ELECTRON BEAM PROCESSING TO IMPROVE BIODEGRADABLE POLYMERS AND FOR INDUSTRIAL WASTEWATER TREATMENT AND RECYCLING

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Abstract

The aim of the two studies was to apply the electron beam radiation technology for controlling plastic pollution and environmental protection. (1) Mobile irradiation unit - The treatment of wastewater and industrial effluents by electron beam irradiation is a promising technique. The design and construction of a mobile unit by the Nuclear and Energy Research Institute, containing an electron beam accelerator of 0.7 MeV and 20 kW is innovative to demonstrate the effects and positive results of this technology. The mobile unit has as one of its main advantages the possibility of treating effluents in the place where the source is located, eliminating costs and bureaucratic problems associated with the transportation of waste, besides publicizing the technology in several places in the country. To implement the project, IPEN-CNEN has been consolidating partnerships with national and international companies. The resources for the development of the unit have been supplied by the Brazilian Innovation Agency (FINEP Process N. 01.18.0073.00 - Implementation of mobile facilities to make the technology generated available to the productive sector and society) and International Atomic Energy Agency, financing the “IAEA TC Project BRA1035 - Mobile electron beam accelerator to treat and recycle industrial effluents”. The Institute has associated with a specialized company (Truckvan Industry) in an innovation project for the unit design and development. (2) PBAT/PLA polymeric blend Ecovio® - The mechanical properties of the biodegradable polymer were evaluated. Products, such as injected packaging, films for tube production, plastic bags, packaging for cosmetics and food packaging, among others made with this biodegradable polymeric blend need to be resistant to cross sectional demands, impact and thermal stability and should have an average lifetime of 1 to 5 years. Then, it is recommended to use the PBAT/PLA polymeric blend Ecovio® irradiated by electron beam with adsorbed dose of 65 kGy.

1. INTRODUCTION

In the world, there is a growing increase in the demand for water for human consumption, as well as the prioritization of the use of available water resources for public supply. The United Nations World Water Development Report 2017 estimates global freshwater withdrawals at 3,928 km³ per year. An estimated 44% (1,716 km³ per year) of this water is consumed, mainly by agriculture through evaporation in irrigated cropland. The remaining 56% (2,212 km³ per year) is released into the environment as wastewater in the form of municipal and industrial effluent and agricultural drainage water. Globally, it is likely that over 80% of wastewater is released to the environment without adequate treatment.

On the other hand, almost 79% of the total plastics produced worldwide were discarded directly into the environment. Therefore, 6.5 billion tons of plastics may have caused negative environmental impacts, denigrating the image of the plastics, as well as damaging the environment and global sustainability. To solve this problem, one of the ways is the use of biodegradable polymers, which are used for making consumer goods and when discarded are degraded faster than products made with non-biodegradable polymers, thus contributing to global sustainability.

1.1. Industrial wastewater treatment and recycling

In developing countries, such as Brazil, about 90% of wastewater is dumped untreated into rivers, lakes or oceans. Therefore, it is necessary to adopt strategies that aim to maximize the use of water resources and minimize the negative impacts related to the generation of effluents by the industries. The necessity to preserve the environment as well as the demand for sustainable development has generated various actions by non-governmental groups and changes in legislation in many countries. As a consequence, restrictions have been imposed regarding the release of effluents into the environment. Currently, several technologies are used in the treatment of industrial effluents for recovery and reuse of these waters [1-2].

The irradiation system with an electron accelerator allows treating different types of effluents. Depending on the effluent, the amount of ionizing radiation energy required for treatment may vary, as well as the amount of treated effluent per day [3]. In this context, the Radiation Technology Center at IPEN-CNEN decided to develop and build a mobile electron beam irradiation facility for the treatment of industrial effluents in the place where the source is located, without the transportation of wastes [4]. The type of treated effluent, the treatment cost per m^3/day and other information regarding the cost of maintenance and operation of the mobile irradiation facility were obtained from the Business Plan of the Mobile Facility [5-6].

