Low environmental impact alternatives for the recycling of the expanded polystyrene worldwide

Alternativas de bajo impacto ambiental para el reciclaje del poliestireno expandido a nivel mundial

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Resumen

El artículo presenta una revisión bibliográfica sobre alternativas de bajo impacto ambiental para el reciclaje de poliestireno expandido a nivel mundial, basado en el uso de recursos naturales y los impactos ambientales asociados a estos. El impacto ambiental de cada técnica se determinó por medio de la construcción de una matriz en Excel® donde se registró la frecuencia de empleo de: (I) técnica primaria, secundaria o terciaria, (II) los recursos naturales usados y (III) los compartimientos ambientales afectados. Se consultaron fuentes primarias que abordan el tema del tratamiento del poliestireno expandido a nivel mundial. Se encontró que las mejores técnicas para el reciclaje del poliestireno son la primaria y terciaria específicamente trituración manual y uso de solventes verdes como d-limoneno y p-cimeno, para dejar en últimas posiciones a los tratamientos secundario y terciario, métodos de aglutinamiento y generación de energía, respectivamente.

Palabras clave: d-limoneno; poliestireno expandido; residuos sólidos; reutilización; plásticos; tratamiento de residuos.

Abstract

The article presents a bibliographic review on alternatives of low environmental impact for the recycling of expanded polystyrene worldwide, based on the use of natural resources and the environmental impacts associated with them. The environmental impact of each technique was determined through the construction of an Excel matrix where the frequency of use of (I) primary, secondary or tertiary techniques, (II) natural resources used, and (III) environmental compartments affected. Primary sources that address the issue of expanded polystyrene treatment worldwide were consulted. It was found that the best techniques for the recycling of polystyrene are primary and tertiary specifically manual crushing and use of green solvents such as d-limonene and p-cymene, to leave the secondary and tertiary treatments in last positions, agglutination and generation methods of energy respectively.

Keywords: d-limonene; expanded polystyrene; solid waste; reuse plastics; waste treatment, treatment technique.

Introducción

Expanded polystyrene (EPS) is a foamed polymeric material used in various applications and sectors, including in the construction sector, where its function is to isolate temperature and sound. Its greatest use is the production of food packaging and packaging of various devices (National Association of Expanded Polystyrene [ANAPE], s.f.). The polymer is low-density, light, comes from petroleum, and is of large volume, therefore, it is a high-value waste, easy to recycle, and abundant (Arriola; Velásquez, 2013). Paradoxically, it is not separated at the source for recycling, the recovery percentage of expanded polystyrene is barely 12 %, regarding other recyclable waste, such as paper and glass, which come from different industrial and domestic sectors (Arandes; Bilbao; López, 2004).

Polymeric waste, including EPS, contributes 2,000 million tons of carbon dioxide, equivalent to the year in greenhouse gas emissions into the atmosphere (Rodríguez; Avellaneda; Zerda, 2014). Similarly, EPS is a waste that is harmful to the environment since it does not degrade due to its inert nature. It also reaches aquatic compartments where animals ingest it, filling their digestive system with non-digestible plastic, which causes death. by starvation (Industry Alliance Packaging [IAP], 2009).

The environmental concern for polystyrene revolves around four fundamental elements: (I) slow degradation and the absence of a substitute; (II) the production of waste; (III) its source of generation is oil, a non-renewable raw material; and (IV) some of the chemical inputs used to produce them are harmful to the environment (Tellez, 2012). On the other hand, expanded EPS contains a type of toxic substances called dioxins, which cause reproduction, development, and alterations in the immune system in humans, which can also cause cancer (Thorton, 2002), in addition to affecting the human health, EPS generates different environmental impacts.

Given these problems, various alternatives for its management have been considered worldwide, including recycling. Currently, the following treatments have been used for EPS recycling: primary, secondary, tertiary, and quaternary (Parra, 2010). The primary treatment consists of subjecting the plastic to mechanical operations to obtain a product with similar characteristics, a clear example is crushing (Gaiker Research Alliance, 2007. The secondary treatment consists of subjecting the EPS to high melting temperatures and thereby obtaining a similar plastic that takes up less space (Cadena; Quiroz, 2000). Tertiary recycling, or chemical recycling, pursues its transformation with the use of solvents. Finally, quaternary recycling consists of incineration to recover energy (García; Gracia; Duque; de Lucas; Rodríguez, 2009).

