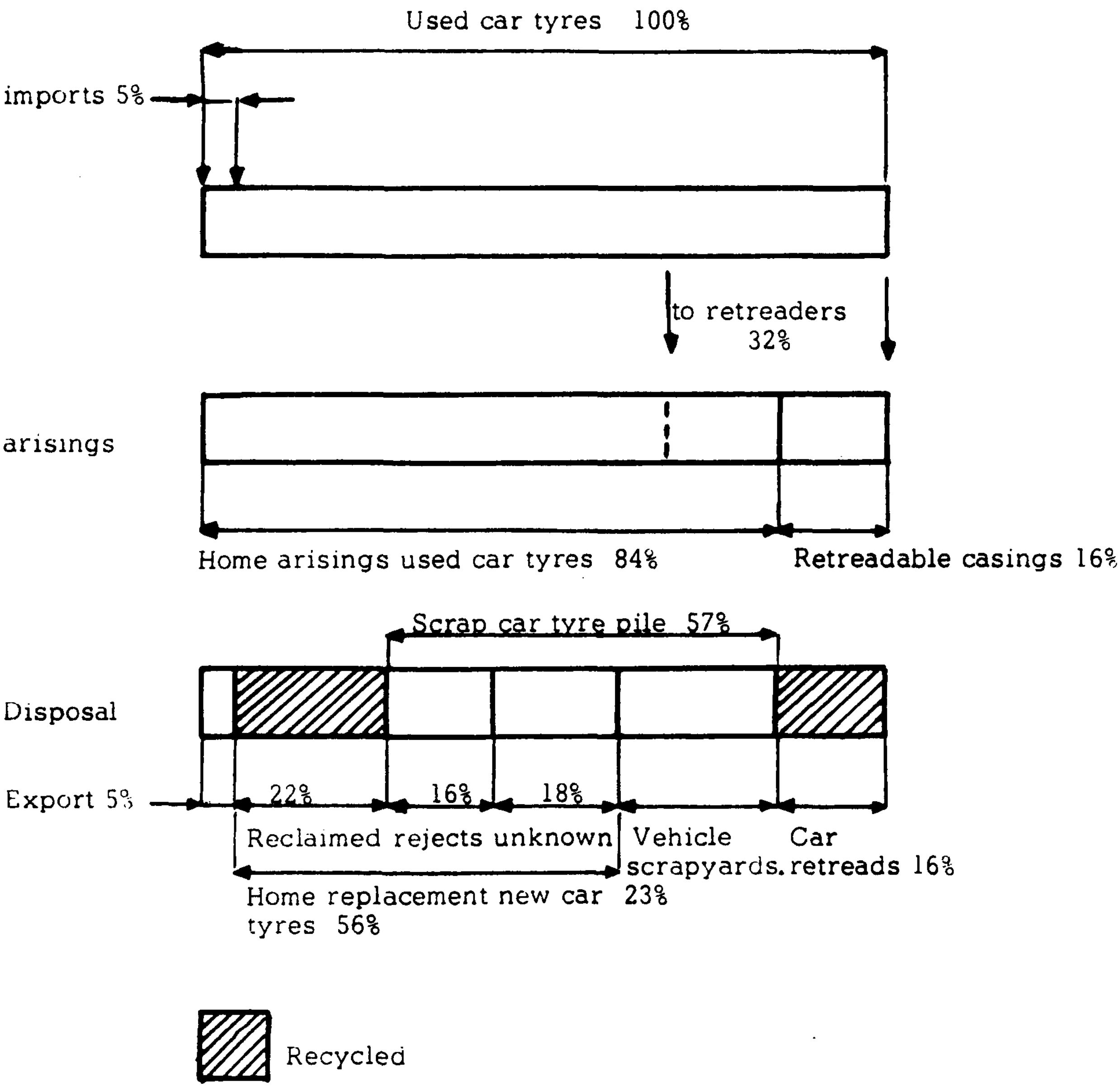
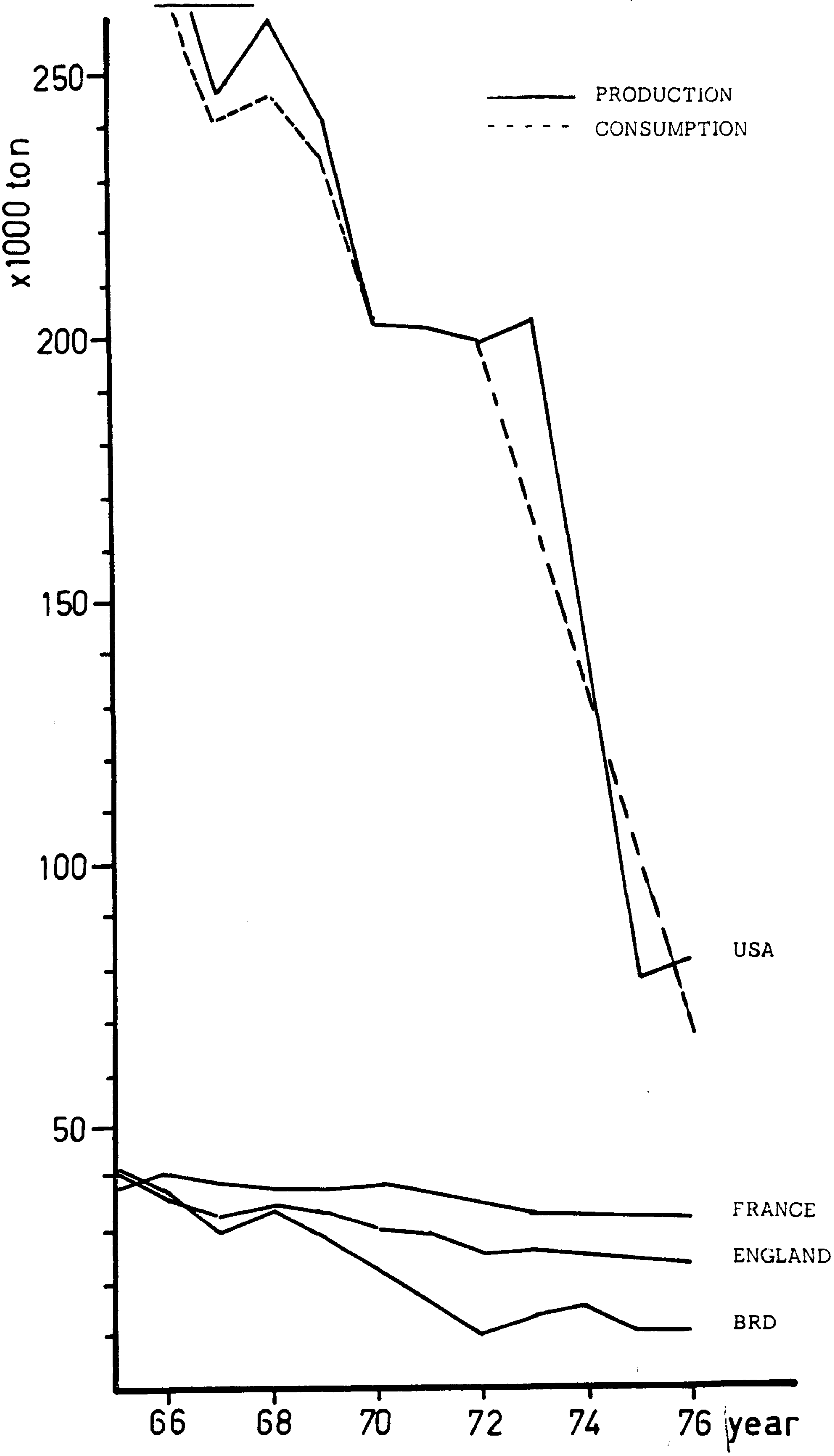


FIGURE 32 REGENERATED RUBBER (RECLAIM).



PART 4. :

REUSE OF SCRAP TIRES

PART 4.

REUSE OF SCRAP TIRES

CONTENTS

4.1. METHODOLOGY.

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CONTENTS

4.1. METHODOLOGY

A methodology has been developed by B.R.G.M. to try to give an homogeneous form to chapters of part four (reuse of scrap tires) and part five (size reduction). It is a fact that for chapters 4.4. to 4.10 and 5, there was a lack of information, but even for these chapters it has been thought useful to express financial figures in homogeneous units.

4.1.1. GENERAL METHODOLOGY.

This report must of course include a synthesis of collected information, but its main aim is to prepare choices for a research policy, and so to compare the interest of various ways to solve the problem. Each way has specific impacts on energy and raw materials supply, environment, keeping in use some activities ... Moreover, industrial application of the processes is more or less quickly possible. The duty of the enquiry is to indicate all known consequences of any choice, but the report must also give data which might help to choose :

- nature and amount of potential raw materials savings,
- potential financial balance,
- time needed before actual application.

Finally, it has to set out recommendations on the opportunity to help development of each class of processes, and to finance research to help such a development.

To gather these informations, each chapter will, as far as possible, include a classification of the processes, a table for the comparison of the processes and a specific conclusion. Moreover, it will be followed by an appendix containing detailed technical and economical information sheets for each process in the class.

Economic calculation has been done according to following method, when possible :

4.1.2. METHOD OF ECONOMIC CALCULATION.

One of the determining criterion in the choice of a policy is the *financial impact of this choice.* It should not of course, be the only criterion, other aspects like savings of raw materials, protection of employment, protection of the environment ... etc, should also be taken into account. But it is indispensable to supply the decision maker whenever this is possible, with information on figures on investments, running costs, market value of the products, probable profit or cost.

Unfortunately, when it is a question of judging the procedure completely, the obstacles are numerous :

- the data at one's disposal are usually confused or incomplete and may represent either evaluation of patentees determined to sell or primary estimations of researchers for processes which are still not perfect ;
- the year of validity is often not mentionned :
- the tax system, the cost of labour, of electrical energy and fuels, the transport costs, depend on the country and even on the town in which the plant is to be installed. In particular, the transport of waste products such as scrap iron, is very expensive compared to their value ;
- data concerning U.S.A., France and other European countries deal with very different kinds of tyre markets (size, durability, nature of the belts, size of installations) ;
- the results can be deformed by the use of inappropirate exchange rate, or a modification of the rate of amortization.

Of course, it would have been possible to fix rules to get around these difficulties, but we are convinced that the results obtained would only have the appearance of trust.

That is why we have chosen to apply a simple method :

- investments and the physical elements of the operational cost (labour, energy) are whenever possible clearly identified ;
- the figures retained are those supplied brought-up-to-date, if necessary, expressed in U.S. dollars for this currency plays an exceptional role in the industrial world and has a clear meaning in all countries ;
- whenever possible the operational costs have been readjusted from their physical components on the basis of \$ 6 per hour of labour, \$.04 per KWh, \$ 120 per tonne of fuel, figures which are reasonable for France in 1977 ;
- an approximate cost of treatment has been calculated from the formula :

$$\frac{\text{investment}}{5 \times \text{annual production}} + \text{running costs} ;$$

- whenever several hypotheses, are worth considering, these have been set out ;
- the costs of collecting the used tyres or other rubber products have not been taken into account. This latter point should be the subject of another study.

The figures thus given, are then *orders of magnitude* because we would be fooling ourselves to hope for better. They are sufficient to compare the financial rentability of classes of processes, like pyrolysis as compared to other classes.

On the other hand, it would be dangerous to use them for comparing for example, two methods of pyrolysis, because of the discrepancies set out above. At this stage, the comparison of equivalent processes, should then be made on technical and physical criterions.

4.2. PYROLYSIS.

4.2. PYROLYSIS

CONTENTS

4.2. PYROLYSIS.

4.2.1. DEFINITION.

A. ETIENNE defines pyrolysis in the following manner : "pyrolysis, pyrogenation or thermal decomposition is *the transformation of chemical compounds, by heat, without the intervention of secondary reagents.*

This fundamental process is characterized especially by the use of temperatures high enough to produce chemical, mineral and organic reactions.

The processes of pyrolysis are classed among the most important and the oldest of the chemical industry for they are, with the processes of air combustion, the most direct means of transformation of natural raw materials : wood, coal, petroleum, minerals, etc... Consequently, the products which they furnish are relatively cheap, utilizable as raw materials for other chemical reactions.

Thus, thermolysis of complex materials, like wood and coal was the basis of the first industrial processes for making compounds (gas and liquids) simpler than the original materials, and solid residual fuels (coke) ; the same treatment applied to liquid oils is more recent. These transformations form part of the process of cracking or of distillation (*) of these complex materials.

Cracking is defined by the Committee for the study of French Technical terms, as the chemical process which breaks and modifies the molecular structure of the hydrocarbons contained in petroleum, so as to transform the heavy fractions of this oil into light products. The implementation of the processes can be done without catalysers : *thermal cracking* or pyrolysis (**), or it can take place in the presence of catalysers, which consitutes *catalytic cracking* or pyrolysis. These definitions can be applied to all chemical compounds other than those of oil".

Pyrolysis of rubber waste consists of the breaking up of the vulcanized network into constituants of high molecular weight which are, in turn, cracked to give a whole range of hydrocarbon compounds of ranged molecular weight :

- a gas, resulting entirely from cracking,
- an oil, which is a mixture of the original oil which was used to make up the blend of rubbers and of products resulting from the depolymerization of the natural and artificial rubbers,
- a solid residue containing the original carbon clack which could come from the pyrolysis and diverse mineral compounds, like zinc oxide.

The distinction between pyrolysis and reclaiming is not as obvious as it seems at first sight, for if the thermal degradation is carried on at relatively low temperatures, depolymerization is not complete and a mixture of polymers and of a solid or pasty residue, quite like reclaimed substance, can be produced. Therefore it has been decided to speak of "reclaiming" when a single compound product, still partly polymerized is recuperated and used by the rubber industry. All other processes of thermal degradation without oxidation, according to this definition , enter into the class of "pyrolysis" processes.

4.2.2. PLACE OF RUBBER WASTE PYROLYSIS IN LITERATURE.

Several tens of laboratories in the world are working or have worked on the pyrolysis of used tyres and of rubber wastes, and as indicated by the bibliographical survey of KRITNO, the scientific literature on the subject is aboundant.

However, all the articles publishedare less than 10 years old, and most of them are less than 5 years old. This explains perhaps the very reduced space given to pyrolysis in the various synthetic reports already published on the problem of elimination of rubber waste products and of used tyres :

- a dozen or so lines in the report of 120 pages "Rubber Reuse and solide waste management", published by the U.S. Environmental Protection Agency in 1968 ;

- three pages out of 18 in the report "Study of the possibilities of recuperation of rubbers and tyres" published in France in 1973 by the Ministry for the Protection of Nature and the Environment. These surveys present only the results of USBM-FIRESTONE in the U.S.A. and the indications given have become entirely out of date ;

- 4 pages out of 125 in "A study of the reclamation and reuse of waste tyres", commissioned by the U.K. Department of Industry, published in 1976, and already a little more detailed ;

- 2 pages out of 40 in "An Economic evaluation of technical systems for scrap tire recycling" U.S. Environmental Protection Agency which also seems to know only the work of USBM-FIRESTONE although the study is dated December 1975.

These is, therefore, a gap, at the level of synthesis, which this report proposes to try to fill in.

4.2.3. CLASSIFICATION OF THE PYROLYSIS PROCESSES.

The parameters susceptible to intervene in a classification of these processes are :

- the chemical mecanism of the reactions (catalystic or not, dissolution, hydrogenation) ;

- the characterization of the products obtained ;

- the type of reactor, and in particular the reaction medium, the heat transfer mechanism, pressure ...

- the range of reaction temperature ;

- the dimension of the products accepted as feed.

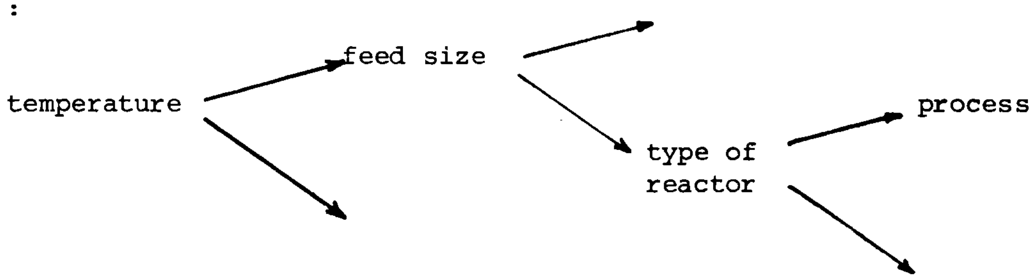
It has been decided to leave out the first two, for the mechanism of the reactions is often very badly known and the products obtained have properties which show very little difference according to the process chosen and which are essentially linked to the temperature used.

On the contrary, the processes existing at different stages of development contrast one from another as regards the last three parameters, and these parameters play an essential role in the investment and running costs.

Thus, the cost of crushing a ton of tyres, varies from \$ 15 for a simple 60 mm shredding apart to about 70 \$ for a reduction to particles of about one millimeter.

A distinction is necessary between the processes working at temperature lower than 300° C for the most recent programmes, the processes working between 450 and 500° C, and the unique experiment of the USBM at 900° C.

We have also adopted in the order of presentation of the processes, in the appendix, and in the recapitulative table below, the following classification :



This classification is not a fundamental one and has as a drawback, for example not to leave specific room for catalytic hydrogenation. It has, however the advantage of bringing out combinations corresponding to an economic reality.

An entirely separate place (sheet n° 15) has been given to the processes permitting the pyrolysis of used tyres mixed with household refuse or industrial waste. Indeed, the massive development of these processes is governed by their interest as regards the other methods of treating these waste products, such as inceneration with heat recovery and the recuperation of raw materials However :

- it would be unreasonable to propose a rubber policy founded on the hypothetical development of processes of treatment of household waste ;

- the relative evaluation of the ways of treating household refuse is quite outside the scope of the study.

Temperature range	Feed size	Reactor type	Process	Sheet n°	Per cent oil recovery	Specific advantages	Specific disadvantages
900° C	no influence	externally heated electric furnace	USBM	1	20		long retention time since heat exchan-ges are inefficient
450-500° C	no influence	externally heated electric furnace	USBM	1	50		long retention time since heat exchan-ges are inefficient
	30-40 mm	Archimede screw in oxygen starved atmosphere	HERBOLD	2	37	presently availa-ble technology	relatively low oil yield
		ceramic halls heating system	TOSCO GOOD YEAR	3	50(?)	original heating technology	complex process
	50-100 mm	fluidised bed	REPROX	4	50	feed size	
			Hambourg University (T = 740° C)	5			
	large pieces	molten salts	two studies available	6		feed size	difficult techno-logy
	120 µm	catalytic hydro-genation in oil slurry	H. RUBBER	7	60	high oil yield	high temperature high presure high cost generated by hydrogen consump-tion
less than 300° C	500 µm	catalytic in oil slurry	DSR	8			very long retention time
	?	oil dissolution without catalyst	H. OIL	9	45	low investments expected	research stage
			PIRELLI	10	20 (+20 : depo-merised rubber)	depolymerised rubber compounds recovered, low temperature	research stage
			Compiegne University	11		low investments expected	research stage
not classfied			WARREN SPRING	12	37		
			FLASH	13			
			IRE	14			
Pyrolysis of urban refuse mixed with tires			FLASH ANDCO-TORPAX DESTRUGAS PYROGAS	15			

CLASSIFICATION OF PYROLYSIS PROCESSES

The nineteen processes which have been encountered during the present survey are described by the technical sheets, in appendix, numbered from 1 to 15, each sheet containing, wherever possible :

- the origin and principle of the process,
- the flowsheet concisely explained,
- the technical parameters:temperature, pressure, residence time, reaction medium, size,
- the products obtained : yield, chemical and physical characteristics, market potential, elements of financial evaluation,
- a synthesis on the interest of the process.

4.2.4. CONCLUSION ON PYROLYSIS.

The examination of the characteristics and calculations exposed in the descriptive sheets (1 to 14) of the processes permits one to draw conclusions in the following fields :

- overall economic evaluation of the pyrolysis of tyres : investments, processing costs market and value of the products, financial impact ;

- classes of the most promising processes ;

- factors preventing development and research into means of removing them.

A first conclusion will be made to compare it with the relative conclusions of other methods for waste rubber recovery.

4.2.4.1. *Overall economic evaluation of the pyrolysis of tyres.*

The investment to foresee for a pyrolysis plant is situated in first approximation between $ 500 000 and $ 1 000 000 per ton/hour of capacity.

The lowest investments correspond to the processes operating at less than 300° C with a simple technology using large pieces of tyres.

The overall cost of processing, calculated by a method set out above, is situated between $ 65 and $ 90 per ton of waste treated.

The products to be commercialized are for all the processes (see technical sheets of the processes for additional details) :

- an oil which can without any doubt, be used as a fuel to replace fuel-oil, and which would thus have a value higher or equal to $ 80 per ton or which could perhaps be consumed by the rubber industry as a raw material; its value in this case could reach up to $ 180 per ton ;

- a carbonaceous residue which is at least the equivalent of powdered coal, the value of which, not counting important transport costs, is on average, in the range of $ 30 per ton.

This residue can eventually be used by the rubber industry as semi-reinforcing charge, but only for manufactured products of law performance (carpets, car-bumpers ... etc). Its value is then, less than \$ 320 a ton (remi-reinforcing charges are sold in France at \$ 0.32 to 0.50 per kg). This use however, remains hypothetical, no indstry for the time being, having tried it out on a big scale.

Taking into account the various outputs of the processes, the market value is situated :

- for a use as fuel between \$ 30 and \$ 50 per ton treated ;

- for a recycling in the rubber industry a little below \$ 200 per ton treated.

The processes of pyrolysis do not then appear ready to be economically sound for a simple production of fuel, at least, as long as the relative price of energy has not gave up by 50 - 100 % compared to 1976. Let us note however that the process developed by the Warren Spring Laboratory is concerned to produce fuel only. The processes of pyrolysis would be on the other hand economically possible with a potential cashflow of about \$ 100 per ton treated if a stable market were found in the rubber industry for the carbonaceous residue.

4.2.4.2. Classes of processes which are the most promising.

The tendency of present research is the study of pyrolysis at low temperature and low pressure. This class of processes espacially when a short retention is possible is economically attractive for the investments and running cost are lower. On top of this, it seems that the products obtained may be of at least as good a quality as those from thermal cracking at about 500° C.

However, the processes in this class are only, for the moment, at the research laboratory stage and their development is as for the existing processes at the pre-industrial stage, governed by the market for carbonaceous residues.

We must insist on the importantce of feed size. A process capable of treating pieces of 50 mm represents an economy of \$ 50 or more per ton treated compared to a technic requiring particles of 500 µm. A process accepting whole tyres would realize an added sawing of \$ 15-20 (cf chapter on crushing).

4.2.4.3. Conclusion on pyrolysis : factors preventing the development of pyrolysis and recommendations for research programs.

Pyrolysis produces oil and carbonaceous residues, the properties of which are suitable for use as substitutes of fossil fuels. Their sulfur content for instance is better than that of most fossil fuels. But these uses are not sufficient to justify pyrolysis on an economic point of view.

Because of its cost, pyrolysis is preferable to incineration with heat recovery only if products are valued otherwise than as simple fuels.

The difficulty of actually recycle the carbonaceous residue, for example as a filler in rubber, is thus the main cause of obstruction noted in the industrial development of rubber pyrolysis.

It is now established that these carbonaceous residues are the equivalent of semi-reinforcing charges of very mediocre quality, for they contain uncontrolled impurities and too much ashes (see especially sheets 1 and following). Moreover, the quality fluctuates if the nature of treated waste varies. In the present state of knowledge they cannont then be used it the tyre industry and it would be better to look towards production of diverse rubber goods, some of which can have very low specifications (car-bumpers, carpets ...);

So, the recommendation for pyrolysis is to promote research programmes in which industrialists, making for example rubber articles of minor quality, would try out, on an industrial scale basis, products furnished by one or several processes of pyrolysis ready at the present time. Other uses of char which would not really be recycling in the rubber industry but which also correspond to savings of high value raw materials can also be tested on an industrial scale.

Some research centres, like the University of Berlin (and Firestone in the past) test the possibility of treating pyrolysis char to make activated carbon. We have not collected points of judgment on this subject, but it is certain that at the outset, pyrolysis carbon black is very different from activated carbon.

It is also possible, but much less urgent to encourage the study at the pilot stage, of processes of pyrolysis at low temperatures (250 - 300° C) and short retention times.

4.2.5. SHEETS 1 TO 15

SHEET n° 1

USBM - FIRESTONE

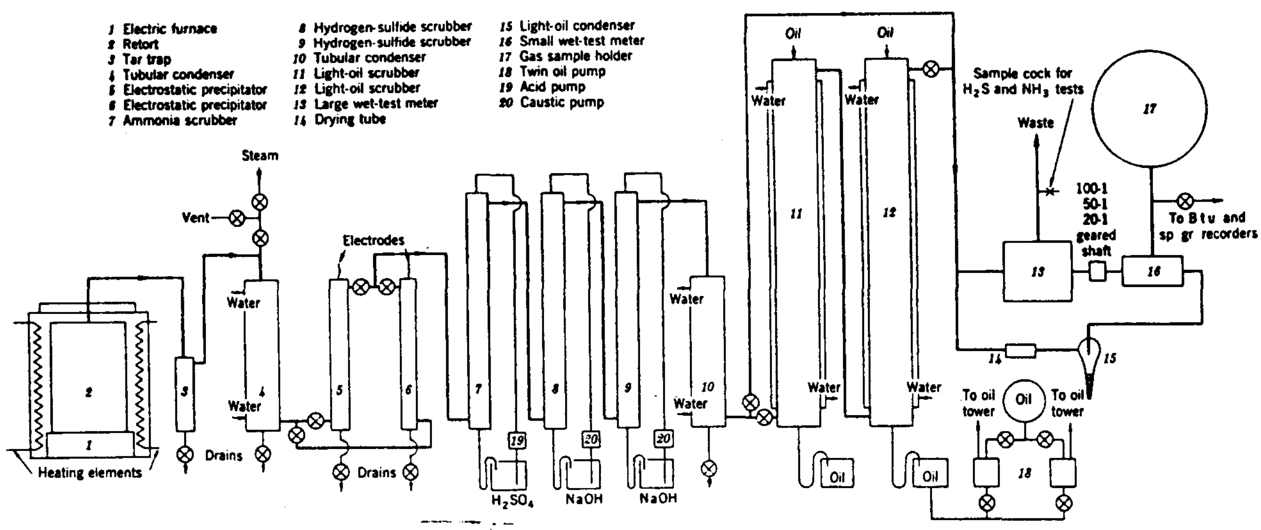
1 - ORIGIN AND PRINCIPLE OF THE PROCESS

Atthe end of the sixties, the FIRESTONE TIRE AND RUBBER COMPANY of AKRON (OHIO,USA) entered into a cooperative agreement with the US BUREAU OF MINES to determine the feasibility of destructive distillation (carbonization) of used tires. The pyrolysis experiments have been carried out at the BUREAU OF MINES Coal Carbonization Group at Pittsburg, on rubber samples provided by the FIRESTONE Company, and the recovered products have been tested by the FIRESTONE Company in AKRON. In a further step of development, FIRESTONE operated the process on a continuous basis.

The whole program can be considered as the first thorough investigation in the field of rubber pyrolysis operation and products evaluation.

The principle of the process is very simple : tires are introduced in an electric furnace in which temperature is kept constant, in the range of 500 to 900° C. The atmosphere quickly becomes reducing and tires are converted into a solid char residue, a mixture of heavy and light hydrocarbon oils and hydrocarbon gas. No mention is made of a steel scrap residue since the converted tires were not of the steel - radial - type.

2 - SCHEMATIC DRAWING OF THE APPARATUS



... / ...

The pilot plant used by the USBM had a complete product recovery train and provided sufficient solid, gaseous and liquid products for analysis and evaluation.

The drawing and the following explanation have been extracted from USBM report of investigation n° 7302 :

"The electric furnace (1) is 26 inches in internal diameter and 48 inches deep. A cast refractory block, 18 inches in diameter and 11-1/2 inches high, is located at the bottom-center of the furnace to support the retort. The furnace is heated electrically by nickel-chromium resistors, evenly spaced in the furnace wall. The retort (2) is constructed of 16-gage mild steel in the wall and 10 gage steel in the top and bottom. It is 26 inches high and 18 inches in diameter. The effluent gases and vapors pass from the retort through a 2-inch-diameter pipe, located at the top-center, and enter an air cooled trap (3), where the heavier oils are collected. The gas and vapors then pass trought a water-cooled tubular condenser (4), where they are cooled to room temperature and additional heavy oil is collected. The last traces of the heavy oil mist are removed by one of the alternate electrostatic precipitators (5 and 6). The gas then passes successively through packed scrubbers, where ammonia is removed with sulfuric acid (7), and carbon dioxide and hydrogen sulfide with caustic soda (8 and 9). In these series of tests, the refrigerated water condenser (10) and the oil scrubbers (11 and 12) were bypassed and the gases passed directly to the large (13) and small (16) meters, which are geared together so that sampling of the gas is continuous and automatic. Dependent on the carbonizing temperature, the gear ratios are set so that 99 percent of the gas is flared and 1 percent passes through an ice-water cooled condenser (14) and a condenser immersed in acetone and solid carbon dioxide (15) to remove the light oil. The quantity of light oil recovered, which is from only that portion of the gas that passes through the small meter, is calculated of a total gas yield basis. The gases then pass through the small meter (16) to the gasholder (17). Steam, which is shown connected atop condenser (14), is used to remove heavy oil from the air-cooled condenser (3), water-cooled condenser (14), and piping at the conclusion of the test."

