

**EFFECTS OF WASTE TIRES,
WASTE TIRE FACILITIES,
AND WASTE TIRE PROJECTS
ON THE ENVIRONMENT**



May 1996

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Attachment A	Scope of Work
Attachment B	Initial Keyword List
Attachment C	Revised Keyword List
Attachment D	List of Records Submitted to the Library
Attachment E	Bibliography

1.0 Introduction

This report outlines through available literature the conditions which waste tires, waste tire facilities, and waste tire projects would create adverse effects on the environment. Analysis was performed under the work-for-others contract LL-4406, signed by The Executive Director of the California Integrated Waste Management Board on June 9, 1994 and by the Department of Energy Contracting Officer on June 10, 1994. The scope of work, Attachment A, calls for an investigation of the effects of waste tires and tire rubber on soil, water, and air under various conditions or combinations of conditions. There are 4 tasks associated with this contract.

1.1 Work Scope

As performed, Tasks 1 and 2 included a literature search to investigate the effects on the environment of wastes tires as they relate to:

- acidity
- alkalinity
- ultra violet radiation
- high and low temperatures
- particle size (whole, shredded, chips, crumb, granulate)
- moisture
- contact time
- tire composition
- reaction kinetics associated with chemicals present in the environment
- rates of diffusion
- environmental partitioning of components or byproducts of components
- leaching potential
- and other environmental effects.

In addition, Task 3 was to draw conclusions from, discuss validity of, and identify gaps in compiled research. Also determined were the conditions under which tires are likely to be considered toxic, hazardous, or create adverse effects on the environment, the necessary mitigation measures to minimize or prevent these effects, and mitigation

measures for siting waste tire processing or manufacturing facilities in compliance with CEQA.

This report encompasses:

- the methodology used by DOE to develop information herein,
- the actual work performed leading to the creation of this report, and
- problems encountered during report development, and solutions used to solve those problems.

A list of references is found in the attachments, conclusions are drawn and discussed related to task 3, and recommendations for field and lab work are also addressed.

1.2 Methodology

A literature search was performed related to task 1 and task 2 simultaneously. To initiate the literature search, abstracts of waste tire literary articles were selected based on a prepared list of key words. The abstracts selected were read and the literature was selected from the abstracts that seemed most pertinent or had the most promise in providing the information needed to develop the report. Literature was photocopied or borrowed, as appropriate. Articles, papers, and texts were grouped together into categories of composition, tire manufacturing, thermal processing, and miscellaneous topics. Those that fit more than one category were grouped together as multiple topics. The literature reading was assigned to personnel based on knowledge, experience, and interest. During assigned reading, topics related to the scope of work were analyzed, excerpted, recorded and compiled. Discussions among staff were performed and concluded, report sections were outlined and organized, and the report was written.

1.3 Work Performed

On August 10, 1994, a list of words corresponding to tire issues was prepared and submitted to the Lawrence Livermore National Laboratory (LLNL) library to initiate the literature search. The list consisted of 4 key words (tires, waste tires, rubber, and styrene-

butadiene rubber) and 27 words associated directly to the scope of work in the contract. Attachment B is a copy of the word list submitted to the library.

On August 11, 1994, the library staff initiated the literature search using the word list. The number of articles from the initial search exceeded 5 million records. The list was scaled down to 3 key words (tires, waste tires, styrene-butadiene rubber) and 10 words to be associated with the key words. Attachment C is a copy of the scaled down word list submitted to the library. Using the scaled down list, the number of records was reduced to approximately 5,000. Further cuts were made by selecting titles that were English only and selecting articles that were no more than 10 years old. The total number of records came to 531.

General information concerning the 531 records were retrieved from the library and the information was formatted to show the author, journal, title, abstract, keywords, and other information that appear pertinent to the subject of interest.

On August 22, 1994 the information (e.g., abstracts, titles, keywords) from the 531 records was reviewed by LLNL and the records that appeared pertinent to the subject of interest were selected. In some instances, several abstracts (or records) covered the same information or topic. When abstracts contained similar information, the abstract that was the most detailed was selected. The remaining abstracts were set aside for future use if the need for additional information should arise. The review narrowed the selection down from 531 records to 75 records.

On August 24, 1994, the list of 75 records was submitted to the LLNL library to obtain the articles. Attachment D is a list of the records submitted to the library. The key words in Attachment C are highlighted in bold text. The list of remaining records was filed and is to be used at a later date if information from the selected abstracts is insufficient. This list is available upon request. Some of the articles from the library could not be obtained and additional articles were added based on reviews. New items that were identified during the review process of the articles were added to the list. These items were cited in the reference section of existing articles. The final bibliography in Attachment E shows those documents that were reviewed. In the review, pertinent information was recorded, analyzed and later compiled to be used in this report.

1.4 Organization of Subsequent Sections of this Report

This report is organized into sections and subsections that discuss all phases of tires as they may adversely effect the environment. Background information is discussed in these various sections as well as many of the details pertinent to effects caused by tires in the environment. The following sections discuss: (1) tire processing and manufacturing, (2) environmental and health effects based on composition and the vulcanization process, (3) recycling, reuse and disposal of waste tires, (4) environmental and health effects based on tire reuse and disposal, (5) CEQA evaluation factors, and (6) recommendations for future work.

2.0 Processing and Manufacturing of Tires

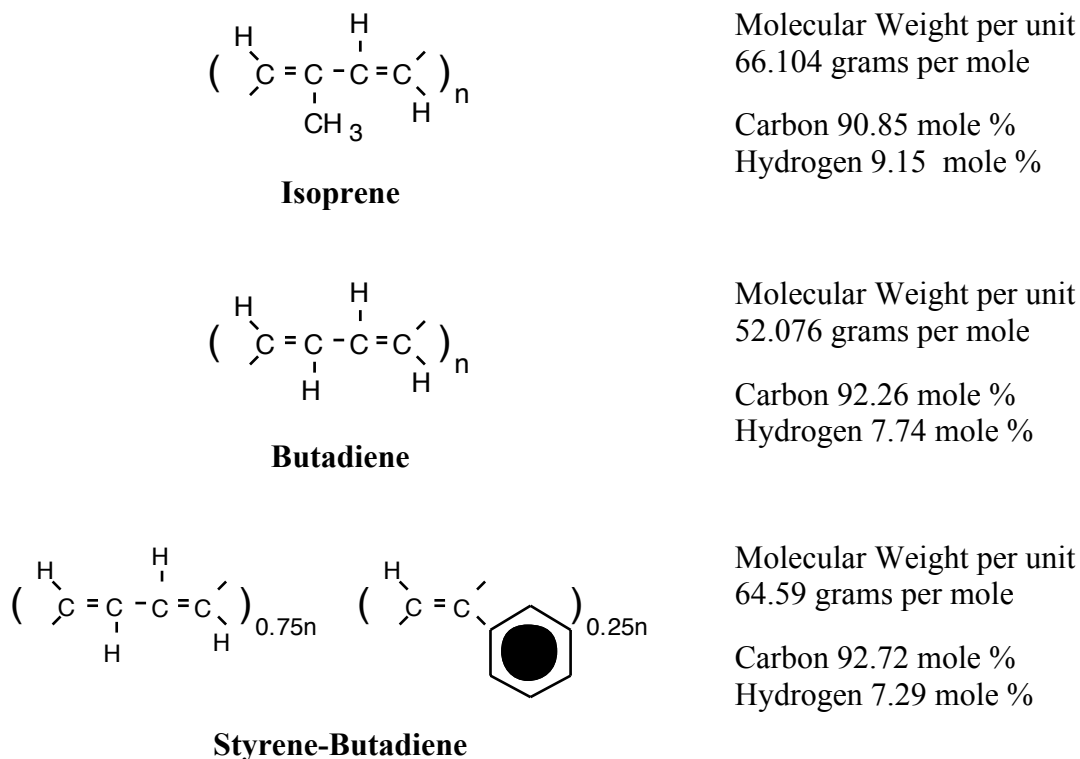
Processing and manufacturing of tires are discussed here because formulations and chemical compounds used to make tires may give insight into environmental effects of waste tires. This discussion is broken down into rubber manufacturing, tire manufacturing, and materials required to manufacture tires. The focus of much of the literature reviewed is related to tire performance, durability, and ease in manufacture.^{1, 2, 3, 4, 5, 6} Some articles discussed additives and chemistry that related to the effects of the environment on the tire.^{7, 8, 9, 1} A couple articles discussed composition as it relates to the value of old tires^{10, 11} and fire retardation additives.¹² Others articles relating to waste tire processing, environmental effects, and physical and chemical parameters, are to be discussed in subsequent sections of this report.

2.1 Rubber Manufacturing

The rubbers used in tire manufacturing are all thermal set polymers. These polymers have various additives that serve a variety of functions. The basic units of the polymer(s) used in tires are natural rubber (NR), synthetic polyisoprene (IR), polybutadiene (BR), and presently the most commonly used styrene butadiene (SBR). The monomer units are shown in Figure 1. Note that natural rubber contains approximately 5000 monomer units¹³ (330,500 grams per mole) and that tire rubber composed of the monomers of

butadiene and styrene have uniformly distributed linkages were 75 mole percent are butadiene and 25 mole percent are styrene.

Figure 1. Monomers, Units Used in Tire Rubber



2.1.1 Overview of Monomer Production

During the manufacturing process of synthetic rubbers, it is difficult to determine exact chain substitutions. In Figure 1, bonds are shown in place of hydrogen atoms at the end of the monomer unit. In almost all cases the saturated bond of one of the monomers become unsaturated during condensation (or polymerization). There are about 5 primary processes that manufacture monomers of butadiene in the United States.¹³ The Haudry process (one of the more common processes) catalytically dehydrogenates butane and butylenes from light end refinery fractions. There is one primary process that is used to manufacture styrene. Styrene is manufactured from alkylated ethylene with benzene to form ethylbenzene and subsequent dehydrogenation to styrene. Catalysts for dehydrogenation are aluminum chloride, solid phosphoric acid, and silica-alumina.

There is no indication of how much residual catalyst may be found in the monomer. Aluminum chloride is fairly reactive when finely divided and should not pose environmental harm. Silica-alumina is fairly expensive, environmentally benign and should be recovered well. Phosphoric acid, if found in appreciable amounts, may cause harm to phosphate sensitive organisms but no papers were informative on the subject.

2.1.2 Overview of Added Material During Rubber Production

There are several additives that go into the monomers and/or polymerized rubbers. Activators are zinc oxide, stearic acid, litharge, magnesium oxide, amines, and amine soaps. These are added for the vulcanization process that occurs later. Primary activators for tire rubbers are zinc oxide, stearic acid, and amine soaps. These compounds reduce the time to vulcanize rubber from several hours to a few minutes. They also allow the vulcanization process to use less sulfur and still maintain a uniform vulcanite. These compounds are said to activate sulfur to form the sulfur bridge necessary for good vulcanization of the rubber.

Age resistors or antioxidants are also added to the rubber to provide for longer life without degradation. These materials protect the tire from oxygen and ozone. They are derivatives of p-phenylenediamine (PPD). These compounds stop chain destruction of the rubber by combining with the free radicals formed as intermediates during degradation of the tire rubber.

Softeners and extenders are also added. These are used to increase the workability of the rubber during preliminary processing before vulcanization. They consist of mostly petroleum oils and coal tar fractions. Peptizers or catalytic plasticizers, generally thiophenols, other thiol compounds, and disulfides can be used as well to reduce the viscosity of the rubber during preliminary processing. These compounds are usually recovered in solvent extraction processes but can be found in proprietary rubber compositions.

The major pigment in tires is carbon black. For white walls, titanium dioxide is used. Carbon black is also called a filler. In many cases, filler is known to reduce tensile strength. But for tire rubber the appeal of the black color, the resistance to staining by

other additives such as antioxidants, and its ability to improve tire rubber tensile strength and abrasion resistance, make it the ideal filler. Carbon black is by mass the largest amount of additive in tire rubber.

Carbon black is defined by adsorption properties and particle size much like carbon used to adsorb organics from water and air. Typical parameters include nitrogen sorption surface area measurements (typically 150 square meters per gram), adsorption of dibutyl phthalate (typically greater than 120 ml per 100 grams), and particle diameter (typically 40 to 80 μm). There are other additives that increase tensile strength and abrasion resistance. Second to carbon is silica but carbon black is always added with it.

2.1.3 Overview of Rubber Processing

The specific formulations of tires can be quite complex as indicated by the patents and the records of invention examined.^{14, 2, 15, 4, 16, 17, 18} Formulations of SBR are categorized in terms of polymerization process (either solution or emulsion). Styrene content and oil extensions make up from 0 to 50 mole percent of the rubber. Vinyl may also be in SBR at up to 80 mole percent.

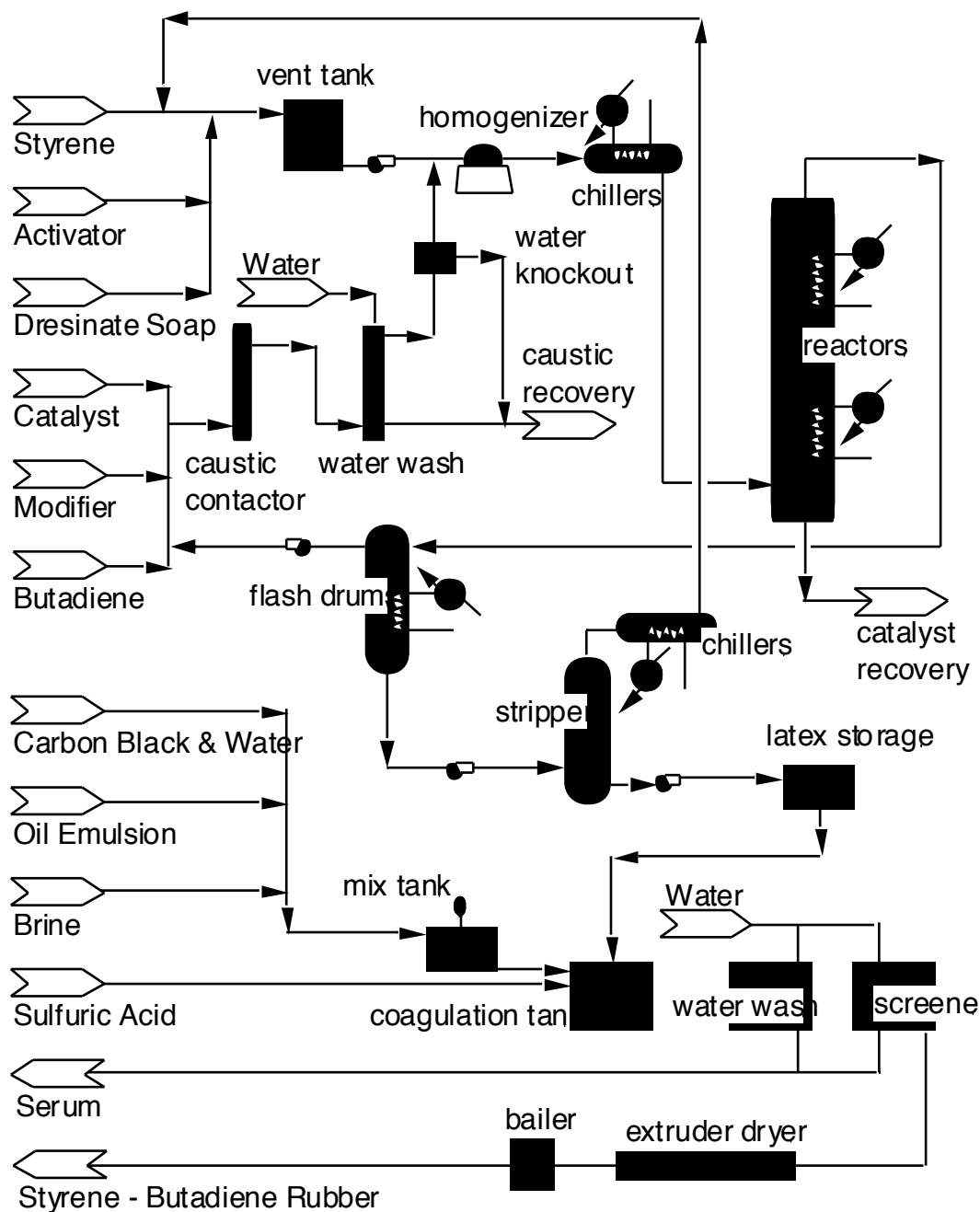
There are two general processes referred to as an emulsion process and solution process.¹⁹ Table 1 gives one of many recipes for the emulsion process. The reaction begins with the initiation of mercaptyl free radical. This is formed by oxidizing the mercaptan with peroxide. The mercaptyl free radical then attaches itself to a monomer (either styrene or butadiene). The free radical continues to grow by attacking monomers. The active radical is terminated by attacking another free radical (bimolecular coupling) or by disproportionation (hydrogen free radical transfer). The molecular weight can usually be controlled by mercaptan type or concentration. The solution process is a more complex process involving alkyllithium based catalysis. The complexity arises from the widely varying reactivity ratios. It is difficult to get consistent molecular weights and degrees of branching.

Table 1. Emulsion Process for SBR Manufacturing

Component	weight %
Ferrous sulfate heptahydrate	0.01
p-Methane hydroperoxide	0.02
Sodium formaldehyde sulfoxylate	0.02
tert-Dodecyl mercaptan	0.05
Tetrasodiumdiaminetetraacetate	0.10
Trisodium phosphate decahydrate	0.15
Rosin acid soap	1.31
Styrene	8.45
Aromatic oil	10.93
Butadiene	20.69
Water	58.27

A flow chart in Figure 2 depicts the process of manufacturing styrene-butadiene rubber by use of the monomers in the emulsion process. After the rubber is manufactured it is bailed and can be stored for years.