Therefore, the objective of this article is to carry out a comparative analysis of the environmental impact of the techniques used worldwide for recycling expanded polystyrene, highlighting those with the least environmental impact.

Global experiences of treatments for recycling expanded polystyrene

The recycling of expanded polystyrene (EPS) consists of reducing the size of the grain and the gas it contains, which allows reducing its volume. The feasibility of EPS recycling increases more and more given the decrease in this waste and the low environmental impact generated in the recovery process (Gaiker Research Alliance, 2007).

Regarding Europe and the United States, the recycling of this waste has focused on two main alternatives: the use of energy, in which the waste is incinerated, and mechanical recycling, where it is crushed and compacted (Betancourt, 2015). However, environmental arguments regarding toxic emissions are building public resistance against the incineration process. For its part, mechanical recycling is often more expensive than virgin plastic. Therefore, other processing schemes must be explored to reduce the cost of the two recycling processes (Rojas, 2014).

In Turkey, an innovative treatment of EPS is the dissolution with suitable solvents, to achieve a volume reduction of more than one hundred times (without degradation of the polymer chains), because if the dissolution takes place in the source of Transportation, waste production is more efficient than conventional system recycling (Samper; Ferrandiz; López, 2008). In this way, EPS solubilized in different solvents plays an important role in the recycling of polystyrene and constitutes itself as a different alternative to incineration and mechanical recycling, since it is the cheapest and least polluting (Jaramillo; Zapata, 2008).

In Colombia, the company Natura together with the University of Antioquia is the pioneer in the management of polystyrene waste. The treatment is carried out mainly by pyrolytic methods, which has brought disadvantages such as the use of excess energy, atmospheric emissions, heat production, and by-product production, without a final destination in the market (García *et al.*, 2009).

The Verde Natura Foundation under the slogan "we recycle EPS for a better world", is the only Colombian non-profit foundation, which provides the environment with an alternative recycling of expanded polystyrene (EPS) and extruded polystyrene (XPS for its acronym in English) that helps minimize damage to the environment by reducing these wastes. To do this, they have developed recycling lines directly with the actors involved in the plastic processes from its production to its final disposal; There they receive and collect the waste to treat it and finally make a resin with characteristics similar to the original plastics, increasing the life cycle of these materials (Natura, 2019).

Methodology

Globally, the countries that research on the problem and management of expanded polystyrene were selected, 50 documents were consulted. The information on the recycling alternatives used by the authors of 26 articles and 4 theses and the countries in which this research was carried out was systematized (see Table 1). Similarly, in the same documents, the categories of analysis of the documents were chosen by the type of treatment (primary, secondary, tertiary and quaternary), the use of resources (water, energy, and human) and the environmental impact resulting from the use of resources (discharges, emissions, and soil contamination). Finally, for the study of the analysis categories: type of technique used, use of resources and generated environmental impact, the systematization of the information consulted was taken as a base, such as the bibliographic references mentioned below and the review of the 20 authors remaining gave the body to the document.

Table 1.
Information source systematized in the review

Author and year	Kind of document	Country	Type of treatment used
(García *et al.*, 2009)	Article	Germany	Primary and tertiary
(Saltos; Chango; Aldás; Quiroz, 2015)	Article	Brazil	Primary and tertiary
(López *et al.*, 2014)	Article		Primary
(Carrillo; Caamal; Couoh; Gamboa; Cruz, 2014)	Article		Primary
(Aminudin; Fadhil; Mohamad; Noor; Iwao, 2011)	Article	Colombia	Tertiary
(Samper; Ferrandiz; López, 2008)	Article		Tertiary
(Ehrig, 1992)	Article		Primary and tertiary
(Noguchi; Miyashita; Inagaki; Watanabe, 1998)	Article		Primary, secondary and tertiary
(Hattori *et al.*, 2008)	Article		Primary and tertiary
(Quintero, 2013a)	Article		Primary and tertiary
(Dickens, 1980)	Article	Ecuador	Tertiary

