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Life Cycle Analysis for the Recycled Expanded Polystyrene (EPS) and Polypropylene (PP) Mixture as an Alternative to the Material in the Construction Sector

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The continuous generation and accumulation of solid waste is a critical problem at the world level and require urgent action. Therefore, the present paper contains an alternative of using two solid plastic wastes, determining the use of polymeric synthesis made from recycled polypropylene (PP) and expanded polystyrene (EPS). First, the research developed a new material using these two recycled raw materials and evaluated its physical-mechanical properties. The next step was the comparison of the properties with different potentially replaceable materials. Finally, polyvinyl chloride (PVC) was the material identified as possible to be replaced by the mixture (EPS+PP) because of the similar values of its properties, with specific use for coating electrical installations and internal communications. The study uses the Life Cycle Assessment methodology (LCA) to evaluate the material's environmental performance. This paper reports the inventory data of the new material process validated in a plastic plant in Bogotá (Colombia). Consequently, by using the mass and energy balances, the authors evaluate the environmental indicators for the process proposed and then compare the results with the ones of PVC in the Ecoinvent databases. The study used a "cradle to door" approach and SIMAPRO software in this step. The LCA results show that the new material generates less environmental impact than conventional (PVC). Furthermore, the present research results allow new possibilities for incorporating circular economy models in the construction sector. As a result, the new material produces a lower environmental impact than PVC.

1. Introduction

The continuous generation and accumulation of solid waste is a critical worldwide problem, especially in Latin American countries, such as Colombia (Caballero et al.,2011) and Mexico (Molano, 2019), where waste is deposited directly without treatment in the open air and landfills, thus causing the continuity of linear economic models that are not sustainable with the resources of the environment. Notably, plastic solid wastes produce more concern and uncertainty, since the governmental entities of these countries, among others, need to do adequate management, sending them to sanitary landfills (Caballero et al.,2011; Molano, 2019). This is a global problem (Martínez and Laines, 2014) as there seem to be two apparent logical solutions: avoiding using the product and investigating treatment models targeted at these materials. For this study, the case of polyethylene (PP) and expanded polystyrene (EPS) was analyzed. The problem with avoiding plastics is that plastic products are so attractive to various markets because they are economical to manufacture. Furthermore, its possibilities of use vary due to its thermal and acoustic qualities. In addition to this, it has extended durability. However, when EPS reaches its useful life, as it is an economical material and complex management, it is usually a single-use product. Thus, looking for alternative uses for materials such as EPS is necessary.
This research consisted in defining the practical and functional use for a polymeric synthesis already developed, which was based on mixing EPS with an easily recoverable polymer such as PP, based on a comparative analysis of the physical-mechanical properties of the material obtained (EPS+PP) with potentially replaceable

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materials used in the construction sector. PVC is a prevalent material used for covering electrical installations and internal communications of construction that has a favorable technical-environmental evaluation according to its life cycle analysis. "*LCA results provide a rigorous quantitative assessment of the environmental efficiency of products or systems and constitute strong evidence to inform policy decisions*" (ISO, 2006, cited by Bishop, 2021). A comparative LCA was developed to demonstrate that the new material (PP+EPS) generates a lower environmental impact than the traditional one (PVC). It should be clarified that the LCA of the PVC was taken from the ECOINVENT database. At the same time, polymeric synthesis was analyzed in this research introducing the material and energy balances, taking as reference some process of the company "DIMACOL Diseños y Manufacturas Colombianas LTDA." The company used as a reference is in Bogota and is dedicated to manufacturing recycled plastic products. Therefore, it was necessary to model the process using some theoretical adjustments to design the industrial production of the proposed material. Thus with the development of this research, we are innovating in circular economy models, essential for sustainability, as stated in items "12: Responsible Production and Consumption" and "13: Climate Action" of the UN "Sustainable Development Goals and Targets" (UN, 2022).