3 - OPERATING PARAMETERS

The effect of various parameters have successively been tested by the USBM :

. Kind of tires : passenger cars and truck tires, styrene-butadiene emulsion copolymer.

. Feed size : shredded tires with or without beads, 7 cm pieces, 35 mesh and 20 mesh samples.

. temperature : from 500 to 900 ° C.

In all tests the pressure was about 150 kg/cm^2 and the useful retention time was of 8 to 12 hours.

.../...

The only parameter which appeared to have a significant effect on yields and caracteristics of the recovered products is temperature. Feed size or presence of fabric had very few implications.

4 - RECOVERED PRODUCTS : YIELD AND CARACTERISTICS

The yields and main analytical caracteristics of the products obtained during batch tests are summarized in the following tables :

. yield of products for 1 ton of porolysed tires :

operating temperature	solid cha	hydrocarbon oil heavy	light	gas
500 °C	400 kg	479 l	46 l	42 m^3
900 °C	550 kg	145 l	67 l	336 m^3

It is possible to choose any intermediate yield for any product by selection of an adequate temperature during the test. Lowering the temperature increases liquid production.

. main analytical caracteristics of the products :

Solid char

operating temperature	Ash content (percent)	C per cent	S per cent	Heating Value kcal/kg	Specific m^2 / g
500 ° C	10 - 15	80 - 85	2 - 3	7500	25 - 50
900 ° C	7 - 8	90	1.7 - 1.9	7500	20 - 30

... / ...

Gas

Operating temperature	Heating value kcal/m^3	CO_2 per cent
500 ° C	7000 - 8000	9 - 20
900 ° C	6300	< 2

Heavy Oil

Operating Temperature	Specific Gravity	Paraffins and Naphtalones (per cent)	Aromatics (per cent)
500 ° C	0.93	30	50
900 ° C	1	2 - 5	80

During continous tests operated by FIRESTONE, the yield of char was between 30 per cent and 40 per cent, compared to 40 per cent to 50 per cent in batch operation.

FIRESTONE has explored the market value of these products.

Obviously char which is primarily elemental carbon, is at least equivallent to powdered coal with a good heating value. More over, the chemical and physical properties of ground char have been compared with GPF carbon black, a semi-reinforcing agent for rubber, produced from crude oil. A significant difference between GPF black and char black is ash content : about 10 weight per cent for char compared toless than 0,75 per cent.

Vulcanizates have been prepared with commercial GPF black and an experimental ground char black, and the properties of both have been compared.

A summary of the results of this comparison can be found in the following table :

Properties	Char black data compared with GPF black data
- modulus	< (Slightly insufficient)
- tensile strength	<
- scortch time	= (no difference)
- cure rate	=
- hot stress-strach behaviour	<
- aged stress strain behaviour	=
- steel tall rebond	=
- extrusion properties	=

Char black has not as good reinforcing properties as GPF black and vulcanizates especially have not as good elastic properties. The type of rubber fed to the pyrolysis does not have an effect on the quality of char : tread rubber allows the production of better black.

As a conclusion, char black might be used as a semi reinforcing agent, but only in ordinary performances products such as carpets, car bumpers... etc.

Another potencial use of char black explored by FIRESTONE is the preparation of activated carbon by a 980° C steam treatment. Such a treament is indeed possible and the activated black might be used for water purification.

Oil properties have also been investigated. Oil can be considered as an easily stockable and transportable fuel but better economics would be reached if a chemical use was possible. Probably, it could be used under certain conditions as a chemical for rubber compounds. FIRESTONE encouraged by the presence of resin precursors as phenols, indenes and alkylated styrenes, has also tried to prepare an hydro carbon resin from this oil. Many difficulties remained unsolved.

5 - ECONOMIC ASSESMENT

It has not been possible to collect sufficient data to make a complete economic calculation on the process. An order of magnitude of the potencial market value of the products can be attempted :

Product	minimum value $ 1977/ton of product	maximum value $ 1977/ton of product	minimum value $/ton of tire 500°C	900°C	maximum value $/ton of tire 500°C	900°C	heating value kcal/kg of tire 500°C	900°C
Oil (10 000kcal/kg supposed)	80*	180**	39	15.2	88	34.2	4880	1900
Char (7500 kcal/kg	30***	300****	12	16.4	120	164	3000	4125
total			51	31.6	208	198.2	7880	6025

* slightly inferior to ordinary fuel oil price in France

** special oil for rubber industry in France

*** powdered coal it should practically strongly depend of the geographical localisation

**** commercial semi reinforcing blacks are 0.32 to 0.50 $/kg in France

The finantial value of the products is 10 to 20 $ higher when pyrolysis is operated at 500 °C and then less energy is needed. But as the yield of gas decreases with temperature, the energy balance is not obvious and no data have been published by USBM and FIRESTONE on this topic.

This is a very wide range of unknown factors, especially on char value, related to the above-mentionned technical baniers. These is a low probability that char can used by the rubber industry since its quality is too low and might not be constant if the tires are of uncertain origin.

Collected information does not allow us to calculate investment and operating costs, but with a retention time of 8 to 12 hours, pressures about 150 kg/cm^2 and temperatures of 500 ° C and more, one can easily guess that investment cost would be rather high compared with other pyrolysis processes (a one ton per hour plant should include a 25 m^3 reactor, assuming that heat transfer should remain fast enought).

6 - GENERAL EVALUATION OF THE PROCESS

The USBM - FIRESTONE experimentation has been the starting point of tens of studies all over the world. It allready gave a lot of details about the three kinds of products which can be recovered and their possible use. It has shown that a very important parameter is to find a market for char black, and that such a market might perhaps exist in the rubber industry, but only for ordinary performance goods and with a modification of black black specifications.

However, all research has now been stopped on this process and no industrial plant will be built, the main reason being the combinaison of high temperature, high pressure and high retention time which lead to high investment costs.

SHEET n° 2

HERBOLD

1 - ORIGINE AND PRINCIPLE OF THE PROCESS

This process has been developped in the Federal Republic of GERMANY by HERBOLD-PYROLYSE GmbH, with the help of government organisations. A small pilot plant, which has been visited, is already operating in MECKESHEIM, near HEIDELBERG, and HERBOLD-PYROLYSE GmbH states to be ready to build an industrial plant.

The fundamentals are the same as USBM-FIRESTONE's process, that is thermal cracking, in an oxygen free atmosphere, of rubber wasts pieces, without any catalyst. The main caracteristic of the process is that a fast and homogeneous heat transfer is achieved through in an externally heated kiln having a small diameter (two tens centimeters), in which the products are transported and mixed by an Archimede's screw. Such a technology is well adapted to small units as european rubber processors may need, to eliminate their own production of waste.

This process can perfectly treat tires, but can also be applied to plastics, painting residues...

2- FLOW SHEET AND APPARATUS

Rubber pieces are fed into the kiln through a gate. They are then transported and mixed by the Archimede's screw which is driven by an electric motor, the speed of which is automatically regulated according to the temperature of the kiln. The walls of the kiln are made of graphite and have a one year long life.

Black carbon is extracted by another screw and is then discharged in a container. Other solid carbon particles are removed from the hot gases in a cyclone. The hot gases are thereafter condensed (cooling can be provided by air, water, or even liquid nitrogen). Hydrocarbon oil is pumped from the bottom of the column, filtered and tank stocked. Non condensable gas is burned to fuel the operation and if it is too abundant, it is air burned as waste, since only 1000 kcal are needed to process 1 kg of rubber.

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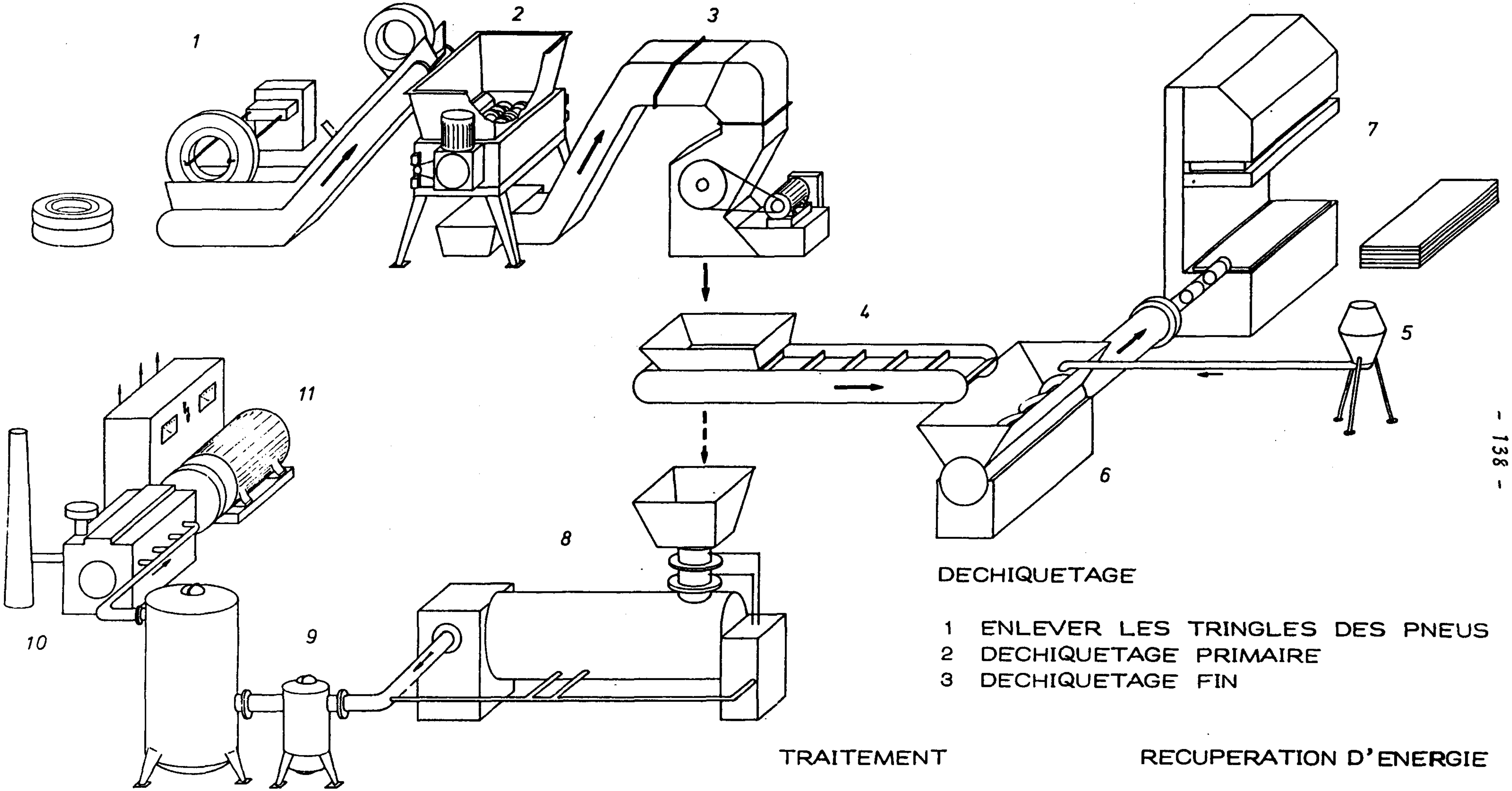
WIEDERVERWERTUNG von Altreifen

RECYCLING of waste tires

RECYCLAGE de pneus



DECHIQUETAGE

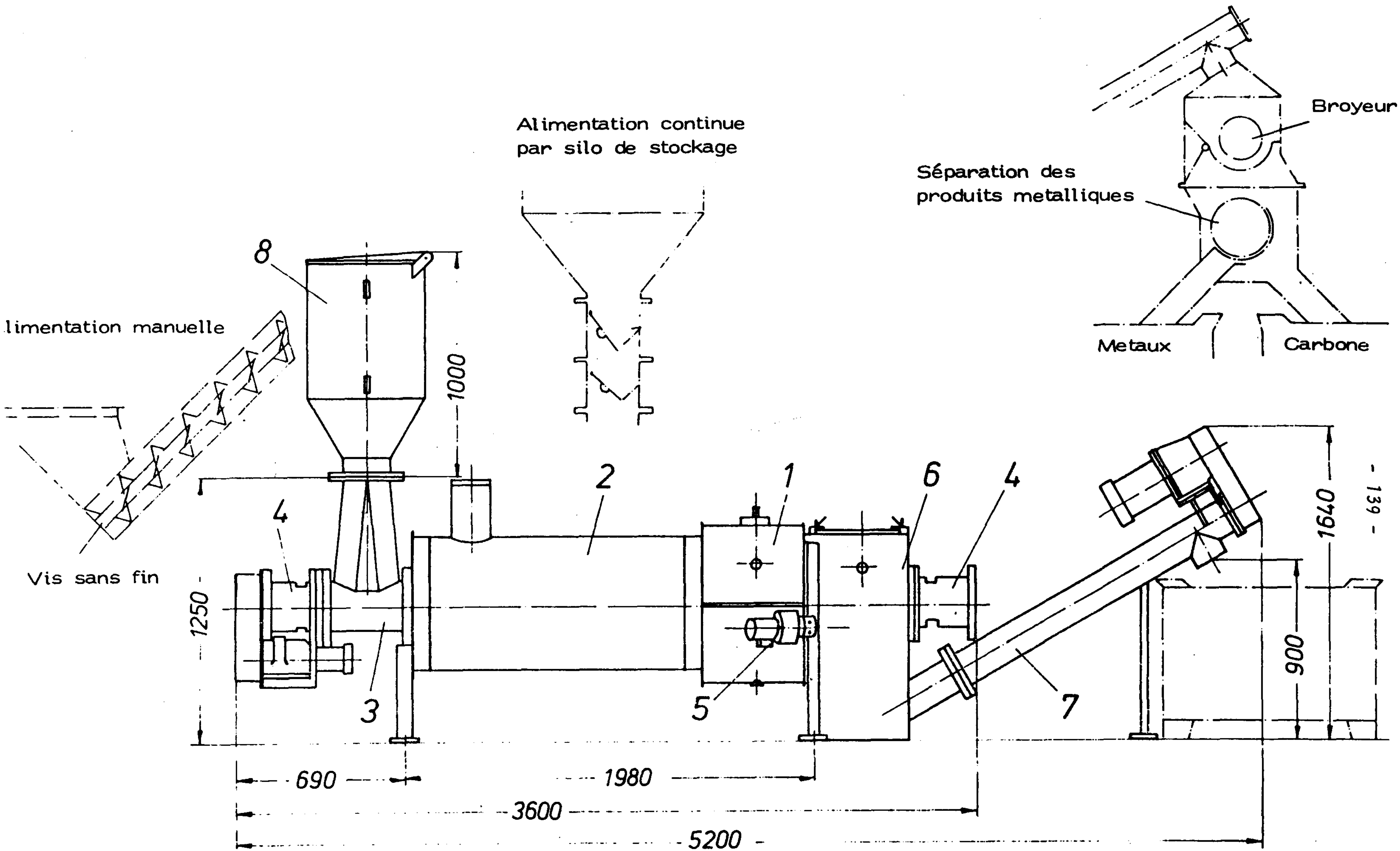
1 ENLEVER LES TRINGLES DES PNEUS
2 DECHIQUETAGE PRIMAIRE
3 DECHIQUETAGE FIN

TRAITEMENT

4 DOSAGE CAOUTCHOUC
5 DOSAGE DU LIANT
6 MELANGEUR
7 PRESSE

RECUPERATION D'ENERGIE

8 PYROLISE
9 EPURATION
10 COMBUSTION
11 PRODUCTION D'ENERGIE ELECTRIQUE



limentation manuelle
Vis sans fin
Alimentation continue
par silo de stockage
Broyeur
Séparation des
produits metalliques
Metaux
Carbone
8
4
2
1
6
4
3
5
7
1000
1250
690
1980
3600
5200
1640
900

3 - OPERATING PARAMETERS

- According to M. HERBOLD, the optimum temperature is approx. 430 - 450°C
- The internal pressure is about 0.97 atm, which corresponds to a slight underpressure.
- A good size for rubber waste pieces is 30 - 40 mm. Such a preparation is needed so that the temperature be homogeneous in the rubber mass. The process includes a shedder.
- Retention time is about 15 to 20 min.

4 - RECOVERED PRODUCTS

For one processed ton, one may account for

0.35 - 0.40	ton of hydrocarbon oil (cold water condensation)
0.45 - 0.50	ton of char black
0.05	ton of steel scrap

Detailed information about obtained products caracteristics are avaible but only the main data related to char black and hydrocarbon oil have been summarized here :

Char black

ignition lost	88.7 %
C	79.8 %
Fe_2O_3	2.5 %
CaO	2.6 %
MgO	1.8 %
ZnO	2.0 %
S	1.7 %
H_2O	3.4 %
Heating value	8 500 kcal/kg

Hydrocarbon fuel oil

Start of distillation	135 °
5 %	160°

... / ...

10 %	180 °
15 %	200 °
21 %	220 °
26 °	240 °
31 %	260 °
36 %	280 °
41 %	300 °
50 %	320 °
49 %	340 °
69 %	360 °
87 %	380 °
95 %	395 °
end of distillation	400 °
specific gravity	0.94045
burning point	39 ° C
viscosity	2.5 ° Engler
S	1.12 %
Cl	0.07 %
heating value	9 500 kcal/kg

5 - FINANTIAL EVALUATION

Since HERBOLD PYROLYSIS GmbH is trying to market the process, all usefull data to draw up a finantial balance have been easily obtained.

Let us first examine the processing cost for a 24 tons per day plant, using the previously defined methodology :

... / ...

	shredding to 40 mm	pyrolysis	products recovery	TOTAL
Investment	400 000 $	400 000 $	180 000 $	980 000 $
Labour — man x hour/processed ton				3
Labour — $ / processed ton				18 $
Electric power — kWh / processed ton	100	20		120
Electric power — $ / processed ton	4 $	0.8 $		4.8 $
Miscellaneous (including building and maintenance)	10 $	10 $	8 $	28 $
TOTAL = $\frac{\text{Investment}}{5 \times \text{year capacity}}$ + operating cost	about 29 $	about 25.8 $	about 17 $	72 $

M. HERBOLD has plenty of ideas to use char black, such as :

- a semi-reinforcing black in the rubber industry
- as activated carbon after a special treatment which can be a steam treatment
- a water depolluting agent
- a black charge for shoe shine
- a colouring agent for black ink

In some of this *theorical* potential uses, the market value might reach 500 $ / ton.

The hydrocarbon oil, the properties of which are similar to USBM - FIRESTONE and other similar process, should, according to M. HERBOLD, be used as a naphta oil for rubber processing (sulphur should then be quite convenient), with a market value of aprox. 160 $ / ton.

Steel scrap price evaluation is not easy for we have not been able to get any sample. According to M. HERBOLD, it should be around 50 $ / ton, but

... / ...

according to our own experience of this cyclic market, an average price of 22 $ / ton should be more realistic.

Product	yield per processed ton of tires (average)	Price per ton of product		Price per processed ton of tires	
		mini	maxi *	mini	maxi
Char	0.47 t	30 $ **	500 $ *	14 $	235 $
Oil	0.37 t	80 $ ***	160 $ *	29.6 $	59.2 $
Steel scrap	0.05 t	22 $ ****	50 $ *	1 $	2.6 $
TOTAL				44.6 $	296.8 $

* According to M. HERBOLD

** Powdered coal : it should in pratice strongly depend on the geographical localisation

*** Slightly inferior to ordinary fuel oil price in France

**** Our own estimate, as explained above.

The obvious conclusion is that the process has an actual finantial value only if any use other than poundered coal equivallent, can be found for char black.

6 - GENERAL EVALUATION OF THE PROCESS

As it has been seen when visiting the pilot plant, the process is presently operationnal, even if it still seems to need industrial experience. It is perfectly well adapted for small-scale applications of pyrolysis.

The problem remains exactly the same as for other process of similar type : the finantial balance can be positive only if char black is sold as a substituent for black carbon, and this may be difficult to achieve.

SHEET n° 3

TOSCO - GOOD YEAR

1 - ORIGIN AND PRINCIPLE OF THE PROCESS

This process had first been developed by the OIL SHALE CORPORATION (TOSCO) as a shale-oil extraction process.

Run of mine shale is first ground then pre-heated in a fluid-bed by hot gases, and mixed thoroughly with hot 20 mm diameter ceramic balls in a rotating drum. The heat realized by balls is sufficient to realise thermal cracking of shales in an oxygen free atmosphere. When the mixture is discharged from the drum, warm balls are easily separated in a trommel, and heated again by combustion off-gases TOSCO built a 25 ton/day pilot plant.

THE GOOD YEAR TIRE AND RUBBER COMPAGNY and TOSCO formed an association to apply this technology to tyre pyrolysis. Good Year planned to produce carbon char and hydrocarbon oil of suitable quality for replacement of oil-based carbon and oil in part of its own products.

These principles does not differ from the USBM - FIRESTONE process but the interest of the process is an original technology to enserre quick heat transfer to rubber pieces.

2 - FLOWSHEET

3 - OPERATING PARAMETERS

- The process requires a feed preparation involving bead remoral and shredding to about 3 cm.
- Rubber temperature is raind to approximatily 480 ° C, when it is vaporized, condensed and the oils recovered.
- Ceramic balls have to be heated at about 540 ° C.

4 - RECOVERED PRODUCTS

For one ton of rubber waste, the yields published in litterature are :

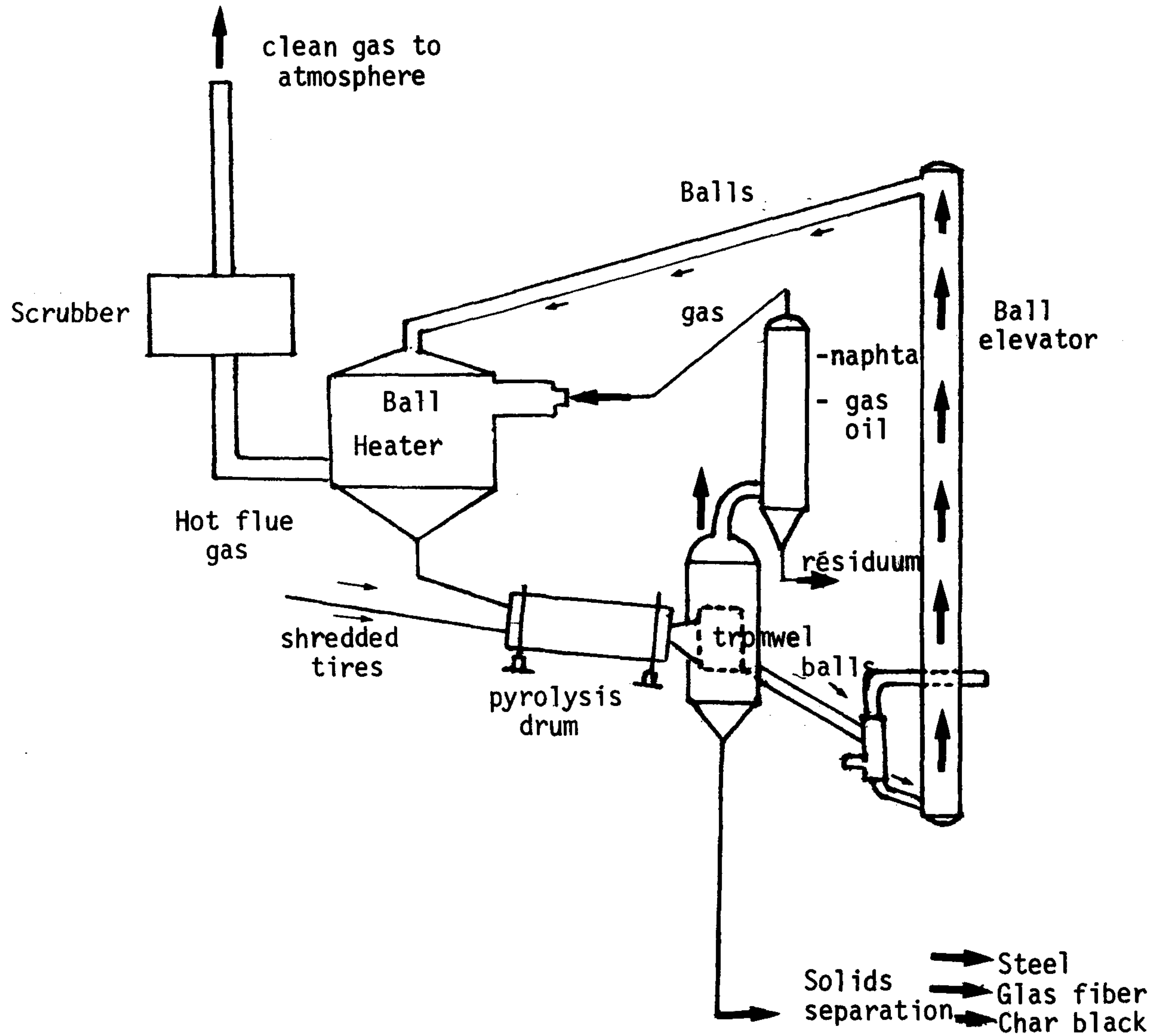
320 kg of char black

595 l of hydrocarbon oil

20 kg of steel scrap

The oil yelds is clins higher that in the USBM-FIRESTONE process and char yield lower. This is correlated to a slightly lower pyrolysis temperature.

FLOWSHEET


clean gas to
atmosphere
Scrubber
Balls
gas
-naphta
- gas
oil
Ball
elevator
Ball
Heater
Hot flue
gas
résiduum
shredded
tires
trommel
balls
pyrolysis
drum
Solids
separation
Steel
Glas fiber
Char black

But in their answer to our survey, the GOOD YEAR TIRE AND RUBBER COMPAGNY indicates for one ton of processed rubber waste :

0.25 t of oil

0.14 t of carbon black

0.02 t of steel

No information has been released on the properties of the products but it is most unlikely that they differ significantly from USBM's.

The aim of GOOD YEAR was to reuse the products for tire manufacturing, and as they decided very quicly after the first experiments to build a 3600 tons per year pilot unit (now operating), it can be assumed that it is quite possible to incorporate char black in some GOOD YEAR rubber manufactured goods.

Gases generated by the process are recirculated and burned to fuel the operation.

5- ECONOMIC EVALUATION

GOOD YEAR is presently studying a 220 000 tons per year plant and has indicated that there is a cost banier, related to the location of the plant and the tire collection centers.

It can then be assumed that the out-put value is very slightly higher than the processing cost.

No concordant figures have been published about the economics of the process, but the order of magnitude is :

- investment : 18 000 000 $ 1976 for a 100 000 t per year plant

operating cost : 50 $ 1976 / ton

These figures *seem* to include shredding

According to the methodology that has been used in this report, the processing cost would be :

$$\frac{18\,000\,000\ \$}{100\,000 \times 5} + 50\ \$ = 86\ \$\ /\ \text{processed ton.}$$

A market value of the products can be presented :

... / ...

Product	yield per processed rubber waste ton		value $ /ton of product		Value $/ton of processed rubber waste		
	A published	B indicated in the enquiry	C mini	D maxi	B x C	B x D	A x D
Gas	burned to fuel the operation						
Oil	0.55 t	0.25 t	80 *	180 **	20	50	99
Char	0.32 t	0.14 t	30***	300****	4.2	42	96
Steel	0.02 t	0.02 t	22*****	50******	0.4	0.9	0.9
Total					25	92	195

* slightly inferior to ordinary fuel price in France

** oil for rubber manufacture

*** powdered coal (dependent of plant localisation)

**** semi reinforcing charges one 0.32 to 0.50 $/kg

***** our own average evaluation

****** GOOD YEAR's evaluation

According to the fact that GOOD YEAR is looking at recycling of products in the tire industry and that the economic balance seems very tight it can be considered that the potential value of these products is quite inferior to the "theorical" maximum - e-g. char black has very bad semi-reinforcing properties and its use is quite limitated - and that the yields are probably extremely low.

6- GENERAL EVALUATION OF THE PROCESS

The GOOD YEAR experience has shown that direct recycling of pyrolysis products in the tire industry is not unrealistic, but there is a strong presumption that the value of the products is still then rather poor.

The technology used to bring heat simultanneously in all parts of the reactor is very good, but the economic balance still remains difficult to equilibrate.

SHEET n° 4

REPROX

1 - ORIGIN AND PRINCIPLE OF THE PROCESS

The REPROX process has been developed by JGC CORPORATION (ex JAPAN GASOLINE CORPORATION) and NIPPON ZEON Co in cooperation with the Japonese Government Industrial Laboratory.

It is a thermal cracking process which operates in a fluidized bed. This kind of reactor provides the best performance in terms of temperature control, heat transfer, solid/gas reactivity and stability.

The fragments are fed on an airborne fluidized medium such as char heated up to the cracking temperature. When the temperature of the rubber pieces raises, they become extremely crumbly, losing elasticity and in the reactor this property is used since tire fragments are crumbled into granules. Further thermal cracking is then very fast.

