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Mini Review

Rubber Wastes Management And Recycling

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Abstract

Rubber is widely used in automotive industry, mainly for tires, and in non-automotive industries producing a wide amount of waste to be properly managed and collected. Waste management schemes exist only for few rubber wastes streams, the majority of which being left to the private initiative of manufacturing or importing enterprises. Recycling approaches currently in use are reviewed for the different rubber waste streams.

Introduction

The high elasticity properties of rubbers depend on the presence of very flexible chain segments between tie-points in the chemical structure of them. Therefore, rubbers are mostly thermosetting materials which reach the final shape in an irreversible vulcanization process. This pones problems about recycling of end-of-life rubbers, because, as for all thermosets, it is not possible to directly reprocess their waste according to the circular economy model. World's global rubber consumption has reached 29.6 million tons in year 2020 [1] of which 12.9 million tons are natural rubber (NR) and 16.7 million tons are synthetic rubber (SR) [2]. NR is collected as a latex from several species of tree, Hevea Brasiliensis mostly growing in east Asia countries. Even though from a renewable resource, NR is not completely sustainable because land grabbing and exploitation of child labor can occur in latex production and collection. SR comprises a range of fossil-source elastomers: the most prevalent is styrene-butadiene rubbers (SBR). Other synthetic rubbers include polyisoprene, polybutadiene, chloroprene, nitrile rubber and ethylene propylene rubber (EPM and EPDM). Rubbers are employed in automotive and non-automotive application. Tires account for 65% of the total consumption of rubber [3]; 13% of the total consumption is for automotive non-tire application [4]. Footwear, civil engineering and other mixed application account for the remaining 22%.

Rubber waste management strategies

The high amount of rubber consumption results in a high amount of waste of end-of-life rubber items. A successful rubber waste management requires an adequate collection system. End of life tires (ELT) management lack of over-national regulation and various management schemes are applied such as State responsibility (Denmark, Slovakia and Croatia) or Producer responsibility (Many European countries, Turkey, Brazil, South Korea and Russia). Free market systems are applied in Argentina, Far East Asian countries, Mexico, Nigeria, UK, Germany, Switzerland, Austria, Serbia and the USA [5]. In Europe and in Japan automotive non-tire rubber wastes are subject to regulations relating to the management of end-of-life vehicles (ELV) which promote recycling and provide incentives for environmentally friendly vehicle design [6]. Other rubber waste escapes any regulation and their management depends on producers/importers volountary initiatives. Most of the rubber waste stream contains a mixture of different rubber types to which homogeneous recycling technologies can be hardly applied. In most cases the recycling of rubber waste requires a prior shredding/granulation phase and then both material and energy recovery can be performed.

The appropriate recycling technologies depend on the type of the rubber waste.

Tires: [7] Tires are complex items made with several components: NR and SR (45-47%), Carbon Black and Silica (21-22.5%) Metals (Steel Beads, Belts, 14-23.5%), Textiles (Carcass, 1-5.5%) Vulcanizing Agents (Sulphur, peroxides and metal oxides, 2.5-3%) Additives (antioxidants, antiozonants, extenders 6.5-8%) [3]. End-of-life tires (ELT) in landfills or stockpiled represent a loss of material and a possible source of environmental damage because they are highly flammable and favor the proliferation of the insect. As a result, several states have placed restrictions on landfilling tires. According to the Scrap Tire Management Council, [8] in average, one scrap tire per person per year is generated. Retreading is the option of choice to valorize worn-out but still usable tires and it concerned 30 million tires in USA in 2019 and 26 million in China in 2020 [9]. Retreading preserves 70-75% of the original rubber and can be performed up to four or five times. This results in a 20% material cost, compared to a new one. Retreaded tires are marketed at 60-70% of the original cost, representing a valid economic return [10].

There are many ways to recover ELT that can be grouped into the two main categories: material recovery [3] and energy recovery. As far as material recovery is concerned the following possibilities could be mentioned:

Crumb rubber production: [11] After extraction of steel wires, the tire is grinded into different sized pieces and the granules of crumb rubber are sized for specific applications: rubber chips (25 mm to 50 mm) and rubber powder (4.75 mm to 0.075 mm). Crumb rubber finds application as landscaping mulch, rubber mat, playground with the benefits of reduction of vibration and sound control, or as partial replacement of fine aggregate in concrete/masonry brick and in engineered cementitious composites, getting lighter items at the expense of reduction of the compressive and tensile strength [12] or as absorbent of pollutants in water after appropriate functionalization [13]. In 2019, the ground rubber market consumed over 25% of the scrap tires in USA.