2. Methodology

2.1 Definition of material use

This first stage of the research was based on the search for a material with physicomechanical properties like the polymeric synthesis already developed in the laboratory, which was divided into two sub-stages, as follows:

Determination of the sector
First, a bibliographic review was carried out about the use of type 5 (PP) and kind 6 (EPS) plastics to delimit the sector to which the project should be directed, finding that there are several studies on the reincorporation of plastic waste, such as polyethylene terephthalate, high-density polyethylene, polyvinyl chloride, and polypropylene in different production cycles. One of the sectors with more research in the reincorporation of various plastics is the construction industry, with an extensive background in roads, buildings, insulation, and roof waterproofing, among others. Therefore, the search for the definition of the use of polymer synthesis in this sector was based on discarding any use of water, mainly drinking water, because when using waste as raw material, they could alter the properties of water, such as toxicity, salinity, turbidity, a decrease of dissolved oxygen, apparent color, and taste, as required (in Colombia) in the RAS 2017 (Minvivienda, 2017). However, this sector offers many possibilities, so it was selected.

Physicomechanical properties comparison
Subsequently, the physical-mechanical properties of the PP+EPS mixture were compared with different construction materials to replace the conventional material and thus avoid as many environmental impacts as possible by not consuming it. Still, without altering its specific function, i.e., the physical-mechanical properties of the new polymer should be as similar as possible to those of the material to be relieved. The properties compared were stress-strain, flexural strength, and impact. The PP+EPS polymeric mixture was made at different proportions to evaluate and choose the ratio with the highest resistance and physical-mechanical behavior so that from this, the properties described with values close to the same in materials of the construction sector. It was found that rigid PVC has similar properties according to the plastic parts manufacturing industry precision machining and the thermoplastic resin-producing company Braskem (Braskem, 2022). For this research, the mixture was selected 90PP%+10%EPS. However, taking into account that these values may be susceptible to change when in contact with water, as well as the fact that the two PM (PP and EPS) of which the final product is made were a solid waste, the material cannot be used if it comes into contact with drinking water, so any use that comes into contact with water, whether hot water (bathrooms, showers, dishwashers, etc.), wastewater or drinking water, should have been discarded. Therefore, the specific use of PVC in coating electrical and internal communications installations of work was defined, i.e., the so-called trunking PVC, practical use for the new material.

2.2 Life cycle assessment

Life cycle analysis (LCA) allows for estimating and evaluating the environmental impacts attributable to the life cycle of a product, such as climate change, stratospheric ozone depletion, tropospheric ozone generation, eutrophication, acidification, toxicological pressure on human health and ecosystems, natural resource depletion, water use, land use and noise and others (Rebitzer et al., 2004).
Thus, in this second phase of the research, we demonstrated that applying the new material has a lower environmental impact than replacing the conventional material. The most reliable method to corroborate this postulate was by performing a life cycle analysis for the polymer synthesis using Simapro software and

comparing it with an LCA of PVC (analysis available in the software), for which a series of steps were necessary: Design of the proposed industrial process for the material, goal, and scope definition, inventory analysis, impact evaluation and, results comparison.

Design of the proposed industrial process for the material

It was necessary to develop an industrial process for the polymeric synthesis and thus be able to enter its data into the software, so taking as a basis the process carried out in the laboratory (Betancourt, 2015) to make the new material, we proceeded to develop it on an industrial scale (theoretically), which is why the block diagram proposed for this procedure was elaborated. The company Dimacol agreed to allow technical visits to take the manufacturing process of one of its products as a reference. Thanks to this visit, some shortcomings and improvements in the design of the block diagram could be evidenced to assume a complete and commercially functional product, such as adding operations to clean the raw materials and, most importantly, using as a reference the data of the company's industrial equipment, data such as electrical energy consumption, the maximum capacity of each equipment and the time required by each machine for its specific function The figure 1, show the diagram of the industrial process proposed.