Heat is provided by partial combustion of tire pieces and the thermal efficiency is high.

2 - OPERATING PARAMETERS AND FLOWSHEET

- The process can be fed with 5 - 10 cm fragments. Such pieces are told by JGC Corp. engineers, to be cracked in less than one minute. Bead wires do not have to be removed.

- reactor size : A 80 - 100 cm diameter cracker enables the treatment of 140 scrapped passenger can tires per hour to be carried out.

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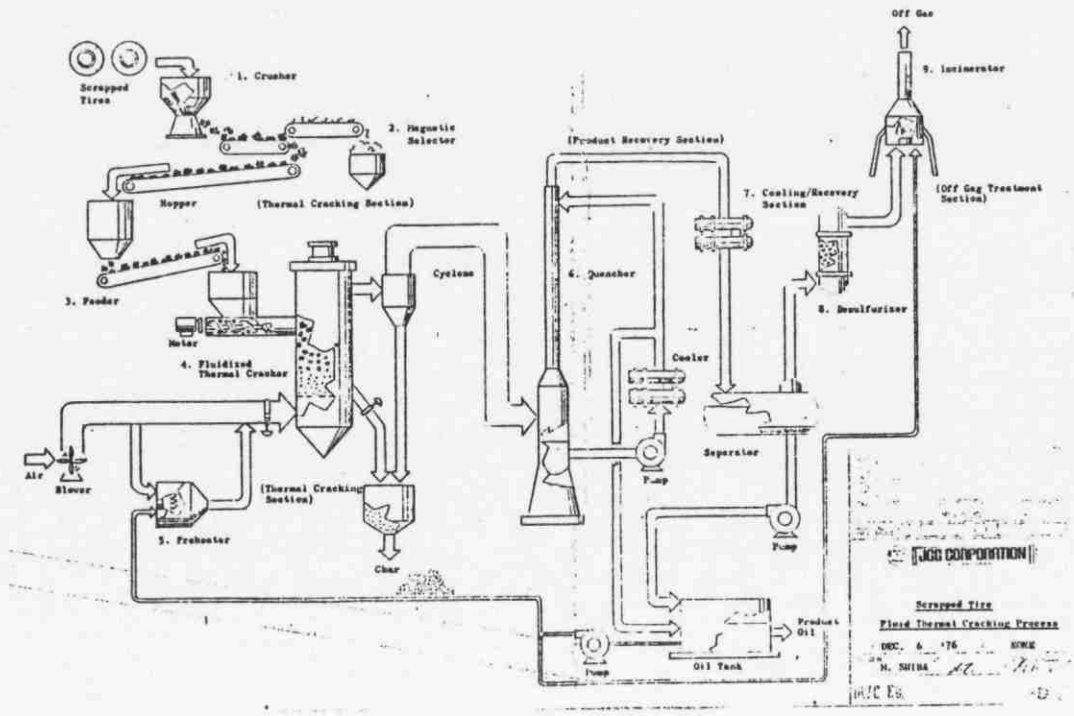


3 - PRODUCTS

The produced values are of course of the same type as with other thermal cracking process.

According to released data, from one ton of tire scrap, one can get :

0.5 t of oil, 1.0 to 1.3 weight % of sulphur

0.1 t of gas 0.5 to 0.6 volum per cent of sulphur

0.3 t of char 2.0 to 2.5 weight per cent of sulphur

0.1 t of wire.

Such a balance is quite approximate since the amount of products directly consumed in the process do not appear.

- Off-gases are actually burned (after dusulfurization if needed by environmental constraints)
- Oil is considered as commercial fuel oil
- Research on reuse of recovered carbon is being continued : this is the last, but extremly important, point jet to be completed.

4 - OVERALL EVALUATION OF THE PROCESS

No financial data has been given. The only comment that can be made is that this process has interesting advantages :

- relatively large pieces can be directly feed, and so preparation cost should be low (complete preparation by a rotary shearing cutter is included in the proposed commercial plant)

- heat transfer is homogenous and quick.

However, as for other pyrolysis processes, it is obvious that actually high value use has not yet been found for recovered carbon.

SHEET n° 5

HAMBURG UNIVERSITY

fluidized bed pyrolysis process

1 - ORIGIN AND PRINCIPLE OF THE PROCESS

This process has actually been developped for thermoplastics pyrolysis, but rubber scrap pyrolysis has also been tested.

Stable fuidization is obtained with the help of 0.1 - 3 mm diameter quartz sand in the bed. The fluidizing medium is preheated pyrolysis gas and heat is provided by radiating pipes in which either propane or pyrolysis gas can be burned.

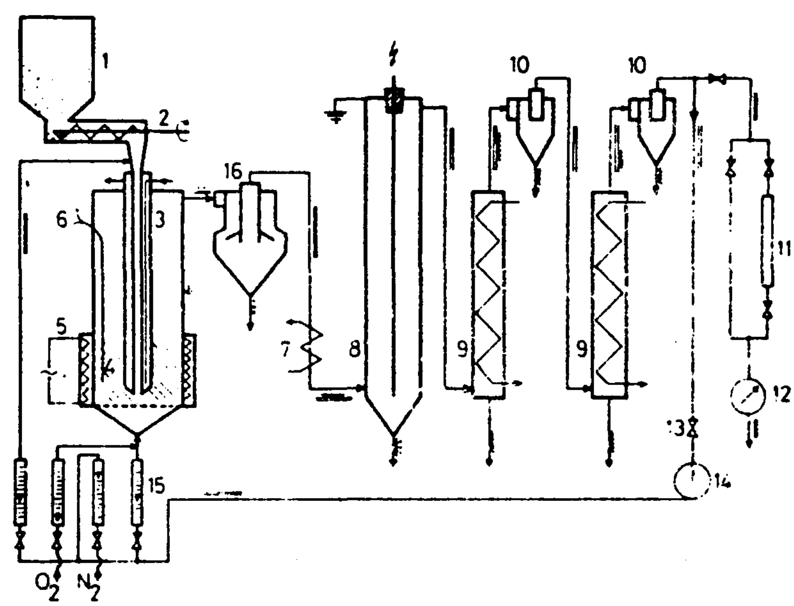
A small pilot apparatus has been built with the help of the government of the Federal Republic of Germany and the german plastics manufacturing industries, in order to carry out a research program. The present capacity of the plant is about 10 - 20 kg per hour and the reator contains 100 kg of sand.

2 - OPERATING PARAMETERS

- Tested temperatures are around 740° C
- Rubber (or plastic) scrap has to be crumbed to 10 - 25 mm, but in some publications, sizes are mentionned as a potential development.

3 - DRAWING OF THE FLOWSHEET

Processing of plastics scrap in fluidized bed
1 Plastics feeder hooper; 2 Screw conveyor; 3 Downpipe with cooling jacket; 4 Fluidized-bed reactor; 5 Electric heating; 6 Temperature measurement; 7 Cooler; 8 Electrostatic precipitator; 9 Intensive cooler; 10 Cyclone; 11 Gas sampler; 12 Gas meter; 13 Throttle; 14 Compressor; 15 Rotameter; 16 Cyclone



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4 - OBTAINED PRODUCTS

In the answer to survey the following data was included :

product	yield per processed ton	potential use
carbon	400 kg	rubber industry
filler	50 kg	ZnO recovery
oil	225 kg	aromatics recovery
steel	100 kg	steel
gas	225 kg	

No further information on the properties of these products was provided but it seems that the above indicated potential use are optimistic.

SHEET n° 6

PYROLYSIS IN MOLTEN SALTS

1 - ORIGIN AND PRINCIPLE OF THE PROCESSES

Using molten salts as a heating medium for tire pyrolysis is an attractive idea since it solves one of the main technical difficulty of high temperature thermal cracking : the bath has a good thermal conductivity and provides quick and homogeneous heat transfer to rubber pieces. There is then no thermal barrier to the direct treatment of whole tires. Moreover the heat exchanges can be speeded up by mechanical or nitrogen agitation. So, the retention time can be short and the molten salt stays clear and colourless so that it can be relatively easily recycled several times.

Two research program have been mentioned on this topic :

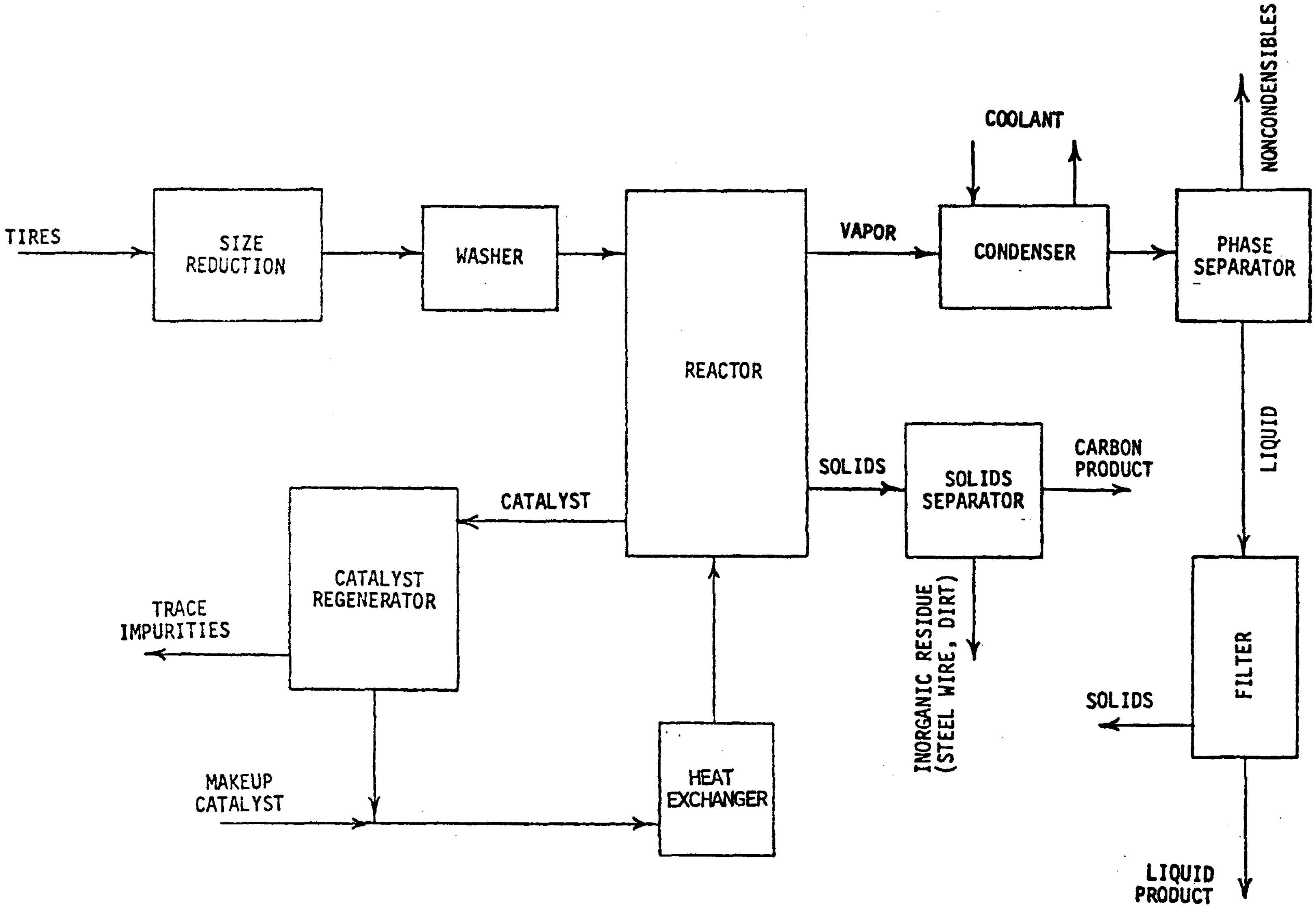
- Dr LARSEN and his team of the University of Tennesse (U.S.A.) has carried out some batch experiments of pyrolysis at 500°C in a Licl-Kcl mixture and in molten $ZnCl_2$. Following table summarizes the yield of oil, gas and solid residue :

Salt	Temp., °C	Oil wt%	Residue, wt%(1)	Gas wt% (2)
$ZnCl_2$	500	43	45	12
LiCl-KCl (3)	500	47	43	
none	>450	45	38	17
none	500	45,2	42	9,2

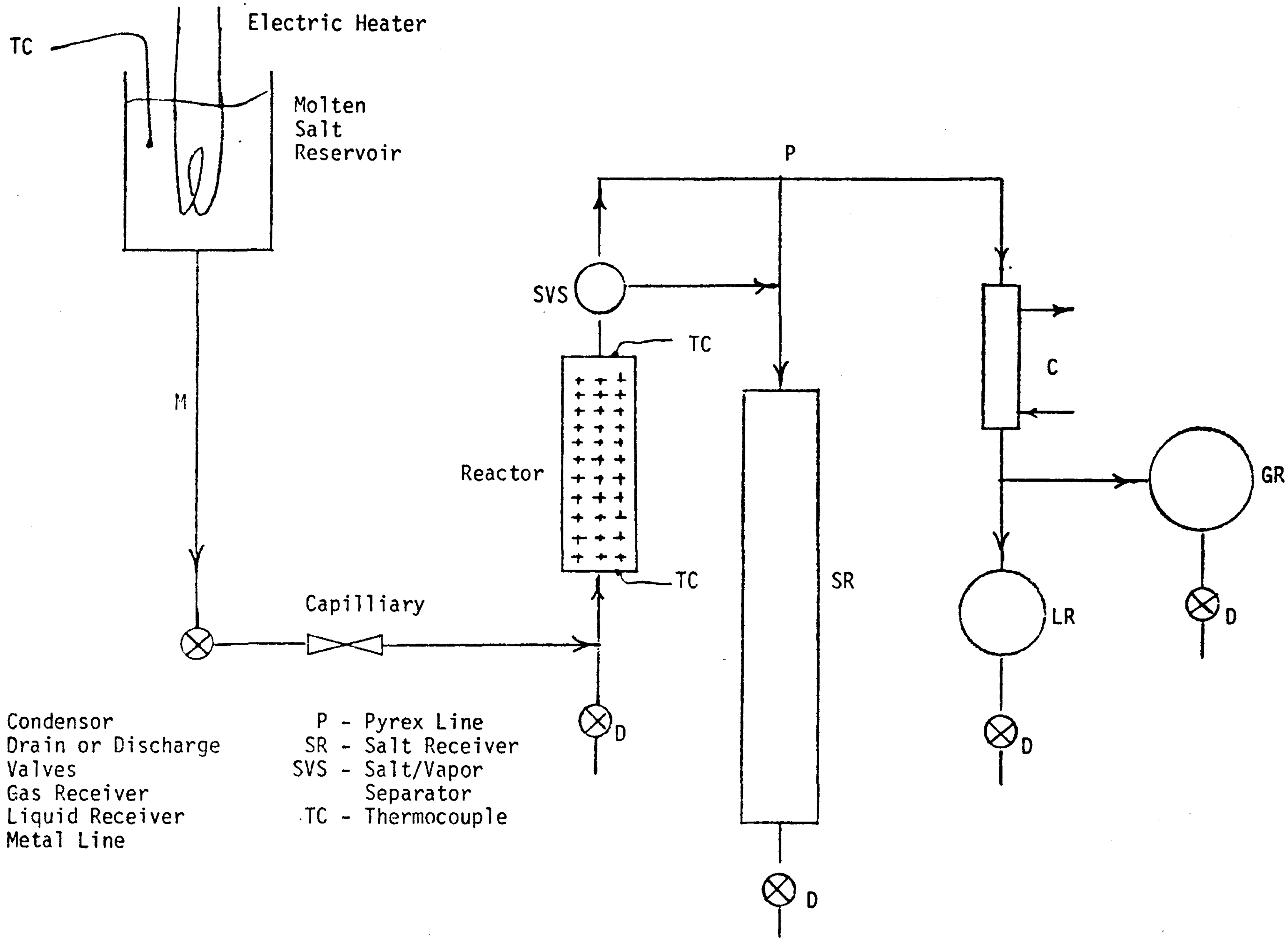
(1) Carbon black containing ∿ 8% ZnO and SiO_2
(2) By difference
(3) 40 mol %.

Carbon black quality is told to be very dependent of the time of contact with salt.

The process may or may not be catalytic. Dr LARSEN has sent us a very tentative flow sheet and his bench scale flow experiment lay out, which are printed on next two pages.



Tentative Flow Sheet for Molten Salt Catalytic Process

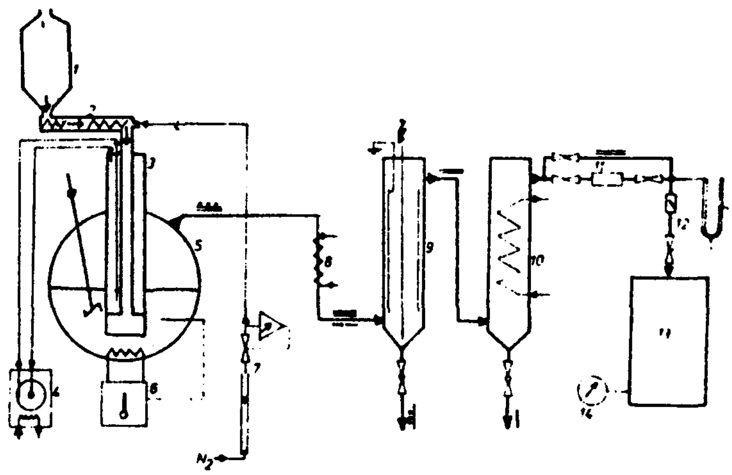


C - Condensor
D - Drain or Discharge Valves
GR - Gas Receiver
LR - Liquid Receiver
M - Metal Line
P - Pyrex Line
SR - Salt Receiver
SVS - Salt/Vapor Separator
TC - Thermocouple

Bench Scale Flow Experiment Layout

- Dr PERKOW and Dr SINN in the University of HAMBURG (Federal Republic of Germany) have carried out experiments, mainly on plastics but also on rubber with the apparatus described on the following drawing :

Apparatus for recycling of plastics in molten salt.
1 Plastic feed hopper; 2 Screw conveyor; 3 Downpipe with cooling jacket; 4 Thermostat; 5 Reactor flask with stirring mechanism; 6 Temperature measurement and regulation with electric heating; 7 Rotameter with differential pressure regulator; 8 Cooler; 9 Electrostatic precipitator; 10 Intensive cooler; 11 Gas sampler; 12 Control manometer with throttle and magnet valve; 13 Evacuated gas sample holder; 14 Manometer



For both processes, a major problem so far has been the development of a technology to separate the solid residues from the molten salt.

According to Dr PERKOW the energy consumption is relatively good, but severe corrosion problems would have to be solved.

2 - <u>OVERALL EVALUATION</u>

This class of process is actually included in the simple thermal cracking process group since it concerns the same range of temperature and the same kind of products at a similar yield.

Presently available information is not sufficient to draw an economic balance of the processes. It can only be noticed that all research programs have now been stopped.

SHEET n° 7

H. RUBBER

1 - ORIGIN AND PRINCIPLE OF THE PROCESS

This process is the result of an investigation by Hydrocarbon Research Inc. of the use of catalytic hydrogenation as a mean of producing recyclable carbon black and other useful products.

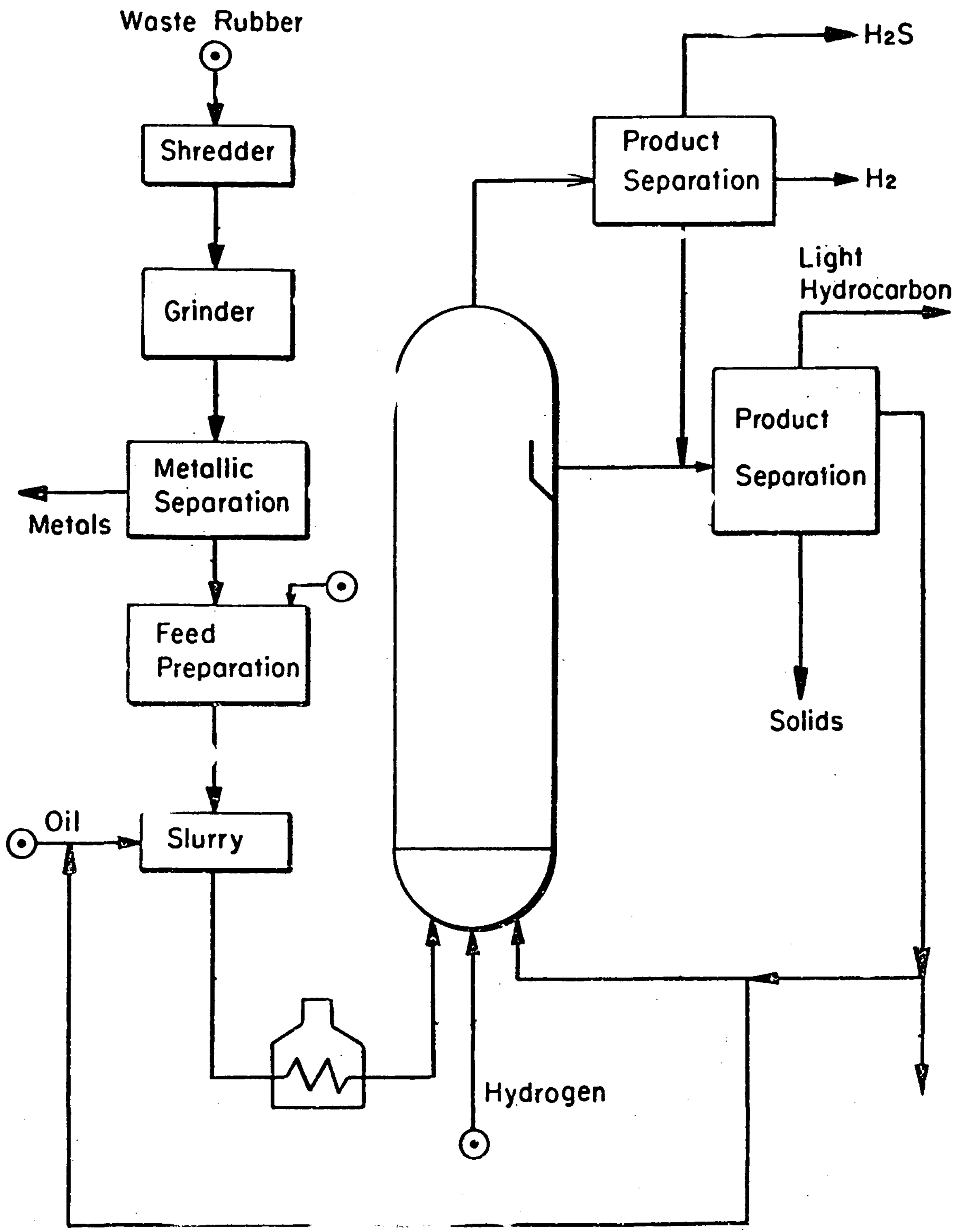
Rubber, ground to approx 120 µm is slurried with oil made in the processing operation and fed to a continuous three-phase (hydrogen containing gas - liquid - solids fluidized) bed reactor containing a catalyst suitable for desulfurization and hydroconversion such as cobalt molybdate on alumina.

Although the precise mechanism is not known, it appears that the rubber first depolymerises partly in the slurry oil when it enters the reactor, then undergoes a hydrogenative cracking action to form naphta-range boiling components.

The catalyst acts both to desulfurize these products that are in the liquid phase in the reactor and to hydrogenate the hydrocracked heavy oils which prevent the formation of carbon deposits in the reactor.

... / ...

2 - DRAWING OF THE FLOWSHEET



3 - OPERATING PARAMETERS

- As previously mentionned, rubber products have to be ground to approx 120 µm (100 - 500 µm) and cleaned of any metallic component

- The gas contains over 60 per cent hydrogen

- The temperature in the reaction zone reaches 450° C

- Pressure is beetwen 35 and 200 kg/cm^2, the optimum being 70 kg/cm^2 The gas rate must be sufficient to maintain the particulate material suspension in the liquid in the reaction zone. The space velocity of the slurry (1200 kg/h/m^3) is such that any inconverted inorganic compounders of small particle size are carried over while the rubber particles are converted to lower molecular weight liquid hydrocarbons

- A good catalyst size is 0.8 mm.

4 - OUT PUT PRODUCTS

According to the fact that part oil is recirculated in the process, the net out put for one ton of rubber waste is around

- 0.61 t of low sulfur (0.1 per cent) and highly aromatic oil.

- 0.03 t of fuel gas (including 0.018 t of H_2S)

- 0.37 t of carbon and inorganic compounds

There is a presumption that oil is of a better quality that with simple thermal cracking process, for it contain less sulfur.

The carbon product, with a specific area of 100 m^2/g and 15 % ash content is not obviously of better quality that in the USBM process.

No mention is made of steel scrap, but if any (as for instance when processing average european tires) it should be extracted after grinding and should probably not be of great value (submillimetric sizes, high impurities content)

5 - ECONOMICS

1973 figures related to an hypotetic 270 000 ton per year plant have been published by HYDROCARBON RESEARCH INC. It has been attempted to actualise them according to previously defined methodology :

- processing cost.

Investment : 10 000 000 $ 1973 30 000 000 $ 1977

Running cost per processed ton :			1977
Hydrogen	180 m^3	0.14 $ /m^3	25.2 $
Labour	0.12 h	6 $/h	0.72 $
Miscellaneous (including energy, replacement)			50 $
			76 $

So, approximate processing cost should be :

$\frac{30\ 000\ 000}{5 \times 270\ 000}$ + 76 \$ = 22 \$ + 76 \$ = 98 \$ - This cost seem unrealistic according to the very small size of rubber feed.

- output value

One can set a table in the same way that for simple thermal cracking processes. Of course this table should be modified for application to steel containing european tires.

product	yield for one tonne processed	Value			
		$ per tonne of product		$ per processed tonne	
		minimum	maximum	minimum	maximum
carbon	0.37 t	30 *	300 *	11	111
oil	0.61 t	100 *	180 *	61	110
total				72	220

* See for instance USBM-FIRESTONE (Sheet n° 1)

** Slightly higher than for simple thermal cracking processes for the sulfur content is lower.

As for simple thermal cracking processes, the economics are closely related to carbon black price.

6 - OVERALL EVALUATION OF THE PROCESS

Catalytic hydrogenation generates higher yields of carbon and oil product (and oil product is of better quality) than simple thermal cracking.

However, the economics remain closely related to the carbon residue price.

The investment are high because of relativly high temperature, high pressure, and catalyst.

The operating cost is also high, partly because of hydrogen consumption. Both are probably highen than annonced since very small sized feed is required.

The fact that Hydro carbon Research Inc. has stopped working on this process shows as an evidence that market price of char black is far from the theorical maximum indicated above.

Hydrocarbon Research Inc. is actually studying and trying to developp another kind of process, the "H - Oil" process which will be discussed in another sheet.

SHEET n° 8

FIRESTONE DSR

1 - ORIGIN AND PRINCIPLE OF THE PROCESS

D.S.R. stands for Depolymerised scrap rubber-Tires are heated in an aromatic oil which is both usefull for heat transfer, for rubber dissolution and as a chemical intermediate for chains transfer pentachlortiophenol used as a catalyst. The aim is to get black carbon in an oil suspension and to use the whole suspension as an ingredient to make new rubber compounds.

2 - OPERATING PARAMETERS

- particle size : - 35 mesh
- temperature 250 - 275 ° C
- rentention time : 12 to 24 hours

3 - OBTAINED PRODUCTS

The DSR suspension is unfortunatly not of good enought quality to be used in the rubber industry. The resulting vulcanisates would have bad performances. Various other applications have been proposed but they correspond to lower value recovery.

4 - OVERALL EVALUATION OF THE PROCESS

The value of the products is not higher than for simple thermal cracking processes and the required size reduction and the long retention time are heavy disadvantages.

SHEET n° 9

H OIL

1 - ORIGIN AND PRINCIPLE OF THE PROCESS

This technology has been studied by HYDROCARBON RESEARCH INC since 1975 and is considered as an improvement on the H - rubber process. It is still at the research stage.

The aim remains the recovery of high quality black carbon and liquid fuel.

The following data have been given by H. R. Inc to M. GELUS of the University of Compiegne in 1975 but H. R. Inc have given the information their research program that they have stopped.

The process would include the following step :

- grinding
- oil slurrying and dissolution
- depolymerization
- black carbon recovery (and purification ?)

2 - OPERATING PARAMETERS

- temperature 200 ° C
- pressure 3 bars
- no catalyst, no hydrogen needed

3 - OBTAINED PRODUCTS

Per metric tonne of processed scrap tire, the yield should be :

0.34 t of black carbon

0.49 m^3 of fuel oil

4 - FINANCIAL BALANCE

An hypothesis has been proposed for the figures related to a 180 ton a day plant :

investments 3.5 x 10^6 $ (1975)

operating cost 55 $/t (1975)

... / ...

According to the methodology, the roughly calculated processing cost would be :

$$\frac{3.5 \times 10^6}{180 \times 350 \times 5} + 55 = 66 \text{ \$/ processed ton} \quad (1975)$$

Of course, as long as the process is not commercially available we should be suspicious about these estimated figures, but it is not surprising that investment are rather low since the technology involus low temperature and low pressure apparatus.