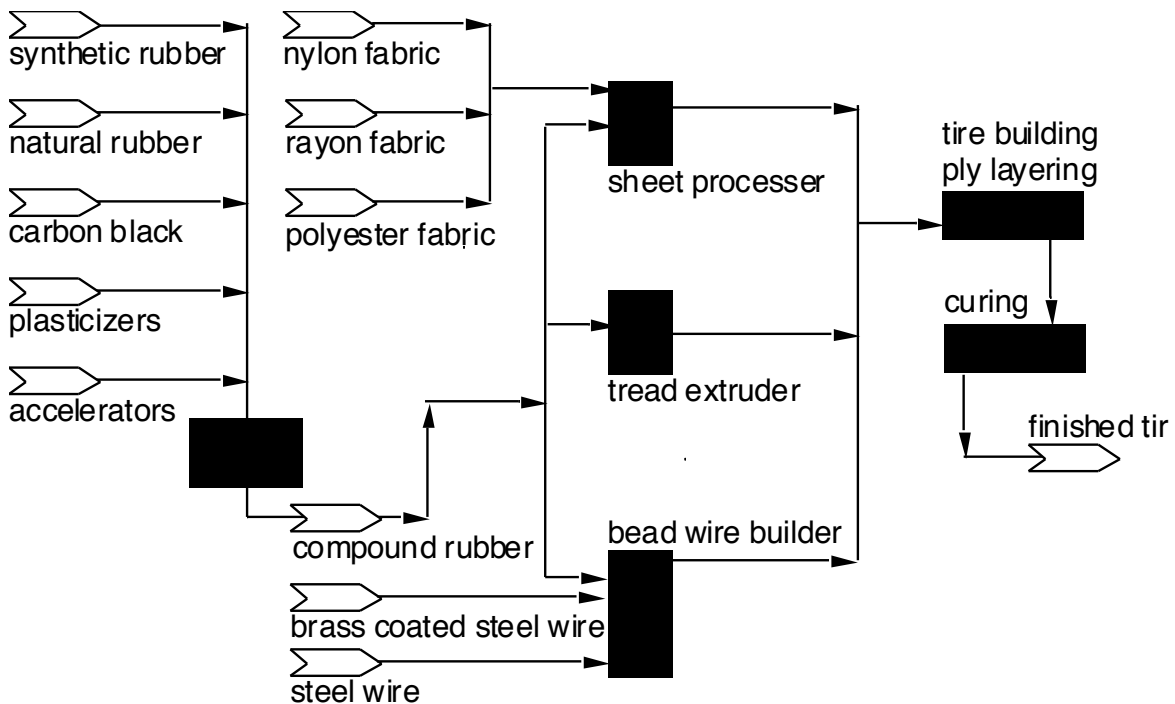
Figure 2. Styrene Butadiene Rubber Manufacturing Process



2.2 Tire Manufacturing

The tire manufacturing process includes the manufacture of rubber and placing additives in the rubber. It also includes the coating of fabrics for the radial belts and bias plies and integrating them into the rubber. Rayon, nylon, and now more commonly polyester in addition to building wire bead stock, make up the structural components of tires. The fabric with rubber, the bead stock with rubber, and the rubber tread is combined on a drum by layering (the tread is put on last). There can be as many as 40 layers of fabric and steel bead wire on a truck tire. Once the layers are put on, the tire stock is put into a mold over an inflatable steam heated tube. The tube is inflated and the mold is closed. The tire is heated and cured and the excess rubber extrudes out of weep holes in the mold. Curing times and temperatures vary widely between manufacturers and tire compositions. Typical curing times are around 20 minutes with temperatures around 160°F. The curing is where the vulcanization takes place. Figure 3 flow charts the process as a brief summary.

Figure 3. Flow Chart Summarizing Tire Manufacturing Process



2.2.1 The Vulcanization or Curing Process

The main applications of elastomers require that the polymer chains be cross-linked after being formed into a desired shape (like a tire). After cross-linking of the polymer chains, which is called curing or vulcanization, the article is elastic. It deforms under stress but returns to the shape it had when vulcanization occurred if the stress is removed. The most common method of cross-linking elastomeric polymers is through the use of sulfur. The sulfur forms a bridge between large chains of polymer, linking them together in a fixed pattern.

Tire rubber manufacture requires a variety of operations that produce and require heat, e.g., mixing, extruding, calendaring, molding, etc. during which cross-linking of the polymer to an appreciable extent cannot be tolerated. The need to prevent premature cross-linking has been met by the development of delayed-action accelerators. These materials are not accelerators initially but undergo chemical reactions during processing to produce the active accelerator species in a delayed manner. The main accelerators in use exhibit some degree of delayed action. If more delay is required, a vulcanization retarder can be incorporated.

A large portion of the vulcanization accelerators produced in the United States are comprised of derivatives of 2mercaptobenzothiazole (MBT). There is a large variety of crosslinked polymers. They range from polymers having a high degree of unsaturation to those with very low levels or no unsaturation. This variety in polymers and the wide variety of vulcanite physical-property and processing requirements has resulted in the industrial use of a large number of different accelerators and curing agents.

Although a good deal of effort has been directed at understanding the chemical mechanism of sulfur cross-linking, the exact steps are in contention. The main uncertainty is whether the steps are ionic or free radical in nature. The evidence indicates that the following general steps occur:

- The accelerators which are generally organic sulfur anion or radical, attacks S_8 to form a polysulfide adduct.
- The adduct becomes attached to the polymer chain through sulfur as a pendant polysulfide and is capped by the accelerator.

- The cross-link forms through these pendant polysulfide groups by one of several possible mechanisms.
- The average number of sulfur atoms in the cross-link decreases as the vulcanization process continues (this decline is probably a continuation of attack on the polysulfide groups by the accelerator).

2.2.2 Cord and Fabrics, Structural Importance and Chemical Make

A tire must safely support a specified load under dynamic conditions with a minimum of power loss, overcome minor obstacles, and provide a reasonable endurance life. In addition, a tire should provide a long wear life, a smooth and quiet ride with good cornering, adequate skid resistance, and traction under various road conditions. A tire is also expected to have a pleasing appearance to complement the vehicle.

The cord and fabric of a tire provide for the tires continued structural integrity, increased wear resistance, and road grip. The rubber alone would not provide durability under conditions for which a tire is used. Excessive stress due to carrying large amounts of weight at high speeds in various weather conditions requires tires to be structurally sound. The layers of fabric made from rayon, nylon, and polyester, provide wear resistance and structural integrity. One of the most important factors in maintaining this integrity and wear resistance is the adhesion of the fabrics to the rubber. This is done by placing a steel wire bead around the circumference of both side walls of the tire. This bead is then used to tie on the fabric layers during tire building. Steel and brass coated steel may be used in addition to rayon, nylon, and polyester to form the plies. Steel is drawn and twisted in the same fashion as the fabric (yarn). The configurations of fabric and steel vary with manufacturer and make of tire.

The fabric layers or plies of reinforcing material are firmly adhered to the rubber and remain effective after the article has been subjected to repeated and varying strains in use. Thus, the tire's durability and its ability to perform under increasingly severe operating conditions is directly linked to the adhesion of the ply material to its adjacent rubber surface.

A technique for obtaining good adhesion between fabric plies and tire rubber is the dry adhesive system in which the bonding agents are mixed directly into the rubber compound. Bonding agents used in the dry adhesive system are as follows: 2.5 parts resorcinol (dihydric phenol) and 1.6 parts HEXA, 2.0 parts Bonding Agent R-6 (a resorcinol donor) and 1.0 part Bonding Agent M-3 (a methylene donor), 2.5 parts hexamethoxymethyl melamine, and 3.0 parts of the condensation product of resorcinol and formaldehyde that is deficient in formaldehyde.

Good adhesion between rubber and metal is of considerable importance in tires. The composite may include more than one compound discussed below. It is preferable to use more than one compound with different ligand groups if the metal is an alloy. Thus, if the metal is a brass-coated steel tire cord, there may be present three different compounds in each of which there is a different ligand group, particularly compounds in which the ligand groups are benzotriazole, mercaptobenzothiazole and 1,2,3-trihydroxybenzene. The compounds are used in proportions depending on the composition of the brass coating and steel. A typical mixture of compounds would be such as to provide molar 30-60 molar percent, benzotriazole ligand groups, 30-60 molar percent, mercaptobenzothiazole, and 5-30 molar percent of 1,2,3-trihydroxybenzene ligand groups totaling 100%. Other compounds used to form ligands are:

- 6(hexa-2,4-dienoylamino)-2-mercaptobenzothiazole;
- 6(undec-10-enoylamino)-2 mercaptobenzothiazole;
- 6(2,4-bis(allylamino)-s-triazin-6-ylamino)-2-mercaptobenzothiazole; and
- 6(2,4-bis(diallylamino)-s-triazine-6-ylamino)-2 mercaptobenzothiazole.

2.2.3 Descriptions of Tire Rubber Recipes

Table 2 gives a series of formulations used in tire manufacturing.^{5, 4, 3} These are examples which may provide insight into the wide variety of rubber compositions used in the tire industry. It is believed that mercaptans and other additives are not included in these formulations because they are included in the rubber formulations themselves and are not itemized in Table 2. Brand and proprietary names are also called out. It is assumed that HA-oil is an aromatic oil extender, "polymer" varies. The numbers or "codes" in the carbon black descriptors in Table 2 are manufacturers' or distributors'

codes. These may be related to adsorption properties, particle size, and specific surface area as discussed earlier. Santoflex 13²⁰ was found to be an antiozonant (formulation unknown), and Santocure MOR is actually 2-benzothiazoyl-N-morpholinosulfide.²¹ Sundex 790 may be a copolymer it was not found in our literature search but, it has a high concentration. DTPD and IPPD as well as antioxidant 6C are p-phenylenediamine derivatives. MBTS and MBS are mercaptobenzene derivatives. TMTM is tetramethylthiuram monosulfide another accelerator compound. The values in the Table 2 are mass percentages but the most common units used in the tire industry are parts per hundred of thermal set polymer (phr).

Table 2. Typical Tire Compositions[§]

Compound Name Formula 1	Mass %	Compound Name Formula 2	Mass %	Compound Name Formula 3	Mass %	Compound Name Formula 4	Mass %
Polymer	18.28%	styrene butadiene	88.89%	styrene butadiene	46.78%	natural rubber	44.70%
						butadiene rubber	11.18%
N-299 Carbon Black	10.97%			carbon black	45.59%	N-375 Carbon Black	30.73%
				aromatic oil	1.74%	HA-oil	4.47%
zinc oxide	0.55%	zinc oxide	2.67%	zinc oxide	1.40%	zinc oxide	2.79%
stearic acid	0.37%	stearic acid	1.78%	stearic acid	0.94%	stearic acid/ org. zinc salts	1.40%
Santoflex 13	0.18%	Antioxidant 6C	2.67%	Antioxidant 6C	1.40%	IPPD	0.84%
Sundex 790	69.01%					DTPD	0.84%
Santocure MOR	0.23%	wax	0.44%	wax	0.23%	antiozone wax	1.12%
MBTS	0.05%	Accelerator CZ	1.33%	Accelerator CZ	0.75%	MBS	0.34%
sulfur	0.37%	sulfur	2.22%	sulfur	1.17%	TMTM	0.07%

§ Formula 1 and Formula 2 represent two different test formula to test tire properties, Formula 3 is a passenger tire recipe and Formula 4 is a truck tire recap. Steel and fabrics generally compose less than 5% of the final tire mass.

2.3 Materials Required for Tire Production

Materials required for tire production were discussed in the preceding sections related to the production of tire rubber and the manufacture of tires. This section discusses the materials used in rubber and tire production in summary and provides some additional details related to their usage. The discussion includes descriptions of all materials and

compounds used to manufacture tires to the extent possible. This section may be used to reference materials that may partition themselves in the environment.

2.3.1 Dry Pigments

Dry pigments other than those added to rubber as vulcanizing agents or vulcanizing aids are loosely classified either as reinforcing agents or fillers. The former improve the properties of the vulcanites and the latter serve primarily as diluents. There is no general agreement among rubber technologists as to what reinforcement is, how it can be measured, or precisely where the dividing line is that distinguishes the reinforcing materials from the fillers. Many records of invention and patent disclosures discuss these materials and show a wide range of physical and chemical properties of the rubber and the tire. One statement can be made and that is most carbon black additives increase abrasion resistance and tensile strength. Reinforcement increases with a decrease in particle size. There is more disagreement with respect to the non carbon black fillers, but it is generally conceded that some reinforcement results from the use of fine-particle zinc oxides, fine precipitated calcium carbonates, calcium silicates, amorphous hydrated silicon dioxide, pure silicon dioxides, fine clays, and fine-particle magnesium carbonate.

2.3.2 Softeners and Extenders

Softeners include a wide variety of oils, tars, resins, pitches, and synthetic organic materials and are used for a number of reasons, some of them having little or no relation to softness of either the raw, uncured stock or the vulcanite. Some of these reasons are to decrease the viscosity and thereby improve the workability of the compound, to reduce mixing temperatures and power consumption, to increase tack and stickiness, to aid in the dispersion of fillers, to reduce mill and calendar shrinkage, to provide lubrication so as to aid extrusion and molding, and to modify the physical properties of the vulcanized compound. A few of these reasons are exact opposites, so it is important to be able to pick the type of softener that gives the desired effect.

Extenders are materials possessing plastic or rubber-like properties and can be used to replace a portion of the rubber, usually with a processing advantage. Both softeners and

extenders can be used simply as diluents. Thus the distinction between a softener or extender and a diluent is somewhat arbitrary. Certain materials may be used as both softeners and extenders on one hand and as extenders and diluents on the other. Extenders may be of similar makeup as the softeners described above. Scrap tire rubber can also be considered an extender.

2.3.3 Plasticizers

Chemical plasticizers like 2,2'-dibenzamidodiphenyl disulfide and activated dithiobisbenzanilide are used in very low concentrations and their effect is chemical rather than physical. The chemical plasticizers or peptizers are generally used to lower the viscosity of the uncured compound. They function in the thermomechanical and thermooxidative breakdown of rubbers as oxidation catalysts at high temperatures but as radical acceptors at low temperatures. They have little effect on vulcanite properties. The addition of certain compounding ingredients to the batch like clay, carbon black, and sulfur, stops their plasticizing action. These compounds are not used in the tire rubber but can be used in the adhesion materials and the chord for the bias plies and radial plies.

2.3.4 Activators

Activators are metal oxides and stearic acid. These materials are added to "activate" the accelerators. Presently stearic acid and zinc oxide are used exclusively. Zinc oxide does provide some reinforcement like pigments but the primary purpose of this material is to allow accelerators to act fast in vulcanizing rubber. The mechanism of how this activation occurs was not discovered in the literature. Other metals were used in the past, especially lead oxide.

2.3.5 Accelerators and Retarders

When elemental sulfur is used as the vulcanizing agent, certain auxiliary materials must also be added to obtain desirable properties. The most important of these materials is the organic accelerator. The accelerator has a profound influence on the nature of the sulfur

cross-link, which largely determines the thermal stability, flex-cracking, and aging resistance of the vulcanite. Because of the use of organic accelerators, scorch of rubber compounds play an important part in the preparation, storage, and further processing.

Accelerators are frequently used in combination in order to produce a faster cure than can be obtained by either material separately. The most common combinations consist of an acidic accelerator like mercaptobenzothiazole (MBT) or one that becomes acidic during vulcanization like benzothiazyl disulfide (MBTS), combined with a basic type like diphenylguanidine (DPG) or thiuram disulfide.

Occasionally retarders are used to lengthen the scorch time and to slow the cure rate of excessively fast accelerator combinations. Retarders are chemicals that prevent the premature vulcanization of rubber compounds during mixing, calendering, and other processing steps. In the absence of the processing safety provided by retarders, scorched stocks, and consequently, waste results either during the processing steps or during the storage of the fully compounded green stocks. Retarders are often called antiscorching agents, scorch inhibitors, cure retarders, or prevulcanization inhibitors. Retarders having a sulfonamide group are called prevulcanization inhibitors, whereas such conventional retarders as salicylic acid, benzoic acid, phthalic anhydride, and N-nitrosodiphenylamine (NDPA) are simply called retarders.

The main compounds used in rubber curing accelerating and retarding appear in Table 3.²² Table 3 gives names, chemical formula, and uses. Acute oral LD₅₀ ranges from 375 mg/kg for guanidine to greater than 16,000 mg/kg for MTB. These compounds contain sulfur and nitrogen with, in general, high degrees of saturation. These compounds become part of the rubber's structure and are generally not recovered.

Table 3. Accelerators, Curing Agents, Vulcanizers, and Retarding Agents

Compound	Structure	Uses
2-mercaptobenzothiazole (MBT)		primary accelerator for natural rubber
bis(2,2-benzothiazolyl) disulfide (MBTS)		primary accelerator for natural rubber (scorch safety)
N-tert-2-benzothiazolesulfenamide (TBBS)		delayed action accelerator for natural rubber
N-cyclohexyl-2-benzothiazolesulfenamide (CBS)		delayed action accelerator for natural rubber
2-(4-morpholinylthio) benzothiazole (MTB)		delayed action accelerator for natural and styrene butadiene rubber
2-(4-morpholinylthio) benzothiazole		accelerator and sulfur donor for natural and synthetic rubbers
1,3-diphenylguanidine		secondary accelerator used with thiozoles, sulfenamides, and thiurams
Tetramethylthiuram monosulfide (TMTM)		booster for thiozole acceleration
N-oxydiethylenethiocarbamyl-N'-oxydiethylenesulfenamide		primary accelerator for natural and synthetic rubber (scorch safety)
4,4'-dithiobismorpholine		vulcanizing agent for natural and synthetic rubber (excellent heat aging)
N-(cyclohexylthio)phthalimide (CTP)		retarder for synthetic rubber used with sulfenamides

§ Trade names are numerous, manufacturers are Akron Chemical, American Cyanamid, BF Goodrich, Monsanto, Mobay, Ouchi Shinko, Pennwalt, Uniroyal, Sanshin, Sumitomo, Vanderbilt, and Vulnax

2.3.6 Protectants

Natural rubber is different from SBR and other synthetic rubbers of the diene types in its need for protection. Latex as taken from the rubber tree contains natural antioxidants, proteins, and complex phenols, which protect it from deterioration during the coagulation and drying steps. These natural protectants are destroyed during vulcanization and thus synthetic protectant must be added to ensure an adequate service life of cured natural-rubber products. On the other hand, synthetic rubber of the diene type is quite unstable when freshly prepared and requires synthetic protectants both during the flocculation and drying of the polymers and sometimes after vulcanization. Protectants are called stabilizers prior to the vulcanization process and are called antioxidants or antiozonants after vulcanization.

Antioxidants are substances that retard oxidation by atmospheric oxygen at moderate temperatures (autoxidation). Autoxidation is a free radical chain reaction and, therefore, can be inhibited at the initiation and propagation steps. Antioxidants are used in the manufacture of all tire rubber. Autoxidation often has a long kinetic pathway. Therefore, agents that interrupt the propagation step markedly reduce the oxidation rate.

Many different commercial antioxidants have been developed for specific applications:

- Amines;
- Phenols;
- Metal salts of dithioacids; and
- Bound antioxidants.

The amine-type antioxidants (N-phenyl-N'-isopropyl-p-phenylenediamine, or CD and N-phenyl- β -naphthylamine, or PBN) usually are the most effective in rubber and are used in the largest volume. They can be classified further as ketone-amine condensation products, diaryldiamines, diarylamines, and ketone-diarylamine condensation products. Both solid and liquid products are marketed. Most are discoloring and staining and are used in applications where this property can be ignored.