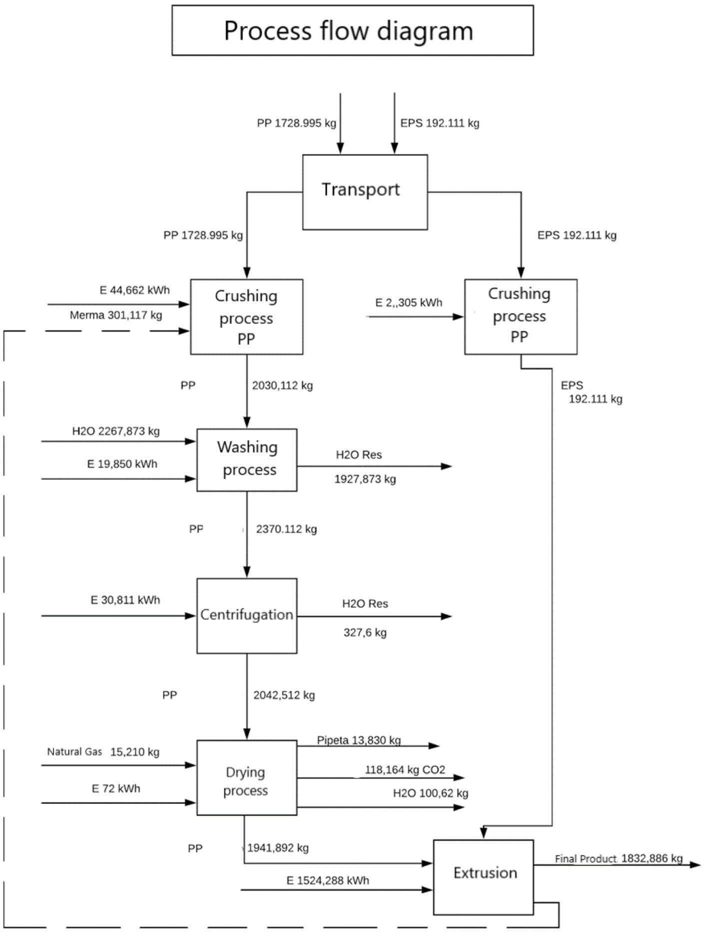

Figure 1: Block diagram of the industrial process for producing the new material.

After the design of the industrial process, a material and energy balance and an emissions balance of the proposed method for the material were carried out, with accurate data, to count in each unit operation the material and energy flow used to develop the product and, with these, enter the data into the SimaPro software, to evaluate the potential environmental impacts generated in the production of the new material made of 2 recycled materials and compare them with the environmental impacts of PVC, to verify that the polymeric synthesis has a lower environmental impact than the conventional material, and thus promote the use of this type of materials that are by the guidelines of the circular economy.

It should be clarified that the calculation base chosen was 2000 kg of polypropylene, which means that all other quantities of PM, inputs, waste, etc., are also in units of kg. As for the department of measurement for electricity consumption, it is kW*h.

Goal and scope definition

It was proposed to evaluate the potential environmental impacts generated in the production of the new material resulting from the mixture of recycled EPS+PP to develop the new recycled polymeric material as an alternative for the use of solid waste in Colombia, in the sector of materials for civil works, which will generate an option for the mitigation of environmental damages, as a result of the decrease in the potential environmental impacts concerning those caused by the production of the conventional material, specifically in the soil and air components. For the research, a reference flow was defined for a plant that would process 2222,223 kg of recycled PP and EPS in a 90-10 proportion, respectively, having 1 kg of the finished product as a functional unit. The two raw materials of the industrial process are recycled PP and EPS, which are acquired (within the proposed model) in 2 sorting and recovery stations (ECA) located in Bogotá, 15.8 km and 17 km from the defined location. The PM transport was established using a 3.5-ton capacity truck with Euro 4 technology (specifying the type of vehicle, as well as the distance for the transport of the PM, is required by the software). As for the system's limits, the LCA was originally projected from door to door since the material balance considered the data to produce the material if they start within the company and until the product is manufactured in its entirety. However, the software considers the environmental aspects generated in the extraction of each raw material and input and its transportation, i.e., the LCA of the product is from cradle to gate since it covers from extraction to production.

Inventory analysis

In this stage, the identification and quantification identification and quantification of inputs and outputs in each of the unitary processes for the manufacture of recycled EPS+PP were carried out. Based on the production processes of DIMACOL, some of the production processes were taken as a reference for the proposed production of the new material, such as transportation, PP crushing, washing, centrifugation, drying, EPS crushing, and extrusion of the final product. However, for some quantification data, it was necessary to make theoretical adjustments because it is a product not found in the market and, therefore, no industry manufactures it. Likewise, the material, energy, and emission balances were considered for their assignment within the software and the process diagram for the material in question. In the inventory, the electricity consumption inputs corresponding to electricity for each unitary operation were considered, defined in SimaPro as low-voltage electricity produced in Colombia. In addition, the quantities of raw materials for the process, i.e., recycled PP and EPS, were taken according to the proportion of 90% PP and 10% EPS.