To calculate the market value of the recovered products are has to use the same figures as for other processes :

	yield per processed ton of rubber wast	value $/ton product		value $/processed ton	
		Mini	Maxi	Mini	Maxi
Oil	0.45 t	80 *	180 *	36	81
Black	0.34 t	30 *	300 *	10	102
TOTAL				46	183

* See USBM - FIRESTONE process (Sheet n°1)

So, even with low investment, the financial value of the process remains uncertain until a high market value has been found for carbon char. This is probably why all research has been stopped now.

SHEET n° 10

PIRELLI

1 - ORIGIN AND PRINCIPLE OF THE PROCESS

PIRELLI has started in 1976 a 4 year research program, the aim of which being the definition of an industrial process for partial depolimerization of vulcanised rubber.

This company has been kind enought to provide some details about its research program :

Depolimerization occurs when heating rubber waste for about one hour at 200 ° C. Depolimerized rubber can be recovered from the vulcanizate by solvent extraction. The blend of non-depolimerized rubber, carbon black and other inextractable components of the original compound can be pyrolised in order to recover the necessary energy for carrying out previous steps.

2 - OBTAINED PRODUCTS

The approximate following materials balance can be draw per tonne of processed tires waste :

- depolimerized rubber = 200 kg
- carbon black = 200 kg
- pyrolysis oil and gas = 200 kg
- iron scrap = 100 kg
- energy consumed in processing = 100 kg
- final waste = 200 kg

At the present stage of the work, it can only be stated that the recovered rubber can easily be compounded with raw and vulcanized rubber.

3 - EVALUATION

It is too early to set a judgement on this class of process we can just notice that it seems more attractive than high temperature pyrolysis since it is possible to obtained depolimerized rubber having a rather high value and since industrial energy requirements might be low.

SHEET n° 11

UNIVERSITY OF COMPIEGNE (FRANCE)

This process is still at a research stage. The research program has been financed by the french "Ministère de la Qualité de la Vie" and has been carried out by the Chemical Engeneery Department of the University of Compiegne.

The technology under study is low temperature (less than 300°C), low pressure, short retention time and pyrolysis is conducted in oil. *We have not been allowed to mention further details* since the project is at a critical stage of development. We can however tell that this way is of high interest for it might lead to low energy consumption and low investments plants compared to 500°C pyrolysis.

According to M. GELUS, who manages the research program, the products are similar, or of better performances than those obtained by previously described technologies.

SHEET n° 12

WARREN SPRING LABORATORY

1 - ORIGIN AND PRINCIPLE OF THE PROCESS

This process results from a project which has been under investigation in the pilot scale since early 1975, at Warren Spring Laboratory and on behalf of Batchelor Robinson Metals and Chemical Ltd.

Limited information is available since the investigation will be complete in september 1977 and Batchelor Robinson Metals ans Chemicals Ltd whishes to be in the best position to make a commitment in 1978 to a full scale tyre pyrolysis plant in the United Kingdom.

The process consists of destructive distillation of tyres in an oxygen starved atmosphere and as expected produces an oil, a carbonaceous char and steel.

Presently, test periods of 1500 tonnes are performed to define the operating parameters and provide design data for a 50 000 tonne per year tire pyrolysis plant.

Technical feasibility has already been demonstrated.

2 - OBTAINED PRODUCTS

The average expected production is the following :

oil 370 kg per metric ton of rubber waste

char 300

steel 140

Oil is planned to be used as a replacement product for Heavy Fuel Oil and char for coal. Their main properties are summarized below :

	Oil	Char
Heating value (kcal/kg)	10 000	6 500
Sulphur content (%)	0.5	2

... / ...

Both are told to be suitable for burning on existing convential equipment.

Steel scrap seems to be a low value since the copper level is higher than allowed by specification.

3 - ECONOMIC BALANCE

The process sponsors are quite optimistic on the economics. However pilot experiments still have to be carried out to allow economic assessments to be made under conditions of reduced uncertainly, and to test market on a realistic scale.

The stated energy consumption would be of 80 kWh per processed ton and labor requirement of 0.6 man x hour per processed ton.

4 - OVERALL EVALUATION OF THE PROCESS

Such an evaluation is impossible since there is a lack of information. The originality of the program is that oil and char are not expected to be recovered except as fossil fuel equivalents . So the finantial balance is not related to the market value of the products which is probably quite well known, but to the processing costs.

Rubber, Raw Material - Containing no fabric or bead

Particle size: -30 + 45 mesh*

Oil and liquid content: 60% by weight+

Ultimate analysis:

C:	≈69% by wt.
H:	≈7
N:	0.3
O:	≈17.5 by difference
S:	1.5
Ash:	≈4.4

Char, Product - Yield: ≈33 to 40% by wt. of raw material

Particle size:

-100 mesh:	92% by wt.
-140 mesh:	83% by wt.
-200 mesh:	69% by wt.
-250 mesh:	57% by wt.

Tar and Liquid Content:	1% by wt.
Ash Content:	≈9.6% - includes ZnO
ZnO Content:	≈1.5%
Sulfur Content:	1.5%
Heating Value:	11,000 to 15,000 Btu/lb**

Oil and Liquid, Products - Yield: 0 to ≈50% by wt. of raw material**

Heating Value:	≈ 18,000 Btu/lb
Specific Gravity:	1.0
Moisture Content:	≈1%

Ultimate Analysis:

C:	83%
H:	9%
N:	0.7%
O:	≈4% by difference
S:	1.1%
Ash:	<1%

* All data indicates considerably larger particles can be used.

\+ Determined by Fischer assay.

** Depending upon severity of temperatures used.

SHEET n° 13

FLASH PYROLYSIS

This process is also described in sheet n° 15 as an urban refuse pyrolysis process. But in the early days of OCCIDENTAL RESEARCH CORPORATION research program, shredded tires have been pyrolysed alone to produce a high heating value liquid fuel and carbonaceous char. According to ORC, the char has been tested by two tire companies in the U.S. and found to be an acceptable substitute for carbon black in the compounding of new tire material.

The released data concerning these experiments have been summarized as follows :

SHEET n° 14

IRE

An answer to the questionnaire has been received from the "INSTUTUT NATIONAL DES RADIO ELEMENTS" of BELGIUM in which it was indicated that this institute is carrying a two year research program on the pyrolysis of pieces of tires. Tests are performed on 400 - 500 g samples and consist of pyrolysing pre-treated materials. No further information on the type of treatment was available in the answer.

SHEET n° 15

PYROLYSIS OF RUBBER WASTE MIXED WITH URBAN REFUSE OR OTHER WASTES

It semms difficult to recommend such a way in a study which only deals with rubber waste as far as urban and industrial waste pyrolysis technology does not tend to develop spontanneous by or quickly. It should not be a reasonnable scry tire policy to wait for this specific class of processes far solid wastes to develop and the evaluative comparison of theses processes with other classes of municipal waste treatment process is not part of the present work.

Moreover few data are avaible on the consequences on plant design and on the quality of the recoverable products of treating rubber together with other solid waste in a pyrolysis plant.

However, are should mention three urban waste pyrolysis processes which might treat rubber wastes easily :

- the FLASH PYROLYSIS process
- the ANDCO-TORRAC process
- the DESTRUGAS process
- the PYROGAS process

1 - The FLASH PYROLYSIS process has been developped by OCCIDENTAL RESEARCH CORPORATION in the United States (Formerly this company was GARRET RESEARCH AND DEVELOPMENT COMPANY).

The technology seems suitable for pyrolysing scrap tires alone or as a constituent of municipal solide waste. In the presently developped municipal solid waste process, the scrap tires which are present in waste are shredded, dried and pyrolysed as part of the mixed refuse.

A simplified flowsheet of the process is given on the following page.

2 - The ANDCO-TORRAX process is applied at the BUFFALO municipal waste pyrolysis pilot plant, in the United States.

Heat is provided by 1000° C preheated air, solid residue is water quenched and eliminated by a slurry pump. Pyrolysis gas is burned to fuel the process and to produce 3 kg of steam for 1 kg of average municipal refuse.

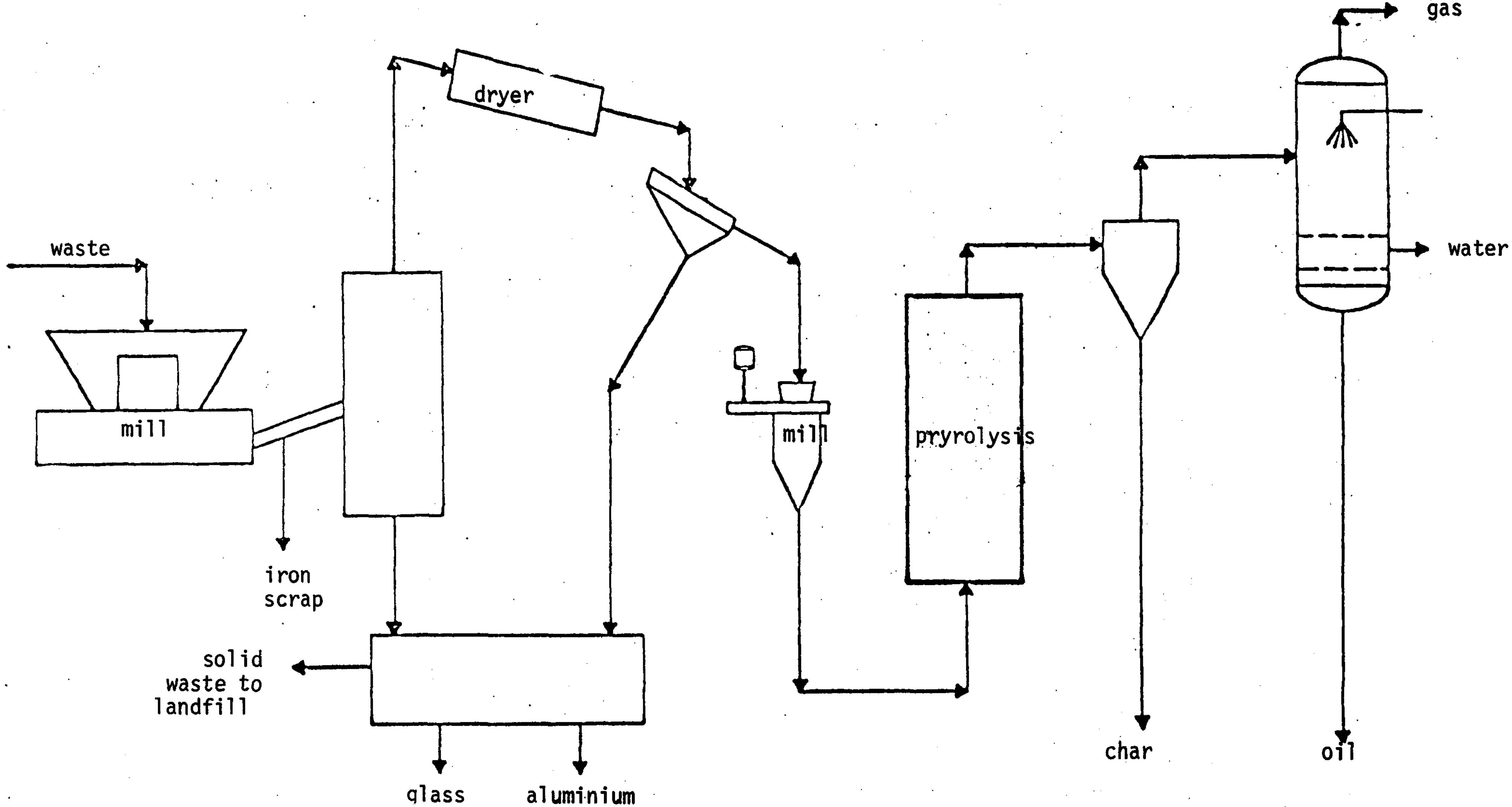
3 - The DESTRUGAS process is presently developped by POLLUTION CONTROL in DENMARK.

Since the start in 1971, the company has operated a demonstration plant in KALUNDBORG and is preparing a detailled project for a 90 ton/day plant.

The materials are pulverized, fed into vertical indirectly heated retort tubes where the refuse is decomposed by pyrolysis in the absence of oxygen at a

... / ...

GARRET process



temperature of 900 - 1000 ° C. The process produces a gas the composition of which is quite similar to ordinary coal gas. Just like in the FLASH PYROLYSIS technology, part of the gas is fed back to fuel the system and the surplus is used for other energy purposes.

According to the answer that has been received, the char could be used as a soil improver after mixing it with sludges from sevage treatment plants.

4 - The PYROGAS process, on which it has not been possible to collect sufficient data, seems to have been applied by AB MOTALA VERKSTAD in GISLAVED in SWEEDEN. This plant would treat the 27000 inhabitants town municipal waste together with the GISLAVED rubber manufacture waste. The fuel consumption of the rubber plant would be reduced by 25 per cent.

4.2.6. SOME REFERENCES ON PYROLYSIS.

- BECKMAN J.A. - Rubber age, april 1973, 105, n°4, U.S.A.
- COX W.L. - Recycle and reuse of tires - Technical paper of the Society of Manufacturing Engineers, Michigan, 1974.
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- GOTSMALL W.W. - A process for manufacture of carbon black from scrap rubber, Washington symposium on rubber waste disposal, June 1977.
- KAMINSKY W., MENZEL J., SINN H. - Some remarks about recycling thermoplastics by pyrolysis, Plastics and rubber processing, June 1976, PP 69-76.
- LARSEN J.W., CHANG B. - Conversion of scrap tires by pyrolysis in molten salts, Rubber chemistry and technology, Vol. 49, n° 4, Sept-oct. 1976, U.S.A.
- SINN H., KAMINSKY W., JANNING J. - Processing of plastic waste and scrap tires into chemical raw materials, Angewandte chemic, Vol 15, n° 11, November 1976, PP 660-672.
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- WOLFSON D.E., BECKMAN J.A., WALTERS J.G., BENNETT D.J. - Destructive distillation of scrap tires, USBM RI 7303, September 1969.

4.3. INCINERATION WITH HEAT RECOVERY.

4.3. INCINERATION WITH HEAT RECOVERY.

CONTENTS

4.3. INCINERATION WITH HEAT RECOVERY.

4.3.1. CLASSIFICATION OF THE PROCESSES.

Incineration without heat recovery has not been studied during the enquiry since it is obviously not a way to same anything. On the opposite incineration with heat recovery is often considered as a easy way to recover values from scrap rubber and scrap tires. It seems a easier way to save fossil fuels than pyrolysis, which has been shown to be attractive only if recovered products can be recycled, in the rubber industry for instance, but not used as fuels.

Incineration of tires or rubber waste can be performed either in specifically designed furnaces or in traditionnal coal furnaces. The advantages of the first class of processes is that incinerators are designed in such a way that they can be fed directly with whole tires and that steel scrap can be easily and often continuously, removed. Its disadvantages are that these incinerators require heavy investments, specially if a high thermal efficiency is asked for.

The main disadvantage of the second class of processes is that scrap rubber or scrap tires has to be prepared by grinding, blending, steel removing. If the preparation of tires were not done the plant would have to be stopped once a day to remove steel scrap.

The following table summarizes the classification of the processes which have been studied in the present work.

Specific furnace design	Feed size	Mixture with other fuels	Process	Sheet number
yes	whole tires	no	LUCA	1
			UHDE	2
			CEC-CEA	3
no	whole tires	coal	HBNPC	5
	shredded tires	coal	HBA	6
	centimetric rubber pieces	coal	MICHELIN	4
		coal+oil	HBA	6

These processes are described and technical and economical data are given in sheets 1 to 6 (green pages).

4.3.2. ENVIRONMENTAL IMPACT.

First of all it has to be pointed out that the sulfur content of scrap tires is about 1.2 to 1.8 per cent, that is much less than that of most fossil fuels.

More over, as tires contain zinc oxide, part of sulfur is combined after incineration as zinc sulfate ($ZnSO_4$).

Zinc oxide is not released into the atmosphere, but it forms deposits in the boiler, where it generates some technical problems ; it can sometimes be recovered as a by-product.

High temperature (1 000 - 1 400° C) and also generally high excess of air (80 to 120 per cent) are required to have complete combustion. These conditions are fullfilled by all processes now available and pollution cheks have been made around tires incinerators in Germany, United States, England, France, and always with positive results (i.e. nopollution).

4.3.3. ECONOMICS.

Cost of incineration is rather low if it can be performed in an existing old-fashioned grate coal boiler. The only cost is then that of shredding or grinding, eventually steel removing, but for a grate boiler, this last step is not always required. More over, according to obtained data, it seems that when rubber is burned with coal, less excess air is required and a high thermal efficiency is obtained.

In such a case the cost should be around 20 to 30 $ per tonne of scrap tire with fossil fuels savings around 45 to 60 $.

On the opposite, incineration of whole tires in modern power plants, as has been investigated by the French Houillières du Bassin du Nord et du Pas-de-Calais (HBNPC), is a bad solution which leads to considerable losses.

When incineration of whole tires is performed in specially designed furnaces, high investments are required ($ 500 000 to 2 000 000 for a capacity of one tonne per hour). These investments are of the same order of magnitude and even higher than for pyrolysis, the reason being that temperature in these furnaces is very high. Overall processing costs are between 30 and 110 $ per tonne if a 20 per cent of the investments depreciation + financial costs is used, and 20 to 80 $ per tonne if a 10 per cent rate is used.

Steam produced is the equivallent of steam produced by a fuel or coal fired boiler, the cost of which, on a one tonne scrap tire basis should be around 60 to 80 $. By products such as steel and zinc oxide would only have a small impact (about 1.5 $ per tonne of tire).

So a small positive cashflow can appear if the plant is large enough and not too sophisticated.

4.3.4. CONCLUSION ON INCINERATION AND RECOMMENDATIONS.

- Incineration of scrap tires is technically feasible, either ground and burned with coal in old grate coal boilers or in specially designed installations.

- It is economically more attractive than pyrolysis if pyrolysis is only considered as a way to produce fuels. Economics can even be very good in some specific cases where it can justify keeping alive old coal plants. In other cases economics are such that a 10 to 20 $ per tonne positive cashflow can appear, sometimes only if long enough depreciation time is considered.

- Incineration with heat recovery can be quickly applied and provides much better economics and savings (of energy) than dumping. But the savings are done with low efficiency and small positive cashflow, so that this process cannot on a general point of view be considered as the best solution for the future to recover values from scrap tires. It can only be considered as a solution either for immediate application waiting for the development of other techniques, or in some very specific cases as a way to avoid expenses for building new installations by reusing old grate coal incinerators.

- The recommendation is not to spend funds on research about incineration. However, it should be usefull to study and perhaps promote some experiments of reconversion of old fashioned power plants, such as La Taupe in France, the design of which is suitable for scrap tire incineration.

4.3.5. SHEETS 1 TO 6.

SPECIALLY DESIGNED INCINERATORS

FOR WHOLE TIRES

SHEETS n° 1, 2 and 3

Sheet n° 1 - LUCAS

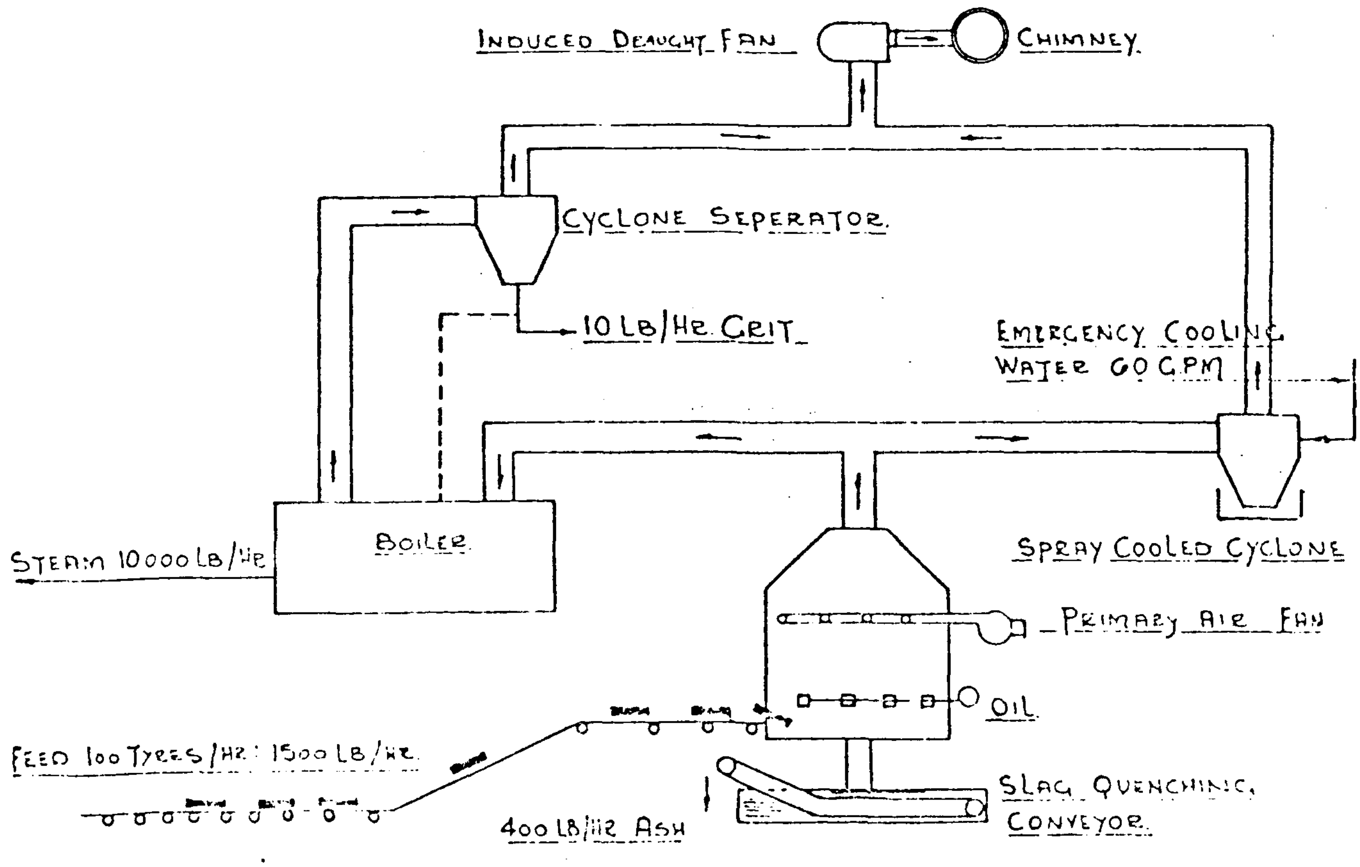
1. ORIGIN AND PRINCIPLE OF THE PROCESS.

This type of incinerator has been designed by LUCAS FURNACE DEVELOPMENT, Ltd, of England and most of the following information have been provided by two companies which have ordered and are using LUCAS furnaces : AVON Rubber Co, Ltd, England and GOOD YEAR Tire and Rubber Company, Ohio, USA.

The incinerator is a tire fired boiler which uses whole tires without previous size reduction. It operates on the principle of cyclonic combustion-principle relies on the creation within a cylindrical furnace body of a spiral gas flow pattern initiated by a number of high velocity air inlets directing the gas flow tangentially into the furnace at a slightly descending angle. The kiln has a rotary hearth which is sloped to a central ash discharge point.

One of the advantages of cyclone combustion is that it allows a relatively low temperature of outer walls and in the mean time high temperature in the center of the kiln.

2. SCHEMATIC DRAWING OF THE APPARATUS.



This drawing is related to the AVON Rubber Co furnace, which has been described by this company :

> "The plant start up is initiated by the firing of four oil burners to bring the system up to its design operating temperature. When this temperature is achieved after around 2 1/2 hours from cold condition, the tyre feed conveyor system is brought into operation and remains in continuous use providing internal incinerator temperatures are within a preselected temperature range. Outside the control range of 150° C tyre feed is halted until the temperature is corrected either by oil burner operation in the case of low temperature or natural cooling with high temperature. It is found in practice that the need for boosting temperature with the oil burners is very rare.
>
> Tyres are fed at regular intervals through the furnace charging door by means of a pushing ram. As the solid hearth of the incinerator is rotating slowly the tyres are transported around the outer periphery. The revolving speed is so designed that 17 feedstock batches are on this outer section undet varying stages of burning. After $\frac{7}{\Sigma}$ revolution half burnt material is transferred to a point midway towards the hearth centre thereby leaving space for the new feedstock. At the completion of a further revolution in this area of the hearth, all combustion has been completed and the ash residue from the tyre is forced further into the centre by the action of the ash pusher and the following tyre. The ash now falls into a water cooling tank and is removed by scraper conveyor.
>
> Combustion gasses are drawn by means of an induced draught fan through refractory lined ducting to the boiler and gas cleaning plant and are finally emitted to the atmosphere from a 60 ft. high chimney".

A main problem is raised by the behoviour of zinc. During the initial furnace operations of the Good Year Tyre and Rubber company, analyses showned that the ash was extremely low in zinc. It has been concluded that the temperatures reached in the presence of the tire hydrocarbon componants were high enough to reduce zinc compounds to metallic zinc, distilled from the burning tire and reoxidized by excess air to zinc oxide. This zinc oxide forms a deposit of very low thermal conductivity in the boiler which has to be cleaned once a week in the AVON Rubber Co.

This zinc oxide can be recovered as a by-product suitable for metal lurgy.

Air pollution does not seem to be a major barrier to tire incineration. Nevertheless, the sulfur content of tires, less than 1 to 2 %, is not higher than that of fossil fuels which can go up to 4 % in heavy fuel oil.

The Good Year company can run a 2 t/hour incineration using only water, not caustic solutions, in the desulfurizer system. Sulfur dioxide emission remain lower than those locally permitted. The majority of solid matter carried over from the furnace in fact separates out in the boiler. The colour of the chimney plume is usually light grey.

3. OPERATING PARAMETERS.

The temperature in the central vortex area is about 1 450° C, while the outer walls are at around 850 - 900° C. Gas temperature at the furnace outlet is 1 000 to 1 200° C.

Retention time within the incinerator is about 35 minutes.

In the boiler, gas temperature is lowered to 250° C. The thermal efficiency of the plant is rather low (40 - 60 %) and depends of the cleanlines of the boiler. It cannot be raised since an excess of combustion air (80 - 100 %) is required to achieve complete combustion and to prevent smoke ans smell.

4. RECOVERED PRODUCTS : YIELD AND CARACTERISTICS.

The average steam production is about 4 300 kcal in steam by kg of scrap tire, that is for instance 6.75 kg of steam with a 6.1 atm pressure or 6.53 kg of steam with a 17 atm. pressure. This range of temperature and pressure is typical of the needs of rubber plants.

Considering that oil and coal fired boilers efficiency is 0.9 (in fact, the efficiency of oil fired boilers is higher than for coal fired boilers), the fuel savings are about 4 750 kcal in the form of fossil fuel per kg of incinerated scrap tire.

Zinc oxide as a by product of this process probably has a commercial value, but no information has been released about it.

This value should he around 60 $ per tonne of zinc oxide that is about 1 $ per tonne of scrap tire.

5. ECONOMIC ASSESMENT.

Financial balances can be drown up for the two plants. Information has been obtained by using our own economic calculation method.

AVON RUBBER

Capacity 680 kg/h x 120 h/week* = 4 200 t/year

Cost of 4 300 Mcal in steam, produced from 1 tonne of scrap tire.

* The capacity cannont been increased by increasing the running time since cleaning and maintenance is needed once a week.

		Processing cost/t of scrap tire
Investment	about 340 000 $	16 $
Labour	2.2 man x hour	13.2 $
Oil for start up and maintaining temperature	0.02 t	2.4 $
Miscellaneous (including plant maintenance services, supplies)	10 $	10 $
TOTAL		41.6 $

GOOD YEAR

Capacity 16 800 t/year

Cost of 4 300 Mcal in steam, produced from 1 tonne of scrap tire.

		Processing cost per tonne of scrap tire
Investment	about 1.8 x 106 $	21.4
Labour		4.7
Miscellaneous		5.8
TOTAL		31.9

This processing cost can be compared with the cost of oil and coal fined boiler producing the same amount of steam.

	Oil	Coal
Investment	4.6	11.4
Fuel	57	35
Labour	3.6	4.7
Miscellaneous	1.7	4.2
TOTAL	66.9	55.3

One more time, we have to point out that these figures are only orders of magnitude, but they are sufficient to conclude that incineration with a LUCAS furnace lead to a saving of about 15 to 25 $ per tonne of scrap tire compared to a coal fired boiler. Of course, saving is a function of plant capacity. Compared to oil fired boilers, saving is about 25 to 35 $ per tonne of scrap tire.

Incineration with this type of furnace leads to fossil fuel savings on average equivalent to 0.475 t of fuel oil per tonne of scrap tire.

6. GENERAL EVALUATION OF THE PROCESS.

Some technical difficulties such as zinc oxide deposits do not seem to be solved and involve rather high maintenance cost. However, this kind of incinerator seem actually to work and is one way to solve the scrap tire disposal problem, to save energy and to generate a small profit from scrap.