Phenolic antioxidants are less discoloring than amines. They are used in applications where staining is undesirable. Because of this, these compounds are of increasing

commercial importance. Most of the newer commercial antioxidants are of this type, such as alkylated hydroquinones (e.g., 2,2,4-trimethyl-1,2-dihydroquinoline, or TMQ). In high temperature applications, polynuclear phenols generally are preferred over monophenols because of their lower sublimation rates.

Most phenolic antioxidants are readily prepared by alkylating either hydroquinones, phenols, or cresols. All aromatic amine antioxidants or antiozonants are made from aniline or substituted anilines. Diphenylamine and p-phenylenediamine likewise are derived from aniline and are the basic raw materials for other products.

Metal salts of dithioacids act as hydroperoxide decomposers and propagation inhibitors, and are used in conjunction with other antioxidants, particularly phenols for rubber, petroleum products, and plastics.

Recently, antioxidants have been developed that are copolymerized into the elastomer chain. These are called bound antioxidants. The main advantage of such a system is low antioxidant extractability in applications where the elastomer is in contact with solvents capable of extracting conventional antioxidants.

Atmospheric ozone (O_3) is, by far, the most damaging factor on rubbers. The failure of rubber tires in service is often the direct result of O_3 attack. Fatigue and mechanical failure is initiated by the surface cracks produced by O_3 oxidation.⁹ Atmospheric ozone degrades polydiene rubbers by reacting directly with polymer main chain unsaturation.²³ Research on ozone induced crack growth established that the rate of ozone absorption for a typical diene polymer is linear and directly proportional to the ozone concentration, and that unstressed rubber still reacts with ozone to form oxidized surface films even though it does not show the characteristic cracking patterns.²³

Today rubber vulcanites are protected through the use of chemical antiozonants. These protectants possess several common features:

- all effective materials react competitively and directly with ozone;
- they must migrate to the surface of the rubber to be effective;
- their presence decreases the rate of cut growth; and

- some materials such as the N,N'-dialky-p-phenylenediamines and the N-alkyl-N'-aryl-p-phenylenediamines also affect the polymer by raising the apparent critical stress.²³

Two broad groups of additives are used commercially to inhibit ozonolysis of unsaturated elastomers. One group includes relatively unreactive, film-forming waxes. The other comprises certain reagents that react rapidly with ozone and possibly ozonolysis products. In order to be effective, waxes must quickly diffuse to the elastomer surface to form a protective film, or so-called bloom. Wax protection alone is inadequate for products, such as tires, that flex in service causing the film to break. In general, the N, N'-disubstituted p-phenylenediamines are the most effective commercial antiozonants, and continue to enjoy widespread growth, especially for tire applications. Certain dihydroquinolines, thioureas, metal dithiocarbamates, and N, N'-diaryl-substituted p-phenylenediamines, such as N, N'-diphenyl-p-phenylenediamine, also have weak antiozonant activity.

The effectiveness of antiozonants is also increased through their combined use (reactive antiozonants and blooming materials). With dual use, the amount of reactive antiozonant needed to provide adequate protection in tires is reduced. The reactive antiozonants are thought to protect the tire from direct oxidation while the waxes protect the rubber during static rest periods.²³

PPDs with wax are much less toxic than the dibutyl analog, and the presence of the longer chain alkyl groups markedly reduces the volatility. The IPPD system maintains the high activity of the dialkyl- system, but it is quite volatile and is easily extracted from the rubber vulcanite through contact with acid rain. Today, the use of 6PPD in the United States is far greater than that of all the other phenylenediamines combined.²³

2.3.7 Flame Retardants

Flame retardants are added to rubber as a fire prevention function. Flame retardants such as halogens, metal hydroxides, and phosphorous (or a combination of materials) are added to the rubber composition. To prevent degradation of the rubber and reduce the amount of additive required for the process, red phosphorus is used as the fire retardant in

conjunction with SBR (and other comparable rubbers) and rubber that contains a nitrile group. The nitrile group containing elastomer consist of rubber, such as, acrylonitrile-butadiene rubber (NBR) and acrylonitrile-styrene-butadiene terpolymer (ABS), that have a nitrile group content between 15-45% by weight.¹²

2.3.8 Structural Materials

Structural materials include synthetic fabrics such as rayon, nylon, and polyester which may have steel and brass coated steel integrated into them. Steel beads are also used to tie down the fabric. These materials form the plies that give the tire structural integrity. They are bonded to the rubber by adhesive systems discussed previously. Steel is bonded to rubber as ligands with mercaptobenzoylthiazole systems. Synthetic fabrics are bonded with dry systems dispersed in the rubber based on dihydric phenols and resorcinol.

3.0 Environmental and Health Effects Based on Composition and the Vulcanization Process

This sections of the report will discuss the environmental and health effects of tire compositions. It will also discuss the environmental and health effects identified with the vulcanization process when manufacturing tires. Environmental effects associated with waste tire recycling, reuse and disposal options will be discussed later in this report.

3.1 Effects Based on Composition

Various raw materials used in the manufacturing of tires have been documented to pose adverse health and environmental effects. Natural rubber alone poses a dangerous fire hazard and when heated to decomposition emits toxic fumes of SO_x .²¹ Base materials used in polymer rubber production, such as butadiene and styrene, are suspected human carcinogens, and many of the polymer additives can cause systemic toxic effects. In the proceeding text, the effects of specific individual compounds associated with a tire's composition will be discussed as well as certain effects that tires may cause on the environment.

Monomers and Polymers:

Isoprene is a mild toxic by the pathway of inhalation. It also reacts with air and ozone to form dangerous peroxides. Butadiene is a confirmed carcinogen and teratogen in animals and a suspected human carcinogen. Inhalation of high concentrations of butadiene can cause unconsciousness and death. Human systemic effects of butadiene by inhalation include coughing and hallucinations. Styrene is a suspected carcinogen. It has been found to be poisonous by ingestion, inhalation, and intravenous routes. Human systemic effects of styrene include eye and olfactory irritation. All three of these monomers are dangerous fire hazards when exposed to heat, flame or oxidizers. The most stable of these compounds is styrene but still biological half-lives are small.

The styrene-butadiene polymer is an eye irritant and questionable carcinogen. This polymer, much like the monomer from which it is derived, is a dangerous fire hazard.

Antiozonants and Antioxidants:

Most of the antiozonants are phenylenediamine derivatives. The phenylenediamines are poisonous by ingestion routes. They are a skin irritants and questionable animal carcinogens. The p-isomer is more toxic and a stronger irritant than the o- and m-isomers of phenylenediamine. They are combustible when exposed to heat or flame.²¹

Studies show that concentrations of antioxidant in tires rapidly decreases between production and several months of use indicating that it breakdowns or escapes into the environment. The antioxidant, PBN (N-phenyl-b-naphthylamine), is possibly carcinogenic so others are used when possible.²⁴

Aromatic amines are used in the rubber industry as inhibitors of the rubber degradation which occurs with aging through processes mainly caused by oxidation and ozonolysis.²⁵ Aniline is a suspected animal carcinogen and a poison. It is also a skin and severe eye irritant. Diphenylamine is a poison by ingestion, but it has not been identified as a carcinogen. When heated, diphenylamine emits highly toxic fumes of NO_x. The inhibitor, o-toluidine, is a suspected human carcinogen and confirmed animal carcinogen. It is moderately toxic by ingestion and when heated emits highly toxic fumes of NO_x.²¹

Tire Filler:

The tire filler, carbon black, is mildly toxic by ingestion, inhalation and skin contact. It is a questionable animal carcinogen, and in high concentrations it is a nuisance dust. The tiny particulates of carbon black contain some molecules of carcinogenic materials; however, the carcinogens are apparently held tightly and are not eluted by hot or cold water, gastric juices, or blood plasma.²¹

Zinc oxide is added to tire rubber at relatively high concentrations. Zinc oxide is moderately toxic to humans by ingestion. Some human systemic effects associated with the inhalation of zinc oxide are chills, fever, tightness of the chest, and coughing. When mixed with chlorinated rubber, an explosion has occurred.²¹ Although not discussed in the articles of the literature search, zinc oxide will not leach out of tire rubber at concentrations that exceed Soluble Threshold Leachate concentrations under the California Assessment Manual.

Tires have been historically manufactured with appreciable amounts of lead oxide. Lead oxide was used during vulcanization processes and has been used frequently in European countries. Lead oxide is moderately toxic by ingestion and is combustible by chemical reaction with reducing agents. When heated to decomposition, lead oxide emits toxic fumes of lead.²¹ Analysis of combustible waste tires shows lead at concentrations of 100 ppm and zinc at concentration of 26,000 ppm in sample tire rubber combustion products.²⁶

Mercaptans can form SO_x when decomposed²¹, and many can react with water to produce flammable vapors. There is no likelihood that these compounds would form with the decomposition of tires. These compounds are not environmentally stable at small molecular weights. Oxides of sulfur, however, should always remain a concern for thermal tire decomposition.

Paraffin wax is a confirmed animal carcinogen. When heated to decomposition, paraffin wax emits acrid smoke and irritating fumes.²¹

Softeners that are used in the largest concentration are pyrolytic oils. The higher the aromatic content of the oil the more easily it disperses into the rubber. Softeners were not described fully in the literature, but they are assumed to have properties similar to that of diesel and petroleum oils. Petroleum is a questionable carcinogen and a dangerous fire hazard. These materials have high aquatic toxicity and can be released into the environment at high concentrations during partial pyrolysis. The release of these oils under landfill conditions and other non-thermal conditions were not studied within the literature reviewed.

3.2 Effects of Vulcanization

Large air contaminant fractions are released during the vulcanization process. Operators working in the vulcanization areas are exposed, even though at low concentrations, to curing fumes containing not only the antidegradant introduced in rubber compounding, but also other aromatic amines which are formed probably as thermodegradation products throughout the manufacturing process. Compounds in working areas are antiozonants and decomposition products from antiozonants and accelerators. The compounds include aniline, o-toluidine, diphenylamine, 6PPD, and 7PPD.²⁵ Studies have indicated a low dispersion of 6PPD and 7PPD (exposures up to respectively 1 and 0.3 $\mu\text{g}/\text{m}^3$) in the vulcanized areas and higher concentrations of the other aromatic amines: up to 10 $\mu\text{g}/\text{m}^3$ of aniline and up to about 1 $\mu\text{g}/\text{m}^3$ of o-toluidine and diphenylamine. Moreover, as expected, high exposures to IPPD and 6PPD (ca. 1 mg/m^3) were found when these solid raw materials were weighed, owing to the lack of any technical prevention.²⁵

Two other compounds of concern in air emissions from rubber processing plants are thioureas and the secondary alkyl nitroamines. Many thioureas and nitroamines produce cancer in animals.²⁷

4.0 Recycling, Reuse and Disposal of Waste Tires

Tire recycling, reuse and disposal are discussed here to provide an overview as to the magnitude of the waste disposal problems and the various paths at which the tires enter

into the environment. Subsequent sections of this report will discuss the environmental effects associated with waste tire recycling, reuse and disposal.

4.1 Recycling and Reuse of Waste Tires

In order to prevent waste rubber and in particular discarded automobile tires from damaging the environment, it is highly desirable to recycle this material. However, the total mass quantity of tires currently recycled in a given year (not including reuse, retreading, or combustion) is less than 7% of the annual tire generation rate.¹⁰ A majority of the markets for recycled tire products can be expanded; but even if these markets reached their full potential, the number of tires generated each year would continue to far exceed the demand for scrap and used tires. Only a small portion of the waste tires are retreaded, and a very small portion is devulcanized by tedious processes.²⁸ The asphalt highway construction business holds the greatest potential for the demand of scrap and used tires in the form of ground rubber.¹⁰

The reuse options for waste tires are significantly affected by the tire's particle size. Some of the recycling applications for tires based on particle size are shown in Table 4. Some recycling alternatives use whole tires, thus requiring no extensive processing, while other alternatives require that tires be split, punched, or shredded to make new products.

Recycling of waste rubber from tires can be carried out by grinding the tire and adding the waste rubber particles to rubber mixtures for manufacturing new products. This process, however, leads to a strong deterioration of the desired physical properties of the rubber. Yet, another method of recycling is to reclaim the waste rubber in which the network formed by vulcanization is thermally degraded. The reclaimed material can be added to rubber mixture for manufacturing new products. This process also leads to a loss of the desired physical properties of the rubber, in comparison with virgin polymers.²⁹

Table 4. Alternative Applications for Waste Tires based on Particle Size¹⁰

Particle Size	Applications
Whole Tire:	Artificial reefs and breakwaters
	Playground equipment
	Erosion control
	Highway crash barriers
Split or Punched Tire:	Gaskets, seals, washers, shims, and insulators
	Floor mats, belts and shoe soles
	Dock bumpers
	Muffler hangers
Shredded Tire:	Lightweight road construction material
	Playground gravel substitutes
	Sludge composting
Ground Rubber:	Rubber and plastic products (e.g., molded floor mats, mud guards, carpet padding, and plastic adhesives)
	Rubber railroad crossings
	Additives for asphalt pavements

In some recycling applications, removal of the metal bead in the waste tire is not required. For example, processed waste tires (or chipped tires) can be used as a lightweight fill material without requiring the removal of the metal from the rubber chips. Normal construction machinery can successfully operate on top of fill material consisting of tire chips provided that precautions are taken to prevent exposed wires at the edge of the chips from puncturing the tires of the machinery.³⁰ Other recycling applications require the removal of the steel bead. Splitting of tires requires removal of the steel bead prior to stamping or punching. Manufacturing of crumb rubber and the use of tire chips as a substitute for playground gravel requires the tires to be shredded and magnetic separators be used to remove all steel fragments. In addition to removal of steel beads, several recycling applications require other modifications to the tire, such as, removal of polyester fragments and colorizing the rubber material.¹⁰

Tires can be used as fuel alternatives. Combustion facilities currently using tires as fuel include: (1) power plants; (2) tire manufacturing plants; (3) cement kilns; (4) pulp and paper plants; and (5) small package steam generators.¹⁰ In addition to fuel alternatives, pyrolysis of tires can be performed to chemically alter the materials of the tire or to derive various products such as carbon black. Burning tires whole obviates the need for expensive shredding operations. However, the burning of whole tires requires a relatively sophisticated high temperature combustion facility to keep emissions within environmental limits. It also requires equipment capable of handling the whole tires and feeding them into the combustion chamber. Most plants currently burning tires for fuel, excluding cement kilns, do not have the capability to burn whole tires. Instead the tires are shredded into chunks ranging from 2 to 6 inches in size prior to being introduced as a fuel. Typically, rubber chunks contain steel wire from the tire beads and steel belts. If the combustion process requires removal of the wire, the cost for combustion is increased. The wire removal from rubber chunks is an expensive process, which requires fine shredding and the use of powerful magnets.¹⁰

4.2 Disposal of Waste Tires

Tires that are not recycled or reused are usually shredded and disposed of in landfills, or stockpiled whole.¹⁰ Stockpiling whole tires creates two significant hazards: mosquitoes and fires. Due to their shape and impermeability, tires managed in stockpiles tend to hold water for long periods of time. This stagnant water provides an ideal breeding ground for mosquitoes and sites for mosquito larvae development. Tire stockpiling has contributed to the introduction of non-native mosquito species as used tires are imported from other countries to the United States. These new mosquito species are often more difficult to control and spread more disease.¹⁰

Stockpiling whole tires also poses a significant fire hazard. These fires, some of which may be started intentionally, generate large amounts of heat and smoke and are difficult to extinguish. This is due to the fact that: (1) tires, in general, have more heat energy by weight than does coal (37,600 kJ/kg vs. 27,200 kJ/kg)³¹; and (2) there is a 75% void space present in a whole waste tire, which makes it difficult to either quench the fire with water or cut off the oxygen supply.³⁰ Some tire fires have burned continuously for months, such as the 9-month Rhinehart tire fire in Winchester, VA.^{31, 6} In addition, tire

fires cause damage to surrounding areas. For example, in New Jersey a tire blaze beneath an elevated highway melted the asphalt.⁶

The landfilling of whole tires consume a large volume of landfill space because the tires are relatively incompressible and 75% of the space a tire occupies is void.^{30, 10} This void space provides potential sites for gas collection and harboring of rodents. In landfills, waste tires capture explosive methane gas and "float" upward sometimes shooting to the surface with tremendous force and piercing the landfill cover.^{6, 10} The primary advantage to landfilling whole tires is that processing costs are avoided. However, landfills' bad experience with whole scrap tires has led to extremely high tipping fees or total bans on whole tires.¹⁰

Shredding or splitting of tires is becoming increasingly common as part of the disposal process.^{30, 10} Shredded tires stored above ground pose less of a hazard than do whole tires. Shredding eliminates the buoyancy problem and makes tires into a material that can easily be landfilled. Shredding can reduce a tire's volume up to 75%. This volume reduction can also reduce transportation costs because fewer trips are required and maximum hauling weights may be achieved more easily.¹⁰ The main disadvantage of shredding waste tires before landfilling is that an extra processing step is required.¹⁰

5.0 Environmental and Health Effects Based on Tire Reuse and Disposal

This section of the report will discuss the environmental effects associated with waste tire recycling, reuse and disposal options. The report will identify potential hazards and environmental effects with combusting, pyrolyzing, and irradiating tires during the recycling and reuse activities. Further discussions will identify the environmental effects as a result of disposing of tires. Such disposal topics will include exposing tires to aqueous media, degradation of tires in air, and open burning of tires.