Author and year	Kind of document	Country	Type of treatment used
(Vaikathusseril-Sekharan; Thattekatt-Abraham;	Artícle	Spain	Tertiary
Thomas-Thachil, 2012)	Artícle		
(Shin, 2006)	Artícle		Tertiary
(Grote, 1999)	Artícle	United States	Tertiary
(Agoua; Allognon-Houessou; Adjovi; Togbedji, 2013)	Artícle		Primary and secondary
(Gutiérrez; Rodríguez; Gracia; de Lucas; García, 2013)	Artícle		Tertiary
(Rajaeifar; Abdi; Tabatabaei, 2017)	Artícle		Tertiary
(Chaukura; Gwenzi; Bunhu; Ruziwa; Pumure, 2016)	Artícle	India	Primary and tertiary
(Bicer; Kar, 2017)	Artícle		Primary and secondary
(Brandão; De Castro, 2015)	Artícle		Primary
(Ghambari; Reyes-Gallardo; Lucena; Saraji; Cárdenas, 2016)	Artícle		Primary and tertiary
(Shah; Jan; Adnan; Zada, 2015)	Artícle		Tertiary
(Agoua; Allognon-Houessou; Adjovi; Togbedji, 2013)	Artícle	Japan	Primary
(Hattori, 2015)	Artícle		Primary and tertiary
(Schmidt; Cioffi; Voorwald; Silveira, 2011)	Artícle		Tertiary
(Cjuno; Arroyo; Ale; Pacheco, 2005)	Artícle	Korea	Tertiary
(Quintero, 2013b)	Thesis	México	Primary and tertiary
(Torres, 2004)	Thesis	Perú	Primary and tertiary
(Arcila; Miranda, 2015)	Thesis		Tertiary
(Benítez; Vélez, 2013)	Thesis	Switzer-land	Tertiary

Source: self-made.

Results

EPS recycling research countries

According to what was consulted, the countries that write most frequently on the subject are Colombia, the United States, and India, as can be seen in Figure 1, given by their production models, which is problematic with expanded polystyrene waste and their growing concern for the environmental quality of their countries (Jaramillo; Zapata, 2008).

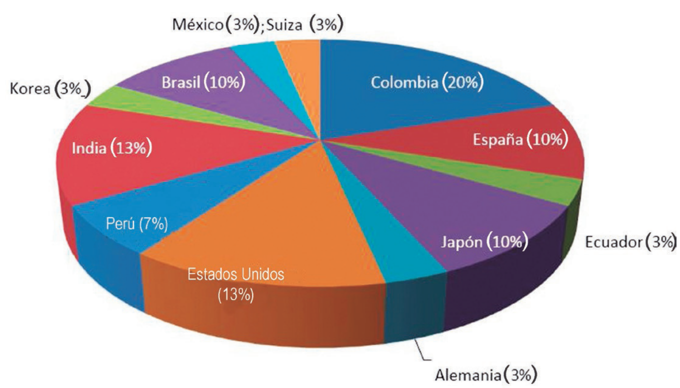

Figure 1. Percentage of participation of countries in research on EPS recycling.
Source: self-made.

EPS treatment alternatives

Treatment alternatives were identified and classified into primary, secondary, tertiary, and quaternary, all of which lead to the recycling of the material and, therefore, the prolongation of its useful life (García *et al*., 2009). Table 2 shows that the most used techniques are tertiary with d-limonene and primary with mechanical and manual crushing, this is due to the sustainability and ease of implementation of the techniques (Brandup; Bittner; Michaeli; Menges, nineteen ninety-six).

Table 2.
Treatment techniques in the review

Type of treatment	Technique	Review techniques (%)
Primary	Mechanical Manual	14,29 16,07
Secondary	Agglutination	7,14
Tertiary	Toluene	12,50
	Benzene	7,14
	Chloroform	7,14
	Tetrahydrofuran	5,36
Tertiary	D-limonene	23,21
Tertiary	P-Cimeno	1,79
Quaternary	Energy production	5,36

Regarding the primary treatment, the containers and packaging resulting from post-consumption can be reused by crushing, since it facilitates the elimination of foaming and its subsequent use in new products since this material does not lose its initial chemical characteristics (Hattori; Shikata; Maekawa, 2010). Among other uses, the EPS residues once crushed and discarded are used to be combined with edaphic material and in this way, improve their drainage and aeration. They can also be used for the aeration of compostable organic waste, constituting a valid option for obtaining the bio-fertilizer. Similarly, EPS residues after grinding to different grain sizes are mixed with construction materials, which gives the material properties of lightness and greater porosity (Asila; Miranda, 2015).