Sheet n° 2 - UHDE

1. ORIGIN AND PRINCIPLE OF THE PROCESS.

The first industrial plant for tire incineration with energy recovery has been built in 1967 by UHDE - GmbH for the GUMMI MAYER Company in LANDAU (German Federal Republic). The plant which has been visited during the enquiry has been designed for disposal of scrap which mainly consist of whole used tires which are not suitable for retreading.

2. SCHEMATIC DRAWING OF THE PLANT.

Before starting incineration, the kiln has to be preheated for about 10 hours with fuel-oil so as it reaches tyre firing temperature which is about 800° C. Then, oil burners are stopped and group of two tires are fed in the furnace. As soon as tires are in the hot atmosphere, hydrocarbon gas is generated and starts burning. Temperature then reaches 1 400° C.

A special grate composed of three moving parts automaticly moves burning tires through the furnace.

Problems related to wall and grate quality seem to have been solved by using appropriate materials.

The following pages show a flowsheet of the plant and photographes of the building and of the feeding system.

3. OPERATING PARAMETERS.

Plant capacity is 0.9 t/h of scrap tire, or 138 passenger car tires per hour. The incinerator has to be stopped for cleaning four times a year and a yearly 3 weeks stop is needed for general maintenance. On the average it works 45 weeks per year, so that its annual capacity is of 6 800 t.

The highest temperatures in the kiln is 1 400° C, and gas entering the boiler is at 1 000° C.

4. RECOVERED PRODUCTS : YIELD AND CARACTERISTICS.

Of course the main product of the plant is steam which is partly used to produce electric power and partly to supply the retreading plant.

According to released figures, the efficiency seems better than in LUCAS furnace since it is possible to produce 7.5 kg of 56 atmosphere over-heated steam from 1 kg of scrap tire so that fossil fuel savings should be about 5 400 kcal in fossil form per kg of scrap tire.

By products are iron slag and zinc dust. Their production and caracteristics are summarized by the following table :

	Iron slage	Zinc dust
Production per tonne of scrap tire	75 kg	15 kg
Typical chemical analysis	Fe_2O_3 30-40 % FeO 50-60 % Fe 1 % SiO_2 2- 6 % Zn <1 % Cu 0.15 %	ZnO 60-70 % $ZnSO_4$ 20-30 % H_2O 0.3 % miscellaneous 8-10 %
Estimated commercial value	0-6 $ per tonne	about 60 $ per tonne

5. ECONOMIC ASSESSMENT.

Just like for the LUCAS furnace, it is possible to calculate the processing cost of one tonne of scrap tire, and to compare this cost to the cost of producing equivallent amount of steam by oil or coal fired boilers.

		Processing cost $ 1977 per tonne of scrap tire
Investiment	$2x10^6$ $ 5000 t/year	80
Labour	2.7 man x hour/tonne	16
Maintenance	50 000 $ per year for 5 000 tonne per year	10
Miscellaneous		8
By-products recovery		-2
TOTAL		112

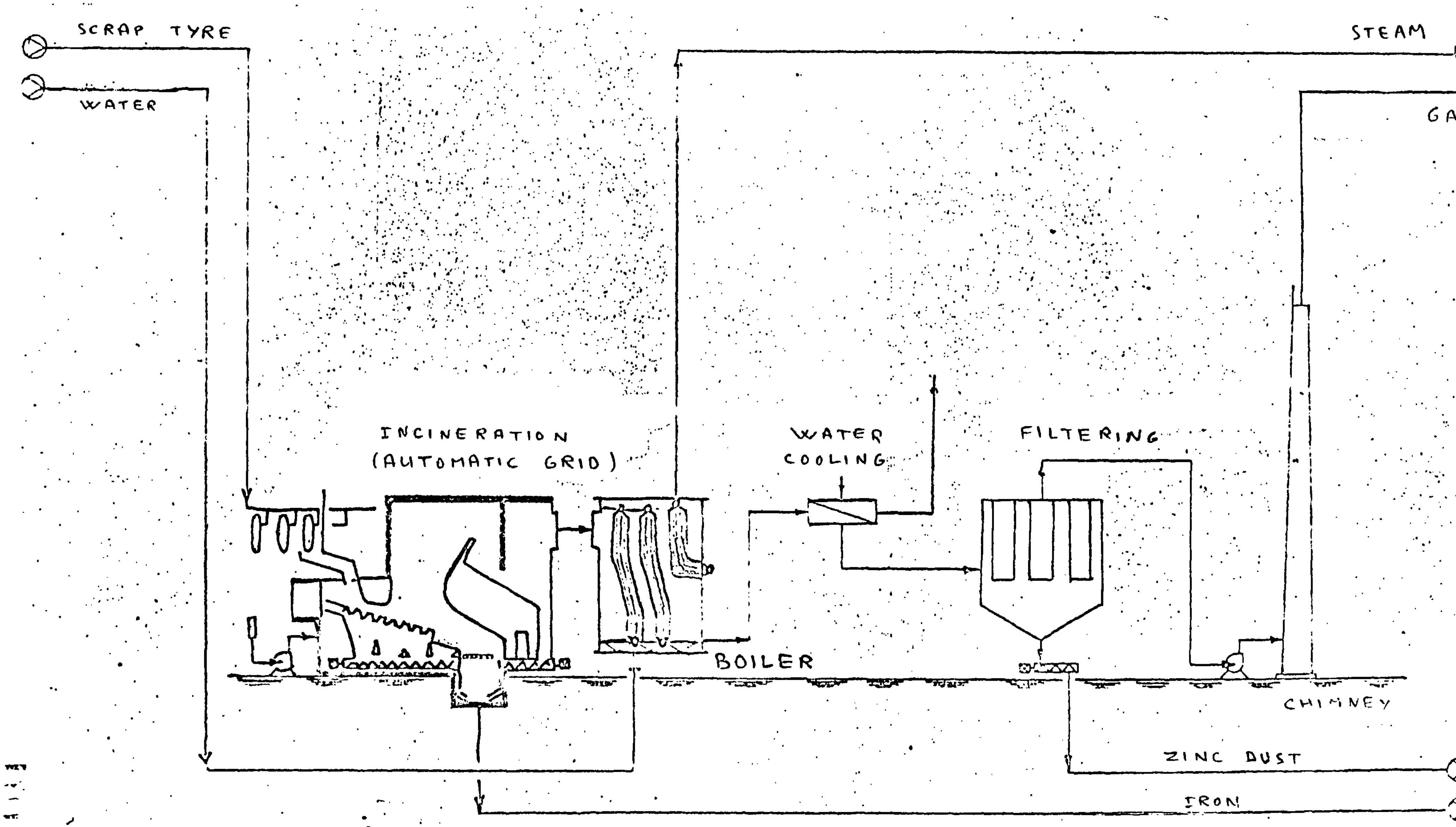
Using the same figures that for LUCAS furnace, but considering that the efficiency of the UHDE furnace is better, the cost of an equivalent amount of steam would be about 80 $. However, this does not mean that the process is actually a way to a financial loss since investments are very heavy and if it is possible to amortize on 10 years or more, the financial balance becomes positive.

The GUMMI MAYER Company built the plant because it allows them to make a profit, compared with waste dumping.Of course we have considered no dumping cost in our comparison.

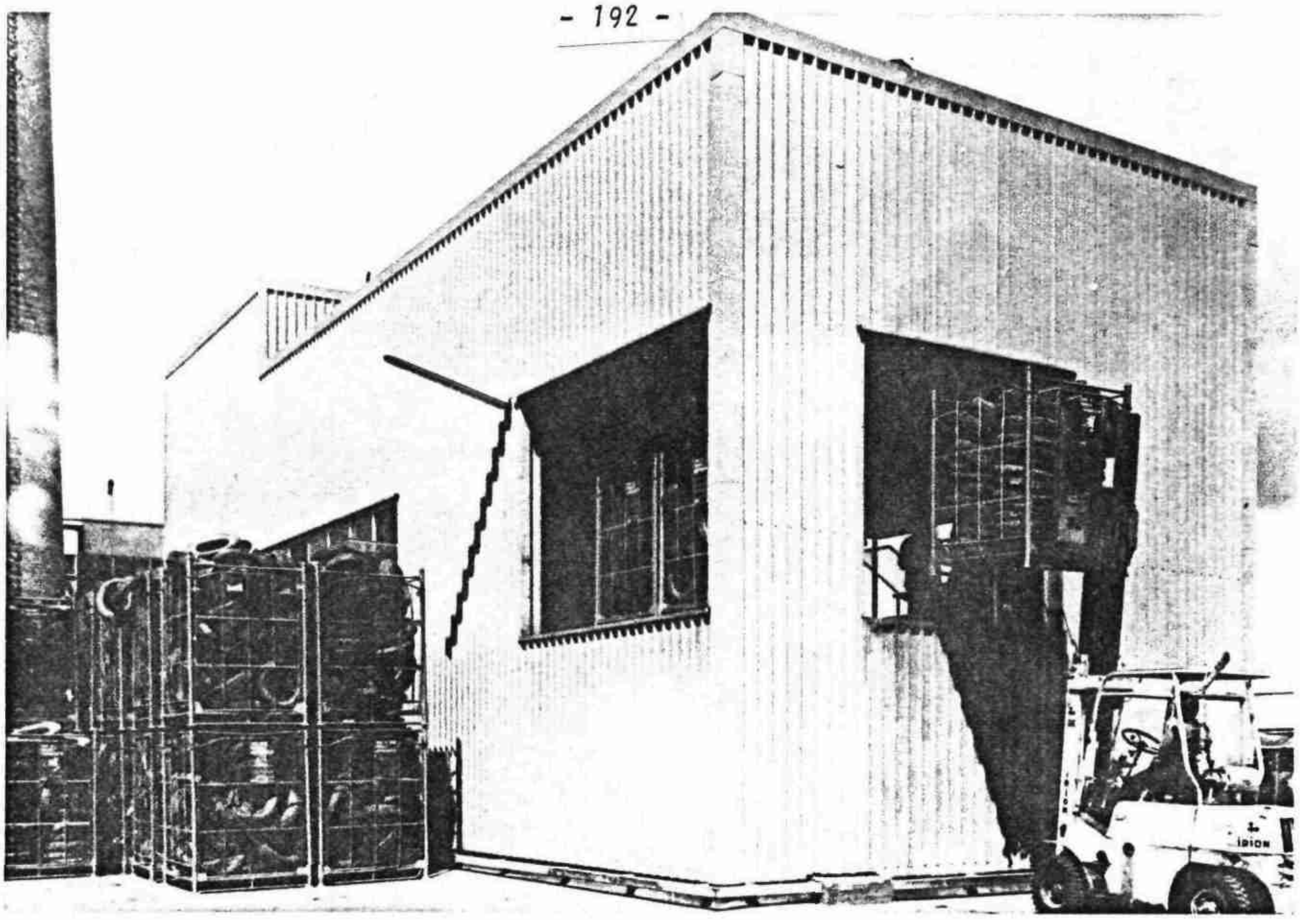
6. GENERAL EVALUATION OF THE PROCESS.

There is no doubt that this class of incinerator works well, and is able to produce high pressure overheated steam with good efficiency on an industrial basis. The plant has been visited during the enquiry and the visit has been a confirmation of this point.

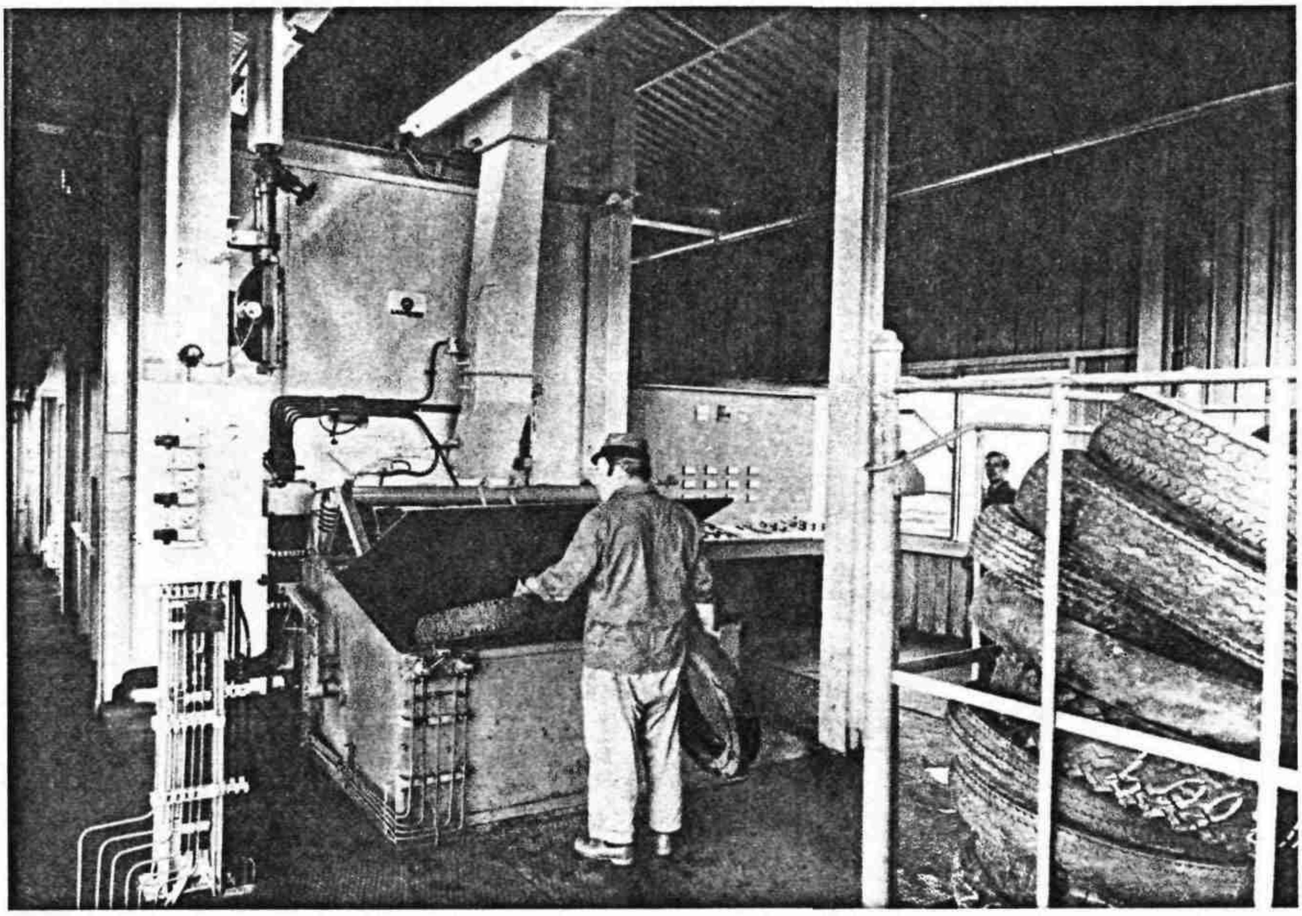
However, compared with other incinerators with heat recovery processes, it has higher investment cost, which can only be recovered after about 10 years.



Schematic drawing of the plant.



Building containing incinerator and boiler.



Feeding system.

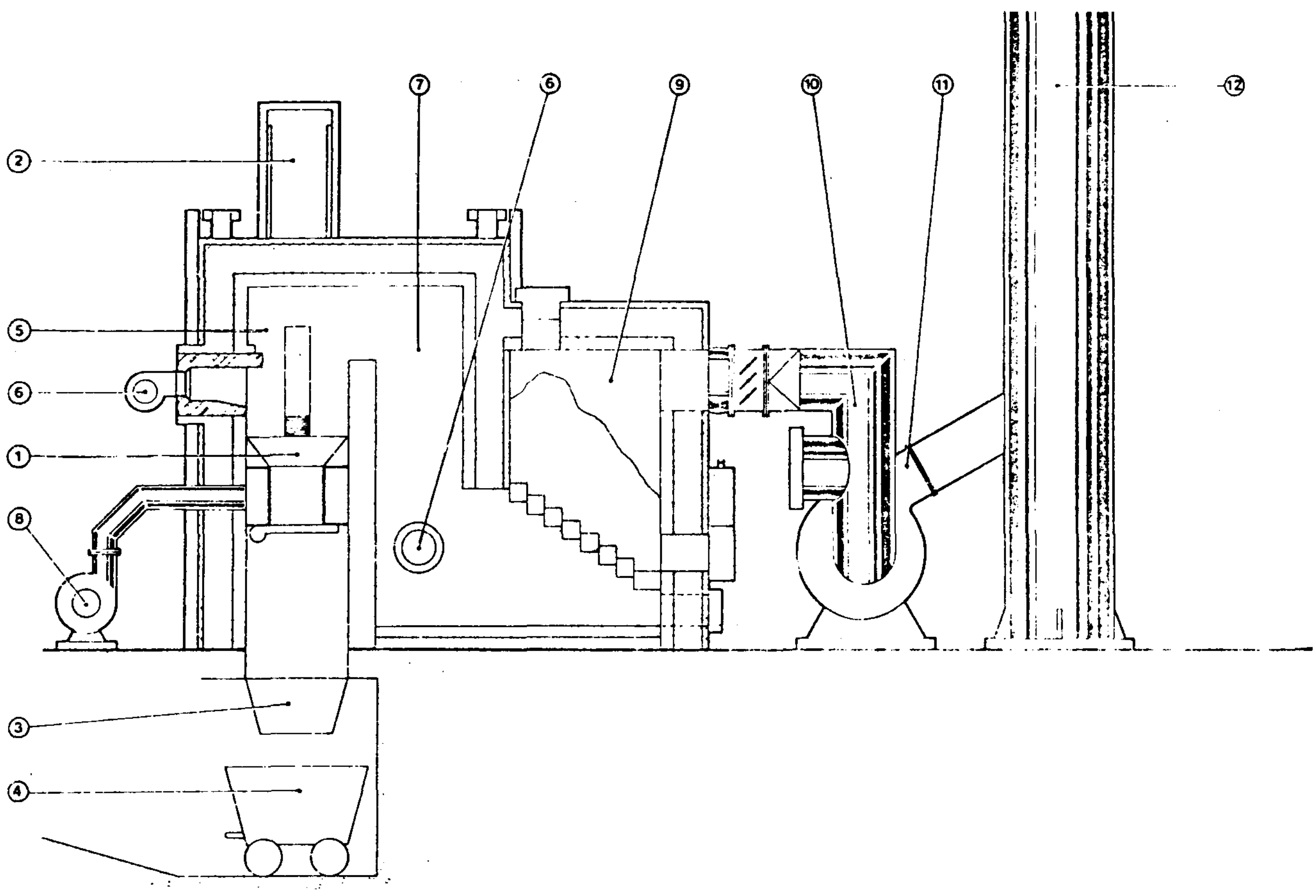
Sheet n° 3 - CEC - CEA

1. ORIGIN AND PRINCIPLE OF THE PROCESS.

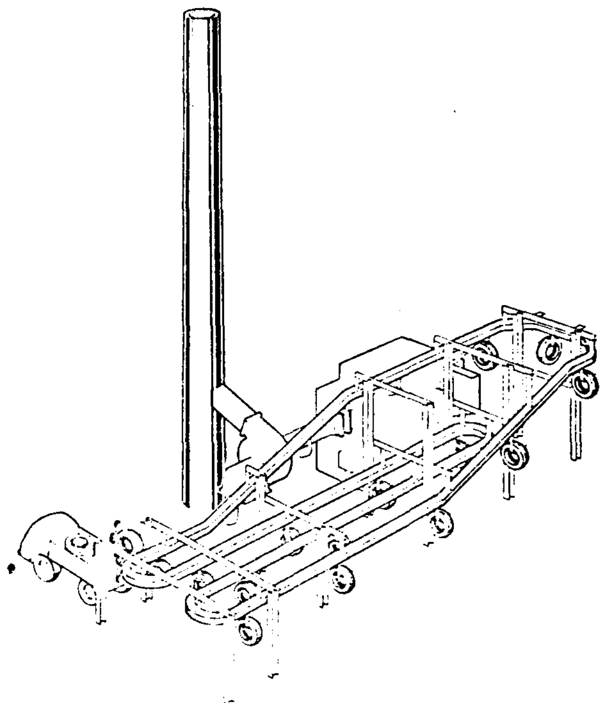
This process for tire incineration had initially been designed for radioactive waste incineration. This application is now developped in France and in Japan.

CEA (French Commissariat à l'Energie Atomique) and CEC (Carbonisation Entreprise et Céramique) are now able to sell up to 600 kg per hour incinerators for used tires. A pilot plant used to work a few years ago and according to engineersof these organisations,it worked very well, with no negative environmental impact. The interest of the process is that post combustion chamber allows a complete incineration (CEA patent).

2. SCHEMATIC DRAWING OF THE APPARATUS



1. Grid
2. Feeding system
3. Ash container
4. Waggon for ash transportation
5. Combustion chamber
6. Burners
7. Post combustion chamber
8. Fan
9. Post combustion chamber
10. Gas dilution
11. Fan
12. Chimney



Automatic conveyor
for the feeding system

3. RECOVERED PRODUCTS.

5 to 6 tonnes of 15 atmosphere pressure steam are expected to be produced from one tonne of scrap tire.

4. ECONOMIC ASSESSMENT.

Processing cost for one tonne of tires processed on a 600 kg per hour basis :

Investment	1.2×10^6 $*	60 $/tonne
Electric power	20 kWh/t	1
Fuel oil	90 liter/t	10
Labour	6 man.t	36
Miscellaneous	unknown	unknown
TOTAL		110 $ per tonne
* 5 700 000 FF for a 600 kg per hour, including incinerator, boiler, cooling system, fabric filter, and fan, but not including buildings		

5. GENERAL EVALUATION OF THE PROCESS.

The process is technically attractive and very different from other processes for incineration of whole tires since oil burners are used to perform complete incineration. Overall thermal efficiency is not high, considering that about 800 Mcal are provided by oil burning for each tonne of scrap tire.

OTHER TYPES OF INCINERATORS

OF RUBBER WASTE AND SCRAP TIRES

SHEETS n° 4, 5 and 6

Processes described by sheets 1, 2, 3 dealed with incineration of whole tires. Another way to burn tires and to recovery energy is to incinerate them in traditionnal coal fired boilers. This is particularly attractive when existing boilers can be used since no new investment is required for incineration.

Several approaches are possible :

- incineration of whole tires or large pieces of tires. This approach raises the problem of eliminating scrap iron remaining after steel belt tires combustion ;

- incineration of small pieces of rubber after magnetic separation of steel components ;

- incineration of rubber scrap alone or mixed with coal or other solide fuels.

During the enquiry, we met several very interesting realisations or investigations on these approaches :

- the MICHELIN Company in France is now carrying out incineration of all fabrication plant wastes in an old coal-fired boiler. Rubber waste is ground and mixed with coal ;

- the "Houillères du Bassin du Nord et du Pas-de-Calais" are investigating on a 1 000 ton basis incineration of whole tires in a existing coal fired power plant. This research is sponsered by French Ministry of Culture and Environment ;

- the "Houillères du bassin d'Auvergne" are investigating incineration of pieces of shredded tires in an old power plant and incineration in a fluidized bed ;

- the MITRE Corporation, METREK division (Mc LEAN, Virginia, U.S.A.) is thinking in burning scrap tire alone or mixed with coal in a fluidized bed reactor.

We had the opportunity to visit and to see operating MICHELIN and Houillères d'Auvergne plants.

Sheet n° 4 - MICHELIN

1. ORIGIN AND PRINCIPLE OF THE PROCESS.

MICHELIN started looking for a way to solve the problem of rubber waste in its plants in 1971. The aim was to stop open-air incineration at the lowest cost possible.

Until 1974 the problem seemed almost impossible to solve since commercially available incinerators were considered as badly designed and not able to provide constant quality steam required by the plants. After the energy crisis it appeared economically reasonnable to use old grate boilers which can be fed with a mixture of coal and 10 % or more rubber.

Rubber waste has to be ground to a centimetric size and carrefully blended.Moreover steel has to be removed from it. About 100 kWh/t is required for grinding.

One tonne of a mixture of 90 % 7 500 kcal/kg coal and 10 % 9 000 kcal/kg rubber can produce 9 to 9,5 tonne of 22 atmospheres steam, that is about 6 500 kcal in steam per kg of mixture.

The furnace has a traditionnal grate. It seems that there is no pollution problem. Rubber suflur content is not higher than that of coal. There are some zinc oxide deposits in the boiler, but Zn is also helpfull in fixing part of the sulfur in the form of $ZnSO_4$

2. EVALUATION OF THE PROCESS.

According to coal price (about 50 $ per tonne) and size reduction plus blending cost (our estimation is about 20 to 30 $ per tonne of tire), there is not doubt that the solution applied by MICHELIN (which does not only burns tires but all kinds of scrap has good economics since no new heavy investment has been done. It is an example showing that, on an economic point of view, this kind of problem can find interesting solutions in specific places.

But of course, to solve the problems of old tires, this cannot be considered as a general solution.

Sheet n° 5 - HOUILLERES du BASSIN du NORD et du PAS-DE-CALAIS.

1. ORIGIN AND PRINCIPLE OF THE INVESTIGATION

The investigation has been sponsered by the French Ministère de la Culture et de l'Environnement, and the prefectures du Nord et du Pas-de-Calais (France) and its aim is to incinerate 1 000 tonnes of old tires in an existing electric power plant, designed for coal incineration.

Tires must be able to self feed ; they are carried to the plant by an elevator and then run into the ash compartment of the furnaces by themselves. The main fuel of the plant is still powdered coal.

Firing is generated by radiating heat. Steel scrap is removed when the furnace is stopped. The process is not really continuous and the plant has to be stopped once a day, that is not really compatible with electric power supply.

2. ECONOMIC EVALUATION.

2 kWh of electric power plus 8 man hours of labour are required to incinerate one tonne of tyre. The cost is then more than 50 $ per tonne, plus the investment in the feeding system.

According to the engineers of the Houillères du Bassin du Nord et du Pas-de-Calais, heat recovery only pays fifty per cent of running cost.

3. OVERALL EVALUATION OF THE PROCESS.

There is little doubt that this is not a correct approach to solve the problem. The plant has not been designed to burn tires. They could either be ground and freedfrom steel or incinerated somewhere else.

Sheet n° 6 - HOUILLERES DU BASSIN D'AUVERGNE

ORIGIN AND PRINCIPLE OF THE INVESTIGATIONS.

The power plant of La Taupe (Puy de Dôme, France) has been designed in 1953 to burn unmarketable coal. It is obviously an absolete plant, old fashioned and with very bad thermal efficiency (more than 4 thermies per produced kWh).

But it is the only point of power production in this part of France and it provides work for several tens of people. So it has been thought that instead of closing it for ever, a better idea would be to use it to investigate incineration of various classes of wastes, such as oil residues and scrap tires. It is equipped with a grate boiler and a fluid bed boiler which are old fashioned for coal, but the design of which is attractive for waste.

Two kinds of incineration of scrap tire have been investigated :

- incineration of shredded tires, mixed with coal, in a furnace equipped with a mobil grate ;
- incineration of centimetre size ground rubber waste, as part of a blend containing 10 % rubber, 10 % oil, 80 % coal, in a fluidized bed furnace.

This program is the result of a cooperative agreement between Houillères d'Auvergne, Michelin and Babcock.

During the enquiry, it has been possible to see an experiment of incineration of shredded tires and it is a fact that it actually works. Of course it is not possible to give consistent data about economics and environmental impacts, but it is true that this plant can usefully be used as a pilot plant to test incineration of various kind of waste.

OTHER TYPE OF INCINERATION EXPERIMENT ON WHICH LIMITED INFORMATION HAVE BEEN COLLECTED

- Süddentsche Kalkstickstoff-Werke Ak tiengesellschaft : coke subtitution by rubber in a lime oven has been investigated in 1975. The time oven was fed with 64 tonnes of lime and 5.6 tonnes of shredded old tires. Thermal efficiency was only 50 per cent and pollution by zinc oxide was so impressive that all research has been stopped.

- The Good Year tyre and rubber Company in Great Britain is now building a new high temperature incinerator to produce steam with high efficiency.

- Watts Tyre and Rubber Ltd in England has an incinerator with heat recovery.

4.3.6. SOME REFERENCES ON INCINERATION.

- MICHELIN - Demande de brevet d'invention français n°74-20055.

- SHANG JER-YU, CHRONOWSKI R.A. - Tyre disposal by fluidized bed combustion, June 1977, Whashington symposium on rubber waste disposal.

- SMERGLIA J.M. - The tire fined boiler, the EPA sponsered conference on environment aspects of chemical use in rubber processing operations, Akron, OHIO U.S.A., march 13, 1975.

4.4. ROAD AND RECREATIONAL APPLICATIONS.

4.4. ROAD AND RECREATIONAL APPLICATIONS.

CONTENTS

4.4. ROAD AND RECREATIONAL APPLICATIONS.

4.4.1. ROAD BUILDING.

4.4.1.1. Present situation.

Over the past 40-50 years, there have been extensive research programmes conducted on the potential use of rubber scrap in combination with bitumen in either road construction or maintenance ([1],[2]).

Full scale field tests have been conducted in Arizona since 1960 for rubberized seal coats in street resurfacing and, today, the process is applied industrially in the city of Phoenix ([3]).

Another process, derivated from the previous one, called stress-relieving interface process (SRI), has been successfully tested in Texas, since 1972. This impervious film has the property of controlling smooth propagation of soil movement to the upper layer and generates a better durability of the road ([4],[6],[9]).