1.2. Biodegradable polymers

Almost 79% of the total plastics produced worldwide were discarded directly into the environment. Therefore, 6.5 billion tons of plastics may have caused negative environmental impacts, denigrating the image of the plastics, as well as damaging the environment and global sustainability. To solve this problem, one of the ways is the use of biodegradable polymers, which are used for making consumer goods and when discarded are degraded faster than products made with non-biodegradable polymers, thus contributing to global sustainability.

Biopolymer classification in relation to the environment can be observed in Fig. 1. In the horizontal axis the polymer is evaluated in relation to its biodegradability and in the vertical axis the raw materials of this polymer are evaluated based on whether they are renewably sourced [7].

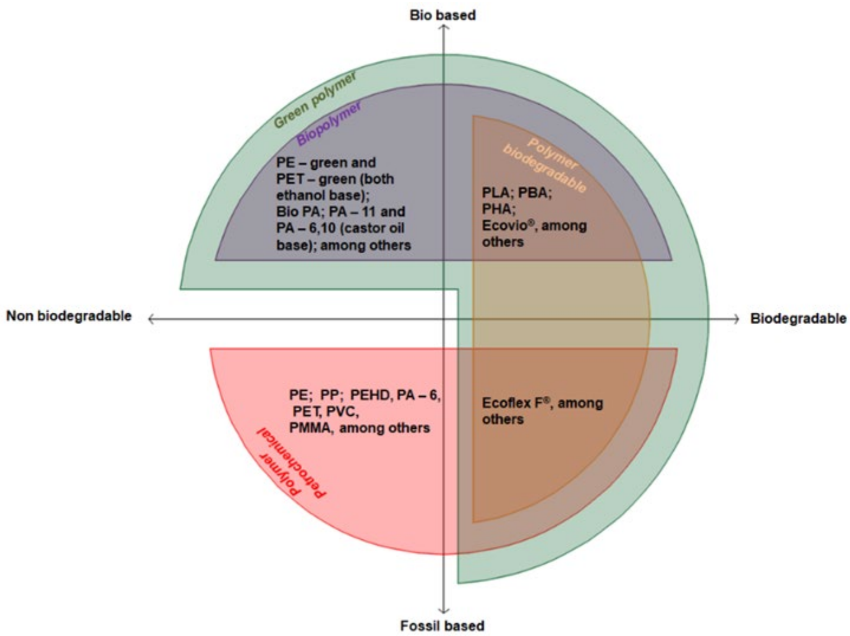

FIG.1: Classification of polymers based on environmental criteria.

In Fig. 1, the first, second and fourth quadrants represent the green polymers. The first and second quadrants represent the biopolymers and the biodegradable polymers are represented by the first and fourth quadrants. Finally, the third and fourth quadrants represent the petrochemical polymers. The designation as a green polymer is used to differentiate all polymers from the petrochemical polymers. When a polymer is classified as biodegradable, it should automatically be classified as a green polymer. It may also be a biopolymer if this biodegradable polymer was produced from a renewable source. Therefore, the PBAT/PLA polymeric blend polymers can be classified as both biodegradable biopolymers and green polymers.

In the 21^{st} Century there is a concern about the development of biodegradable polymers, with the launch of PLA [Poly (lactic acid)] in 2003, Ecovio® in 2006 and Ecoflex®, produced from renewable sources in 2010, among others. Attention is also being paid to biodegradable polymers in several searches [8].

For PBAT and PLA, theirs world productions were 300,000 and 334,000 tons in 2019, respectively, which represent approximately 25% and 28% of the world's production of the biodegradable polymers in that year. Increases in production were due the increased market competitiveness of both biodegradable polymers in relation to other polymers [9]. However, prior researches have indicated that electron beam irradiation may affect the mechanical properties of the polymeric blend PBAT/PLA. Afterward, a systematic evaluation of these effects is warranted.

2. MATERIAL AND METHODS

2.1. Mobile irradiation unit

A 3D model study of the control room and laboratory space was done to facilitate understanding the internal distribution of the laboratory analysis equipment (Gas Chromatography Mass Spectrometry, Total Organic Carbon and UV-Visible Spectroscopy). The irradiation system with industrial electron accelerator (700 keV, 28 mA, 20 kW, scan horn 640 mm) allows treating different types of effluents. Depending on the effluent, the amount of ionizing radiation energy required for treatment may vary, as well as the amount of treated effluent per day. For the construction of the mobile unit, the estimated cost is about US$ 1.5 million. In the Fig. 2 is shown the architectural design of the mobile electron beam irradiation facility developed by IPEN-CNEN in partnership with Truckvan Industry.