Secondary treatment refers to the process that consists of heating the material, agglutinating it, and forming a block of it. By joining the material in favor of heat, its volume is minimized, but the process consumes a lot of energy (Cempre Uruguay, 1998).

Tertiary or chemical recycling is based on the use of solvents to solubilize the material, according to its polarity characteristic, using a solvent with the same characteristic (Scheuermann, 1989). According to García *et al*., (2009), polystyrene is an apolar compound, with which, for the tertiary recycling process, an apolar solvent must be used to form solutions, giving good characteristics and reaching saturated solutions, guaranteeing the total dissolution of the material.

Quaternary recycling consists of the incineration of the material to generate energy, a process that is highly criticized socially for the environmental problems it can generate. This method is interesting for energy recovery of plastic materials, which have a high calorific value (polyethylene, 43 MJ/kg; polypropylene, 44 MJ/kg; polystyrene, 40 MJ/kg; chloride polyvinyl PVC, 20 MJ/kg, among others) (NOVA Chemicals Corporation., 2005). This combustion process must be subject to strong emission controls to neutralize solid waste and gaseous effluents that could negatively contribute to the environment and human health (such as hydrogen chloride from PVC combustion) (Arandes *et al*., 2004).

Environmental impact of treatment alternatives

Between 5% and 7% of the world's oil extraction is destined for the production of plastics. It is estimated that the production of 1 kg of plastic requires the use of 2 kg of oil. The plastic industrial sector is versatile and has high technological development, characteristics for which the sector grows in the economy in percentages that are estimated at 4% annually, creating products that are used in packaging, housing, clothing and all kinds of consumer goods (Betancourt; Solano, 2016). In 2011, world EPS production increased by 10 million tons to almost 280 million tons (Arandes *et al*., 2004).

The residues of this plastic have significant environmental implications and are part of a problem of great impact and scale, the environmental concern is growing and revolves around its difficulty to degrade, its volume and the problem that recycling has represented (Tellez, 2012).

For the recovery of the residue, several techniques have been implemented that use resources such as water, energy, and humans, as evidenced in Figure 2. For their estimation, the information integrated into an Excel matrix was systematized, where a sample of the mentioned analysis categories was collected by each technique used, in such a way that each document that made use of some of the treatment techniques, use of resources and associated environmental impact, had a contribution from one unit in them.

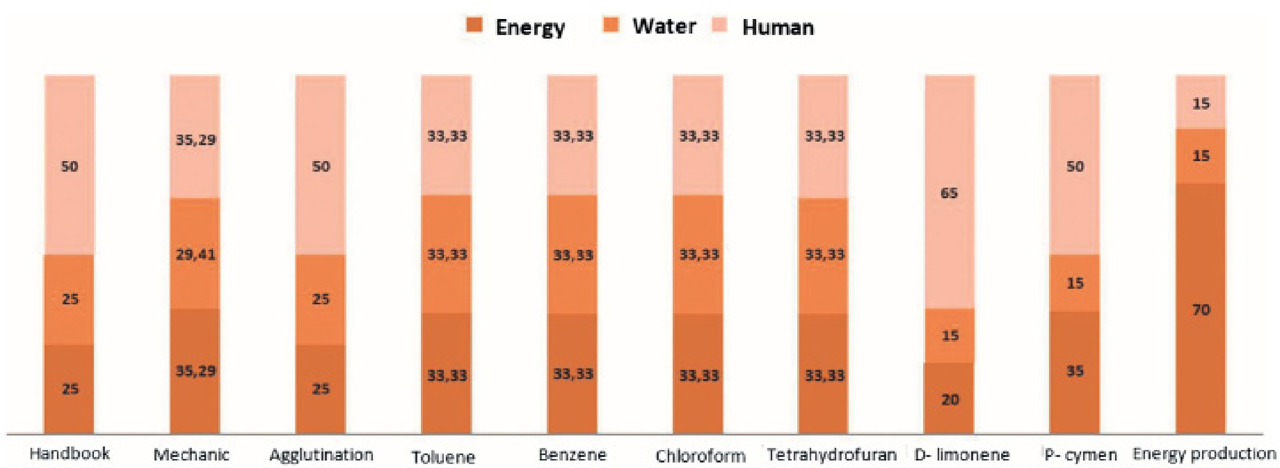

Figure 2. Percentage use of resources by category of technical analysis used.
Source: self-made.