Pyrolysis: [14] In the pyrolysis process the decomposition of ELTs at around 300-900 °C in an inert environment produces tire derived char, oil, and gas. The design of the reactor and the thermal profile affect the composition of the pyrolysis products. The gas fraction can be used to supply the energy needed for the pyrolysis process or other thermal applications. The oil can be added to petroleum refinery feedstock or used as a source of refined chemicals (i.e limonene from NR) used in turn as feedstock for plastic, pharmaceutical, surfactants. Eventually the charred residue can supply coke.

Devulcanization: [15] Devulcanization returns rubber from its thermoset, elastic state back into a plastic, moldable state by selectively severing the sulfur bonds in the molecular structure. The process enables rubber manufacturers to use a much larger percentage of recycled material without compromising quality or performance. Rubber devulcanization can be performed with physical technologies (Thermal, mechanical and thermo-mechanical devulcanization; microwave electromagnetic irradiation; ultrasonic irradiation) and chemical technologies by using appropriate reactants to break the tie points. While devulcanization is in line with the circular economy principles it suffers from the fact that most of the technologies currently available are batch processes. As far as energy recovery is concerned Tire derived fuel (TDI) can be cited [16]. Scrap tires are typically used as a supplement to traditional fuels such as coal or wood. TDI are burned in the cement industry in kilns used to make clinker, or in boilers at pulp and paper mills or in boilers at electric utilities. In 2019, the ground rubber market consumed over 43 percent of scrap tires the USA.

Automotive non-tire rubber products

Automotive non-tire rubber products (hose, gasket, seals, about 3% of the vehicle weight) follow the vehicle recycling scheme: after removing valuable components (tires, engine, windscreen, etc), the car is crushed and shredded. Shredded metals are separated from the automotive shredding residue (ASR) whose composition depends on the separation efficiency of the plant and of the following refining operations. ASR are collected as light fluff (plastics) and heavy fluff (different rubber, in pieces of few mm to few tens of cm size). One of the emerging options of valorization of car fluff is the pyrolysis, to produce oils and gases suitable for further refining as chemical building blocks or gasoline [17].

Non-automotive rubber products

Footwear products are constituted with over 40 different types of materials, making their recycling extremely challenging. Some technical possibilities exist for the recovery of rubber, leather, foams and textiles from footwear waste. However, there are still open questions about the commercial viability of these processes. As an example the SOEX footwear recycling is based on a mechanical recycling process with a delaminator and air-separators [18]. RE-SHOES project provides an alternative solution: new materials to be used directly in the production of new recycled shoes are recovered through hydrolysis of the leather and a specific attention on rubber waste generated during the cutting of the shoes [19]. Civil engineering membranes. High amount of EPDM membranes installed on roofs are approaching now the time for replacement. The material was removed from roofs and ground into a powder which can be marketed for walkway pads for new or existing roofs [20].

Conclusion

Rubber is widely used in automotive industry, mainly for tires, and in non-automotive industries. A wide amount rubber waste occurs at the end-of-life of rubber items occurs, to be properly managed and collected. Official waste management schemes exist only for few rubber wastes streams, the majority of which being left to the private initiative of manufacturing or importing enterprises. To date, several recycling technologies exist, however most of them are intended to extend the life of rubber materials including the waste in various matrices or to use rubber waste as a substitute of fuel. However new rubber material is needed for substituting wasted goods. Devulcanization in principle is strictly in line with the circular economy principles, making the life of the rubber virtually endless; however, this is often a batch process and therefore not very suitable for large scale productivity. To increase the sustainability the amount of waste must be reduced and researchers/producers are strongly committed in the "design for recycling" approach. As an example, manufacturing techniques have doubled the useful life of tires since 1955. Environmentally friendly approaches tend to decrease the use of fossil materials, such as utilization of bio-based EPDM to reduce the processing carbon footprint and the industries reliance on oil or to phase out solvents and blowing agent to sustainable alternatives.

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