The use of an asphalt-rubber mixture for crack sealing is now extensively used in many U.S. states for the maintenance of high ways and concrete pavements ([1]).

Finaly tests have been implemented in many countries in Europe for using scrap rubber in replacement of a part of stone and gravel. In that case, rubber is not heated and partly disolved in bitumen ([9]). Additional tests would be required to determine the exact relationship between rubber and bitumen at the interface in order to assess cohesion of the rubber particles in the mix.

4.4.1.2. Economics.

The application in roads of worn tyres in the form of reclaim or crumb heated and partly disolved in bitumen is accepted by several local authorities in the U.S.A.

An economic survey of the different processes has been implemented by the US. Environmental Public Authority ([1]). This survey indicates substantial savings (money, time, safety, etc...). Table n° 1 gives a figure for this saving. In comparison with the other processes reviewed by the present study, these values seem to be over evaluated.

Our recommendation is that these economic calculations should be performed by several EEC countries within their local contraints in order to confirm or not EPA's results and to have an objective basis of judgment.

	$ 1972/t
Seal coat	1 370
Joint and crack filler	640
Stress relieving interface	---

TABLE N°1 : Relative net benefits per ton of scrap ([1])

4.4.1.3. *Research recommendation.*

The three processes : seal coat, stress relieving interface and rubber mix for joint and crack filler, give an appreciable cost savings and substantial technical improvements.

Field tests should be encouraged as soon as possible in order to confirm the economics of seal coat and to demonstrate the economical and technical improvement due to a stress relieving interface in the classical procedure of road building.

On the other hand, our recommendation is that fundamental research in the field of scrap rubber use as a substitute for stone in road resurfacing would not be scheduled as urgent.

The description of the main processes are presented in the sheets n°1 to 4 :

- seal coat
- stress relieving interface
- joint and crack filler
- scrap tyre used as replacment for stone.

4.4.1.4. *Sheets 1 to 4.*

SHEET N° 1

SEAL COAT

Rubber seal coats have been most extensively tested in the city of Phoenix, Arizona. The experiments and industrial applications are well known now and the studies done by Charles H. MAC DONALD and the Phoenix Materials Testing Section have been fully demonstrated by field application since 1966.

These seals are placed over existing streets to cover cracking and prevent the propagation of elastic vertical movement under traffic of some parts of the street substructure.

TECHNIQUE USED :

The process starts by heating asphalt at a temperature of 177°C to 204°C. Ground tire tread rubber, 0,7 mm to 1,2 mm diameter, is added in the proportion of 25 % to 30 % by weight. Within 30 min to one hour a gelling effect occurs between the two components and the temperature is low enough to permit the addition of 5 % to 7 % of kerosene so as to reduce the viscosity sufficiently for spraying.

Researchers note that rubber only partially disolves, so that the particules themselves serve as units of elastic interference to the propagation of crack from the road base.

In 1971, 174 000 m^2 of streets have been overlaid by the following procedure : One or two days before the application of the rubberized asphalt, a light tack coat of diluter asphalt emulsion is applied on the clean street surface. The hot kerosene - diluted asphalt - rubber mixture is then applied followed by spreading prewated 10 mm stones, at a specific rate of 20 kg/m^2. The surface is then ralled. One night later, excess chips are swept and the street is opened to traffic.

ECONOMICS :

Data are extracted from two references : C.H. MAC DONALD's publication in Public Works - 1972 ([3]), and GODDARD's review U.S. A.P.A. december 1975 ([1]).

C.H. MAC DONALD has written in 1972 : "*Reconstruction of a major street in our city (Phoenix) will often cost $24 000 per one city block by four times (approximately 3100 m^2). The cost of an asphalt-rubber overlay is approximatively $2 400 for the same area.*"

On such economic base, GODDARD has done in 1975 an economic evaluation of this process and precisely evaluate the incremental benefit of the rubberized seal coat. Some assumptions were made mainly for the equivalence of the expected life of the seal :

8 years for rubberized seal
3 years for non-rubberized seal.

The cost of each seal is respectively :

$ 2 400 for 3100 m^2 (0,77 $/$m^2$)
$ 1 920 for the same area (0,62 $/$m^2$).

Savings are substantial and average 2 050 $ for a city block by four lanes area in terms of rubber about 1 370 $/ton of scrap.

Compared with various processes reviewed along the present study, the potential benefit seems extremely high and probably further economical studies, accounting local contraints, would be needed to confirm this evaluation.

SHEET N°2.

STRESS RELIEVING INTERFACE (S.R.I.)

This procedure, rather than new process, has been designed by D. BYNUM and B.M. GALLOWAY (U.S. Reclaiming Co) as a crack arrester in highway construction. A rubberized asphalt films is overlaid between the underlayers and the new road surface to prevent transmission of movement from the base structure to the ripper layer.

TECHNIQUE USED :

Approximately equal volumes of ground scrap rubber, sand and emulsified asphalt are blended in a mixing tank and a film of the mixture is applied by a slurry-seal machine.

A classic stone chip seal is then overlaid and rolled.

The film is 6,3 to 9,5 mm thick and allows to reduce by three to four times the required thickness of the last layer. Bench scale tests have been carried out to simulate movements of the substructure of a road : on two metallic plates, a classic asphaltic concrete mixture is overlaid with and without an intermediate film of rubberized-asphalt mix. After appropriate rolling, the plates are separated progressively until cracks appear. With a 6 mm thick film, cracks appear for a distance between the plates of 6 mm, without film and 2,5 cm with the film. The cohesion force is increased by a factor of four.

No precise economic evaluations have yet been done but this procedure would be helpful for heavy traffic roads by lowering the maintenance of the upper surface.

SHEET N°3.

JOINT AND CRACK FILLER

Joint sealing is performed on the New-Yerd thruway since 1968, tested by 19 U.S. states and 6 states have adopted it for routine use.

TECHNIQUE USED :

Hot poured sealauts for filling cracks and joints are made on the site of utilisation by mixing devulcanized crumb or ground rubber (20 % by weight) to hot liquid asphalt.

The addition of rubber to the filler reduces both asphalt bleeding out in hot days and enbrittelment in cold weather and thus increases the skid resistance of the surface.

ECONOMICS :

GODDARD in his evaluation has written that the service life of the joint increases by 100 % using the mixture ; the labor costs are reduced.

The net savings should be about $ 13 per km and the use of scrap would be advantageous at any rubber price up to $ 640 per ton.

In his evaluation :

. Labor cost is taken at $ 56/km. $ 28 are served because of the longuer service life of the filler.
. Increased materials cost is evaluated at $ 5,6/km.
. increased labor cost for filler preparation at $ 9,3/km.
From their economic evaluation of seal coat application, potential benefits seems extremely high.

SHEET N°4.

SCRAP TYRES USED AS REPLACEMENT FOR STONE AND GRAVEL

Tests have been implemented in many countries (U.R.S.S., Poland, France...) to investigate the possibilities of using rubber chips in replacement of stone and gravel in asphalt mixes.

Some bench scale experiments with reclaimed crumb have been carried out in France by the Laboratoire Central des Ponts et Chaussées in 1975-1977 and negative conclusions were drawn from the insufficient cohesion of the rubber chip in the mix. Better results would be obtained with fine crumb (80 µm - 1 mm) for a 4 % by weight mixture.

Field experiments have been done in Poland but due to the difficulty of compacting, results were negative. Experimental test roads were completely destroyed unless than 6 months.

A focus of research in this field will be the determination of the asphalt rubber interface reaction in order to assess better cohesion of the rubber particle in the asphalt mix.

4.4.2. RECREATIONNAL APPLICATIONS.

The feasability of using shredded scrap rubber as a component in synthetic ground material for play ground areas, out door tracks, all-weather sport ground has been fully investigated all around the world because of the various advantages of this surfacing.

The rubberized surfaces require, mainly, only little maintenance and offer high levels of safety and comfort for the users : sports men, children and pedestrians in comparison of the conventionnal asphalt surface or earth-rolled surface (4 , 7 , 8).

4.4.2.1. *Technique used.*

Two main procedures of laying are used :

1. A 13 to 20 mm thick monolayer of crumb (dimension 1 to 10 mm) bonded with an organic resin, for example, is overlaid on an appropriate structure i.e. : sand, gravel or concrete.
2. 15 mm to 20 mm thick multilayers are successively overlaid :
   - black layers of bonded crumbs are used as an elastic underlay.
   - The upper layers give the aspect, the toughness of the surface ; such layers can be made of plastic material. A coating or a painting can be overlaid for additionnal wear resistance, water proofing or for the final coloration of the surface.

Numerous kinds of binders are used : polychloroprene latex, natural an synthetic latex, epoxyresin ..., their applications depend of the final result wanted : in door or out door areas, water proofing or not, toughness ...

Laying of the material can be done by hand or mechanically or by adjusting prefabricated blocks.

4.4.2.2. *Economics and recommendations.*

No precise data was available from the different companies questionned by the enquiry since there are a lot of different kinds of surfaces which could be built and also, because information information is kept confidential.

A wide market could be foreseen if public administration opened the market of school play grounds, pedestrians paths and all recreationnal areas for example, taking account of the main qualities of such surfaces : principally safety, comfort, maintenance.

As the process is widely industrially applied, and sometimes combined with expensive cryogenic grinding of rubber, there is no doubt that its economics is very good. But several processes seem to be fully investigated and so, there is no opportunity for a governmental aid for research in this field.

4.4.3. REFERENCES.

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[2] E.A. SINCLAIR - K.E. BRISTOL - Elastomer addition - Rubber World - December 1969 pp 67-71 - january 1970 pp 66-69.

[3] J.A. STOKELY - C.H. MC DONALD - Hot rubber asphalt seal coats to cure cracking streets - Public Works july 1972 pp 46-48.

[4] J.A. BECKMAN and all - Scrap tire disposal - Rubber Chemistry and Technology vol 47 n° 3 - july 1974 pp 597-622.

[5] G.A. GERRITSE c/o TNO - Critical survey of the literature on the recycling and disposal.

Enquiry results

[6] ABV-SKEGA - S 930-40 - ERSMARK (Sweden)

[7] WATTELEZ G. - 78300 - POISSY

[8] BAYER A.G. - 5090 Leverkusen-Bayerwerk W.GERMANY

[9] Laboratoire Central des Ponts et Chaussées - 58 Bvd Lefebvre - 75732 PARIS Cedex 15.

4.5. ARTIFICIAL REEFS.

Y. ROUSSIN

4.5. ARTIFICIAL REEFS.

CONTENTS

4.5. ARTIFICIAL REEFS.

4.5.1. DESCRIPTION OF THE TECHNIQUE.

Many natural shelters for marine fauna exist along the shores of Europe, but they have often been destroyed. Fishermen and divers recently observed that wrecks are heavily populated and the creation of artificial wrecks therefore seems to be a means for counteracting the depopulation of the sea bed. Artificial reefs were first constructed about thirty years ago and have been used methodically in Japan since 1959. In the U.S., large quantities of old tires have been sunk and this succeeded in multiplying sea bed productivity by a factor of ten (wild fauna only).

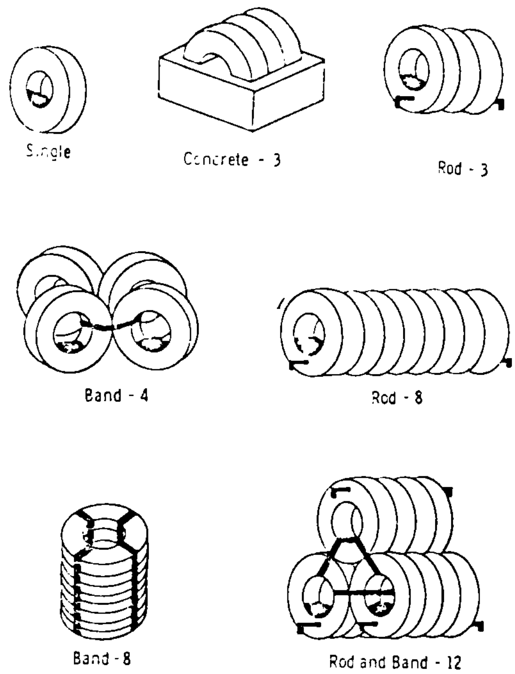
The Federal Sport Fisheries Laboratory at Sandy Hook (New Jersey, U.S.) published a detailed work containing a report on the sinking of tires and recommends that large quantities of tires be sunk in the high seas :

- 2,6 million tires for a small bank,
- 6,4 million tires for a medium sized bank,
- 12 million tires for a large bank.

4.5.2. APPLICATIONS.

4.5.2.1. U.S. and U.K.

In the U.S.A., grants have been made to individuals and professional fishermen for the sinking of banks off the coast of Maine in order to repopulate this zone with lobsters. This will make it possible to sink two reefs, one at a depth of 7 meters and the other at 30 meters, each consisting of about 100 000 tires. The tires will be arranged as follows :



Basic building blocks for artificial reefs.

- Either individually with blocks of stone as ballast ;
- or in the form of 30 to 150 meters long chaines, after the tires have been cut up and the pieces linked together ;
- or in the form of pyramids 1,20 meters high.

Since 1965, studies have been made for the development of this technique by the Department of Sports Fisheries and Wildlife. Experts estimate that it is possible to sink 1,6 billion scrap tires off the Atlantic coast of the U.S.A.

Some experiments were made in the U.K., but only a small amount of data has been available for the present study.

4.5.2.2. *France.*

Testson sinking tires in the sea begun much more recently in France and there have been many administrative obstacles. In addition, the excellent results in the U.S. and Japan involved species different from the local ones and their experiments cannot be repeated unchanged in the Western European climate.

4.5.2.2.1. *The Mediterranean Coast of France.*

The first experiment apparently took place in 1968 at Palavas-les-Flots, in the Mediterranean. Scrap automobiles were sunk with the tires (D. TREO 1974) and the results over three years were as follows :

- 1st year : 80 % covering of sunken structures ; the fish and shell-fish population was small.
- 2nd year : total covering of the habitat with various incrustations and associated fauna ; fish and shell-fish observed in larger number.
- 3rd year : definite development of the population with appearance of economically interesting species : hog-fish, spiny lobster, capelin, conger-eel, picarel, sea-bream, squill-fish, molluscs, oysters, scallops.

4.5.2.2.2. *The Atlantic and Channel Coasts of France.*

In this survey, special attention was given to the settlement and development of fauna on the Langrunne-sur-Mer reef (Calvados, France), which was visited during this study.

INSTALLATION OF THE REEF

A site for tire deposit was sought which would satisfy the following three requirements :

- the location must be promising from a biological point of view ;
- the activities of professional fishermen must not be hampered ;
- it should be possible for divers to follow the operation without taking too many risks.

The tires were sunk one mile off Langrunne-sur-Mer at a depth of 12 meters and are arranged in a vertical band linked by 1200 kgs of chain. The reef is marked by a buoy.

The administration authorised the deposit of only 52 tires, consisting of truck and farm machinery tires.

The deposit took place from a barge at the beginning of November 1975 after the state of the sea bed had been explored by divers. The sea bed consisted of fine sand over hard mud and the population was small.

DEVELOPMENT OF THE POPULATION

At the time of the first dives two months after the deposit, Hydroida (Obelia Geniculata) and various sponges were already fixed on the tires. Crabs (Portunus Puber) and a school of small godes (Gadus Puscus) had found shelter there. Traces of blennies were visible on the sand inside the circle of tires.

The reef was rapidly colonised. It should be stressed that while mobile animals were able to travel from neighboring zones, the fixed species, Hydroida and sponges were able to establish themselves only because of the presence of larva in the plankton. The summer of 1976 probably contributed to the development of the plankton on which the main species feed. Many dive were made and this made it possible to indicate the diversity and richness of the population.

Fixed species : Along with the Hydroida and sponges many algae (Ulva Lactuca, Dictyota Dichotoma, Laminaria Flexicoulis, Ceramium Mubrum, etc...), many barnacles (Balanus Balanoides) and several ascidians fixed themselves. It is important to determine whether the flora-fauna equilibrium will remain the same during next years or whether certain species are competing strongly with others for space and food. It would also be interesting to find out why some tires do not seem able to fix algae and barnacles and stay bare in the middle of tires which are covered with organisms.

Mobile species : The species encountered are as follows in order of importance :

- Gades (Gadus puscus) including numerous young specimens. This point is of interest since it makes it possible to suppose that the reef has really acted as a shelter for the development of fry and that the fish found there are not simply migrants ;
- More than one hundred crabs (Portunus Puber) ;
- Several dozen labrus (Labrus Bergylta) and blennies (Blennuis Phopis) ;
- Yellow pollock (Gadus Pollachyus) mixed with gades ;
- Some yellow gurnards (Callionymus Lyra) ;
- Some Galatheidae ;
- On the other hand, the sea-perch (Morhua Labrax) which have been observed in varying numbers are probably transient although this should be verified.

At the end of a year it appeared that the reef population exceeded forecasts in quantity and variety.

The reef is located on a plateau at a shallow depth where currents are relatively strong and has been modified and taken on a pear-shaped form with the point directed towards the current.

FISHING ON THE REEF

Fishing tests were made on the sunken reef at Palavas-les-Flots.

- Hand-lines : as a distance of approximately one hundred meters from the habitat fishing is practically unproductive. On the habitat, the average yield for two hooks is 10 kgs/day ;

- Trawl-lines : many conger-eels are present so that fishing is regularly carried on with trawl-lines and the yield around the habitat for a 25 hook unit is 50 kgs par day (the weight varies from 3 to 22 kilogrammes) ;

- Drag-net fishing : the yield at the habitat is three times greater and includes more rock fish.

4.5.3. IMMERSION COST.

According to american figures, up-dated immersion cost would be about 0.4 to 6 $ per truck tire, or about 10 to 150 $ per tonne. In France, the OTAM report indicates costs of about 2 $ per truck tire or about 50 $ per tonne. These costs do not include collection and transportation costs.

Costs remain very high and can be minimized only by building large reefs, not too far from shore and no too deep.

4.5.4. RECOMMENDATIONS.

Artificial reefs building with scrap tire cannot be considered as a cheap way to dispose waste. However, it is of interest to provide new areas for wild life and fishing along sea costs and so some new artificial reefs could be built and our recommendation is that some money could reasonnably be spent to investigate this field.

However, care must be taken not to enter the field too quickly :

- environmental impact of these reefs is only partly known and it would be a pity to build too many reefs too quickly and then to discover that they are another source of sea pollution.
- There is a real danger that tires may just be thrown into the sea anywhere and anyhow with the results of this uncontrolled dumping being called an artificial reef.

Research programs could concern the following :

- Determining whether the various components entering into tire manufacture are liberated into the environment in the long run . This phenomenon should be studied before beginning the large scale development of artificial tire reefs ;

- An analysis should be made of tires which are not covered by organisms in order to determine the reason for this sterility. It seems that the tires of farm tractors are better covered than truck tires. It is difficult to determine whether it is the external tire structure or its chemical composition which favors or hampers biological development. Analyses should be made in order to clarify this problem in order to construct reefs which will be as biologically receptive as possible ;

- Competition between the settled species should be followed by comparative studies of the surface at regular intervals. It may be necessary to slow down the settlement of a species which has a small interest for the biological cycle of the reef so as to favor more interesting species ;

- Certain organisms should be marked so as to determine whether or not the reef has become their principal, or even exclusive, habitat ;

- Tests should be developed with tire pieces or with tires partitioned with bricks so as to create cells in which crustaceans can develop better ;

- Tire surfaces should be inspected in order to determine whether the liming and scraping of the tires has increased settlement for the various species ;

- New and larger reefs should be sunk so as to obtain further data on this relatively new rubber-fauna system.

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4.6. SORPTION OF OIL, HEAVY METALS AND OTHER POLLUTANTS.

Y. ROUSSIN.

4.6. SORPTION OF OIL, HEAVY METALS AND OTHER POLLUTANTS.

CONTENTS

4.6. SORPTION OF OIL, HEAVY METALS AND OTHER POLLUTANTS.

4.6.1. ABSORPTION.

4.6.1.1. *Absorption tests with dilute mercury solution.*

Absorption tests with dilute mercury solution on old tire pieces were made in the U.S. by researchers of Du Pont de Nemours (Russell 1975) :

"In initial tests, one gram of rubber filings was added to 200 ml of 0.001M HNO_3, containing 1.53 mg Hg^{2+}/ml. The solution was shaken for 30 minutes, and a sample was taken for atomic absorption analysis. The product contained 1.35 mg Hg^{2+}/ml. Allowing the solution to stand in contact with rubber for one week with intermittent shaking reduced the mercury concentration to 0.9 mg Hg^{2+}/ml. The rubber was not completely wetted in the first 30 minutes, but appeared to be so after one week standing.

The relatively slow uptake of mercury apparently results from incomplete wetting of the rubber. In order to demonstrate that the mercury was tightly absorbed, the rubber was thoroughly washed with water and analyzed for mercury content. The washed rubber contained 75 mg Hg/g of rubber, or about half of the total mercury originally added.

Hard rubber (ground ebonite) was also tested as an absorbent but was difficult to wet. The maximum absorption of mercury on this material was only about 8 µg/g rubber, and no further tests were made.

COLUMN OPERATIONS.
Since batchwise contact with rubber removes only a port on (10 % to 50 %) of the mercury from solution, a multistage process is required for quantitative mercury removal. This is most readily achieved by column techniques. While the reaction between mercuric ion and the organic sulfide is fast, the overall rate of reaction is limited by incomplete wetting and perhaps aise by diffusion into crevices. As the results of exploratory batch experiments indicated, wetting and pore penetration after the initial rapid uptake of mercury are rather **slow**.

MERCURY ABSORPTION AT VARIOUS ACIDITIES.
Since the acidity of waste waters containing Hg^{2+} can vary considerably, absorption of Hg^{2+} from dilute acid and neutral solutions was compared using the batch contact method. The data in Table 2 indicate that more mercury is absorbed from very slightly acidic solutions (10^{-3} M) than from neutral solutions or those higher in HNO_3.

RECOVERY OF ABSORBED MERCURY.
Several unsuccessful attempts were made to elute absorbed mercury from shredded rubber. No more than 66 % of the absorbed mercury could be removed from rubber with ZM HNO_3-2 % H_2O_2.Elution by other reagents such as 0.SM sodium polysulfide, 7M HNO_3, and IM Na_2CO_3 were less complete.

Destructive distillation of rubber containing absorbed mercury was tested as a method for improving mercury recovery. Heating the material to 250 - 300°C in air yielded oils, a disposable white ash, and approximately 100°C of the mercury in elemental form. in several tests the volatile fraction was collected by bubbling through water ; mercury sank to the bottom of the vessel as small droplets, and the oils floated. Suche a process could recover both mercury and the potentially useful oils in a relatively pure form.

INCREASED MERCURY REMOVAL CAPACITY.
As described in the introduction, natural rubber is nonporous and very resistant to wetting. Consequently, few active sites (S-H and S-S bonds) are exposed to the solution. The possibility of an expensive wash or treatment that would enhance the wetability or capacity of the rubber was therefore investigated.

This investigation demonstrated that treatment of shredded rubber with a sodium polysulfide solution slightly increases its mercury removal capacity. Rubber treated with hot IM Na_2S containing 10 grams of powdered sulfur per liter, after a wash to remove excess sulfide, absorbs 10 to 25 % most Hg^{2+} than untreated rubber. The increased capacity could result from several effects, singly or in combination : better wetability of the rubber, deposition of sulfide in the rubber pores, or incorporation of sulfide into the structure. There was no consistent relationship between the increased amount of Hg^{2+} absorbed and the duration of exposure of the rubber to the polysulfide solution."

4.6.1.2. *Hydrocarbon absorption tests.*

Hydrocarbon absorption tests were made at the Institut Français du Pétrole (I.F.P.), which was visited for the survey, where for three years attempts have been made to find a way to replace mineral absorbants where results were relatively satisfactory but whose applications were limited while the problem of elimination after absorption had not been solved.

The first tests were intended to reduce organic pollution from refineries. At first, the replacement systems for absorbants were cellulose products but these had to be specially manufactured. Research on other products was directed towards scrap and especially rubber crumb.

The latter was at first used raw for the recovery of dispersed hydrocarbons. It seems that particle size and operating techniques and techniques of collection after use have an enormous effect on hydrocarbon absorption capacity. The I.F.P. has developed an activation technique which increases rubber crumb absorption power five times.

Experimental tests were made at sea in order to counteract the effects of accidental displacement by dredging with promising results although much study is still necessary concerning crumb activation, and deposition and collection techniques at sea.

In this technique many factors seem to affect the absorption capacity of rubber crumb such as :

- Particle size of the rubber crumb, ranging from 100 μm to 5 mm ;
- The type of hydrocarbon to be eliminated (heavy, light, old) ;
- Working conditions (deposition, collection) ;
- The environment (fresh or sea water) ;
- The mode of dispersion of the products to be collected.

This technique should be operational in 1978 for decanted hydrocarbon residues.

The cost price of activation processing for rubber crumb should be about 150 to 250 $ per tonne of crumb.

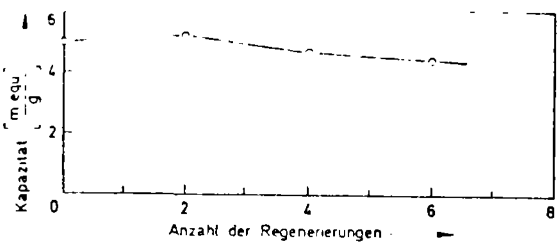
4.6.2. USE AS ION EXCHANGE MATERIAL.

"In U.S.A., rubber has been converted to an ion exchange material by several techniques. In one method, the rubber was treated with concentrated sulfuric acid to produce a sulfonated ion exchanger. Alternatively, the rubber was degraded and converted to an ash that had ion exchange properties. Another method for forming a mercury-absorbing ion exchanger involves chemical addition of (-C-SH) groups to polymer structures. These processes all involve chemical processing that adds to the cost and process complexity. The process described here makes use of tire rubber as discarded, with minimal pre-treatment."

Similar studies were made in Germany (Schnecko 1974 and Dunlop patent) and several problems were pointed out concerning the various elements entering into tire manufacture. Tests were made with reagents such as acids or oxidising products but these produced superficial reactions. Several examples of active groups are given in the following table :

Type	Reagent	Capacity (meqv/g)
Cation	SO_3	4,6
	HSO_3Cl	3,9...5,3
	PCl_3, O_2	1,8
Anion	SO_2Cl_2 ; NEt_3	2,6...3,2
	SO_2Cl_2 ; NMe_3	4,9
	$ClCH_2$-OCH_2 ; NMe_3	2,7

Encouraging capacities were reached in comparison with commercial products whose exchange capacity is closed to 2 meq/g. The figure below shows that regeneration stability is also satisfactory :



When rubber crumb is used as an ion exchanger the constituent products should not enter the solution. This is to be avoided in industrial use for example in seawater desalting.

4.6.3. CARRIER IN GAS CHROMATOGRAPHY.

This is a very special use. Approximately 0.2 mm diameter, powder can be used without previous preparation as a carrier material (Schnecko 1971).

The following table gives elements for the comparison of the properties of rubber crumb and some commercial products and polyurethane powder. The values "n" and "HETP" are the usual values characterising separation capacity in chromatography or gas chromatography (Kaiser 1960), and the carriers improve as "n" rises and HETP falls.

	Ether		Chloroform		Xylol	
	n	HEPT	n	HEPT	n	HEPT
Di-n-Decylphthalat	148	13,5	475	4,2	1 330	1,51
Porapak Q (150°C)	735**	2,6	660**	3,05	—	—
Porapak Q (250°C)	346	5,8	535	3,7	815	2,45
Silikonöl DC 200	30	66,6	92	21,7	460	4,35
Polymethane	100	20	280	7,1	410	4,85
Rubber crumb 0,2mm	249	8,05	520	3,85	880	2,37

HETP : Height Equivalent of a Theoretical Plate
** = Tailing

Rubber crumb gives very satisfactory results.
Tests have been made using rubber crumb as a carrier for gel chromatography.

4.6.4. CONCLUSIONS AND RECOMMENDATIONS.

No detailed financial information is available now, but it is possible to state that the cost would be relatively high (several hundreds $ per ton) since it must include grinding to a very small size, specific treatment, and for hydrocarbons removal from polluted water, transportation and placing in water, removal of used crumb and disposal of the latter (by incineration for example).

The most promising application of sorption seems to be hydrocarbon adsorption for polluted rivers or seas, but the market would probably not exceed 10 000 t/year for France. The economics and the specific advantages of this method for the solution of such an important pollution problem still have to be discussed, but our recommendation is that some research could be encouraged in the following fields :

- Application in water containing NaCl (sea water) of the I.F.P. process, which gives a very good result in river water.
- Collection of used crumb from water surface and incineration techniques for hydrocarbon containing wet crumb with the possibility of heat recovery.

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4.7. MICROBIOLOGICAL DETERIORATION OF RUBBER.

Y. ROUSSIN

4.7. MICROBIOLOGICAL DETERIORATION OF RUBBER

Microorganisms are living organisms which attack a large variety of substances in order to extract elements necessary for synthesizing protein.

Form any years, researches have studied this problem and its applications to the deterioration of polymers.