Impact evaluation

This stage was carried out using the Environmental Product Declaration (EPD 2018) impact assessment method, which provides product consumers with information about the environmental impacts generated by the production and use of the product during its life cycle and allows producers to obtain green certifications that prove that the product is environmentally friendly. This method is made up of 8 impact categories, which define the environmental indicators of each process.

3. Results and discussion

Thus, the polymeric mixture can be used for coating electrical and internal communications installations in civil works. For this research, some of the most relevant ones were chosen because they gather the most important results of the product's negative or positive impacts according to the stages mentioned in the LCA methodology. The category that presented the most significant contributions is acidification due to the emission of 0.001 kg SO2 eq of sulfur dioxide from diesel fuel in transporting raw materials. However, to reduce this emission, it is proposed to transport the PM over shorter distances in search of the nearest suppliers' collection points and to use a more efficient vehicle. Likewise, eutrophication, abiotic depletion, and global warming are caused by using fossil fuels, in this case, to produce thermoplastics. However, the category with the most significant impact is ozone depletion due to the emissions created during the drying stage, which are considered greenhouse gases. Therefore, investing in new drying machines with greater capacity is necessary to reduce it, which are more efficient, modern, and do not require so much natural gas consumption.

The term process contribution refers to impacts modeled independently according to each stage of the process, and as mentioned, impact analysis is general modeling, which projects the environmental effects, either positive or negative, that the product will have at the end of the process concerning the eight impact categories established by the EPD 2018 method. The results obtained in this study were compared with the LCA of rigid PVC, available in the Ecoinvent database. The environmental profile illustrated in Figure 2 was developed with the impact analysis data and the process contribution data, unifying two results into one and highlighting others independently, as is the case of energy consumption, an environmental aspect with evident improvements to be considered because that there is an energy deficiency in extrusion since this operation corresponds to 90% of the total consumption of the process.

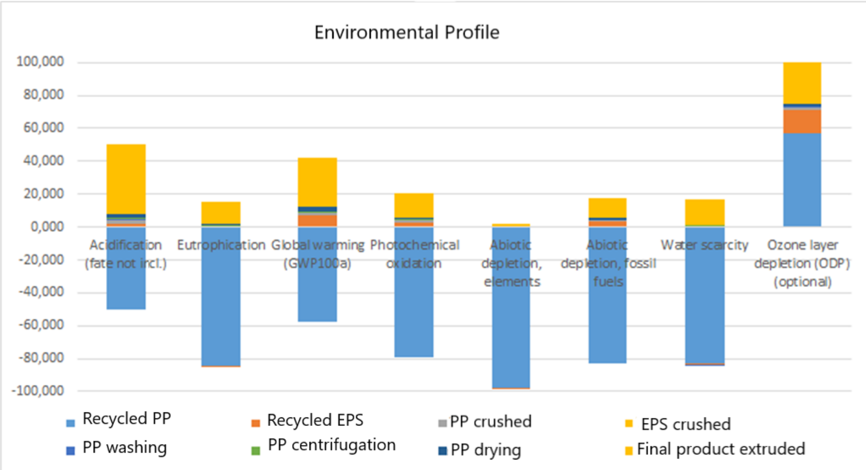

Figure 2: Environmental profile of the new material.

As mentioned, the LCA environmental profile of PVC was obtained from the Ecoinvent database. The data exported for comparison with the polymeric synthesis correspond to those of the impact analysis, i.e., the final impact value, compared with the impact analysis values of the new material. In 7 categories, the environmental impact of PVC is superior to that of the PP+EPS mixture, and not only that, but in 6 impact categories, from "Eutrophication" to "Water scarcity," the values are negative, which implies that not only are they not hurting the environment but that their contribution is so significant that it is beneficial to it. Additionally, it is essential to clarify that synthesizing is "higher" in the ODP category because the LCA of PVC did not provide the final value for that category. Even so, representing an advantage over seven impact categories out of 8 means an enormous environmental benefit of the new material over the conventional one. Figure 3 shows the graphical representation of the comparison results, where the orange bars correspond to the values of the environmental profile of PVC. In contrast, the blue bars represent the profile of the new material.