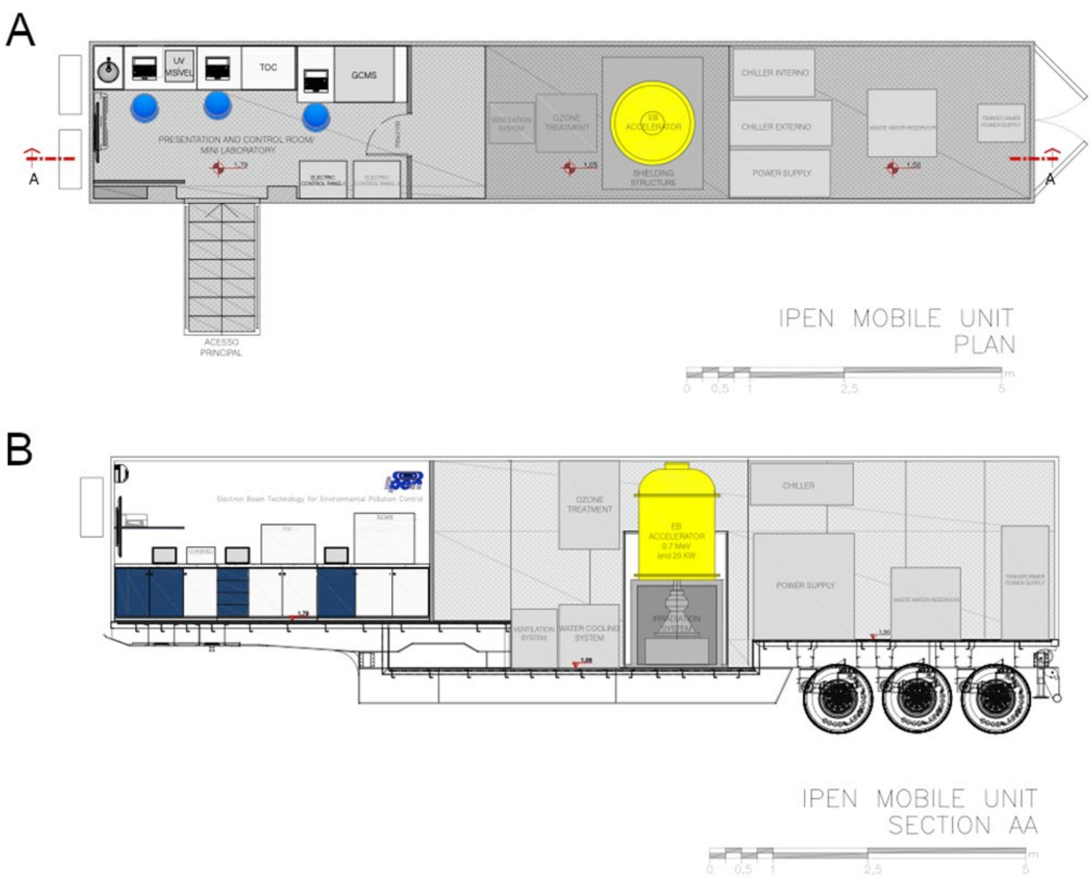

FIG.2: Architectural drawings of the IPEN-CNEN's mobile facility Plan(A) and section AA(B).

In the Fig. 2, the cart is divided into three separate parts: (a) Control room and laboratory for analyses, technical and scientific dissemination of the technology; (b) Industrial electron beam accelerator, hydraulic units, ventilation system, cooler and bunker with irradiation device; (c) Transformer and power source supply.

2.2. PBAT/PLA polymeric blend Ecovio®

The polymeric blend Ecovio® was the material used in this research. It is composed by 80% of renewable compounds, since the PLA and PBAT are made with 100% and at least 64% of renewable resources, respectively. The PBAT/PLA polymeric blend is completely made from biodegradable products, and can be classified as a biopolymer, green polymer and biodegradable polymer, also has a translucent semi-crystalline structure and good thermal stability up to 230ºC.