Microbiological attack can be applied to various classes of rubber :

- Natural Rubber : This is the main type which has been studied for microorganisms deterioration. The main types of microorganisms which are being developed are mycelia of the aedynomycetes and streptomycetes family.
- Butadiene-Styrene SBR : Microorganism attack on these compounds presents many problems and the presence of polysulphide joints (Heap 1968, Leeflang 1963, Blake 1949, Blake 1955), which increase the stability of the compound, may be responsable.
- Neoprene : Two types of neoprene are manufactured, one of which contains sulphides. In reality, the two polymers are very resistant to all kinds of bacterial activity. The presence of chloride may hamper the microorganisms (Cundell 1973).
- Butyl-Nitrile : These are very resistant to microbiological attack.
- Silicon : These rubbers are considered resistant (Heap 1968).
- Polymethane : This polymer has amide functions of the peptic type which can be attacked microbiotically (Houp 1968).
- Tires : Under the appropriate conditions it would be possible to ferment scrap tire by means of yeast. Fungi would attack various kinds of rubber but the effects of some additives which are used in tires should not be underestimated.

Research is now under way at the University of Clermont-Ferrand (France) which has been visited for the survey. Cultures were collected and determined and then selections were made. One of the cultures attacks oil in the presence of an elastomer containing oil.

Tests were made in a closed vessel but at the end of 20 days the pH drops and this leads to the stopping of bacterial attack. The best development takes place at 27°C.

White natural rubber becomes black after attack and the mycellium even penetrates into the interior of the piece of rubber. The viscosity as well as analysis of the fragment by one dimensional and gel chromatography shows that the long chains are cut up into components with low molecular weight.

The microorganisms are fed not only by the rubber supplying carbon but also from the nitrogen point of view by ammonium salts which are necessary for protein synthesis.

This research still seems to be in its first stages. Best results were obtained with natural rubber alone, while any addition of a synthetic product seems to slow down or stop microorganism activity. It also seems to be true that nitrogen must be supplied in the form of ammonium salts. Lastly, certain pathogenic types of microorganisms amongst those mentioned transmit thrush.

In conclusion, it is relatively difficult to transform tires into proteins with the microorganisms used and, according to Schnecko (1974), the deterioration is due first of all to aging. In addition, certain microorganisms of the funguns type have a relatively low yield for protein production, 3 per cent by weight of humid matter, while the higher plants give 5 per cent. In addition, the proteins obtained are of relatively low molecular weight and lastly the deterioration phenomenon requires a relatively high relative temperature with a high energy cost.

Our conclusion is, therefore, that microbiologic conversion of scrap tire is probably not a possible future solution for scrap tire disposal and our recommendation is that no research program in this field should be encouraged by EEC or governments.

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4.8. AGRICULTURAL USES.

Y. ROUSSIN

4.8. AGRICULTURAL USES.

The use of scrap tires in agriculture has shown relatively unsatisfactory results in soil improvement which vary a great deal depending upon whether the rubber is mixed in bulk in the soil.

In Germany, (Schnecko 1974) added rubber in varying proportions to soil in order to grow parsley. The results were presented during a visit and they were not very conclusive. Parsley will grow badly with 10 % rubber crumb admixture, with 20 % admixture growth is very sickly and with 30 % there is no growth at all.

In Canada, rubber crumb was spread in orchards (Teskey 1975). The main observations are the following :

- Heat is well retained and the soil temperature in full sunlight has a tendancy to be too high ;
- In case of frost, a thick coat of rubber crumb reduces the effects of excessive temperature differences. Soil temperature fell to - 3,9°C and frost reached a depth of 5 cm under the rubber crumb while with the bare soil it reached a depth of 25 cm ;
- Results for humidity retention are equivalent to those obtained with straw (hay) ;
- Sunlight and ultraviolet rays have a very important effect on this material. They seem to favor and develop oxidation, hydration and often the nitrification of synthetic polymers and also to alter stability. After 6 years of tests the rubber crumb mass has decreased to such an extent, that it can no longer be considered as performing the function of straw.

Another use for old tires is to ballast silo covers in the fields. Several millions of tires are used in this way in EEC, but this application will not require many more tires in the future. <u>It should however be considered as reuse and should not, as some propose, be prohibited as pollution.</u>

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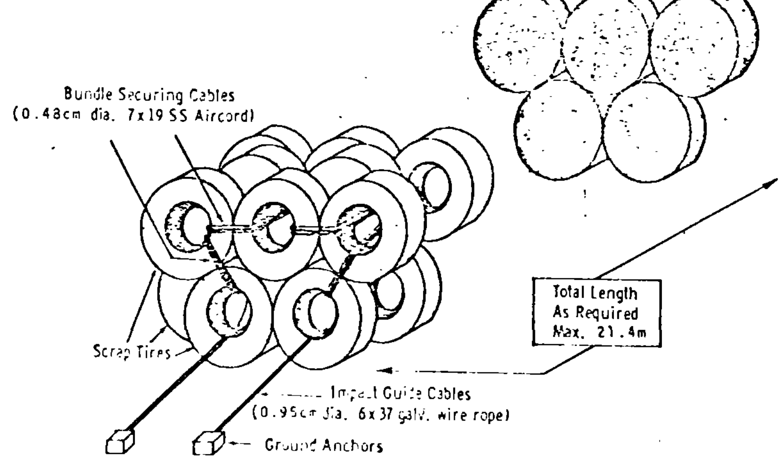
4.9. OTHER APPLICATIONS.

4.9. OTHER APPLICATIONS.

Old tires are recycled very ingeniously in quantities which have not been evaluated during this study for many applications some of which will simply be listed below :

Shock absorbers :

GOODYEAR began their investigations into the crash attenuator application in 1968. Since then work has been done at the University of Cincinnati and the Texas Transportation Institue (T.T.I.) at Texas A & M University to develop a final design similar to that shown in figure. This design and various modifications developed at T.T.I. have stopped vehicles traveling at speeds of 96 km/h with deceleration "G" loadings well below the maximum figure specified in the Federal Instructional Memorandum 40-1-71 (Marquis 1973).



The Goodyear scrap tire cash attenuator.

Insulation against noise :

The Firestone Tire and Rubber Company has shown that ground scrap rubber in various paints and coatings can significantly reduce sound transmission of substrate coated with the mixture (Bechwan 1974). Goodyear, Uniroyal, and U.S. Rubber Reclaiming have been investigating the use of ground scrap rubber with binders of asphaltic type substances to make artificial playing surfaces (Anderson 1972).

Erosion limitation :

Tires deposited on the coast can reduce erosion by the sea by limiting wave action.

Embankment reinforcement :

The incorporation of tires especially in strip form during the construction of road embankments makes it possible to increase embankment slopes and to create what amounts to real reinforced earthworks. Experiments have already been made in Germany and France.

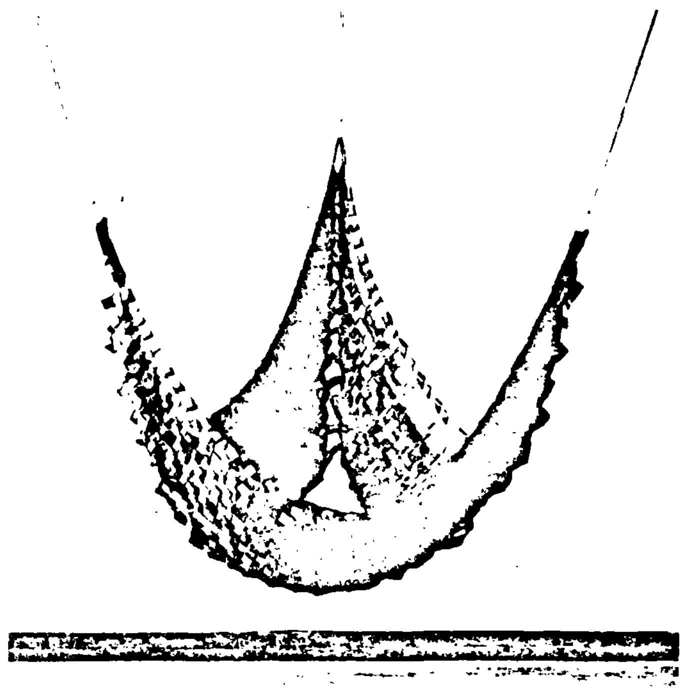
Filler for special concrete (after shredding or grinding).

Playgrounds for children, decorations, minigolf, etc...

Cutting various kinds of goods, such as making shoes.

In some countries of South America, all worn out tires are used to make shoes.

Artistic sculpture :



HANGING **SCULPTURE** entitled "Tired after a Good Year" is composed of strips of discarded inner tubes Artist Bonnie Vierthaler washes, cuts, bonds and weaves the scrap rubber into resilient art works exploring the theory of tension.

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4. 10. RESUME DU SYMPOSIUM CONSACRE AU PROBLEME POSE PAR LES PNEUMATIQUES USES.

RÉSUMÉ DU SYMPOSIUM CONSACRÉ AU PROBLÈME POSÉ PAR LES PNEUMATIQUES USÉS

WASHINGTON, 14 - 15 JUIN 1977

NATIONAL TIRE DEALERS ; RETREADERS ASSOCIATION

TIRE RETREADING INSTITUTE - WASHINGTON

MAURICE GELUS

UNIVERSITÉ DE TECHNOLOGIE

COMPIEGNE

INTRODUCTION

L'association nationale des industriels qui, aux U.S.A., touchent de près ou de loin au marché des pneumatiques - c à d. The National Tire Dealers; Retreaders Association - a organisé en Juin 1977 à WASHINGTON un symposium de trois demi-journées pour tenter d'apporter une réponse au problème posé par le devenir des pneus usés.

Les participants émanaient des milieux les plus divers : agences fédérales, représentants de l'administration de certains états, grandes firmes productrices de pneus, universités,... des communications présentées, une vingtaine, et les discussions qui ont suivis, ont permis de faire le point sur l'état d'avancement des diverses solutions préconisées ou expérimentées.

Si on voulait, non sans une certaine hardiesse, résumer la tendance actuelle, on dirait la chose suivante : il faut aujourd'hui organiser la collecte des pneus usés, trier ceux qui sont réchappables et les réchapper, et réduire les autres à l'état de morceaux. Avec ces déchets broyés, plusieurs traitements sont possibles : le simple stockage, la mise en décharge, l'incinération la pyrolyse... le choix du procédé dépendant des circonstances locales. Afin d'éclairer cette conclusion lapidaire, il y a lieu de présenter avec plus de détails les communications les plus importantes. Après avoir examiné l'intérêt du rechappage, je continuerai par les articles insistant sur l'aspect technologique, et notamment les procédés thermiques de traitement des déchets. Ces différentes technologies étant connues, quelle peut-être l'incidence de la législation, quels sont les problèmes administratifs, quelles tentatives ont été réalisées au niveau local : voilà l'objet des deux chapitres suivants. Enfin, il sera nécessaire de revenir sur quelques articles généraux, faisant le point sur la question.

I- LE RECHAPPAGE

L'intérêt du rechappage n'échappe à personne. Par exemple, on estime qu'un pneu neuf exige, pour sa fabrication, 7 gallons d'huile (1 gallon = 3,79 litres),alors que le rechappage fournit un pneu pour seulement 2,5 gallons. Ces estimations sont citées par T. ROHLA, AMF TIRE EQUIPMENT DIVISION, SANTA ANA, CALIFORNIA (21).Le rechappage est une technique déjà bien répandue aux U.S.A. D'après J.F. HUDSON et E.E. LAKE, URBAN SYSTEMS RESEARCH and ENGINEERING, Inc., CAMBRIDGE, MASSACHUSETTS(10), sur 226 millions de pneus de tourisme mis sur le marché en 1976, 35 millions, soit 15%, étaient des pneux réchappés. Cette proportion, on le sait, est moindre en EUROPE. Cependant il est pratiquement impossible de prévoir comment la part des pneus réchappés va évoluer sur le marché.

Les raisons principales qui pousseraient au développement du réchappage sont connues. Elles ont été rappelées par T. ROHLA (21), par P.R. CASAVINA, SOLID CONVERSION SYSTEMS, Inc., HAMDEN, CONNECTICUT (14), également par H.YAKOWITZ du N.B.S. (22) et par R.R. WESTERMAN, Dpt of MANAGEMENT, UNIVERSITY of CALIFORNIA, SACRAMENTO (8). Cependant, les obstacles qui s'opposent à ce développement sont nombreux.On peut citer le manque de carcasses rechappables, ce qui est lié à l'extension de la carcasse radiale -, la mauvaise image de marque des pneus réchappés réputés moins surs (il est vrai que la bande de roulement d'un tel pneu a tendance à se décoller plus facilement que dans le cas d'un pneu neuf), la trop grande variété des types de pneus,...

Pour augmenter l'importance du rechappage, il apparaît nécessaire de :
- faire des progrès au niveau des techniques pour obtenir un rechappage de très grande qualité;
- promouvoir le marché des pneus rechappés, plus surs qu'on ne le dit généralement;
- standardiser mieux la fabrication des pneus neufs, afin de ne pas multiplier les types de carcasses.

Tous ces différents éléments font qu'il est très difficile de prévoir dans quelle direction la situation va évoluer, même si des efforts locaux ont montré, au niveau de la collecte par exemple (T. ROHA a organisé avec des scouts le ramassage des pneus usés rechappables) que l'on pourrait rechapper plus de pneus.

Une autre solution a été proposée : fabriquer des pneus supportant 100.000 miles et les conséquences d'une telle éventualité ont été étudiées par R.R. WESTERMAN (8).

Il est donc difficile de conclure, si ce n'est en soulignant que le rechappage est une bonne solution, mais que prévoir son développement est un pari audacieux.

II- LES DIFFÉRENTS PROCÉDÉS DE TRAITEMENT

A en croire ce qui a été dit, les techniques sont nombreuses, et peu de progrès marquants ont été faits dans ce domaine dans un passé récent. Il semblerait qu'il soit nécessaire, avant d'aller plus avant, de faire des expériences et des analyses économiques plus fines permettant de décider.

a- La technique qui consiste à immerger des pneus entiers,assemblés selon un réseau héxagonal pour s'opposer aux vagues et réaliser ainsi des jetées, lestés pour en faire des récifs artificiels afin de protéger les berges et favoriser la pêche sportive est connue largement et ne mérite pas un long commentaire car elle restera toujours marginale. Elle a été évoquée par un représentant de GOODYEAR (4) et testée dans l'état de MARYLAND par C.R. ALBRECHT, ANNAPOLIS, MARYLAND (3)

b- L'addition de poudrette à l'asphalte reste un débouché sérieux (H.G. LANDSON, SAHUARO PETROLEUM AND ASPHALT Co., PHOENIX, ARIZONA) (15). On sait que la poudrette mélangée à l'asphalte donne un liant de qualité pour réaliser des revêtements routiers. Le procédé, développé initialement à PHOENIX est largement connu, et sa présentation au symposium n'a pas apporté d'élément nouveau. Une évaluation économique a été réalisée par GODDART (E.P.A.) dès 1975, et concluait à une bonne rentabilité du procédé. Cependant, les nombreuses expériences réalisées n'ont pas encore montré qu'un tel emploi des déchets de caoutchouc avait des avantages techniques et économiques évidents.

c- L'incinération des pneus,entiers ou non, est une possibilité évoquée par GOODYEAR (4) et UNIROYAL (11). Tout le monde s'accorde pour dire que l'incinération n'est pas le procédé destructif le plus intéressant et de loin.

GOODYEAR a construit une installation d'incinération de pneus entiers à JACKSON consommant 35 tonnes (25000lb) par jour et fournissant 12 tonnes de vapeur sous 18 hai (250 psi). La rentabilité d'un tel procédé demande une analyse économique poussée qui est en cours.

UNIROYAL (11) a expérimenté l'incinération de pneus broyés, et par là, acquis une bonne expérience du broyage et de la manipulation des déchets broyés. L'incinération de morceaux suffisamment fins ne pose pas de problème, notamment au niveau de l'émission de SO_2 . Par contre, c'est la réduction des pneus à l'état de morceaux qui influe le plus sur la rentabilité du procédé et qui pose les problèmes techniques les plus difficiles. Pour résoudre cette difficulté, UNIROYAL a testé plusieurs broyeurs; un " Rawls Tire Chopper ", un " Siso Rasper Model 800 " qui en deux passages, fournit des mordeaux de l'ordre de 3 cm, un moyen " Saturn Model 52-32 H/100 hp ", dont les tests vont commencer. Il y a là un travail intéressant, qui aidera certainement celui qui doit broyer des déchets de caoutchouc.

La combustion de ces déchets en lit fluidisé est également possible; ce fait est connu et tous les avantages de cette technique ont été soulignés par JER-YU SHANG et R.A. CHRONOWSKI, MITRE CORPORATION MC LEAN, VIRGINIA 22101, (5), qui, cependant, n'ont pas apporté d'éléments nouveaux dans ce domaine.

d- La Thermolyse, qui vise à détruire le matériau polymérique dans des conditions ménagées de température et de pression a été évoquée par E.L. KAY, FRESTONE TIRE AND RUBBER, AKRON, OHIO (9) .Il s'agit du procédé D.S.R. (Depolymerised Scrap Tire) qui a fait l'objet antérieurement de plusieurs publications de FIRESTONE, et notamment d'une " Defensive Publication " tout récemment. Cependant la dissolution du caoutchouc dans les conditions décrites nécessite un temps de réaction très long, fonction de la taille des morceaux, ce qui enlève beaucoup d'attrait au procédé. Le noir de carbone obtenu contient beaucoup de cendres ($\sim$ 10%) et son extraction est très difficile. Ses propriétés sont voisines de celles d'un noir G.P.F.

e- La Pyrolyse est une technique attrayante car c'est celle qui, à priori,pourrait conduire à la récupération la plus rentable.

E.L. KAY de FIRESTONE a simplement évoqué la distillation des déchets, selon une technique développée il y a quelques années avec le " BUREAU of MINES ". La pyrolyse en lit fluidisé, proposée par les Japonais, ainsi que celle mise au point par l'Université de CALIFORNIE ont été simplement citées par quelques auteurs. La pyrolyse dans un bain de sels a fait l'objet d'une communication par G.C. FRAZIER UNIVERSITY of TENNESSEE, KNOXVILLE, KENTUCKY, (20) mais les essais et les résultats ne permettent pas d'apprécier ce procédé qui, on le sait, avait déjà été étudié par ailleurs (INSTITUT BATTELLE).A priori, il est sûr qu'une telle technique nécessitera des investissements élevés et que la purification des produits sera compliquée par la présence des sels.

Le procèdé TOSCO, mis au point primitivement pour pyrolyser les schistes bitumineux , est utilisé, au stade pilote, pour traiter les déchets de caoutchouc, à l'initiative de UNIROYAL. L'étude est en cours, et il n'est pas possible d'affirmer que l'usine projetée, qui détruira 10 millions de pneus par an, verra le jour. Une autre tentative intéressante a été présentée par W.W. GOTSHALL, Président, CARBON DEV. CORPORATION, WALLED LAKE, MICHIGAN (6). Après une réduction en morceau, les déchets sont pyrolysés dans un four rotatif à 900°C. Les gaz produits fournissent sur place de la vapeur, utilisée pour traiter le noir de carbone. Le noir de carbone, dont les particules sont enrobées d'un produit pour éviter l'oxydation de surface, est aggloméré en granulés et vendu . L'auteur part du principe que la pyrolyse est d'autant plus avantageuse qu'elle est réalisée à haute température. En effet, plus la température est élevée, plus la quantité relative de noir de carbone obtenue est importante et meilleure est sa qualité. Ce deuxième point d'ailleurs mériterait d'être éclairci Comme le noir est le produit le plus cher, il est évident que le bilan économique sera d'autant plus avantageux que ce produit sera fabriqué en grande quantité à partir d'un poids donné de déchets de caoutchouc. W.W. GOTSHALL estime que pyrolyser à 500°C permet d'obtenir des produits valant, à la vente, 1,26 $ par pneu , alors que une température de 900°C permet de porter ce prix de vente à 1,57 $ par pneu. Pour une installation de 2.000.000 pneus par an, ceci correspond à 620.000 $ de plus. Ce raisonnement est intéressant, mais il y a trop d'inconnues encore : le prix de vente supposé du noir est de 13 cents/lb soit 1,40F/k ce qui est peut-être optimiste, ce noir contenant encore 6 à 8% de cendres. Cependant, il s'agit là d'une étude très positive, et le développement du procèdé mérite d'être suivi de près.

A l'issue de ce bref paragraphe consacré à la pyrolyse, il apparait que les problèmes posés et les incertitudes demeurent. En effet, tout converge pour démontrer que la rentabilité est liée au prix de vente du noir de carbone, et donc à sa qualité.Si W.W. GOTSHALL fait le bilan économique avec un prix de 13c/lb, par ailleurs H. YAKOWITZ, du National Bureau of Standard (22), proposait au même congrès, un prix de 8c/lb, soit 0,86 F/kg, tout en mettant en doute l'existe ce d'un large marché pour ce type de produit. On peut donc penser qu'un effort de recherche visant à améliorer la qualité du noir de carbone ne serait pas un effort inutile, ce qui suppose une étude des procèdés, chaque étape influençant la qualité des produits.

Les techniques de valorisation des déchets de caoutchouc sont nombreuses, ce qui a amené certaines administrations locales à mettre sur pied des solutions usant à supprimer la décharge sauvage des pneus usés.

III- Les Solutions Locales

Quelques solutions locales (MARYLAND, CONNECTICUT, CALIFORNIE) ont été évoquées, et il est intéressant de les présenter rapidement.

1°)- Le MARYLAND a créé très tôt un service - MARYLAND Environmental Service - chargé de résoudre les problèmes posés par les déchets solides et les pollutions diverses. Le service a commencé à promouvoir le broyage des pneus avant de les mettre en décharge et a acquis ainsi une expérience certaine dans ce domaine- Il a publié un article en Mai 1977 dans la revue " Public Work " .- La politique qu'il préconise semble pouvoir être résumée ainsi : broyer les déchets, et les utiliser au mieux selon les possibilités locales, la pyrolyse étant à priori la technique la plus avantageuse. Le MARYLAND a également utilisé des pneus entiers pour renforcer des berges ou créer des récifs artificiels pour développer la pêche sportive. Cette expérience fut présentée par C.R. ALBRECHT, ANNAPOLIS, MARYLAND.

2°)- Le CONNECTICUT a, dès 1965, mis sur pied une agence pour traiter les déchets solides (C. KURKER, CONN. STATE DEPARTMENT of ENVIRONMENTAL PROTECTION,HARTFOR D, CONNECTICUT) (7), dont les pneus usés au nombre estimé de 1,7 million . Initialement, ces pneus étaient incinérés, ensuite ils furent vendus à UNIROYAL, qui avait une installation de récupération. Vers 1974, cette usine fut arrêtée, si bien que le débouché pour 80% des pneus usés disparut. A la même époque, l'Etat de CONNECTICUT décida la construction, en collaboration avec la GENERAL ELECTRIC, d'une installation de traitement des ordures ménagères : les déchets organiques combustibles sont séparés, et on peut à ce moment là,y ajouter les déchets de caoutchouc.

Comme dans la plupart des cas, les pneus sont broyés, ce qui réduit leur volume d'un facteur 7. Le stockage est grandement facilité, quelque soit la destination ultime des déchets broyés. Des essais ont été faits pour ajouter de la poudrette à l'asphalte ou utiliser des pneus entiers pour réaliser ainsi des barrières de protection.

3°) DANS L'OREGON , C. ROTHEN, SCRAPT TIRE DISPOSAL, METROPOLITAN SERVICE DISTRICT, PORTLAND, OREGON, a mis au point un système permettant un contrôle rigoureux du devenir des pneus usés. Par exemple, toute personne transportant plus de 30 pneus doit avoir une licence délivrée par l'Administration. On peut retenir également qu'un centre de traitement des pneus demande 25 ¢ (1,25 F) au particulier qui veut se débarrasser d'un pneu de tourisme et 85 ¢ pour un pneu de poids lourd .

Cette expérience qui relate la mise en place d'une politique, souffre malheureusement d'être isolée et les résultats obtenus sont trop partiels pour permettre d'en tirer une conclusion.

4°) LA SITUATION EN CALIFORNIE a été évoquée par D.L. STRAUCH, CALIFORNIA STATE SOLID WASTE MANAGEMENT DEPARTMENT, SACRAMENTO (19). Dans cet état, l'un des plus vastes des U.S.A., le problème est aigü: la " production " annuelle de pneus usés s'élève à 20 millions d'unités environ, et une quantité analogue est stockée.

Actuellement , aucune solution globale n'a pu être apportée. La mise en décharge contrôlée absorbe les 2/3 des pneus usés, mais, comme un broyage préalable est nécessaire, le coût devient dissuasif ce qui favorise ainsi l'abandon des pneus usés dans des lieux sauvages, le long des routes... Une taxe sur les pneus neufs a été instituée, afin de récolter des fonds pour traiter le problème ; après de multiples réformes, elle a été abandonnée.

Des solutions locales ont été tentées. L'utilisation comme combustible, la pyrolyse - mais il reste, au niveau de l'Etat de CALIFORNIE, beaucoup à faire pour résoudre le problème.

De ces quatre expériences locales, on peut retenir un fait essentiel : les pneus usés sont broyés, et le coût du broyage est supporté par le particulier. Ce broyage facilite le stockage, le transport et les traitements ultérieurs.

IV- L'ÉVOLUTION DE LA LÉGISLATION ET LA COMPARAISON DES DIFFÉRENTES TECHNIQUES D'UTILISATION DES PNEUS USÉS

La législation et la technologie évoluent parallèlement. Les différentes technologies et les solutions ont été comparées par E.E. LAKE et J.F. HUDSON (10), dans une synthèse remarquable, basée sur une documentation très complète. P.R. CASAVINA (14) propose aussi le schéma déjà vu : collection, tri avec rechappage si la carcasse le permet, traitements thermiques dans le cas contraire. A.H. PURCELL, TECHNICAL INFORMATION PROJECT, WASHINGTON (12) a analysé très rapidement les raisons qui s'opposent à la mise en place d'une politique globale.

Il semble que, au niveau fédéral, on considère que les technologies sont suffisamment avancées, mais que les problèmes importants sont au niveau politique c.à d. au niveau de l'organisation du ramassage et du traitement, du choix des incitations nécessaires à la mise en place d'un système de récupération, des équilibres financiers. Au niveau administratif, la loi dénommée " Resource Conservation & Recovery Act of 1976 " aura des conséquences importantes, comme l'a exposé C. PETERSON, ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON (2), en donnant le pouvoir aux administrations locales d'organiser la solution du problème posé par les pneus usés. Ainsi l'E.P.A. pourra soutenir la formation de personnel s'occupant de déchets solides, développer des études de marché pour les produits récupérés, réaliser des opérations pilotes...
Ainsi cette loi renforce le pouvoir des administrations locales et fédérales. Cet aspect est important, car il met en évidence qu'une simple économie de marché n'est pas un système qui permette de traiter avec le plus de facilité les problèmes liés à la pollution. On débouche là sur des considérations d'économie politique, qui dépassent les limites de ce simple compte-rendu.
L'impact économique de cette même loi est étudié par H. YAKOWITZ (22). Certains alinéas de cette loi donnent des possibilités d'agir à l'E.P.A. Par exemple, l'Agence pourra soutenir une analyse complète du problème des pneus en tenant compte du ramassage et des technologies actuelles. Elle pourra subventionner partiellement (5%) l'achat de broyeurs pour pneus, mobiles ou fixes. Parallèlement le Secrètariat au Commerce pourra, toujours dans le cadre de la loi PL 94-580, stimuler les marchés, promouvoir certaines technologies, dont le rechappage.

Cette communication a un autre intérêt, car elle contient une bonne analyse économique, basée sur des hypothèses raisonnables. Quelles sont les principales estimations : le broyage 40 ¢/pneu, le noir de carbone obtenu par pyrolyse se vendrait 0,90 F./kg, la fabrication de la poudrette reviendrait à 2,50 $/pneu, soit 6 fois plus qu'un broyage grossier. Cependant, trop d'inconnues subsistent pour définir une stratégie. Mais, là encore, il est souligné que c'est un non-sens économique que de broyer des carcasses rechappables.

CONCLUSION

Ce symposium, très brièvement présenté, a permis de faire le point sur les problèmes posés par les déchets de caoutchouc. Si la décharge controlée reste une voie peu onéreuse, chacun a conscience qu'il s'agit d'un pis-aller, alors que la nécessité de récupérer énergie et matières premières devient de plus en plus évidente. Les technologies basées sur un traitement thermique sont nombreuses ; elles restent cependant coûteuses dans leur état actuel, et les bilans économiques restent à faire.
On peut cependant dégager quelques leçons de portées suffisamment générales pour qu'elles puissent être transposées en EUROPE sans difficulté.

La première est que la recherche d'une solution unique, valable en tous lieux, est illusoire, les circonstances locales intervenant largement dans le bilan technique, économique et écologique final.

La deuxième est qu'il faut rechapper les pneus rechappables, donc, au niveau du ramassage, il faut trier les carcasses.

La troisième est que, pratiquement dans tous les cas, un broyage préalable est nécessaire, l'utilisation des pneus entiers, restant difficile, est marginale.