In most of the techniques, the resources are used homogeneously, except for the treatment with d-limonene that uses mainly the human resource and in low proportion water and energy, a similar case occurs with the p-cymene. On the other hand, paradoxically, the energy production technique is the one that uses the most energy for its generation (Urrea, 2012).

The result of the use of resources has an impact on environmental compartments, expressed in their use. When energy is used, there will be atmospheric emissions; of water, there will be dumping and there will be damage to the soil. To the extent that a resource is used mostly, its environmental compartment will be affected (Gutiérrez *et al*., 2013). As seen in Figure 3, the techniques have a homogeneous use of environmental compartments, according to the resource.

The opposite happens with the solvent d-limonene and p-cymene, which, as a result of their implementation for the recycling of polystyrene, have the generation of discharges due to the use of water, a case similar to the technique of energy production. The best alternative is the technique that has been used most frequently, the one that uses the fewest resources and, therefore, the least impact on the environmental compartments involved.

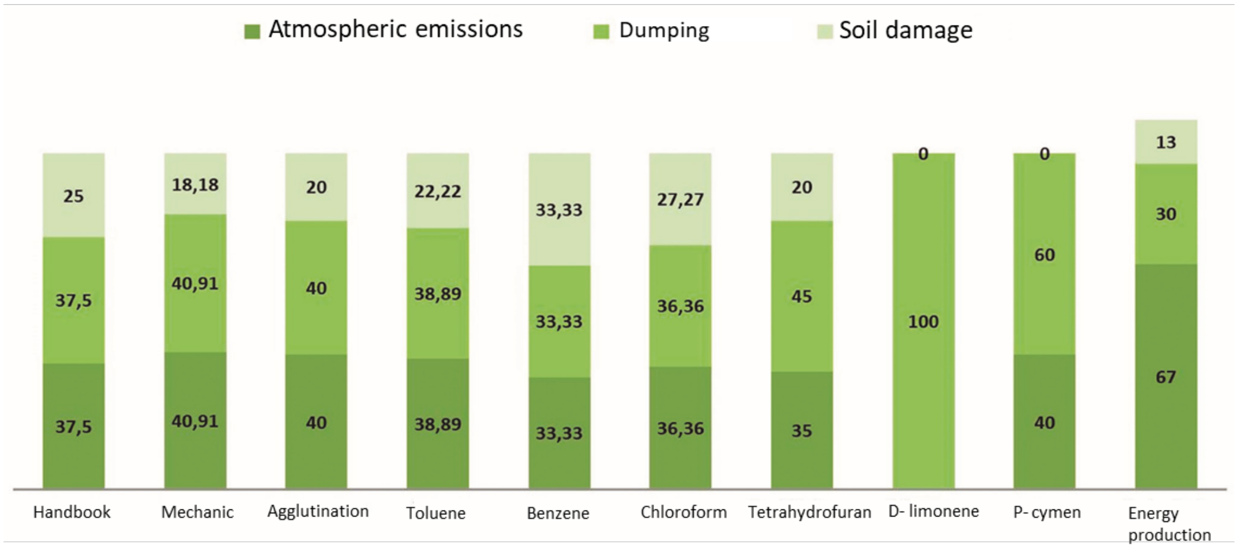

Figure 3. Percentage use of environmental compartments by category of technical analysis used.
Source: self-made.

Conclusion

From the previous review, it can be concluded that there are two alternatives with low environmental impact relevant to the recycling of polystyrene: primary and tertiary. From the crushing material is obtained that preserves the initial chemical characteristics, but without an expanding agent, that is, without foaming, so it will occupy a smaller volume than the material without treatment, however, this technique uses a lot of energy; manual shredding reduces energy consumption and, on the other hand, offers the opportunity to offer employment as an alternative to traditional shredding. When tertiary recycling solvents are used, in particular d-limonene and p-cymene (green solvents), EPS increases its density, thus reducing its volume and obtaining a resin suitable for applications, such as adhesives, paints, and coatings insulating and with a pleasant smell and low foaming, which is ideal as a strategy for its recovery in recycling processes, mitigating its environmental impact and increasing its capacity of use with the projection of use in sanitary landfills. Solvents do not generate emissions, vapors, or damage to the environment, it is also possible to recover it by recirculating it.

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