The PBAT/PLA samples were injected using the Hatian PL 1600 injection molding machine and irradiated by electron beam, as shown in Fig. 3. This process was performed using an electron beam accelerator type Dynamitron®, model DC1500/25/4, manufactured by Radiation Dynamics Inc. (RDI), energy of 1.5 MeV, electric beam current of 25 mA, a scan of 1200 mm and power of 37.5 kW. The irradiation parameters were energy 1.437 MeV, beam width of 1000 mm, electric beam current of 3.26 mA, dose rate of 13.35 kGy.s-1 and dose per tray pass was 5 kGy. PBAT/PLA samples were irradiated at the absorbed doses of 5, 10, 15, 25, 50, 65 and 80 kGy.

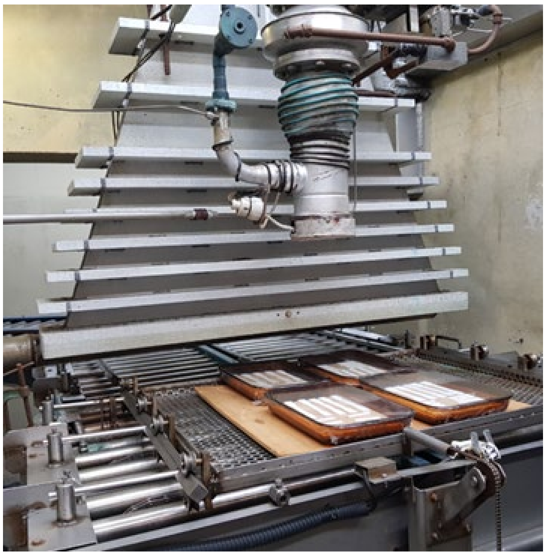

FIG.3: PBAT/PLA irradiated samples by electron beam.

Both irradiated and non-irradiated samples were characterized by Izod pendulum impact resistance, tensile strength at rupture, shore D hardness, thermogravimetric analysis (TG) and differential scanning calorimetry (DSC) tests.

3. RESULTS AND DISCUSSION

3.1. Treatment capacity and costs by type of effluent

The type of treated effluent, the treatment cost per m^3/day and other information regarding the cost of maintenance and operation of the mobile irradiation facility are presented in Table 1. All data were obtained from the Business Plan of the Mobile Facility.

This study achievement was based mainly on bibliographic research, mobile unit structures analysis, visits to Truckvan Industry (responsible for chassis and shelter construction of the mobile irradiation facility) and exchange information between the company managers and operators involved in the project. Furthermore, alternative materials and equipment were searched, and designers consulted to project the laboratory installation. In the project, the priority was to ensure adequate and safe working conditions for operators [10].

To attend the installation necessities, several distribution trials and volumetric studies were done to optimize the area distribution. At this point was crucial to know all the equipment that would be used for the facility operation, to search mainly for approximate dimensions and weights, and then start the structural design.

Regarding the mobile laboratory, several layout options have been developed to better meet the needs of each device and its users. The layout has been discussed with the objective of facilitating the maintenance of the equipment (CG-MS, UV-Vis and TOC); operators well-being and ergonomics; space optimization and also to make compatible the need for the presence of equipment and space for operators.

The structural part of the truck is already built and ready to receive all the equipment that needs to be installed in mobile facility, as shown in Fig. 4.

TABLE 1. Quantities of energy, treatment capacity and costs by type of effluent treated in the Mobile Facility.

Effluent	Dose (kGy)	Amount (m^3/day)	Power (kW)	Capital cost (Million US$)	*Variable cost **(Variable and fixed costs) (US$)	Cost/m^3 of effluent treated (US$)
Removal of geosmine (GEO) and methilisoborneol (MIB) from drinking water	1	1,000	20	1.5	0.20 (0.38)	0.60 (1.14)
Removal of industrial textile dyeing from wastewater	2	500	20	1.5	0.20 (0.38)	1.20 (2.28)
Elimination of coliforms from raw sewage, secondary and chlorinated effluents	3	340	20	1.5	0.20 (0.38)	1.77 (3.36)
Removal of organic compounds from petroleum production water	20	50	20	1.5	0.20 (0.38)	12.0 (22.8)
Removal of PCB from transformers oils	50	20	20	1.5	0.20 (0.38)	30.1 (57.1)

* Variable cost only (maintenance, electricity and labor); and
** Both variable and fixed costs (depreciation, bank interest and management).