5.1 Combustion of Tires in Cement Kilns

The high heating value of tires (approximately 14,000 BTU/lb) make waste tires an effective supplemental fuel for cement kilns. Waste tires supplement coal and/or other

fuels in the cement kiln heating process. Tire derived fuels are consistent fuels. They are constructed within a narrow range of materials and have low moisture levels. However, tires can not exceed 30% of the kiln fuel without adversely altering the chemistry of the cement's curing process.⁶

The supply of tire-derived fuel for cement kilns is broken into two general categories: whole and processed. The basic advantages for using whole tires is: (1) they can be obtained at a positive expense (i.e., kiln operator's can receive a modest tip fee for accepting the whole tire); (2) the feed/weighing system is simplified (simple hooks can be used for weighing and loading the material); and (3) the acquisition process is simplified (whole tires can be picked up from the point of generation and brought directly to the kiln in a covered truck). The major difference between whole and processed tires in this process is the heating value. The less wire (bead and belt) in tire derived fuels, the higher the heating value.³³

The high temperatures (typically around 2600°F) and long residence times inherent in the operation of cement kilns provide a sufficient disposal technique for waste tires with limited emissions. The solid ash constituents from the combustion of tires (i.e., the steel from the tire beads and belts) are absorbed and used by the cement kiln product. Normally iron ore is added to the cement operation. Since tires already contain iron from the beads and steel belts, the addition of iron ore is no longer required.³²

The Scrap Tire Management Council reviewed four air emission reports concerning waste tires that fuel cement kilns. In general, test results have shown that tire derived fuels have no additional adverse effect on emissions when compared to coal. In fact, test results indicate a net reduction of SO_x, NO_x and particulate matter. Many technical considerations under the Clean Air Act that effect tire fuel industries have yet to be determined. Testing protocols and emissions standards have not been developed for all the listed potential emissions.³³

5.2 Pyrolysis of Waste Tires

Pyrolysis is the process of thermally degrading a substance into smaller, less complex molecules. Pyrolysis is also known as destructive distillation, thermal depolymerization,

thermal cracking, coking, and carbonization.¹⁰ High-molecular-weight substances cannot be purified by physical processes such as distillation, extraction, or crystallization; they can be recycled only by pyrolyzing the macromolecules into smaller fragments.³⁴

Pyrolysis of scrap waste tires is complicated because rubbers are poor thermal conductors and the degradation of macromolecules requires considerable amounts of energy. The most common method of pyrolysis is a rotary kiln where the waste must reside in the kiln for 20 minutes or more. The large temperature gradients inside the rotary kiln results in a diverse set of products. To reduce the number of components produced, the pyrolyzing unit should have excellent heat and mass transfer properties and maintain a constant temperature throughout the chamber.

Pyrolysis produces three principal products: pyrolytic char, oil, and gas. The quality and quantity of these products depend upon the reactor temperature and design. Table 5 shows the approximate product distribution as a function of pyrolysis reactor temperature. Table 6 shows the range of composition and properties of the product. Char is a fine particulate composed of carbon black, ash, clay fillers, sulfur, zinc oxide, calcium and magnesium carbonates, and silicates.¹⁰ Other char by-products of pyrolysis may include steel (from steel-belted radial tires), rayon, cotton, or nylon fibers from tire cords. Pyrolytic oils consists of heavy oils (hydrocarbon molecules with 8 or more carbons), light oils (hydrocarbon molecules with 3-7 carbons), benzene and toluene.¹⁰ Pyrolytic gases are typically composed of paraffins and olefins with carbon numbers from one to five.¹⁰ Table 7 shows the chemical composition of pyrolytic gas.¹⁰ Pyrolytic gas also contains non-condensed light oils. The amount of light oils is approximately 2% of the total pyrolytic gas volume. Table 8 shows the chemical composition of light oil condensed from pyrolytic gas at 0°C.¹⁰

Table 5. Product Distribution as a Function of Pyrolysis Reactor Temperature¹⁰

Reactor Temperature (°C)	Gas, %	Oil, %	Char, %
500	6	42	52
600	10	50	40
700	15	47	38
800	31	40	29

Table 6. Products of Waste Tire Pyrolysis³⁵

Product	Composition	Properties
Gas	Hydrocarbon mixture, low sulfur content	Calorific value 19-45 MJ m ⁻³ (500-1,200 Btu ft ⁻³)
Oil	Contains less than 1% sulfur	Calorific value 42 MJ kg ⁻³ (18,000 Btu lb ⁻³)
Char (Solid)	Contains 2-3% sulfur and approx. 4-5% zinc	Calorific value 28-33 MJ kg ⁻³ (12,000-14,000 Btu lb ⁻³)

Table 7. Chromatographic Analysis of Pyrolytic Gas from Shredded Automobile Tires with Bead Wire¹⁰

Constituent	Volume %
Hydrogen	47.83
Methane	29.62
Ethane	18.52
Propane	5.70
Propylene	8.82
Isobutylene	0.73
Isobutane	0.34
Butane	0.23
Butene-1	0.14
trans-Butene-2	0.07
iso-Butene-2	trace
Pentane	not detected
1,3-Butadiene	not detected

Table 8. Chromatographic Analysis of Light Oil Condensed from Pyrolytic Gas at 0°C¹⁰

Constituent	Volume %
Toluene	11.05
Benzene	8.83
1-Hexene	5.85
Hexane	4.07
8-Methyl-8-Butene*	3.55
trans and cis-8-Hexene	3.42
Styrene	3.03
Ethyl Benzene	3.33
Xylene	4.18
3,3-Dimethyl-1-Butene	1.11
8-Methyl Butane*	1.04
2,8-Dimethyl Butane	1.04
8-Methyl-1,3-Butadiene*	1.85
Cyclopentane	1.48
Other	46.17

* **Note:** Constituent chemical name *may* be erroneous. Reference 10 was verified, but allegedly this chemical formation cannot exist.

Table 9. Emission Estimates from Pyrolysis Facility, Conrad Industries¹⁰

	Concentration ($\mu\text{g}/\text{m}^3$)	Emission Rate^b (lbs per MMBtu)
Particulate	2,500	1×10^{-4}
Particulate Matter associated with metals		
Aluminum	1.51	6.7×10^{-8}
Chromium	0.82	3.7×10^{-8}
Iron	9.89	43.9×10^{-8}
Magnesium	0.45	2.0×10^{-8}
Manganese	0.09	0.4×10^{-8}
Mercury	0.05	0.2×10^{-8}
Nickel	2.95	13.1×10^{-8}
Potassium	1.84	8.2×10^{-8}
Sodium	18.62	82.7×10^{-8}
Zinc	0.65	2.9×10^{-8}
Semi-Volatile Organic Compounds		
Bis-(2-ethy-hexyl)phthalate	10.2	45.3×10^{-8}
Butyl Benzyl-phthalate	1.7	7.5×10^{-8}
Di-n-butyl-phthalate	0.9	4.0×10^{-8}
Naphthalene	2.87	12.7×10^{-8}
Phenol	1.4	6.2×10^{-8}
Volatile Organic Compounds		
Benzene	20.2	c
Ethylbenzene	24.1	c
Toluene	30.8	c
Xylenes	16.2	c
Sulfur Dioxide	310,500	7.7×10^{-2}
Nitrogen Oxides	210,000	9.7×10^{-3}

a These emission estimates reflect the composition of pyrolytic gas, which is either burned in the process as fuel or (for the excess pyrolytic gas) vented to the facility's flare. These estimates do not reflect atmospheric emissions.

b These emission rates were calculated by taking the average concentrations reported for the compound and multiplying it by the average flow rate for the test runs. An energy input value of 31 MMBtu was used to calculate lbs/MMBtu.

c Flow rates were not reported. Thus, pounds of emissions per hour could not be calculated.

Pyrolytic units are expected to have minimal air pollution impacts because most of the pyrolytic gas generated in the pyrolysis process is burned as fuel. Additional pyrolytic gas may be vented to a flare system. Assuming complete combustion, the decomposition products of the pyrolytic gas are water, carbon dioxide, carbon monoxide, sulfur dioxide, and nitrogen oxides. Table 9 shows an estimate of the emissions from a pyrolysis facility. The estimates do not reflect atmospheric emissions.

Emissions of volatile organic compounds (VOCs) and particulates are from fugitive sources. VOC fugitive emissions occur from leaks due to worn or loose packing around pump shafts and valve stems, from loose pipe connections (flanges), compressors, storage tanks, and open drains. VOC fugitive emissions can be significantly reduced by specifying components (e.g., pumps, valves, and compressors) specifically designed to minimize fugitive emissions. Fugitive emissions of particulate occur during the handling and processing of char. Operations such as screening, grinding and processing cause particulate matter (PM₁₀) emissions and can be controlled with dust collectors and baghouses. Fugitive emissions can also be reduced by training operators and mechanics in ways to reduce fugitive emissions, good supervision, and good maintenance practices.¹⁰ Quantitative estimates of fugitive emissions were not available.

5.3 Irradiation of Waste Tires

When exposing waste tires to microwaves in a microwave oven, copious amounts of gray gas are produced by the heating action on the tires. The composition of the gases generated during the irradiation process was not identified in the literature. The gases generated in the oven must be removed and sent to a cleaning/scrubber apparatus. After irradiating the tire, the tire can be compressed using hydraulic press into a fine black powder having a particle size of talcum powder. The metal strips contained in the tire can be recovered intact.³⁶

5.4 Environmental Effects of Tires and Tire Rubber as It Relates to Aqueous Media and Leaching

High levels of zinc and cadmium were detected in the Rhine river near Bonn and Strasbourg, Germany in 1988. The major source of the aqueous contamination was attributed to automobile tires that served as a source of fuel for the German cement industry. The river received the metals through air deposition from the burning of tires and storm water runoff from roads which accumulated the metals through tire wear. However, the conclusion that tires are the source of the cadmium contamination is weak. Zinc oxide is understood to be used as an activator additive for tires in large quantities. Cadmium is not a specific additive, but zinc ore contains as much as 1% cadmium.³⁷ Thus, the cadmium impurity in the tire could range from 4 to 200 ppm depending on the zinc ore impurity concentration (from about 0.1% and 1%), and the amount of zinc oxide used in the rubber composition (from about 0.5% to about 3%). Metal testing performed on tires and tire chips show very little cadmium; so the validity that tires are the major contributor to significantly high levels of cadmium in the Rhine river is questionable.

Once released to the environment, metals ions associated with a tire's composition are relatively mobile and can migrate to ground and surface waters through soil leaching and runoff. But in most cases, the concentrations of metals that leached from tires and tire chips are very minute. Consequently, the impact of metals on the environment from tire leaching is relative small. Metals leached from tire stockpiles have been studied and analyzed and the results appear below in Table 10. Metals and metal oxides recovered from the thermal oxidation of tires have a higher potential to impact the environment and should be recovered or stabilized.

Table 10. Trace Metals from Waste Tire Stockpile Leachate

Metal Constituent[§]	Concentration (ppm)
Aluminum	300 to 700
Antimony	.015
Arsenic	not found
Barium	not found
Beryllium	.0009
Cadmium	.015
Chromium	100
Cobalt	100 to 300
Copper	not found
Indium	not found
Manganese	not found
Mercury	.009
Molybdenum	1 to 500
Nickel	not found
Selenium	150
Tellurium	not found
Thallium	not found
Tin	.01
Tungsten	not found
Uranium	.04
Vanadium	.009 to 1
Zinc	15000

[§] Arsenic, Barium, Copper, Indium, Manganese, Nickel, Tellurium, Thallium, and Tungsten are found in raw coal. Aluminum, Cobalt, Selenium, and Zinc were metals that exist higher in tires than in coal, molybdenum values fell within the range of coal concentrations, other metals listed fall below coal values.

A study of the leaching of tire rubber from waste piles was published in 1992 by the U.S. Department of Commerce, National Technical Information Service. The study included the construction of various waste piles (or embankments) at the Dane County land fill in Madison, Wisconsin. The embankments were constructed with varying amounts of earth and tires. One such embankment contained 50% tire chips and 50% sand in alternating 1 foot lifts. The embankment was 6 feet high with an apex area of approximately 2,800 ft² and a base area of 7,200 ft². Two lysimeters were placed in the centers of the

embankment at 30 feet and 90 feet in an overall fill length of about 180 feet. A geotextile cap was placed on the top of the embankment. Extraction Procedure (EP) toxicity tests were conducted on collected samples. The test results showed that the concentrations of hazardous constituents detected in the samples did not exceed the concentration values necessary to be defined as hazardous waste. In fact, manganese was the only analyte which the study indicated as an abnormally high concentration. Table 11 shows water quality tests extracted from the most central lysimeter.

Table 11. Lysimeter Readings From A Tire Embankment

Analyte	Value in 1990	Value in 1991
pH	7.7	7.7
Alkalinity (mg/l)	533	705
Barium (µg/l)	210	350
BOD (mg/l)	14	70
Calcium (mg/l)	170	340
Chloride (mg/l)	400	1400
COD (mg/l)	170	560
Conductivity (µohm/µm)	-	5150
Iron (mg/l)	0.05	0.7
lead (µg/l)	<3	22
Magnesium (mg/l)	150	390
Manganese (µg/l)	270	3200
Sodium (mg/l)	230	200
Sulfate (mg/l)	140	450
Total Solids (mg/l)	2000	4630
Zinc (µg/l)	46	540
Hardness (mg/l)	1100	2500

There is evidence that antioxidants leach from tires. Certain PPD (phenyl phenylenediamine) type antioxidants are leached by water from the surface of rubber vulcanite. Monsanto observed that surface concentrations of IPPD in vulcanite were substantially reduced when exposed to running water. A complete loss of IPPD occurred from SBR vulcanite in water at 85°C in 30 days.⁸ Losses of antioxidants and

antiozonants were reported to be as high as 90% during monsoon seasons where tires were used; but, there was not evidence of controlled experimentation.²⁴ The amount of antioxidant lost due to water leaching is dependent on the molecular weight of the PPD.⁸ An increase in the molecular weight of an antioxidant decreases the loss of antioxidant.

The loss of antiozonant activity has been observed more in water of lower pH.⁸ This is due to the fact that the solubility of antiozonants in water increased as the pH of the water was lowered. Another study suspended thin test probes of NR vulcanite containing IPPD, 6 PPD, and DTPD in water with a pH of 4 for various time durations. The study recorded that after 15 days, at an original concentration of 3 parts of antiozonant per hundred parts of rubber, the vulcanite lost 87.7% of the IPPD, 44.5% of the 6PPD and 1.17 % of the DTPD.⁸

Although antioxidants are leached by water, the largest loss of antioxidants occurs during the curing process of the tire. Antioxidants can also be lost due to elevated temperatures while tires are in storage or during use and due to diffusion as the tire ages.

There has been a long term study conducted on tires immersed in sea water. The study concluded that after 42 years tires constructed of polyisoprene and immersed at a depth of 80 feet showed very little degradation. Analytical tests on the tires identified that the tire rubber absorbed enough water to equal 5% of its mass.³⁸ Concentrations of rubber, carbon black, sulfur, zinc oxide, mercaptobenzothiazole, and stearic acid were within $\pm 10\%$ of those that would be found in the original tire composition. Antioxidants were also analyzed in the tires, but any loss of these compounds could not be confirmed. The iron bead was also analyzed. Trace metals were detected, indicating the bead was a mild steel, and no oxidation appeared to have occurred. The analysis results of the tires immersed in sea water appears in Table 12.

Table 12. Sea Water Concentrations Near Tire Deposits at 80 feet

Parameter	Concentration or Value
Sodium	12300 ppm
Magnesium	1900 ppm
Potassium	590 ppm
Calcium	410 ppm
Strontium	9 ppm
Iron	0.83 ppm
Lead	0.44 ppm
Manganese	0.12 ppm
Copper	0.11 ppm
Zinc	0.07 ppm
Chloride	15000 ppm
Sulfate	2000 ppm
Dissolve Oxygen	8.8 ppm at 80 feet 9.7 ppm at sea level 11 for nearby tap water
Temperature	8°C at 80 feet, 13°C at sea level
pH	7.8 at 80 feet and at sea level

Evaluation of Table 12 shows that tire rubber maintains its composition under a relatively corrosive environment. During the experiment, the oxygen available for oxidation was only reduced slightly from local tap water, and the tire was maintained under a cool environment. Ozone levels as well as UV penetration at 80 feet are not appreciable.³⁹

The study identified that there was some decrease in the desired structural properties of the rubber including an increase in hardness. The increase in hardness may be primarily due to the absorption of moisture as opposed to a loss of rubber material compounds to the environment. Percent changes in physical properties are given in Table 13.

Table 13. Changes in Physical Properties due to Long Term Immersion

Parameter	% change
Tensile Strength	-3%
Tensile Modulus	23%
Elongation at Break	-15%
Tear Strength	no change
Hardness	16%
Compression	-68%

Aside from the sea water immersion study, other studies have concluded that tires lose adhesion properties with elevated humidity.⁴⁰ But this adhesion reduction is probably due to moisture absorption rather than a loss or decay of material compounds in rubber. Humidity aging can be controlled with adjustments in sulfur and accelerator additives. Compounds containing small amounts of sulfur show a decrease in adhesion with increasing amounts of the accelerator additives. However, compounds containing large amounts of sulfur maintain high adhesion even with large amounts of accelerator additives.

5.5 Environmental Effects of Tires and Tire Rubber as It Relates to Degradation from Oxidation in Air

Atmospheric ozone (O_3) is, by far, the most damaging factor on rubbers. The failure of rubber tires in service is often the direct result of O_3 . Atmospheric ozone degrades polydiene rubbers by reacting directly with the polymer chain. Ozone attacks the double bond of the polymer and forms an intermediate organoperoxide (carbonyl) and an aldehyde (if terminal carbon) or ketone. The intermediate organoperoxide bonds with secondary ozonides to form stable organoperoxides and organohydroperoxides. Induced surface cracking or alternatively fatigue or mechanical failure is initiated by the surface cracks produced by O_3 attack.

Antioxidants and antiozonants work together to prevent this oxidation. There are 12 compounds formed as reaction products from ozone-6PPD reactions. These compounds

are non-volatile substances ranging in molecular weight from 184 to 548. These compounds all have nitrogen and benzene functional group.^{9, 23}

Air emissions due to the degradation from ozone are not expected to exist at measurable amounts. Small aldehydes may be admitted into the air. Air emissions of concern (if any) should focus on thermal treatment systems such as pyrolyzers and incinerators.

5.6 Environmental and Health Effects of Open Burning

Results suggest that the open burning of scrap rubber tires poses potential environmental and health effects. Because of the frequent occurrence of unwanted combustion at tire disposal sites and the potential environment and health risks posed by such combustion, prudence would suggest that such sites be reduced or eliminated in size and number.³¹

Considerable research has been performed on the mutagenic and carcinogenic properties of chemicals associated with the rubber industry. These studies have shown that a wide variety of mutagens and carcinogens are present in the rubber industry and that carcinogenic and other types of health effects have been associated with rubber workers. Many chemicals, some of which are mutagens and carcinogens, have been identified in the emissions from both the controlled and uncontrolled burning of rubber tires³¹; however, no studies on the mutagenicity of emissions produced by the open burning of tires was provided in the articles reviewed.