La quatrième est qu'un effort de recherche reste à faire au niveau des procédés de traitement bien que ceux-ci soient déjà nombreux, la dégradation thermique demeurant la voie la plus prometteuse. En effet, la qualité des produits est très liée aux différentes étapes d'un procédé et des études pour mieux connaître l'influence des techniques sur la qualité sont encore nécessaires.

Ces efforts de recherche sont certes nécessaires, mais il faut parallèlement promouvoir quelques expériences avec des technologies existantes mais pas encore suffisamment développées afin d'avoir des éléments essentiels pour faire une analyse économique sure.

PROGRAMMF

1)- H. WALKER Noyes, Program Moderator
Noyes Tire Compagny, Westbrook, Maine
Introduction to Program

2)- C.PETERSON
Environmental Protection Agency, Washington, D.C.
Resource Conservation & Recovery Act of 1976
Discussion of those sections of the Act which are concerned with scrap tire disposal.

3)- C.R. ALBRECHT
State of Maryland Environmental Service, Annapolis, Maryland
Maryland's Waste Tire Program
A description of three on-going projects utilizing scrap tires.

4)- F.R. TULLY
The Goodyear Tire and Rubber Company, Akron, Ohio
An Overview of Scrap Tire Disposal
An examination of several methods used by Good-year to make effective use of scrap tires.

5)- Jer-Yu SHANG and ROBERT A. CHRONOWSKI
The Mitre Corporation, Mc Lean, Virginia
Scrap Tire Disposal by Fluidized-Bed Combustion
A new technology which can be used for an environmentally acceptable means of heat energy recovery from scrap tires.

6)- W. GOTSHALL
Carbon Development Corporation, Walled Lake, Michigan
A Process for Manufacturing of Carbon Black from Scrap Rubber
The economic and technical aspects of recovering carbon black from scrap tires

7)- Ch. KURKER

Connecticut State Department of Environmental Protection, Hartford, Connecticut

Energy Recovery and the Problem of Tire Disposal in Connecticut
The options developed and proposed for disposing of scrap tires in the state.

8)- R. WESTERMAN

California State University, Sacramento, California

Tire Profits ans Waste Management Through Retreading and 100,000 Mile Original Equipment Tires.
A cost/benefit analysis of the profits, benefits, and costs of retreading and 100,000 mile tires.

9)- E.L. KAY

Firestone Tire and Rubber, Akron, Ohio

Reclamation of Scrap Tires
A look at methods to recover raw material from scrap rubber.

10)- E. LAKE and J.F. HUDSON

Urban systems Research and Engineering, Inc., Cambridge, Massachusetts

Federal Actions and Opportunities for Tire Disposal and Reuse.
An analysis of materials flows, technology available for retreading, and the available methods for reuse and environmentally sound disposal of scrap tires.

11)- F. QUERRY

Uniroyal Tire Company, Detroit, Michigan

Ground Scrap Tires As a supplement to Coal Fuel in a Stoker Fired Boiler
Description of Uniroyal Eau plant steam generation process using chopped tires & ccoal.

12)- H. PURCELL

Technical information Project, Washington, D.C.

Research Trends & Information Needs of Tire Recycling Workers
Report on a study relating to trends in waste rubber research & identification barriers retarding research.

13)- C. RHOTEN

Metropolitan Service District, Portland, Oregon

Scrap Tire Processing & Disposal Regulations

Regulations for the Community & industry in an organized system of collection processing & salvage.

14)- P.R. CASAVINA Jr.

Solid Conversion Systems, Inc., Hamden, Connecticut

Scrap Tire Recycling : Myth or Reality

A description of a model for tire recycling that meets the need of the retreading industry and the need for conversation of valuable materials and energy resources.

15)- H.G. LANDSON

Sahuaro Petroleum and Asphalt Company, Phoenix, Arizona

Asphalt-rubber Development, Use and Potential

An attractice incentive for maintenance and construction of highways thru combining asphalt and rubber particles.

16)- W.B. THOMAS

Big " O " Tire Company, Oakland California

Disposal and use of Scrap Tires

How one retread company plans to convert scrap tires into useful energy.

17)- M.A. MOE Jr.

Aqualife Research Corporation, Marathon Shores, Florida

Commercial Fish Propogation

This paper explores the potentials and problems of creating artificial reefs from scrap tires as a basis for controlled seeding and restricted harvesting of fishery resources.

18)- J.F. LOUDIS

National Compactor/American Baler Machine Company, Jacksonville, Florida

Super High Density Scrap Tire Baler

The development of a tire baler to handle bundles of 1,500 to 2,000 pounds Thereby reducing handling and shipping costs.

19)- D. STRAUCH

California State Solid Waste Management Department, Sacramento, California

Current Tire Disposal Problems in California Resource recovery of used tires qwith a look past future legislative action.

20)- G.C. FRAZIER

University of Tennessee, Knoxville, Kentucky

Molten Salt Pyrolysis of Scrap Tires

The search for economical methods to recover oil, gas and other residue from scrap tires thru pyrolysis in molten salts.

21)- T. ROHA

AMF Tire Equipment Division, Santa Ana, California

Let's First Recycle the Worn Tire

Why we must establish means to collect good casings for retreading.

22)- H. YAKOWITZ

National Bureau of Standards, Washington, D.C.

Commercialization of Resource Recovery Technology

Discussion of several strategies available for economic disposal of scrap tires.

23)- J. D. KEITH

National Tire Dealers & Retreaders Assocaition, Washington, D.C.

Final Reamarks on Symposium

N.B: La communication N° 17 n'a pas été présentée

PART 5. :

SIZE REDUCTION OF SCRAP TIRES

G. HUYET

PART 5. SIZE REDUCTION OF SCRAP TIRES

CONTENTS

PART 5. SIZE REDUCTION OF SCRAP TIRES

5.1. STATEMENT OF THE PROBLEM.

It is necessary to reduce the size of tires either for storage or in order to use scrap tires as a raw material for various applications.

For storage, it is necessary simply to reduce the large tire volume for more compact storage and there are no requirements as to the dimensions of the product.

On the other hand, when scrap tires are used as the raw material for an industrial application the required dimensions will depend upon the type of the planned application.

The reduction of scrap tire size is therefore the key to a large number of scrap tire uses and without making recommendations as to the choice between these uses, it is evident that research directed towards lowering costs for this reduction should be encouraged.

Our recommendation in this field is therefore to help in realising the research programmes suggested in the conclusion presented in the last part of this chapter.

Two processes exist : crushing by means of traditionnal shredding or crushing machines at ambiant temperature, and cryogenic crushing.

While the former method is usually used industrially, the second seems to be theoretically less profitable from the economic point of view and research is still being done on it.

Again, from the theoretical point of view, it seems evident that size reduction at ambiant temperature will, since rubber is ductile, produce lamina shaped particles while cryogenic size reduction will produce cube shaped particles. However is the shape of the particles of importance for the industrial applications in which the crumb is used ?

In certain industrial applications, it is necessary to separate the textile part from the rubber part of the fragmented rubber crumb. This seems relatively easy for the cryogenically crushed particles and this point deserves further study.

It also seems to be true that several stages of crushing in series will be necessary in order to reduce the tires to the several hundred microns range.

The comparison between the two processes will therefore be based principally on economic data but it should be remembered that cryogenic crushing is still at the research stage and that there are certain special points which need further study.

5.2. CONVENTIONAL SHREDDING AND CRUSHING.

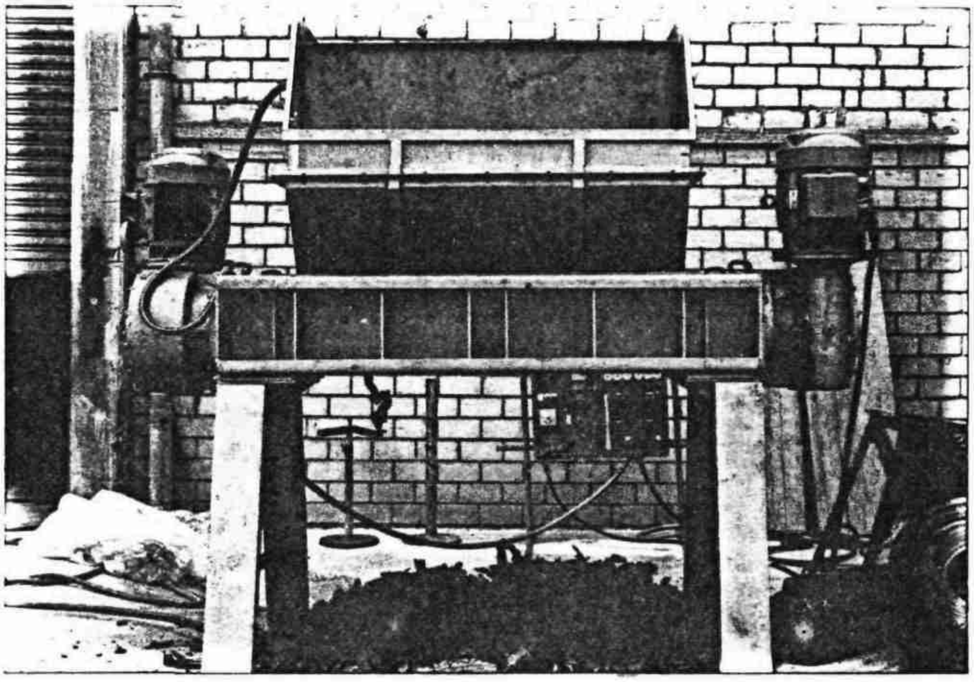
The processes used are principally of the rotary shears type, with one or two shafts, each of which has blades of various shapes. It is not possible to use the usual means for solid scrap size reduction for large quantities of tires and this is, in particular, the case for hammer mills of all types and vertical shears.

These shredders must be robust, and as they are often integradted into continuous pyrolysis processes, they should not cause stoppages. The environment of the apparatus requires that it be very solidly built and maintenance would be easy and inexpensive.

Existing units function industrially and supply rubber crumbs which are now sold on the market, which is not the case for cryogenic plants.

Plate I shows a shredding apparatus.

The prices given for rubber crumb produced in this way are sales prices for rubber crumb from which impurities have been removed (metal, fibres).



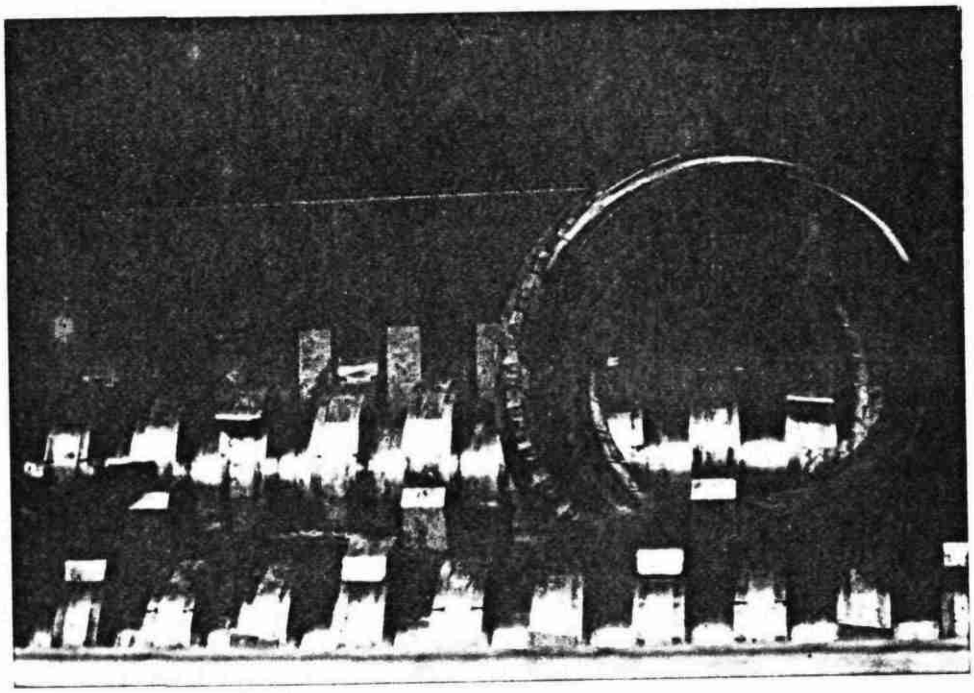


Plate I. : Shredding apparatus

Examples :

- Sales price for rubber crumb : 70 to 400 $ per tonne (per 30 kg sack) for particle sizes ranging from 8-10 mm to 400 microns ;
- The cost of rubber crumb produced by shredding to 40 mm particle size is 29 $ per tonne, with an investment of $ 400 000, a production rate of 1 t/hr and an electrical consumption of 100 kWh/t ;
- A manufacturer is selling a shredding machine without peripheral equipment for $ 146 000 and the cost of rubber crumb reduced to 60 % of < 50 mm is approximatively 12 $/t for a production rate of 12 t/hr ;
- The cost of rubber crumb reduced to approximately 60 mm is 15 to 16 $/t for a production rate of 10 - 15 t/hr with a production staff of 11 persons.

These prices are still relatively high but they give a general view of the problem since rubber crumb is produced in order to be sold as such and not for use as raw material in an industrial process.

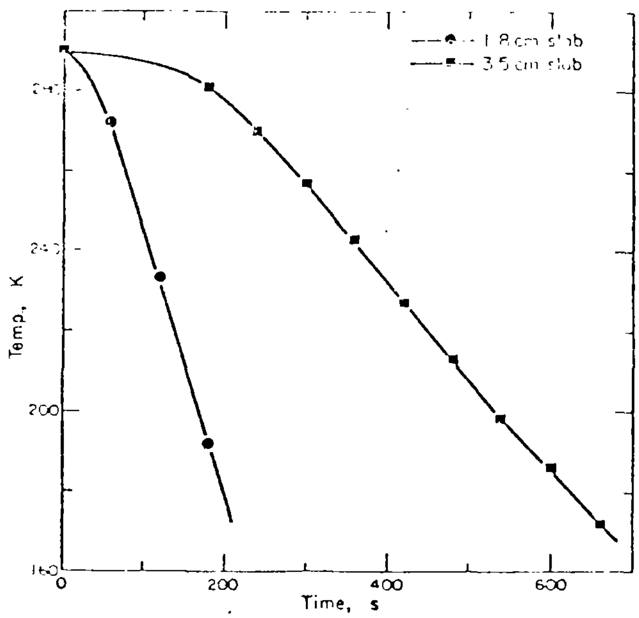
5.3. CRYOGENIC CRUSHING.

When the temperature of materials is lowered, there is a threshold at which certain changes take place rapidly in some of their properties especially in the mechanical properties. Materials such as rubber and plastics lose their ductile character and become brittle and this embrittlement makes it possible to break up scrap rubber and to produce rubber crumb for industrial use by means of mechanical crushing. This constitutes cryogenic grinding.

M.W. BIDDULPH (1) presents the problem as follows :

"When a body at room temperature is cooled, either by contact with cold gas or by dipping into liquid nitrogen, unsteady-state heat transfer takes place. The rate at which cooling occurs is of primary importance in equipment design, and is determined by a number of factors. The temperature difference is very important, as is the material and physical size of the object."

"Since the primary concern of this study is the cryogenic embrittlement of rubber tyre material, two pieces of a large rubber tyre were studied. These sections were cut in the form of slabs, one with a thickness of 3,5 cm and the other a thickness of 2,3 cm. The thermocouple was inserted into the centre of the slab and then the slab was dipped into liquid nitrogen taking care not to immerse the thermocouple leads. The temperature/time relationships for these pieces are shown in :



Cooling curves for rubber tyre slabs.

The process does not, in general, seem to present great diffilcuties.

Professor N.R. BRATON (2) of the University of WISCONSIN states :

"Cryogenic processing of rubber tires is a simple operation and the resulting product is in the form of particles which predominately fall in the 20 (0,83 mm) to 10 mesh (1,17 mm) size when screened. The fiberous reinforcement is readily separated."

The important points are as follows :

- The determination of the cooling temperature which should be low enough so that the material will not loose it brittleness when it heats up during crushing ;
- Exchange conditions for an efficient use if cooling energy ;
- The crushing machine itself is in all cases a hammer mill.

For this process the conventional crusher should be equiped with a specially designed feed system making it possible for it to absorb tires very rapidly so as to avoid heating leading to a reduction in brittleness.

Because of the "selective" embrittlement of the tires, the rubber itself is reduced to relatively fine particles while the steel reinforcements and belts which have been practically removed from the vulcanized rubber become entangled and can be removed either by magnetic drum, scrap remover or manually depending upon the case. Raymond LE DIOURON (*) gives the following flowsheet :

(*) Engineer at AIR LIQUIDE (France).

Whole tires are roughly cut up. Composition :
- Steel reinforcement and belts
- Fibrous reinforcement
- Rubber.

Cooling to - 100°C, - 120°C
- Embrittlement of rubber
- Steel reinforcement little affected by cooling.

Crushing
- Hammer mills
- Roll crushers.

The crushed product :
- Rubber particles (from 100 µm to several cm)
- Metal reinforcement relatively complete
- Fibrous reinforcement shredded.

Separation of constituants
- Magnetic separation
- Screening + blowing
- Elimination of fibres
- Recovery of rubber.

- Recycling of steel reinforcement
- Recycling of rubber crumb (material for tire manufacturing)

(various uses for reclaimed rubber).

At the present time the problem seems to have been most carefully studied in the U.S., especially by Professor N.R. BRATON (2) and hit team, whose work made it possible to develop a portable cryogenic processing plant. Donald MIHOVK (3) presents this work as follows :

"One of the pioneers in applying cryogenics to recycling is Professor Norman R. BRATON of the Mechanical Engineering Dept. of the University of WISCONSIN (UW) in Madison. Students and researchers at UW experimented with cryogenics and scrap tires and found that it could be done, but in laboratory conditions. A working unit that could be put into day-to-day production was the next order of business. Dealers who attended last year's NTDRA show in Minneapolis heard Dr Robert KISIELEWSKI of La Crosse, Wis. describe the gryogenic technique and say that a portable unit was being developed. Today, this unit is completed and being operated regularly.

"The financial angel for this first unit is Harry B. LOCKETZ formed Cryogenics Recycling International, Inc. of Allentown, Pa. This firm has a good deal of knowledge in cryogenics and is a major supplier of liquid nitrogen which does the freezing.

"The unit itself is a self-contained, portable machine designed to travel over most roads including interstate highways. It has its own power plant (diesel) and can be operated by one man. Operation is quite simple. The operator picks up the materials to be processed (cryogenics is not restricted to tires - it has been used to recycle steel, electric wires and plastics) using the crane. He, then, immerses it into a holding tank of liquid nitrogen, a clear liquid which is about - 319°F and gives off clouds of steam when in contact with the atmosphere. The material stays in the tank until the "brittle point" is reached, then it is dropped in to the hammermill where it is pulverized. A tanker of liquid nitrogen is hooked into the unit to provide a constant level in the holding tank."

The existence of this portable unit presents the problem of comparing the latter with the stationary unit. Tires are very widely dispersed geographically and it is both expensive and illogical to transport them intact. On the other hand the stationary unit has the advantage that since no particular geographical position has any advantage from the point of view of tire supply it could be located near a source of supply for the cooling agent, or could have it own production plant. Another advantage of the stationary unit is the possibility of "recovering" calories and this point should be studied.

Under the present circumstances this recovery of calories does not seem to be planned and there would certainly be problems since the hammer mill acts as a large fan. Recovery of gases (generally nitrogen) seems to present fewer problems.

Because of the enormous expense in refrigerating agents involved, (see Table II below) techniques are now being developed for using conventional cooling techniques.

An example has been supplied us by the "Le Froid Industriel d'York" company of LYON (FRANCE) which uses a mixed plant with conventional shredding for the production of 10 - 20 cm fragments, and then a continuous air blower machine at a temperature of - 60°C and then - 100°C, so as to bring the tire fragments to - 90°C. The air is cooled by refrigerating machines and the product size distribution is as follows :

0 - 0,5 mm	5 ± 2 %
0 - 1 mm	15 ± 3 %
0 - 2 mm	30 ± 5 %
0 - 4 mm	50 ± 5 %
0 - 9 mm	71 ± 10 %
0 - 10 mm	80 ± 5 %

with a capacity of 1 t/h or 6 000 t/y and a cost of 40 to 50 $ per tonne ; this capacity can be increased.

This is a pilot plant and the design was based upon a study of cooling by means of liquid nitrogen and mixed liquid nitrogen + conventional refrigeration, then the conventional cooling design alone was finally chosen because of its lower cost.

Table I below is based upon data supplied by various companies. It should be noted that the costs shown in the last column are estimated :

- Either roughly given by the manufacturer or the research laboratory ;
- Or calculated according to the method presented at the beginning of Part 4. of this report.

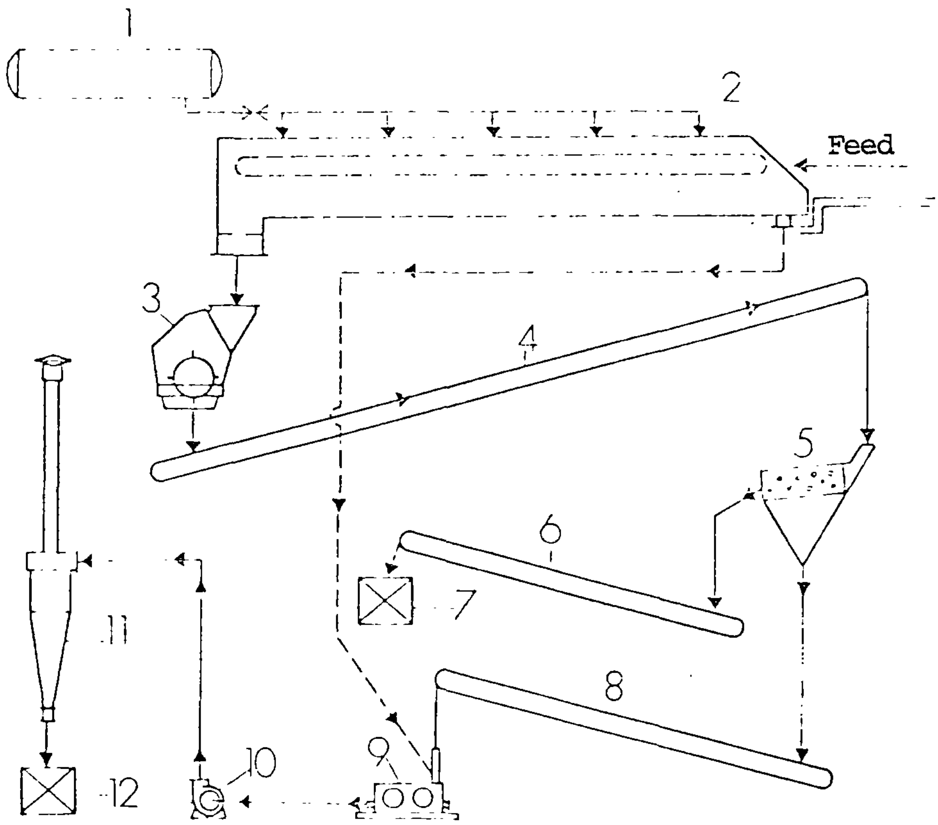
These results are therefore not always comparable and, in particular, it is often difficult to know the sizes of the products since only the limits of the particle size distributions are given.

The nitrogen costs in this table are based upon cost price estimates for a plant linked to the crushing unit (including amortization). This cost is higher if the cryogenic processing plant does not include or is not linked to a liquid nitrogen manufacturing plant.

NAME OF COMPANY	NATURE OF REFRIGERATION	QUANTITY OF NITROGEN	ENERGY KWh	LABOR IN MAN/Hr	PRODUCTION RATE	PRODUCT OBTAINED	INVESTMENT	OPERATING COST PER TONNE OF TIRES PROCESSED
VEM ERZ und STAHL (R.F.A.) (pilot plant)	NITROGEN	600 kg/t	150	4	5 - 6000 t of tires/y	1-3,5 mm and < 0,4 mm		Energy 6 $ Labor 12 $ Nitrogen 45 $ Amortization 3 $ (estimate) 66 $/t
CRYOGENIC RECYCLING INTERNATIONAL (U.S.A.) (portable unit)	NITROGEN				8000 t of tires/y	0,84 to 2 mm	approx. 240 000 $	44 à 46 $/t for this particle size
APPAREILS DRAGON (France) (pilot plant)	NITROGEN	600 kg/t			4200 t of tires/y	0 to 50 mm rubber crumb of various particle sizes	approx. 85 000 $	Energy 1,3$ Labor 4 $ Nitrogen 36 $ Amortization 4 $ 46$/t
BELLAIR HYDRAULICS (U.S.A.) (equipment on the market)	NITROGEN				11375 t of tires/y	20 000 kg of < 6 mm 7 000 kg of fine 7 000 kg scrap steel	approx. 80 000 $	Energy 5 $ Labor 4 $ Nitrogen 45 $ Amortization 1,5$ 63$/t
SOCIETE HAZEMAG (pilot plant)	NITROGEN				1820 t of tires/y	0 to 25 mm		154 $/t

Table I : Economic data on cryogenic processing

The figure below shows an example of cryogenic processing (HAZEMAG).



1. Liquid nitrogen tank
2. Cooling system
3. Hammer mill
4. Belt conveyor
5. Sieve drum
6. Oversize conveyor (reinforcement)
7. Container
8. Conveyor for 0-35 mm particles
9. Novorotor mill
10. Blower
11. Separation cyclone
12. Container for 0-1 mm rubber crumb

Plate II shows a portable unit (Cryogenic Recycling International, Inc).

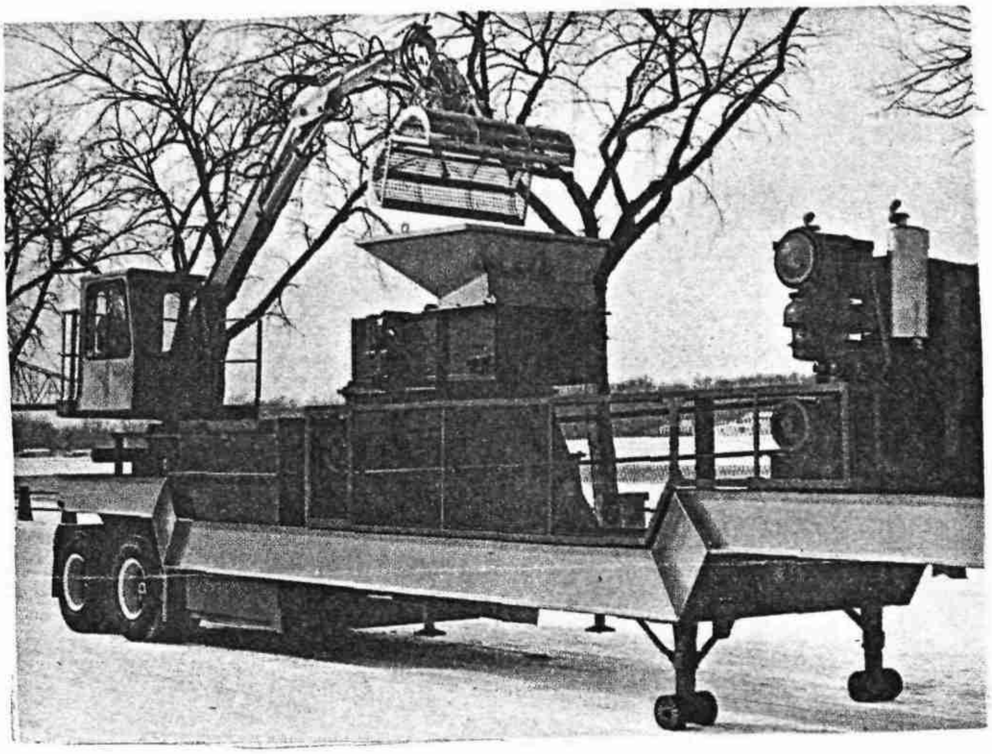


Plate II : Portable cryogenic processing plant

(Cryogenic Recycling International, Inc.)

Cryogenic crushing of tires seems therefore still at the research stage. Existing units are still pilot units even if all industrial conditions are satisfied. Nitrogen costs are extremely high.

5.4. RECOMMENDATIONS FOR RESEARCH ON CRYOGENIC PROCESSING.

Research should be continued on economical cooling field through studies on conventional processes (without liquid nitrogen) for cooling rubber, or by research on the "recovery" of cooling energy.

Research should also be carried on feeders for cooled tires.

From the economic point of view the comparison between the portable unit and the stationary unit involves an estimate of tire transport costs (which was not made for this study) and the tires could be shredded before transport. The coupling of conventional shredding with cryogenic processing requires a double investment and research would be necessary in order to determine exactly the cost of this operation in relation to a purely cryogenic or purely conventional plant.

It is necessary to determine the effects of particle shapes on treatments or uses involving rubber crumb produced by crushing and if this shape has an effect it should be studied in connection with the various crushing conditions.

Lastly, it will be necessary to determine in market terme the optimum particle sizes for crushed products and to study the particle size distribution curves for various processes. Obviously rubber crumb suppliers using conventional shredding machines and offering rubber crumb with sizes on the order of 44 microns can obtain them by screening after crushing large quantities of tires.

This research could shed light on a problem which, at the present time, prevents difficulties since it is impossible to make any kind of comparison.

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