FIG.4: Mobile electron beam irradiation unit for the treatment of industrial effluents in Brazil.

3.2. Results of mechanical and thermal analyses

It is shown in Fig. 5 the general results of the mechanical and thermal analyses of the PBAT/PLA polymeric blend Ecovio® irradiated by electron beam with absorbed doses of 5, 10, 15, 25, 50, 65 and 80 kGy carried out.

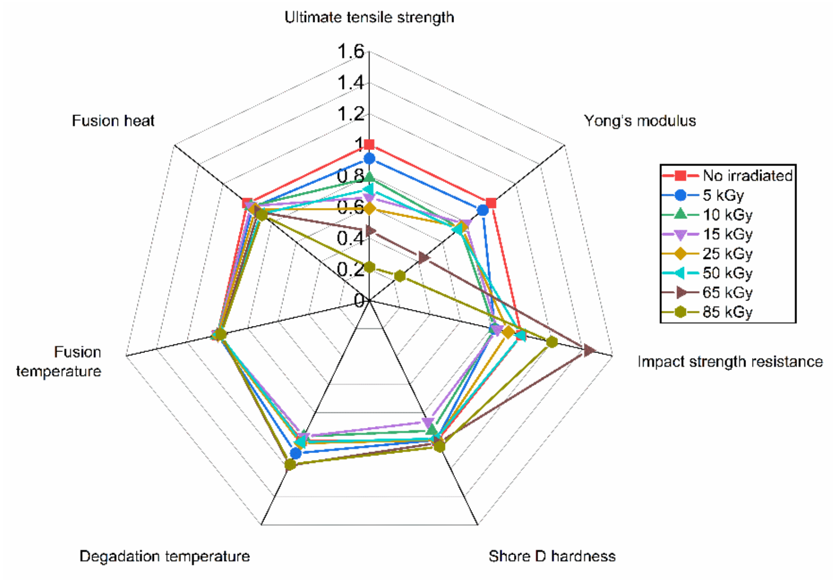

FIG.5: Results of mechanical and thermal analyzes of the PBAT/PLA polymeric blend as a function of the absorption dose.

The results showed an increase of 44% in relation to Izod impact resistance and an increase of 17.4% in thermal stability at a dose of 65 kGy. In this dose was not a substantial change in shore D hardness. However, the module of elasticity decreased 56% and tensile strength at rupture decreased 55% at the same radiation dose. In an absorbed dose of 80 kGy was observed a reduction of the 2.4% in melting temperature and 12.1% in fusion rate. In relation to elongation, significant alterations caused by electron beam irradiation were not observed.

4. CONCLUSION

The design and construction of a mobile unit containing an electron beam accelerator (700 keV and 20 kW) is innovative to demonstrate the effects and positive results of this technology to treat wastewater and industrial effluents for reuse, with particular focus on wastewaters having organic pollutants (reactive dyes and pharmaceutical residues). The Nuclear Energy Research Institute has consolidated partnerships with national and international companies, aiming at the development of a mobile beam irradiation unit which would provide assistance in the treatment of industrial effluents, disseminating this technology in several areas of Brazil. Moreover, this study also designed an internal layout of the mobile unit, focusing on the constructive characteristics, on the materials used in the construction and on the specified equipment that will be installed for industrial effluents treatment and samples analysis.

Radiation technology has been used to control environmental pollution. In this circumstance, electron beam irradiation with an industrial accelerator (1.5 MeV, 25 mA and 37.5 kW) increases at 17.4% in thermal stability and at 44% in Forthe Izod impact resistance of PBAT/PLA polymeric blend Ecovio® with an absorbed dose of 65 kGy. Then, PBAT/PLA irradiated by electron beam is biodegradable and can be used to produce injected products, bags, packaging for food and cosmetics.

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