The organic products of incomplete combustion (PICs) are present in emissions from all combustion processes and, in general, have been found to be carcinogenic in humans and rodents and to be mutagenic in bacteria and mammalian cells.³¹ Mutagenicity bioassays, especially the *Salmonella* mutagenicity assay, have been shown to be useful for evaluating the health effects of airborne mutagens and potential carcinogens present in the PICs from a variety of combustion emissions. Such bioassays have been used to characterize PIC-impacted urban air as well as emissions from the combustion of municipal and hazardous waste, polyethylene plastic, wood smoke, and automotive and diesel exhaust.³¹ The mutagenic emission factor for the open burning of tires was 3-4 orders of magnitude greater than that for the combustion of oil, coal, or wood in utility boilers; it was most similar to values for the open burning of wood and plastic. Open

burning, regardless of feed stock of fuel, appears to result in greater mutagenic emission factors than does controlled combustion as provided by various types of incinerators or boilers. However, caution must be exercised in extrapolating these bioassay results in bacterial to potential health risks in humans. Further bioassay studies in mammalian cells and rodents would be necessary to provide a clearer understanding of the biological effects of these emissions to higher organisms, including humans.³¹

The emissions from stockpile tire fires affect not only the atmosphere but also the land and groundwater due to the liquefaction of the rubber during the combustion process.³¹ In addition, water on tire fires often increases the production of pyrolytic oil and provides a mode of transportation to carry the oils off-site and speed up contamination of soils and water.³⁰

Operators of tire stockpiles take precautions to prevent tire fires. Generally, this involves providing fire lanes between the segments of the tire pile. Some of the better prepared tire piles have also provided emergency water supplies for fighting potential fires.⁶ It is also necessary to provide surveillance to keep sources of flames away from the tires, particularly guarding against arsonous intruders. Operators of tire stockpiles often provide security measures such as watchman, guard dogs, chain link fences, and bright lighting at night.³²

If the agricultural lands polluted with heavy metals such as cadmium are no longer limed, the pH of the soils, previously maintained at levels of 6 or higher, could decline rapidly over a period of decades, resulting in an increase in the mobility of trace metals in the top soil. It is projected that the pH of forest soils in the lower Rhine Basin could decline to levels of about 4.0 by the year 2000. Abandoned agricultural land polluted with heavy metals has an enhanced uptake of heavy metals in new vegetation. This could harm wildlife and increase leaching to groundwaters for drinking-water supplies.³⁷

5.7 Parameters to Determine Environmental Pathways

Materials used to manufacture tires and materials found in thermal processing of tires were briefly evaluated based on environmental pathways. A general discussion of these materials and their fate in the environment is given in this section. Some key compounds

along with many of the pertinent parameters related to environmental fate will be quantified by standard estimating techniques. The environmental effects for many of these materials are not known, nor were they eluded to in any of the literature. Some toxicity effects are discussed in Section 3 and 5 of this report.

The parameters discussed in this section are water solubility (S), biological concentration factors (BCF), and soil adsorption (K_{OC}). These parameters were calculated based on correlations of related compounds and chemical structure. When available, physical properties were used in the estimate of other parameters. Some compounds were not evaluated because they are not tire materials specific, pose little or no environmental risk, or have well established properties far beyond what is discussed here. Compounds not evaluated are hydrogen, methane, ethane, propane, propene, butanes, butenes, pentanes, hexane, hexenes, nitrogen oxides, and sulfur oxides. Metals are also well studied and are not evaluated here. Metal toxicity is fairly well known and their environmental fate has been diligently studied. Table 14 below shows a few key chemicals that were evaluated and various parameters that were calculated. Solubility was correlated as a function of soil sorption and biological accumulation based on functional groups similar to those found in rubber compounds.³⁹

Table 14. Estimated Values for Solubility, Soil Adsorption, and Biological Concentration

Compound	Log S	S (ppm)	Log Koc	Koc (ml/g)	Log BCF	BCF (g/g)
benzene	3.21	1,611	1.27	18	-0.16	0.7
benzothiazole	3.64	4,338	1.16	15	-0.28	0.5
bis(2-ethyl-hexyl)phthalate	-0.41	0.39	3.64	4,371	2.49	312
1,3-butadiene	3.43	2,690	1.06	11	-0.40	0.4
dibutylphthalate	-0.42	0.38	3.57	3,675	2.41	257
ethylbenzene	1.97	93	2.02	105	0.68	4.8
formaldehyde	3.08	1,200	1.11	13	-0.34	0.5
2-mercaptobenzothiazole	4.17	14,725	0.92	8	-0.55	0.3
naphthalene	1.75	56	2.19	154	0.87	7.4
phenol	4.23	17,116	0.75	6	-0.74	0.2
p-phenylene diamine	4.58	38,000	0.59	4	-0.92	0.1
resorcinol	5.21	160,645	0.25	2	-1.30	0.1
styrene	1.95	89	2.03	107	0.69	4.9
toluene	2.54	347	1.67	47	0.29	2.0
xylene	1.97	93	2.02	105	0.68	4.8

A review of Table 14 shows that, compared with the other tire compounds, phthalates have a larger biological concentration factor; thus, a higher degree of accumulation in aquatic organisms. Table 14 also shows that soil sorption would be high for phthalates and moderately substituted aromatics and polynuclear aromatics. Compounds higher in molecular weight that are accelerators tend to be relatively reactive in the environment and decompose to smaller aromatic and heterocyclic compounds. (e.g., Substituted phenylene diamine is reactive to oxygen and also has a short biological half-life.) Compounds formed by ozonation and oxygenation of phenylene diamine derivatives are complex aromatics in which health effects are not studied.⁹

Environmental pathways can only be predicted for some tire rubber compounds. The literature reviewed provided only a small amount of information concerning tire leaching and emission. Waste tire products in long term storage or processed in thermal treatment units have been under limited study. Detailed pathways analysis for waste tire storage and processing were not discovered in our literature investigation. Based on comparable waste component, it would appear that waste tire pathways can be predicted based on similar circumstances with municipal landfills and coal burning facilities.

6.0 CEQA Evaluation Factors

As stated under the California Environmental Quality Act (CEQA), the policy of the State of California is that public agencies should not approve a project as proposed if there are feasible alternatives or feasible mitigation measures available which would substantially lessen the significant environmental effects of the project. (See Section 21000 of California's Public Resources Code). In order to adhere to this policy, an assessment of a proposed waste tire activity should be conducted to evaluate the following:

- all substantial, adverse environmental impacts that the proposed activity may cause;
- all irreversible environmental impacts that the proposed activity may cause;
- any feasible mitigation measures that would reduce such substantial adverse environmental impacts; and
- any feasible alternatives, including design alternatives, to the proposed project that would reduce such substantial adverse environmental impacts.

Based on the findings of the literature search conducted for this report, the potential environmental impacts of a waste tire processing facility will depend largely upon the processes employed by the facility. Each type of storage, handling, size reduction, destruction, or recycling activity a facility operates will have a unique potential impact on the environment. Table 15 provides recommendations of some issues that should be evaluated under an environmental assessment of different waste tire processes.

Table 15. Recommended Issues for Evaluation

Proposed Activity	Evaluate	Reasons for Evaluation
Stockpiling (whole tires)	Stagnant Water Mitigation Measures Fire Prevention Measures Fire Control Capabilities	Minimize mosquito breeding ground Reduce the risk of fire Reduce impact of potential fires
Stockpiling (shredded or chopped tires)	Fire Prevention Measures Fire Control Capabilities Stormwater Runoff Control for particulates	Reduce the risk of fire Reduce impact of potential fires Reduce the risk of surface water and soil contamination
Stockpiling (crumb or granulated tires)	Fire Prevention Measures Fire Control Capabilities Stormwater Runoff Control for particulates Dust Suppression Measures	Reduce the risk of fire Reduce impact of potential fires Reduce the risk of surface water and soil contamination Reduce particulate emissions due to wind
Volume Reduction (shredding/ chopping)	Particulate Emissions Particulate Control Measures	Evaluate impact of particulate release Evaluate effectiveness of particulate control
Combustion	Emissions of Priority Pollutants and Particles of Incomplete Combustion (PIC) Metal Emissions Air Pollution Control Measures	Evaluate impact of emissions of priority pollutants and PICs Evaluate impact of metal emissions Evaluate effectiveness of air pollution control system
Landfilling	Volume Reduction Methodology Fire Prevention Measures Fire Control Capabilities	Evaluate volume reduction technology for environmental impacts (see Volume Reduction) Reduce the risk of fire Reduce impact of potential fires

The findings of the literature search did not reveal the potential for significant environmental impacts resulting from waste tire land application (i.e., use as road bed material), ocean disposal, or reuse in oceans as artificial reefs. Information on the environmental impacts of retreading or remolding tires was also not found; however, the New Source Performance Standards (NSPS) established under the Federal Clean Air Act regulate emissions of volatile organic compounds from facilities of the tire manufacturing industry conducting the following operations: undertread cementing, sidewall cementing, tread end cementing, bead cementing, green tire spraying, Michelin-A operation, Michelin-B operations, and Michelin-C automatic operations. The sources of volatile organics from these operations are the cements and green tire spray. The regulations and definitions of these operations can be found in Title 40, Code of Federal Regulations (CFR), Part 60, Subpart BBB.

The Federal Clean Water Act establishes provisions applicable to discharges of process wastewater pollutants resulting from the production of pneumatic tires and inner tubes in tire and inner tube plants. These provisions are found in Title 40 CFR Part 428, Subpart A. Further review of these regulations should be conducted to determine their applicability to retread operations.

7.0 Recommendations for Future Work

7.1 Additional Literature Review

The scope of the literature search for this report was limited to published articles and chemical references. A majority of the articles focused on the performance of tires and the effect of the environment on tires versus the effect of tires on the environment. Information pertaining to the physical behavior of chemical additives associated with the rubber and tire manufacturing industry was found to be limiting. Reports directly related to the effects of waste tires on soil and the effects of soil acidity and alkalinity on tires were not found in the literature search. No literature was found directly identifying the chemical kinetics associated with tire components exposed to different environmental media, including rates of diffusion, environmental partitioning of components, and component by-products. Reports on the leaching potential of tire additives did not formally address whether or not hazardous constituents are produced from the leaching of the antiozonants and antioxidants.

Although the reports from the tire manufacturing industry do not contain all of the valuable chemical property data required to identify the behavior of tires in the environment, the tire manufacturing industry may possess this data. It is recommended that corporations within the tire manufacturing industry be directly contacted and requested to supply chemical property data on tires and tire additives. A description of the tests performed to obtain the data and available studies on the environmental impacts of tires should also be requested.

Similarly, contacts should be made with the cement manufacturing industry and tire pyrolysis operations to obtain air source testing data related to tire combustion. This data could be used to evaluate stack and fugitive emissions. The data should include: a description of the methodology used to sample for the emissions; the type of air pollution

control methods employed by the emission source; the physical form of the tire as burned; the type of tire burned; and additional fuels used to combust the tire. An analysis of the ash removed from the combustion process would also be helpful to evaluate environmental impacts due to secondary waste from combustion processes.

The Resource Conservation and Recovery Act (RCRA) allows the U.S. Environmental Protection Agency (EPA) to address releases to ground water and all other environmental media through corrective action at all solid waste management units located at facilities requiring a RCRA permit. The corrective action process includes the identification and release characterization for all environmental media from solid waste management units such as tire stockpiles. It is recommended that a review of EPA records be performed to identify and obtain information on corrective action activities associated with solid waste management units strictly consisting of waste tires. The information may include sampling and analysis data of environmental media in the vicinity of a waste tire management area revealing the potential for contaminated leachate and the chemical speciation of the leachate from the management area.

The chemical additives associated with the tire manufacturing industry are very unique. Consequently, it is unclear whether existing analytical methods are sufficient to evaluate environmental media for all of these specific chemicals. A comparison of the chemicals versus available analytical methods should be performed to determine areas where analytical methods are deficient in accuracy and precision. The analytical methods reviewed should include EPA's SW-846, "Test Methods for Evaluating Solid Waste," and methodologies used or recommended by the tire manufacturing industry. Chemicals determined to lack sufficient analytical methods may require the development of new or modified analytical methods.

An extensive search on the toxicological effects of many of the chemicals used to manufacture tires was not performed in the literature search associated with this report. It is recommended that an additional literature search be conducted to evaluate the environmental and human health effects of the identified tire additives and polymers.

7.2 Laboratory Work

As gaps of information are identified from performing the above literature review recommendations, laboratory investigations are recommended on the effects of waste tires on the environment. Recommended laboratory investigations include analyzing the degradation of waste tires with their effects on soil, water and air under various conditions and combinations of conditions. The conditions should include soil and water acidity, soil and water alkalinity, ultra violet radiation, high and low temperatures, tire particle size, and tire contact time with environmental media. Two specific laboratory investigations are provided below.

1. The leaching studies identified in the literature review relating to antioxidants and antiozonants appear inconsistent. According to the information, these materials migrate to a tire's exposed surface and are either degraded or released to the environment. The measurements performed to reach this conclusion analyzed how much of the materials remained in the tire rubber. However, the studies did not demonstrate a consistent approach in verifying the actual demise of the antidegradants. Laboratory studies should be performed to determine the actual rate of the antidegradant's reactivity and/or loss. Experiments should focus on the amount of antidegradant released to the environment (leach media), instead of the amount lost from the tire rubber.
2. Partitioning coefficients and transport phenomena parameters of the binders, accelerators and antidegradants should be measured. The literature search identified only one paper on the diffusivity of antiozonants from tire rubber samples, but the article was neither consistent nor comprehensive. Experiments may be performed to determine solubilities, soil-water-air partitioning coefficients, octanol/water coefficients, vapor pressures, diffusivities, and environmental half-lives. Additional toxicology studies can be performed to determine bioconcentration factors.

7.3 Field Work

The practice of stockpiling tires is still occurring in the United States. Sampling environmental media associated with stockpiles of tires is possible. The collection of soil

and stormwater runoff from a number of stockpiles of different ages is recommended. The collected media should be sampled and analyzed for metals to validate former tests. The collected media can also be sampled and analyzed for tire additive chemicals. Air samples may also be collected to determine release concentrations of tire compounds from a stockpile. Air samples should be collected at various temperatures and solar exposures.

The validity of the laboratory work performed on pollutant fate and biological concentration of tires used for ocean reefs should be researched thoroughly. The bioaccumulation of chemical additives in aquatic life has been evaluated based on the literature review. Field experiments should be performed.

7.4 Recommendations for Best Environmental Management Practices

Based on the literature review, tires in deep, cold salt water do not appear to deteriorate. Consequently, tires used as artificial ocean reefs are a potential reuse technique provided that additive compounds are not determined to accumulate in aquatic life.

The disposal/recycling industry should be encouraged to shred whole tires. This is important for disposal dynamics. Shredding provides easy handling and better compaction in landfills than whole tires. Shredded tires have a lower fire hazard than whole tires and do not allow for the accumulation of stagnant water in stockpiles. The most significant obstacle to shredding appears to be economical.

The evaluation of mitigation measures for waste tire processing is difficult to determine at this time. Analysis of the literature displays a positive light on tire projects such as cement kiln fueling, recovery of materials from pyrolysis, artificial reefs, rubber and road fillers, and other projects. It was understood from the literature that direct disposal of tires provides for the most harm to the environment and neighboring communities based on the harboring of pests, the reduction of landfill capacity, and potential fire hazards. The evaluation of any waste tire project will depend on the processes employed by the project facility.

Attachment A

Scope of Work

The purpose of this contract is to determine the conditions under which waste tires, waste tire facilities, or waste tire projects would create adverse effects in the environment. The Department of Energy (DOE) will conduct investigations that are concerned with the effects of waste tires and waste tire rubber on soil, water, and air under various potential conditions or combination of conditions including, but not limited to, acidity, alkalinity, ultra violet radiation, high temperatures, particle size, and time. If it is determined that waste tires create adverse environmental effects, recommendations for mitigation will be developed.

It is anticipated that the results of this contract will provide valuable information to assist local governments, state regulatory agencies, and private businesses in making informed decisions regarding waste tire management and recycling. Results could provide information for facility siting, permitting, CEQA compliance, and site mitigation for businesses involved in processing and manufacturing.

This agreement represents the first phase and will include a literature search to identify existing information, data assessment of the information, conclusions, mitigation measures, and recommendations for additional work to be done in phase II. The DOE shall perform the following tasks:

1. The DOE shall perform a literature search on the topic "Effects of Waste Tires, Waste Tire Facilities, and Waste Tire Projects on the Environment". This search shall include investigations of the effects on soil, water, and air under conditions (and combinations of conditions) including, but not limited to:
 - acidity
 - alkalinity
 - ultra violet radiation
 - high and low temperatures
 - particle size (whole, shredded, chips, crumb, granulate)
 - moisture
 - contact time
 - other potential environmental effects

Attachment A

2. The DOE shall also perform a literature search on the following topics:
 - tire composition
 - reaction kinetics associated with chemicals present in the environment
 - rates of diffusion
 - environmental partitioning of components or by-products of components
 - leaching potential
3. The DOE shall review and assess all information obtained from the literature searches. DOE shall discuss the validity of the data, draw conclusions from the compiled research, and identify any gaps of information found after completing Tasks 1 & 2.

The DOE shall also determine:

- the conditions under which tires are likely to be considered toxic or hazardous and/or create adverse effects on the environment
 - the necessary mitigation measures/solutions to minimize or prevent adverse environmental effects on the environment
 - mitigation measures for siting waste tire processing or manufacturing facilities in compliance with CEQA
4. The DOE shall provide a camera-ready draft final report and 10 copies to the contract manager including, but not limited to, the following information:
 - methodology
 - work performed
 - problems/solutions
 - list of references from Task 1 & 2
 - conclusions of Task 3
 - recommendations for lab and field work for Phase II
 5. The DOE shall provide a camera-ready final report for the contract manager's approval. Upon contract manager approval, the DOE shall provide 50 copies of the final report.