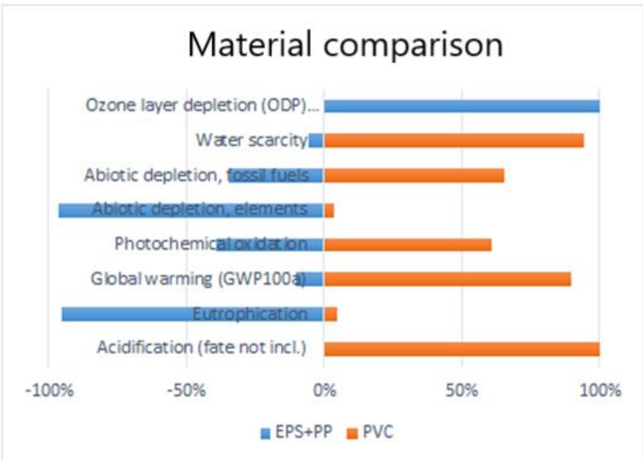

Figure 3: Comparison of the new and conventional material's environmental profile.

4. Conclusions

The new material, in effect, produces a lower environmental impact than the conventional material. This postulate is supported by each of the graphs of the modeling of the environmental profiles of both materials, obtaining benefits in environmental criteria, since in the case of using the product, the manufacture of the conventional one is avoided, with all that it includes, whether it is the emission of greenhouse gases, reflected in the bar "global warming," to the extraction of materials and their transport reflected in "abiotic depletion, elements" and "abiotic depletion, fossil fuels," respectively, plus the water used or contaminated after the manufacturing process, reflected in "water scarcity" and "acidification," respectively. It is also important to remember that this comparative analysis of the new material is specifically with PVC used for covering electrical installations and internal communications in a construction site since PVC in other uses may encounter substances that are not ideal for the new material and could wear it out in the future and prevent it from functioning correctly. By evaluating the impact categories modeled accommodated the EDP 2018 method in the software, it is shown that these were sufficient to define the impact categories. Furthermore, these were sufficient to specify the environmental indicators for each unit process. Therefore, it was found that the critical types are global warming, acidification, and ozone layer depletion, due to the use of fossil fuels for the transportation of raw materials and as input for the operation of some machines.

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References

Betancourt D., 2015, Aprovechamiento del poliestireno expandido (icopor) reciclado como alternativa a la fibra de vidrio en el proceso de producción de autopartes en la empresa ventiladores GBA, <https://repository.usta.edu.co/handle/11634/2909> accessed 10.12.2020.

Braskem, 2002, Propriedades de Referência dos Compostos de PVC, <https://www.braskem.com/Portal/Principal/Arquivos/html/boletm_tecnico/Tabela_de_Propriedades_de_Referencia_dos_Compostos_de_PVC.pdf> accessed 10.12.2020.

Caballero D., De la Garza R., Andrade E., 2011, Landfill: an alternative to the disposal of solid waste. CienciaUAT, 6-2, 7521.

ISO, 2006, ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines. Geneva

Martínez C., Laines J., 2014, Expanded Polystyrene (EPS) and its environmental problems. Kuxulkab',19, 1665-0514.

Ministry of Housing, City and Territory of Colombia, Minvivienda, 2017, Resolution 0330 of 2017 by which the Technical Regulations for the Drinking Water and Basic Sanitation Sector are adopted – RAS, Ministry of Housing, City and Territory of Colombia, <https://www.minvivienda.gov.co/viceministerio-de-agua-y-saneamiento-basico/reglamento-tecnico-sector/reglamento-tecnico-del-sector-de-agua-potable-y-saneamiento-basico-ras> accessed 19.12.2022

Molano F., 2019, Bogota's Juana Landfill: The Political Production of a Toxic Landscape, 1988-2019, Historia Crítica, 127-149.

Organization of the United Nations, UN, 2022, Sustainable Development Goals and target, <https://www.un.org/sustainabledevelopment/es/sustainable-development-goals/> accessed 19.12.2022.

Precision Machining, n.d., Data Sheet of PVC, <https://qcprecision.com/services/materials/> accessed 10.11.2020.

Rebitzer G., Ekvall T., Frischknecht R., Hunkeler D., Norris G., Rydberg T., Schmidt WP., Suh S,. Weidema BP., Pennington DW., D. W., 2004, Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications, Environment international, 30(5), 701-720.

Solano J., Orjuela D., Betancourt D., 2017, Determination and Evaluation of Flexural Strength and Impact, Flammability, and Creep Test through DMA, (Dynamic Mechanical Analysis) for Mixing Expanded Polystyrene and Polypropylene from Municipal Solid Waste, Chemical Engineering Transactions, 57, 2283-9216.