Attachment B

Literary Search for Waste Tires

Key Words:

- tires (*noun*)
- waste tires
- rubber
- styrene-butadiene rubber (SBR)

Words to be Associated With Key Words:

- acidity
- alkalinity
- ultra violet (UV) radiation
- high temperature
- low temperature
- particle size:
 - whole
 - shredded
 - chips
 - crumb
 - granulate
- moisture
- contact time
- residence time
- environmental effects (soil, water, air)
- composition
- decomposition
- reaction kinetics (with chemicals present in the environment)
- rates of diffusion
- environmental partitioning (of components)
- by-products
- leaching (potential)
- toxicity
- processing (or manufacturing)
- manufacturer
- California Environmental Quality Act (CEQA)
- quantity
- vulcanization

Attachment C

Literary Search for Waste Tires Reduced Word List

Key Words:

- tires (*noun*) or waste tires
- styrene-butadiene rubber (SBR)

Words to be Associated With Key Words:

- contact time
- environmental effects (soil, water, air)
- composition
- reaction kinetics (with chemicals present in the environment)
- rates of diffusion
- environmental partitioning (of components)
- leaching (potential)
- residence time
- decomposition
- vulcanization

Attachment C

Literary Search for Waste Tires Reduced Word List

Key Words:

- tires (*noun*) or waste tires
- styrene-butadiene rubber (SBR)

Words to be Associated With Key Words:

- contact time
- environmental effects (soil, water, air)
- composition
- reaction kinetics (with chemicals present in the environment)
- rates of diffusion
- environmental partitioning (of components)
- leaching (potential)
- residence time
- decomposition
- vulcanization

Attachment D

List of Records Submitted to the Library

Record - 3

TITLE - Studies of thermal and catalytic hydroliquefaction of model compounds, waste polymers and coal by high pressure TG/GC/MS

AUTHOR - Liu, K.; Jakab, E.; Meuzelaar, H.L.C. (Univ. of Utah, Salt Lake City, UT (United States))

ABSTRACT - Thermal and catalytic reactions of Styrene-Butadiene Rubber (SBR), as a model compound for waste rubber tires, were studied at pressures of 900 psi with selected catalyst types, viz, ZrO_2/SO_4 , $(\text{NH}_4)_2\text{MoS}_4$ and carbon black by on-line high pressure TG/GC/MS. Compared to thermal decomposition conditions, the superacid catalyst ZrO_2/SO_4 produced a strongly increased rate of SBR decomposition at 370 C; a markedly higher hydrogenolysis activity for α -carbon-carbon bond cleavage and a more highly saturated product suite. As expected, the $(\text{NH}_4)_2\text{MoS}_4$ catalyst clearly promoted hydrogenation reactions at 370 C. Carbon black, on the other hand, had no measurable effect at 370 C, but showed hydrogenation activity above 400 C. The thermal and catalytic decomposition of crosslinked poly(divinylbenzene), thought to be relevant as a coal model compound were also investigated. In conclusion, high pressure TG/GC/MS was found to provide important clues regarding the decomposition, behavior of waste rubber tires, coals and their respective model compounds under thermally as well as catalytically controlled conditions.

TITLE - 207th ACS national meeting; CT- 207. spring national meeting of the American Chemical Society (ACS); CL- San Diego, CA (United States): CY- 13-18 Mar 1994

PU- Washington, DC (United States), American Chemical Society; PY- 1994

PG- 648, Paper FUEL 104, PG- (2247 p); RN- CONF-940301; DT- Analytic of a Book; Conference Literature; JA- EDB94

AV- American Chemical Society, 1155 16th St., N.W., Washington, DC 20036-4899 (United States)

SC- 010405* - Coal, Lignite, & Peat - Hydrogenation & Liquefaction

KEY WORDS - *Coal Liquefaction - Chemical Reaction Kinetics; *Polymers - Chemical Reaction Kinetics; *Polymers - Liquefaction; *Solid Wastes - Chemical Reaction Kinetics; *Solid Wastes - Liquefaction; *Tires - Chemical Reaction Kinetics; *Tires - Liquefaction; Gas Chromatography; Mass Spectroscopy; Thermal Gravimetric Analysis; Chemical Analysis; Chromatography; Gravimetric Analysis; Kinetics; Liquefaction; Quantitative Chemical Analysis; Reaction Kinetics; Separation Processes; Spectroscopy; Thermal Analysis; Thermochemical Processes; Wastes

Record - 5

TITLE - Mutagenicity and chemical analysis of emissions from the open burning of scrap rubber tires

AUTHOR - DeMarini, D.M.; Lemieux, P.M.; Ryan, J.V.; Brooks, L.R.; Williams, R.W.

ABSTRACT - The Salmonella mutagenicity assay and chemical analyses were used to evaluate the emissions from the open burning of scrap rubber tires that had been cut into either of two sizes, chunk or shred. The mutagenic potency in strain TA98 of the dichloromethane-extractable particulate organics were generally greater than that of the semivolatiles. In addition, the open burning of chunk tires produced a higher burn rate and more potent organics in the presence of S9 than did shred tires. These results demonstrate for the first time that the open burning of scrap rubber tires produces a high mutagenic emission factor, posing potential environmental and health effects. (Copyright (c) 1993 American Chemical Society.)

CS- Acurex Environmental Corp., Research Triangle Park, NC (United States); 9531147

PY- 1994

PG- (8 p)

NT- Pub. in Environmental Science and Technology, Vol. 28, No. 1 136-141(1994)

SC- 540120* -- Environment, Atmospheric -- Chemicals Monitoring & Transport -- (1990-); 560300 -- Chemicals Metabolism Toxicology

KEY WORDS - *Combustion Products - Bioassay; *Combustion Products - Chemical Analysis; *Tires - Combustion Chemical Reactions; Oxidation; Thermochemical Processes

Attachment D

Record - 7

TITLE - Elements in automobile and truck tires and their volatilization upon incineration by INAA [instrument neutron activation analysis]

AUTHOR - Polasek, M.

ABSTRACT - It has been proposed to burn waste tires in cement kilns as a fuel supplement. The loading for 18 elements in tread and wall from used automobile and truck tires was determined using instrument neutron activation analysis (INAA); 14 other elements were monitored but only trace quantities were found. Among the elements measured were, Al (150-37,400 [mu]g/g), Ti (30-54,300 [mu]g/g), and Zn (0.86-1.90 wt %). Tires were found to be inhomogeneous in most elements. Inhomogeneity ranged from >5% for Zn to 60% for Na and Br. Tire rubber was incinerated and volatilities for trace components were determined. Losses >95% were determined for Br and Cl, 40% for As, <8% for Sb and Zn, and ca 0% for rare earths. Tire ash was incorporated into cement to determine if the elemental content would be measurably affected by using waste tires as 20% of heat input. Only Zn was determined to increase perceptibly (from 80 to 800 [mu]g/g). The rubber dust from the natural wear of tires as a source of trace element air pollution was determined to be inconsequential when compared to other sources. 23 refs., 46 tabs.

CS- *Toronto Univ., ON (Canada). Dept. of Chemical Engineering and Applied Chemistry;* 6282000

PY- 1993

PG- (86 p); BN- 0-315-83486-2; NT- Thesis (M.A.Sc.)

AV- MF Micromedia Ltd., 240 Catherine Street, Suite 305, Ottawa, Ontario, Canada K2P 2G8 SC- 320305* -- *Energy Conservation, Consumption, & Utilization -- Industrial & Agricultural Processes -- Industrial Waste Management; 540220 -- Environment, Terrestrial -- Chemicals Monitoring & Transport -- (1990-)*

KEY WORDS - *Tires -- Chemical Composition; *Tires -- Combustion; *Tires -- Combustion Products; Ashes; Cement Elements; Neutron Activation Analysis; Activation Analysis; Building Materials; Chemical Analysis; Chemical Reactions; Combustion Products; Materials; Oxidation; Residues ; Thermochemical Processes

Record - 14

TITLE - Characterization of the carbon black produced by vacuum pyrolysis of scrap rubber and optimization of the pyrolysis parameters

AUTHOR - Rastegar, A.

ABSTRACT - Among the recycling processes which have been considered for discarded tires, the pyrolysis route appears to be very attractive. Pyrolysis of tires transforms the feedstock into noncondensable gases, condensable vapors, and a solid residue mainly consisting of carbon black. If the energy equivalent of carbon black is taken into account, ca 70% of the energy used to manufacture the tire is recovered. The total energy saved by using pyrolysis is therefore ca 170% of the energy which could be obtained by using the tires directly as fuels. The economics of tire pyrolysis depend, among other factors, on the quality and quantity of pyrolytic oil recovered and on the quality of the derived carbon black and its marketability. Experiments were conducted to find the best process conditions for recovering high-quality carbon black, to optimize process conditions for maximum oil yield, and to study the influence of post-thermal treatment on the quality of carbon black samples produced at different decomposition temperatures. Experiments were conducted using a vacuum pyrolysis unit operating at 350-700[degree]C and 0.3-20 kilopascals pressure. Properties of carbon black such as specific surface area, pH, elemental composition, and volatile matter content were determined for the different grades of carbon black produced. The results indicate that these properties are affected by temperature and pressure. Specific surface area attains a maximum at 500[degree]C and decreases with an increase in pressure. Optimum temperature for maximum oil production was ca 420[degree]C. Comparison of spectroscopic and chemical analysis data suggests that during rubber pyrolysis, pyrolytic carbon is probably deposited on the solid residue particles. 62 refs., 22 figs., 33 tabs.

CS- *Laval Univ., Quebec, PQ (Canada). Faculte de Sciences et Genie;* 8701323

PY- Dec 1989; PG- (152 p)

AV- MF Micromedia Ltd., 240 Catherine Street, Suite 305, Ottawa, Ontario, Canada K2P 2G8 SC- 320604* -- *Energy Conservation, Consumption, & Utilization -- Municipalities & Community Systems -- Municipal Waste Management -- (1980-320305 -- Energy Conservation, Consumption, & Utilization -- Industrial & Agricultural Processes -- Industrial Waste Management*

KEY WORDS - *Carbon Black -- Chemical Composition; *Carbon Black -- Physical Properties; *Tires -- Pyrolysis; Bench-Scale Experiments; Chemical Reaction Yield; Optimization; Pressure Dependence; Pyrolytic Oils; Temperature Dependence; Carbon; Chemical Reactions; Decomposition; Elements; Fuels; Nonmetals; Oils; Organic Compounds;

Attachment D

Record - 20

TITLE - Heavy metal pollution in the Rhine Basin

AUTHOR - Stigliani, W.M.; Anderberg, S. (IIASA, Laxenburg (Austria)); Jaffe, P.R. (Princeton Univ., NJ (United States))

JOURNAL - Environmental Science and Technology (United States)

ABSTRACT - The Rhine Basin provides an excellent case study of the complex relationships between economic activities and their **environmental impacts**. The region covers 200,000 km² and comprises most of Switzerland and the southwestern provinces of Germany, the north-eastern corner of France, all of Luxembourg, and most of the Netherlands. In this article the authors summarize some results of research on cadmium, lead, and zinc pollution in the Basin from 1950 to 2010. They conducted historical analysis of the pollutants for two reasons. First, it has allowed them to determine long-term trends in the levels and sources of pollution, as well as to attribute these trends to changes in industrial structure or the implementation of pollution control technologies. A second advantage of the historical analysis is that it allows for the modeling of emissions and deposition to the environment in previous decades. As discussed later, such a model is necessary for estimating cumulative inputs of heavy metals in environmental compartments, such as soils and sediments, where the **residence times** of the metals are long. Two major issues highlighted in this paper are: the increasing importance of diffuse-source emissions and how to reduce them, and, second, the **environmental implications** of large-scale changes in land use, and management strategies for mitigating potential impacts on soil and groundwater quality. 30 refs., 4 figs., 2 tabs.

VO- 27:5

PY- May 1993

PG- 786-793

SC- 540320* -- *Environment, Aquatic -- Chemicals Monitoring & Transport -- (1990-); 540220 -- Environment, Terrestrial -- Chemicals Monitoring & Transport -- (1990-); 540120 -- Environment, Atmospheric -- Chemicals Monitoring & Transport -- (1990-); 020900 -- Petroleum -- Environmental Aspects*

KEY WORDS - *Cadmium Compounds -- **Environmental Effects**; *Lead Compounds -- **Environmental Effects**; *Zinc Compounds -- **Environmental Effects**; Agriculture; Air Pollution; Gasoline; Metal Industry; Rhine River; Soils; Tires; Water Pollution; Fuels; Industry; Liquid Fuels; Petroleum Products; Pollution; Rivers; Streams; Surface Waters

Record - 41

TITLE - New tire black sidewall **composition**

AUTHOR - Flowers, D.D.; Fusco, J.V.; Gursky, L.J.; Young, D.G.

JOURNAL - Rubber World (United States)

ABSTRACT - This article describes a new isobutylene-based polymer with improved functionality, completely saturated to provide ozone, oxidation and flex fatigue resistance. This new polymer, in combination with appropriate blends of general purpose rubbers, gives a sidewall **composition** to meet current and future needs while retaining all other basic performance requirements for the tire sidewall.

VO- 204:5

PY- Aug 1991

PG- 26-33

SC- 540120* -- *Environment, Atmospheric -- Chemicals Monitoring & Transport -- (1990-)*

KEY WORDS - *Ozone -- Air Pollution Abatement; *Tires -- Material Substitution; 2-Methylpropene; Chemical Properties; Composite Materials; Design; Fatigue; Flexural Strength; Mechanical Properties; Oxidation; Polymers; Reinforced Materials; Alkenes; Chemical Reactions; Hydrocarbons; Materials; Mechanical Properties; Organic Compounds; Pollution Abatement

Attachment D

Record - 42

TITLE - Technical and environmental assessment of the scrap tire vacuum pyrolysis process

AUTHOR - Roy, C.; Caumia, B. de; Lebreque, B.; Blanchette, D.; Pakdel, H.; Roy, V.

ABSTRACT - Tire recycling has become a necessity because of the huge piles of tires which represent a threat to the environment. There is about one worn tire produced per year and per person in the developed countries. The used tires represent a source of energy and valuable chemical products. By thermal decomposition of rubber under reduced pressure, it is possible to recover the useful compounds. A step by step approach has been used, from bench-scale batch systems, to process development and finally pilot plant, to experiment and develop vacuum pyrolysis of used tires. Yields are: 55% oil, 25% carbon black, 9% steel, 5% fiber and 6% gas. The maximum recovery of oil was performed at 415°C below 2 kPa abs. The specific gravity of this oil was 0.95, its gross heating value was 43 MJ/kg and total sulfur content about 0.8%. It was rich in limonene, benzol and other petrochemical components. The carbon black favorably compared with the low standard grades and may find an application in low grade rubber goods following further research and development. From an environmental point of view, the quality of the gas emissions was found to be acceptable based on the province of Quebec regulations. The aqueous phase contains toxic substances which will be eliminated after blending and burning it with pyrolysis oils used to heat up the reactor. The heat of pyrolysis for the reactions is low, estimated around 700 kJ/kg. The process has been tested in a 200 kg/h pilot plant, which positively demonstrated the possibility of continuously feeding large chunks of rubber under a vacuum. The process feasibility is promising, with returns on the investment of 31% after three years of operation. 9 refs., 4 figs., 8 tabs.

CS- Carbovac Research, Inc., Sillery, PQ (Canada) Laval Univ., Quebec City, PQ (Canada). Dept. of Chemical Engineering; P 1991; PG- (50 p)

SP- Federal Panel on Energy Research and Development, Ottawa, ON (Canada); Department of Energy, Mines and Resources, Ottawa, ON (Canada)

AV- PC Canada Centre for Mineral and Energy Technology, Technical Information Division, 562 Booth St., Room 20-C, Ottawa ON, CAN K1A 0G1; MF CANMET/TID, Energy, Mines and Resources Canada, 555 Booth St., Ottawa, Ont., Canada K1A 0G1.

SC- 090900* -- Biomass Fuels -- Processing -- (1990-); 095000 -- Biomass Fuels -- Environmental Aspects -- (1990-); 320604 Energy Conservation, Consumption, & Utilization -- Municipalities & Community Systems -- Municipal Waste Management - (1980-)

KEY WORDS - *Pyrolysis -- Environmental Impacts; *Pyrolysis, Technology Assessment; *Tires, Pyrolysis; Carbon Black; Process Development Units; Pyrolytic Gases; Pyrolytic Oils; Recycling; Vacuum Furnaces; Carbon; Chemical Reactions; Decomposition; Elements; Fluids; Fuels; Functional Models; Furnaces; Gases; Nonmetals; Oils; Organic Compounds; Other Organic Compds; Pyrolysis Products; Synthetic Fuels; Thermochemical Processes

Record - 43

TITLE - Effects of ozone on tires and the control of these effects

TITLE - Ozone risk communication and management

AUTHOR - Kuczkowski, J.A. (Dept. 400A, Chemical and Specialty Polymers R and D, Goodyear Tire and Rubber Co Akron, OH (US))

AUTHOR - Calabrese, E.J.; Gilbert, C.E.; Beck, B.D.

ABSTRACT - Atmospheric ozone degrades polydiene rubbers by reacting directly with polymer main chain unsaturation. This causes chain scission and reduced surface strength which is grossly manifested by the appearance cracks on the surface of the vulcanized rubber product. Rubbers thus affected include natural rubber (NR), synthetic cis-polyisoprene (IR), styrene-butadiene rubber (SBR), polybutadiene rubber (BR), and acrylonitrile-butadiene rubber (NBR). Other rubbers such as ethylene-propylene-diene terpolymer (EPDM) or chlorobutyl rubber (XIIR) which have highly saturated backbones react very slowly with ozone and do not show this cracking. Ozone cracking characteristically occurs in a pattern which is perpendicular to some applied external or internal stress. The cracking a direct result of chain scission which produces several different oxygen-containing decomposition products.

PU- Chelsea, MI (USA); PU- Lewis Publishers; PY- 1990; PG- 93-104; PG- (205 p)

AV- Lewis Publishers, 121 South Main St., P.O. Drawer 519, Chelsea, MI 48118 (USA)

SC- 360604* -- Materials -- Corrosion, Erosion, & Degradation; 540120 -- Environment, Atmospheric -- Chemicals Monitoring & Transport -- (1990-)

KEY WORDS - *Air Pollution -- Environmental Effects; *Ethylene Propylene Diene Polymers -- Chemical Reactions;

Attachment D

Record - 49

TITLE - Scrap tire reuse through surface-modification technology

AUTHOR - Bauman, B.D.

ABSTRACT - Air Products and Chemicals, Inc. is developing a novel approach for reusing scrap tire rubber. The process involves the combination of scrap tire rubber particles with other materials to form higher value and higher performance composites. The process begins by grinding scrap tire to a fine particle size, and removing steel and fabric. The key to this approach is a proprietary surface-modification step which is critical for enhancing the compatibility with and bonding to other continuous phase matrix materials. Of all approaches for scrap tire rubber reuse, this approach offers the potential to recover (or save) the greatest amount of energy. Furthermore, this is the only approach which is clearly economically viable with current pricing and without a scrap tire tax. The process is environmentally innocuous, and capital requirements for large scale processing plants are projected to be modest. 7 figs.

CS- Air Products and Chemicals, Inc., Allentown, PA (USA)

CS- 0131000; CT- AWMA international specialty conference on research developments for improved municipal solid waste management

CL- Cincinnati, OH (USA); CY- 5-7 Feb 1991; PY- 1991; PG- (14 p)

DT- Report; Conference Literature

SC- 320305* -- Energy Conservation, Consumption, & Utilization -- Industrial & Agricultural Processes -- Industrial Waste Management; 320604 -- Energy Conservation, Consumption, & Utilization -- Municipalities & Community Systems -- Municipal Waste Management -- (1980-)

KEY WORDS - *Rubbers -- Recycling; Composite Materials; Energy Conservation; Particle Size; Tires; Elastomers; Materials; Organic Compounds; Organic Polymers; Polymers; Size

Record - 59

TITLE - Problem of scrapped tires and main activities of Japan Automobile Tire Maintenance Association

ABSTRACT - This paper discusses the environmental problems caused by improperly scrapped used tires in Japan and suggests solutions to these problems. Ways in which used tires can be applied to solve other problems are presented. (FSD)

CS- USDOE, Washington, DC (USA); 9512004

PY- 1988; PG- (37 p)

SC- 090900* -- Biomass Fuels -- Processing -- (1990-); 360603 -- Materials -- Properties; 540200 -- Environment, Terrestrial (1990-); 421000 -- Engineering -- Combustion Systems

KEY WORDS - *Land Pollution -- Legal Aspects; *Refuse-Fueled Boilers -- Economic Analysis; *Tires -- Waste Disposal; *Waste Management -- Cost; Energy Sources; Environmental Effects; Experimental Data; Historical Aspects; Industrial International Regulations; Japan; Uses; Asia; Boilers; Data; Economics; Information; Management; Numerical Data; Pollution; Regulations; Waste Management

Record - 64

TITLE - Waste tire utilization

AUTHOR - Hershey, R.L.; Waugh, M.D.; Hanny, E.J.

ABSTRACT - Waste tire accumulations have become an increasingly important problem in recent years. This is of interest to DOE because the scrapped tires represent a large energy resource, and many requests for information have been received. Therefore, this report has been prepared to help in implementing waste tire utilization technologies.

CS- Science Management Corp., Washington, DC (USA)

PY- 30 Apr 1987; PG- 39

SC- 090400* -- Solid Waste & Wood Fuels -- (-1989); 320301 -- Energy Conservation, Consumption, & Utilization -- Industrial & Agricultural Processes -- Energy Sources; 290300 -- Energy Planning & Policy -- Environment, Health, & Safety; 291000 -- Energy Planning & Policy -- Conservation

KEY WORDS - *Power Plants -- Energy Sources; *Tires -- Waste Disposal; Air Pollution; Ashes; Combustion; Economics; Environmental Effects; Health Hazards; Refuse Derived Fuels; Sanitary Landfills; State Government; Waste Product Utilization; Chemical Reactions; Fuels; Hazards; Management; Oxidation; Pollution; Residues; Thermoechemical Processes; Waste Disposal; Waste Management

Attachment D

Record - 78

TITLE - Thermal depolymerisation of waste tires by heavy oils conversion into fuels

TITLE - Energy conservation in industry. Proceedings. Vol. 3

AUTHOR - Audibert, F.; Beaufils, J.P.; Strub, A.S.; Ehringer, H. (eds.)

ABSTRACT - The process consists of treating whole tires with heavy hydrocarbons which transfer the heat required reach 380/sup 0/C and to dissolve the oligomers resulting from devulcanization and depolymerization reactions. T tire is converted into moderate amount of gas and gasoline and mainly into heavy oil loaded with finely dispersed carbon black. Beside used tires application rubber wastes can be treated such as composite metallic and rubber parts from the transport vehicle industry. This latter case is of great interest for recovering the metallic portion. The energy saving corresponds to about 60% wt of the whole tires and is then of 0.52 TOE per ton of tires feedstock. Results have been obtained on a large size pilot plant making the process directly applicable to the industrial scale.

CT- International seminar on energy conservation in industry

CL- Duesseldorf, F.R. Germany

CY- 13 Feb 1984

PU- VDI-Verl., Duesseldorf, Germany, F.R.

PY- 1984

PG- 38-46

RN- CONF-840204-Vol.3 EUR-9236-Vol.3

SC- 320302* -- Energy Conservation, Consumption, & Utilization -- Industrial & Agricultural Processes -- Materials; 400301 Organic Chemistry -- Chemical & Physicochemical Properties -- (-1987)

KEY WORDS - *Tires -- Depolymerization; *Tires -- Waste Product Utilization; Chemical Reactors; Economics; Energy Conservation; Fuel Gas; Fuel Oils; Gasoline; Hydrocarbons; Material Balance; Pilot Plants; Viscosity; Wastes; Chemical Reactions; Decomposition; Fluids; Fuels; Functional Models; Gas Fuels; Gases; Liquid Fuels; Oils; Organic Compounds; Other Organic Compounds; Petroleum Products

Record - 79

TITLE - Energy saving tire with silica-rich tread

AUTHOR - Ahmad, S.; Schaefer, R. J.

PA- The B. F. Goodrich Company

ABSTRACT - A pneumatic radial tire is provided with a tread having from 1 part by weight of hydrated amorphous fine-particle silica per 3 parts of carbon black tread reinforcing filler, to about 3 parts by weight of the silica to 1 part the carbon black. The amount of silica present is preferably in the range from about 18 parts to about 50 parts by weight per 100 parts of natural or synthetic rubber. When such a tread is compounded with a mercaptosilane in which the mercapto group is reversibly blocked, the tread provides reduced rolling resistance without loss of traction. Such reduction in rolling resistance without loss of traction is not observed when the silica is not coupled with the mercaptosilane coupling agent.

PN- US 4519430

PD- Filed date 29 Jul 1982

PY- 28 May 1985

NT- PAT-APPL-403222

SC- 320203* -- Energy Conservation, Consumption, & Utilization -- Transportation -- Land & Roadway

KEY WORDS - *Tires -- Energy Efficiency; *Tires -- Wear Resistance; Carbon Black; Chemical Composition; Design; Pneumatics; Quantity Ratio; Rolling Friction; Rubbers; Silanes; Silica; Carbon; Chalcogenides; Efficiency; Elastomers; Elements; Fluid Mechanics; Friction; Hydrides; Hydrogen Compounds; Mechanical Properties; Mechanics; Minerals; Nonmetals; Organic Compounds; Organic Polymers; Organic Silicon Compounds; Oxide Minerals; Oxides; Oxygen Compounds; Polymers; Silicon Compounds; Silicon Oxides

Attachment D

Record - 81

TITLE - Tires and tracks: how they compare in the forest

AUTHOR - Burger, J.A.; Kreh, R.E.; Minaei, S.; Perumpral, J.V.; Torbert, J.L.

JOURNAL - Agric. Eng. (United States)

ABSTRACT - The effects of machine type (rubber-tired skidder and crawler), soil moisture, the number of passes over the same area and the effect of these parameters on soil bulk density and porosity were studied in a controlled experiment in a 1.4 ha forested area. In spite of the greater contact pressure of the skidder, changes in soil density and porosity caused by the 2 machines were the same. Neither soil density nor porosity was affected at depths of 15 cm or more, but soil moisture level and the number of passes significantly affected the extent to which these soil properties were changed at the surface. Changes in soil density and porosity increased with soil moisture content. Changes in soil density and porosity increased proportionally as the square root of the number of passes over the same area.

CS- Virginia Polytechnic Inst. and State Univ., Blacksburg

VO- 65:2

PY- 1984

PG- 14-18

SC- 510100* - Environment, Terrestrial - Basic Studies - (-1989)

KEY WORDS - *Forests - Haulage Equipment; *Haulage Equipment - Environmental Effects; *Soils - Density; *Soil - Porosity; Biomass Plantations; Compacting; Comparative Evaluations; Moisture; Parametric Analysis; Soil Conservation; Tires; Vehicles; Equipment; Materials Handling Equipment; Physical Properties; Resource Conservation

Record - 87

TITLE - Ground rubber tire/thermoplastic composites: effect of different ground rubber tires

AUTHOR - Rajalingam, P.; Sharpe, J.; Baker, W.E.

ABSTRACT - Thermoplastic composites containing different Ground Rubber Tire (GRT) materials, Linear Low Density Polyethylene (LLDPE) and, in some cases, a coupling agent (iB'E', an ethylene glycidyl methacrylate copolymer) were prepared by melt blending. The impact energies of all the thermoplastic composites (normally containing 40 wt % GRT) were evaluated using an instrumented impact tester. The effects of the GRT particle size distribution and shape, the mode of grinding, and the oxygen surface concentration were analyzed. The wet-ambient-ground GRT based composites show higher surface oxidation and give better impact energy than cryo-ground and normal air-ground GRT based composites. Smaller GRT process ability of the composites. Of the different GRT surface modification techniques studied for improved composite interfacial adhesion and impact properties the composites from electron beam radiation treated GRT yield higher increases in impact energy in comparison to corona and plasma treated GR based composites. (Author abstract) 40 Refs.

CS- Queen's Univ, Kingston, Can

SO- Rubber Chemistry and Technology v 66 n 4 Sep-Oct 1993. p 664-677

PY- 1993

CC- 818.5 (Rubber Products); 411.1 (Asphalt); 818.6 (Rubber Applications)

CC- 818 (Rubber & Elastomers); 411 (Bituminous Materials)

CC- <General>81 (Chemical Process Industries); 41 (Construction Materials)

KEY WORDS - *Tires; Recycling; Waste Utilization; Asphalt; Bituminous Paving Materials; Reclamation

ID- Waste Rubber; Ground Rubber Tires; Powdered Rubber

Attachment D

Record - 89

TITLE - Batch pyrolysis of tyre waste - fuel properties of the derived pyrolytic oil and overall plant economics

AUTHOR - Williams, P.T.; Besler, S.; Taylor, D.T.

ABSTRACT - Estimates for the generation of scrap tyres in the European Community are of the order of 1.5 million tonnes per year, including approximately 0.4 million tonnes per year from the United Kingdom. The majority of the tyre waste is dumped in open or landfill sites but represents a large wasted energy potential. Incineration has been considered as an alternative to dumping in an effort to utilize the high calorific value of scrap tyres; however, this disposal route may not maximize the potential economic recovery of energy and chemical materials from the waste. Pyrolysis of tyres is currently receiving renewed attention, since the derived oils may be used directly as fuels or add to petroleum refinery feedstocks; they may also be an important source of refined chemicals. The derived gases are all useful as fuel and the solid char has the potential to be used either as smokeless fuel, carbon black or activated carbon. In this paper, halved and whole scrap tyres were pyrolyzed in a commercial two tonne per day batch pyrolysis unit furnace temperatures from 700 to 950 degree C. The proportion of derived products was dependent on pyrolysis conditions, with a maximum yield of 30 per cent oil. The fuel properties of the derived oils, including calorific value, flash point, carbon residue, viscosity, sulphur content, etc., were analyzed and compared to refined petroleum products. In addition the benzene, xylene, toluene, limonene and styrene concentration of the oils was determined to assess the potential of the oils as a source of chemical feedstocks. The oils were also analyzed in terms of their chemical composition via liquid chromatography and Fourier transform infra-red spectroscopy and molecular mass range. The pyrolytic oils derived from tyres showed properties that were dependent on pyrolytic conditions and showed fuel properties comparable to those of petroleum products. (Author abstract) 24 Refs.

CS- Univ of Leeds, Leeds, UK

SO- *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* v 207 n 1 1993. p 55-63
PY- 1993

CC- 818.5 (Rubber Products); 521.1 (Fuel Combustion); 802.2 (Chemical Reactions); 525.1 (Energy Resources)

CC- 818 (Rubber & Elastomers); 524 (Solid Fuels); 521 (Combustion & Fuels); 802 (Chemical Apparatus & Plants); 523 (Liquid Fuels); 525 (Energy Management)

CC- <General>81 (Chemical Process Industries); 52 (Fuel Technology); 80 (Chemical Engineering)

KEY WORDS - *Tires; Refuse Derived Fuels; Combustion; Pyrolysis; Fuel Oils; Energy Resources; Liquid Chromatography; Infrared Spectroscopy; Mass Spectrometry; Composition

ID- Scrap Tyres; Batch Pyrolysis; Economic Recovery; Derived Pyrolytic Oil; Fuel Properties

Record - 104

TITLE - Blends of butyl and EPDM in inner tube applications.

AUTHOR - Jablonowski, Thomas L.; Faiman, David T.

ABSTRACT - Butyl rubber, IIR (isobutylene-isoprene rubber) is most noted for its excellent resistance to air permeability and, hence, is widely used in applications such as inner tubes and tire inner liners. Butyl rubber does, however, have some disadvantages that are generally tolerated in the manufacture and use of inner tubes, such as marginal green strength, fair ozone resistance, and fair heat and reversion resistance. These disadvantages can generally be overcome by the partial replacement of the IIR with EPDM (ethylene-propylene-diene rubber). EPDM has a fully saturated backbone whereas IIR has some unsaturation due to the isoprene units in its structure. The fully saturated backbone of EPDM gives it excellent resistance to the effects of oxygen and ozone. 3 Refs.

CS- Uniroyal Chemical Co Inc, Naugatuck, CT, USA

SO- *Journal of Elastomers and Plastics* v 23 n 2 Apr 1991 p 119-134
PY- 1991

CC- 818 (Rubber & Elastomers); 816 (Plastics, Plant Equipment & Processes); 421 (Materials Properties)

CC- <General>81 (Chemical Process Industries); 42 (Materials Properties & Testing)

KEY WORDS - *Rubber--*Blending; Rubber Products--Mechanical Properties; Tires-- Materials

ID - Butyl Rubber; Ethylene Propylene Diene Rubber; Blend Composition; Inner Tubes

Attachment D

Record - 105

TITLE - AES and factor analysis study of cord-oxidized brass layers and rubber-to-brass interface chemical composition.

AUTHOR - Kurbatov, G. G.; Beshenkov, V. G.; Zaporozchenko, V. I.

ABSTRACT - Auger electron spectroscopy (AES) and factor analysis (FA) were applied to study the chemical structure of oxidized brass layers and rubber-to-brass interface of tyre cords. The optimum requirements of sample preparation, instrument performance, data acquisition and analysis were determined to ensure accurate quantitative data. The elemental and chemical depth profiles of oxidized brass layers plated on steel cord and rubber-to-brass interface for standard vulcanization technology and after ageing were obtained. (Author abstract) 16 Refs.

CS- All-Union Research Cent for Surface and Vacuum Investigations, Moscow, USSR

SO- *Surface and Interface Analysis* v 17 n 11 Oct 1991 p 779-785

PY- 1991

CC- 544 (*Copper & Alloys*); 546 (*Lead, Tin, Zinc, Antimony & Alloys*); 818 (*Rubber & Elastomers*); 931 (*Applied Physics*); 801 (*Chemical Analysis & Physical Chemistry*); 802 (*Chemical Apparatus & Plants*)

CC- <General>54 (*Metal Groups*); 81 (*Chemical Process Industries*); 93 (*Engineering Physics*); 80 (*Chemical Engineering*)

KEY WORDS - *Composite Materials--*Interfaces; Adhesion--Spectroscopic Analysis; Rubber--Adhesion; Brass--Adhesion; Spectroscopy, Auger Electron-- Applications; Tires--Cords

ID - Oxidized Brass Layers; Factor Analysis; Chemical Structure; Chemical Depth Profiles

Record - 106

TITLE - Combining cobalt and resorcinolic bonding agents in brass-rubber adhesion.

AUTHOR - Hamed, Gary R.; Huang, J.

ABSTRACT - Bonding of natural rubber compositions to brass-plated steel cord is critically important in steel-belted radial tires. Good adhesion generally requires high levels of sulfur and a high sulfur to accelerator ratio. In addition, it is often desirable to incorporate bonding agents such as cobalt naphthenate or HR additives (e.g., hexamethoxymethyl melamine, HMMM, and a resorcinol-formaldehyde resin) to promote bonding and enhance durability. In this investigation, the merits of combining cobaltic and HR agents together are studied. 10 Refs.

CS- Univ of Akron, Akron, OH, USA

SO- *Rubber Chemistry and Technology* v 64 n 2 May-Jun 1991 p 285-295

PY- 1991

CC- 818 (*Rubber & Elastomers*); 802 (*Chemical Apparatus & Plants*); 531 (*Metallurgy & Metallography*); 544 (*Copper & Alloys*); 421 (*Materials Properties*)

CC- <General>81 (*Chemical Process Industries*); 80 (*Chemical Engineering*); 53 (*Metallurgical Engineering*); 54 (*Metal Groups*); 42 (*Materials Properties & Testing*)

KEY WORDS - *Tires--*Cords; Rubber--Bonding; Composite Materials--Adhesion; Brass-- Adhesion; Adhesion--Testing; Joints, Adhesive--Mechanical Properties

ID- Cobalt Naphthalene; Hexamethoxymethyl Melamine; Resorcinol Formaldehyde ; Secant Modulus; Squalene Model; Tear Resistance

Attachment D

Record - 107

TITLE - Chemical reactions of resorcinol-formaldehyde latex and coupling agent.

AUTHOR - Xue, Gi; Koenig, Jack L.; Ishida, Hatsuo; Wheeler, Don D.

ABSTRACT - Fourier transform infrared spectroscopy (FT-IR) is used to study chemical reactions of an epoxy functional silane coupling agent with resorcinol-formaldehyde latex (RFL) topcoat in a polyester tire-cord application. Model compounds are used to quantitatively study the reaction rate constants. An aqueous subcoat containing gamma-glycidypropyltrimethoxysilane (gamma-GPS) promotes adhesion of rubber to PET fiber when used in conjunction with the optimum resorcinol-formaldehyde latex (RFL) topcoat. In this paper, studies of the reactions within the gamma-GPS bulk and the reaction between the silane layer and the RFL overlayer are described. The relative reaction rates of these reactions are obtained through the kinetic study. The experimental evidence indicated that various reactions took place between the gamma-GPS and RFL. The epoxy group may react with the resorcinolic alcohol, methylol, and the residual silanol. Some reactions are catalyzed by NaOH or pyridine derivatives. Among the reactants, resorcinolic alcohol is the most active component in the presence of alkaline materials. It also has the highest concentration in an ordinary application. Thus, the resorcinolic alcohol opening the epoxy ring can be considered as a major reaction between the epoxy coupling agent and RFL. The 2-alkylpyridine component of the latex acts as a catalyst for the reaction. The residual silanol may consume the epoxy group upon heating during the processing. Since the reaction rate constant is low as compared to the silanol self-condensation and the interfacial reaction, and, furthermore, the concentration of the residual silanol is low, it will not influence the bonding at the silane/matrix interface. 12 Refs.

CS- Case Western Reserve Univ, Cleveland, OH, USA

SO- Rubber Chemistry and Technology v 64 n 2 May-Jun 1991 p 172-180

PY- 1991

CC- 818 (Rubber & Elastomers); 817 (Plastics, Products & Applications); 802 (Chemical Apparatus & Plants)

CC- <General>81 (Chemical Process Industries); 80 (Chemical Engineering)

KEY WORDS - *Latexes--*Chemical Reactions; Tires--Cords; Chemical Reactions-- Reaction Kinetics; Polyethylene Terephthalates--Fibers; Synthetic Fibers--Adhesion; Silanes

ID- Coupling Agent; Resorcinol Formaldehyde Latex Topcoat; Glycidypropyltrimethoxysilane

Record - 110

TITLE - Influence of compound heat conductivity on the temperature distribution in rotor type curemeters.

AUTHOR - Ernst, G. K.

ABSTRACT - The effective temperature in rotor type curemeters is - according to DIN 53529 - controlled using an unfilled EPDM compound with dicumylperoxide as cross-linking agent. The rate of DCP decomposition has a well-known temperature dependence. This rate is also in all practical cases the same as the rate of cross-linking. Therefore the measured rate of cross-linking indicates the effective temperature in the reaction cavity. The rotor in common curemeters is clamped. Because it can not be heated directly, this rotor is a heat sink in the cavity. The effect is a temperature gradient in the cavity depending on the heat conductivity of the tested compound. This temperature gradient in rotor type curemeters is compared to rotorless curemeters. It is shown that using the unfilled EPDM/DCP compound for temperature calibration leads to a too high effective temperature for filled compounds. (Author abstract) 3 Refs.

CS- Continental AG, Hannover, Ger

SO- Tire Science & Technology v 19 n 2 Apr-Jun 1991 p 68-78

PY- 1991

CC- 818 (Rubber & Elastomers); 944 (Moisture, Pressure & Temperature, & Radiation Measuring Instruments); 641 (Heat & Thermodynamics); 802 (Chemical Apparatus & Plants)

CC- <General>81 (Chemical Process Industries); 94 (Instruments & Measurement); 64 (Heat & Thermodynamics); 80 (Chemical Engineering)

KEY WORDS - *Rubber Products--*Curing; Thermal Conductivity--Measurements; Tires-- Manufacture; Temperature Distribution; Rubber--Crosslinking; Chemical Reactions--Reaction Kinetics

ID - Curemeters; Epdm Compounds; Dicumylperoxide (DCP); Temperature Calibration; Heat Conductivity; Rotor Type Curemeters

Attachment D

Record - 120

TITLE - Optimization of mechanical/physical properties for rubber/epoxy composite coating on asphalt concrete.

AUTHOR - Lhymn, C.

ABSTRACT - The rubber/epoxy composite is an attractive candidate for road-repair patching or for applications requiring ice-rejection during winter. The beneficial aspect of this approach is the use of ground/shredded rubber from discarded tyres so that the environmental waste can be utilized effectively. The theme of the present investigation was based on the perception that the delamination problem is the direct result of thermal and mechanical mismatch between the existing asphalt concrete and the newly coated rubber/epoxy layer. In this letter we address the delamination problem from the mechanical, environmental; and microstructural viewpoints. 7 Refs.

CS- Yoon Technology, Erie, PA, USA; SO- *Journal of Materials Science Letters* v 8 n 9 Sep 1989 p 1019-1022; PY- 1989

CC- 817 (Plastics, Products & Applications); 818 (Rubber & Elastomers); 406 (Highway Engineering); 412 (Concrete); 81 (Coatings & Finishes); 421 (Materials Properties)

CC- <General>81 (Chemical Process Industries); 40 (Civil Engineering); 41 (Construction Materials); 42 (Materials Properties & Testing)

KEY WORDS - *Epoxy Resins--*Fillers; Tires--Waste Utilization; Concrete--Coatings; Roads And Streets--Repair; Coatings--Mechanical Properties; Composite Materials--Optimization

ID - Rubber/Epoxy Composite; Asphalt Concrete; Delamination

Record - 122

TITLE - Dry erosion of epoxy/rubber composites.

AUTHOR - Lhymn, C.; Lhymn, Y.; Richardson, D. E.

ABSTRACT - The dry erosion behavior of epoxy/waste rubber composites has been investigated as a function of rubber content, air pressure (particle velocity), and impact angle. Morphological aspects have also been examined. The experimental data have been explained by means of an analytic equation derived from the crack propagation physics (Author abstract) 14 Refs.

CS- YOON Technology, Erie, PA, USA; SO- *Advances in Polymer Technology* v 9 n 2 Summer 1989 p 139-145; PY- 1989

CC- 817 (Plastics, Products & Applications); 815 (Plastics & Polymeric Materials); 421 (Materials Properties); 921 (Applied Mathematics); 818 (Rubber & Elastomers); 422 (Materials Testing)

CC- <General>81 (Chemical Process Industries); 42 (Materials Properties & Testing); 92 (Engineering Mathematics)

KEY WORDS - *Plastics, Reinforced--*Erosion; Epoxy Resins--Fillers; Materials Testing--Crack Propagation; Erosion--Mathematical Models; Tires--Waste Utilization

ID - Dry Erosion; Epoxy Waste Rubber Composites

Record - 124

TITLE - Effect of ozone concentrations on the tensile strength of different tyre's vulcanizates containing different concentrations of IPPD and DPPD antiozonants.

AUTHOR - Al-Jarrah, Mustafa M. F.; Apikian, Rita L.; Jajawi, Nabil A.; Hatim, Ikbal A.

ABSTRACT - The damaging effect of ozone on natural and synthetic rubber vulcanizates and the effects of antiozonants have been studied using ozone box and tensile tester. Variable concentrations of N - isopropyl - N'-phenyl - p-phenylene diamine (IPPD) and N - 1,3 - dimethylbutyl - N' -phenyl-p-phenylene diamine (DPPD) were used in passenger tyre and light truck tyre recipes. The specimens were exposed to variable concentrations of ozone in the ozone box under static stretch to 20 % elongation and dynamic conditions. Aging was evaluated by tensile strength and found to be dependent on ozone concentration, antiozonants concentration and the type of rubber used. Both antiozonants were highly efficient at the static conditions and no clear preference was observed. The mechanism of rubber ozonation is discussed. (Author abstract) 18 Refs.

CS- Council of Scientific Research, Baghdad, Iraq; SO- *Journal of Petrol. Research* v 7 n 2 Dec 1988 p 73-86; PY- 1988

CC- 818 (Rubber & Elastomers); 802 (Chemical Apparatus & Plants); 804 (Chemical Products); 421 (Materials Properties); 422 (Materials Testing); 601 (Mechanical Design)

CC- <General>81 (Chemical Process Industries); 80 (Chemical Engineering); 42 (Materials Properties & Testing); 60 (Mechanical Engineering)

KEY WORDS - *Rubber Products--*Ozone Resistance; Rubber--Ozonization; Rubber, Synthetic--Ozonization; Chemical Reactions--Reaction Kinetics; Rubber Testing--Tensile Tests; Tires--Testing

Attachment D

Record - 143

TITLE - Chemistry And Technology Of Rubber.

AUTHOR - Vidal, A. (Ed.); Donnet, J. B. (Ed.)

ABSTRACT - This conference proceedings contains 9 papers discussing the chemistry, as well as mechanical and physical properties of elastomers, rubberlike materials, and composites. Specific subjects covered include principles of elastomer synthesis, new telechelic elastomers, mechanical losses in carbon-black-filled rubber, molecular failure processes in elastomers, and an historical review of the radial ply tire.

CS- CNRS, Cent de Recherches sur la Physico-Chimie des Surfaces Solides, Paris, Fr

CT- Chemistry and Technology of Rubber.

CL- Paris, Fr

CI- Lectures from the 1982 International Rubber Conference.

CD- 1982 Jun 2-4

SP- Assoc of French Engineers of Rubber & Polymer Industry, Fr

SO- Applied Polymer Symposia 39. Publ by John Wiley & Sons, New York, NY, USA 151p

PY- 1984

CC- 818 (Rubber & Elastomers); 931 (Applied Physics); 802 (Chemical Apparatus & Plants); 601 (Mechanical Design); 42 (Materials Properties); 817 (Plastics, Products & Applications)

CC- <General>81 (Chemical Process Industries); 93 (Engineering Physics); 80 (Chemical Engineering); 60 (Mechanical Engineering); 42 (Materials Properties & Testing)

KEY WORDS - *Rubber; Elastomers--Synthesis; Tires--Testing; Rubber Testing-- Elasticity; Rubber, Synthetic-- Mechanical Properties; Plastics, Reinforced--Fillers

ID - Telechelic Elastomers; Carbon-Black-Filled Rubber; Molecular Aspects Of Composites; Radial Ply Tires; Failure Processes In Elastomers; Eirev

Record - 145

TITLE - Subcritical And Supercritical Extraction Of Oil From Used Automotive Tire Samples.

AUTHOR - Funazukuri, Toshitaka; Ogasawara, Sadao; Wakao, Noriaki; Smith, J. M.

ABSTRACT - Samples from a used automotive tire were subjected to sub- and supercritical extraction with n-pentane, toluene and nitrogen. Solvent effectiveness for extraction was greatest for toluene and least for nitrogen. When the extraction with toluene was completed at temperature 653 K and pressure 5.2 MPa, for instance, 57% (by weight) of the sample was converted to liquid oils and 40% remained as solid residue. Rate constants for extraction with n-pentane, assuming that the process is first-order, increase with both temperature and pressure. Scanning electron microscope pictures show that many cavities are produced inside the solid during extraction with toluene and n-pentane. From this evidence a qualitative explanation of the process is suggested. (Author abstract) 7 refs.

CS- Yokohama Natl Univ, Yokohama, Jpn

SO- Journal of Chemical Engineering of Japan v 18 n 5 Oct 1985 p 455-460

PY- 1985

CC- 601 (Mechanical Design); 818 (Rubber & Elastomers); 913 (Production Planning & Control); 804 (Chemical Products); 802 (Chemical Apparatus & Plants); 741 (Optics & Optical Devices)

CC- <General>60 (Mechanical Engineering); 81 (Chemical Process Industries); 91 (Engineering Management); 80 (Chemical Engineering); 74 (Optical Technology)

KEY WORDS - *Tires--*Waste Utilization; Mineral Oil--Solvent Extraction; Extraction --Supercritical Fluid; Chemical Reactions--Reaction Kinetics; Microscopic Examination

ID - Used Automotive Tire; Supercritical Extraction; Subcritical Extraction; Rate Constants

Attachment D

Record - 149

TITLE - Resource Recovery.

AUTHOR - Jackson, D. V.; Kercher, S. A.

ABSTRACT - The arguments in favour of reclaiming and recycling waste materials include conservation of materials and energy and reduction in the environmental impact of disposal. Despite these obvious attractions many of the developments in resource recovery over the past decade have not met with commercial success, often because of over optimism and inadequate attention to detail at the planning stage. Developments in resource recovery are reviewed with particular reference to those schemes which have demonstrated technical and economic success. The lessons learned and the implications for future resource recovery are discussed. (Author abstract) 21 refs.

CS- Warren Spring Lab, Stevenage, Engl

CT- Agricultural, Industrial and Municipal Waste Management in Today's Environment.

CL- Coventry, Engl

CD- 1985 Apr 17-18

SP- Inst of Mechanical Engineers, Engineering Sciences Div, London, Engl; Inst of Chemical Engineers, Rugby, Engl; ICE, London, Engl; Inst of Energy, London, Engl; Inst of Waste Management, UK; County Surveyors Soc, UK

SO- I Mech E Conference Publications (Institution of Mechanical Engineers) 1985-4. Publ for Inst of Mechanical Engineers, London by Mechanical Engineering Publ Ltd, Bury St. Edmunds, Engl p 113-123

PY- 1985

CC- 452 (Sewage & Industrial Wastes Treatment); 901 (Engineering Profession); 818 (Rubber & Elastomers); 802 (Chemical Apparatus & Plants)

CC- <General>45 (Pollution & Sanitary Engineering); 90 (General Engineering); 81 (Chemical Process Industries); 80 (Chemical Engineering)

KEY WORDS - *Waste Disposal--*Environmental Impact; Materials--Recycling; Tires-- Waste Disposal; Chemical Reactions--Pyrolysis

ID - Recycling Waste Materials; Estimated Unrecovered Scrap; Metal Scrap; Urban Waste; Typical UK Refuse Composition; Waste As Fuel

Record - 152

TITLE - Processing And Investigation Of Production Of Steel Brass-Coated Cords For Radial Tires. Part II: Structure And Composition Of Coating.

AUTHOR - Ambrosio, L.; de Filippo, D.; Rossi, A.; Spezziga, M. A.

ABSTRACT - The authors studied adhesion of brass to rubber in connection with development of high-strength radial tires with brass-coated steel cords. Adhesive depends on surface composition, structure, and continuity of the coating. The authors give results of a structural analysis of the deposits, ESCA and Auger spectrometry analyses, and electrochemical measurements of corrosion in relation to adhesion. (Edited author abstract) 8 refs.

CS- Gencord SpA, Assemini, Italy

SO- Protection of Metals (English translation of Zashchita Metallov) v 22 n 1 Jan-Feb 1986 p 57-62

PY- 1986

CC- 818 (Rubber & Elastomers); 545 (Iron & Steel); 539 (Metals Corrosion & Protection); 544 (Copper & Alloys); 546 (Lead, Tin, Zinc, Antimony & Alloys); 801 (Chemical Analysis & Physical Chemistry)

CC- <General>81 (Chemical Process Industries); 54 (Metal Groups); 53 (Metallurgical Engineering); 80 (Chemical Engineering)

KEY WORDS - *Tires--*Cords; Steel--Protective Coatings; Brass Plating--Solutions; Copper Zinc Alloys--Adhesion; Surfaces--Spectroscopic Analysis; Corrosion

ID- Radial Tires

Attachment D

Record - 436

TITLE - Adsorption of hydrocarbon vapors by vulcanized rubber

AUTHOR - <INVENTOR> Snyder, Robert Harvey

ID- adsorbent hydrocarbon vapor rubber vulcanizate; benzene adsorbent tire scrap

PA- Uniroyal Goodrich Tire Co.

SC- CA239015 *Synthetic Elastomers and Natural Rubber*

KEY WORDS - Charcoal, activated (desorbents, for adsorbed hydrocarbon vapors in vulcanized rubber); Adsorbents (rubber vulcanizates, comminuted, for hydrocarbon vapors); Tires (scrap, comminuted, adsorbents, for hydrocarbon vapors); Hydrocarbons, uses and miscellaneous (vapors, adsorbents for, comminuted vulcanized rubber as)

Record - 441

TITLE - Structure and properties of a new synthetic tire rubber: high-trans SBR

AUTHOR - Fabris, H. J.; Hargis, I. G.; Livigni, R. A.; Aggarwal, S. L.

JOURNAL - Rubber Chem. Technol., V60, N4, P721-41

ID- SBR tire property; green strength SBR tire; tack strength SBR tire

CS- <LOCATION> Res. Div.; GenCorp; Akron; OH; 44305; USA

PY- 1987

SC- CA239013 *Synthetic Elastomers and Natural Rubber; CA235XXX Chemistry of Synthetic High Polymers*

KEY WORDS - Polymerization catalysts, anionic, living (for styrene with butadiene, for prepn. of SBR with high trans content); Rubber, butadiene-styrene, preparation (high-trans-content, prepn. and structure and properties of); Chain chemical (microstructure of, of SBR with high trans content, polymn. catalyst effect on); Crystallization kinetics; Crystallization, strain-induced; Glass temperature and transition (of SBR with high trans content); Crystallinity (of S with high trans content, effect of temp. and extension ratio on); Extrusion of plastics and rubbers (of SBR with high trans content, rheol. in relation to); Reactivity ratio in polymerization, anionic (of styrene with butadiene); Carbon black, uses and miscellaneous (SBR and its natural rubber blends filled with, properties of); Rubber, natural, properties (SBR blends, carbon black-filled, crack growth in vulcanized); Tires (SBR with high trans content for, prepn. and properties of)

Record - 464

TITLE - Analysis of unvulcanized and vulcanized rubber by physical methods, with particular reference to IR spectroscopy and thin-layer chromatography

AUTHOR - Brueck, D.

JOURNAL - Kautsch. Gummi, Kunstst., V39, N12, P1165-74

ID- pyrolysis IR TLC rubber analysis; EPDM nitrile rubber pyrolysis IR; tire tread pyrolysis IR analysis

CS- <LOCATION> Dormagen; Fed. Rep. Ger.

PY- 1986

SC- CA239011 *Synthetic Elastomers and Natural Rubber*

KEY WORDS - Spectrochemical analysis, IR (combined with pyrolysis and TLC, for rubber compds.); Rubber, nitrile, analysis (EPDM blends, anal. of Perbunan N 287, by pyrolysis-IR spectroscopy and TLC); Chromatography, thin-layer (IR spectrometry combined with, for rubber compd. anal.); Rubber, synthetic, EPDM (nitrile rubber blends, anal. of, by IR spectroscopy and TLC); Tires, treads (SBR-butadiene rubber blends, anal. of, by pyrolysis-IR spectroscopy TLC)

Record - 485

TITLE - Traveling fluidized bed distillation of scrap tires and rubber vulcanizate

AUTHOR - <INVENTOR> Habib, Ikram W.

ID- rubber tire disposal pyrolysis distn

PN- United States; US 4588477 A

SC- CA260004 *Waste Treatment and Disposal*

KEY WORDS - Fuel oil (recovery of, from distn. pyrolysis of tire and rubber scrap); Rubber, synthetic; Rubber, natural reactions (vulcanizates, wastes, distn. pyrolysis of, for disposal); Tires (waste, distn. pyrolysis of, for disposal)

Attachment D

Record - 531

TITLE - Loss of antioxidants from truck tires. Part 2.2: Loss due to **leaching** by water and migration

AUTHOR - John, A. G.; George, Z.; Kurien, J.; Pandit, R. R.; Sridharan, P.; Mukhopadhyay, R.

JOURNAL - Kautsch. Gummi, Kunstst., V37, N2, P115-23

ID- antioxidant migration truck tire; **leaching** amine antioxidant bias tire

CS- <LOCATION> MRF Ltd.; Madras; 600019; India

PY- 1984

SC- CA139013 *Synthetic Elastomers and Natural Rubber*

KEY WORDS - Antioxidants (amines, loss of, from bias-ply truck tires, by **leaching** with water and migration); Tires, sidewalls; Tires, treads (antioxidant loss from, by **leaching** with water and migration); **Diffusion** (of amine antioxidants, from bias-tires)

Attachment E

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Attachment E

- 16 Hirakawa, Hiroshi.; "Rubber-rubber bonded composite structures with improved adhesion and their use". Yokohama Rubber Co., Ltd.
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