

Development of an energy efficient and optimized process for extraction of PHB from Biomass using green solvents

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1. Introduction

The global production of plastics has seen unprecedented growth and has reached a staggering amount of 400.3 million tonnes in 2022 and is only expected to grow ('Plasticsthefastfacts2023-1', no date). Despite the environmental concerns only 9 % of it is recycled while the rest is incinerated or disposed in landfills ('Plasticsthefastfacts2023-1', no date). This trend of the linear plastic economy has significant drawbacks from an environmental, energetic, and financial perspective since the landfilling or incineration of plastics forces more production of virgin plastic feedstocks and approximately 90 % of the current plastics are produced from fossil-fuel-based resources (Hopewell, Dvorak and Kosior, 2009). Bioplastics can play a pivotal role in reducing the dependency on fossil-based plastics and to combat environmental hazards as they are biodegradable in nature (Wu, Misra and Mohanty, 2021). Amongst Bioplastics, Polyhydroxyalkanoates (PHAs) are thermoplastic biopolymers that have gained a lot of attention in the past few years due to its biodegradability and comparable properties to fossil based plastics like PP (Polypropylene) and PE (Polyethylene) (Luengo et al., 2003). PHAs are derived from organic waste synthesized by different types of microbes under stressful conditions. Amongst them, Poly(3-hydroxybutyrate) (PHB) finds its usage in various sectors like biomedical, pharmacological, agricultural, environmental, and packaging due to its biocompatibility, high strength and enhanced gas-barrier properties (dos Santos et al., 2017)

However, the major drawback related to PHB is the high cost of production including upstream and downstream costs (1.18-6.12 €/kg vs < 1€/kg) to that of fossil based plastics (Saavedra del Oso, Mauricio-Iglesias and Hospido, 2021). Extensive work has been carried out to curtail upstream costs whereas limited research is done on extraction and purification of PHB. Studies on PHB extraction have been carried either using conventional hazardous solvents (e.g. chloroform, dichloromethane, methanol, and DMF) or involves energy intensive downstream processes which includes techniques like precipitation of PHB by adding antisolvents (up to 5 times that of solvent) (Pagliano et al., 2021). The aim of this work is to develop a procedure to increase the efficiency of PHB extraction and purification considering factors like economic viability, and environmental sustainability.

2. Materials and Methods

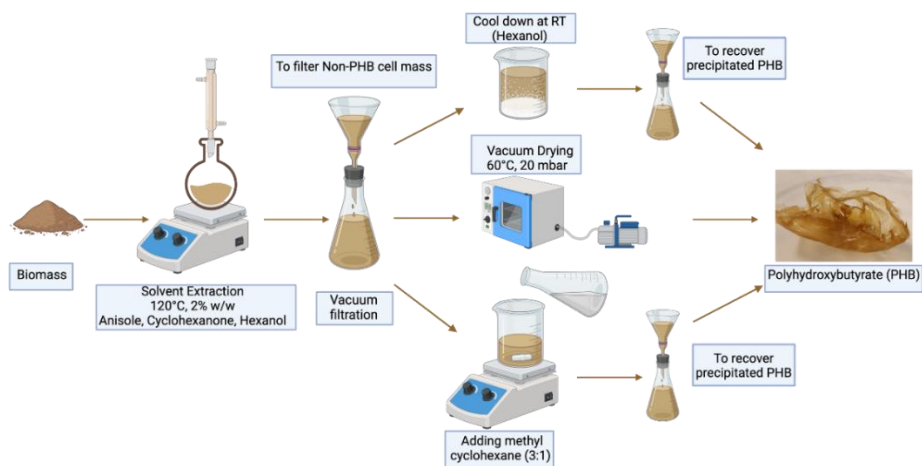


Figure 1: Schematic representation of the Experimental setup

The Schematic representation of the experimental setup is shown above in Fig. 1. PHB-enriched biomass containing 36 % (w/w) PHB was treated using cyclohexanone (Chem-lab>99%), anisole (Merck-Reagent 99%), and 1-hexanol (Chem-lab>98%) as solvents. 1 g of PHB-enriched biomass was heated with 50 gm of solvent, 2% (w/w) in a 100 ml dissolution reactor at 120 °C for 60 min at a stirring speed of 300 rpm. Consequently, the solution was filtered using a vacuum filtration setup using a (Whatman GF/B glass-90 mm) microfiber filter placed on a Büchner funnel to remove the non-PHB cell mass (NPCM). Subsequently, the filtrate was processed either by cooling at room temperature to precipitate PHB with 1-Hexanol or by adding antisolvents like methyl cyclohexane (Merck-Reagent 99%) in a ratio of 3:1 to that of cyclohexane or anisole to precipitate the PHB. In both the cases, vacuum filtration was carried out to obtain PHB and finally dried it in the oven overnight at 80 °C. Lastly, the filtrate was laid in an aluminium foil tray container and placed in a vacuum oven at 60 °C, 20 mbar to evaporate the solvents and obtain the dry PHB.

3. Results and Discussion

In a preliminary screening, 55 potential non-halogenated solvents, which were liquid at room temperature were analysed to select potential solvents that could dissolve standard PHB. This list included types of primary molecules such as alcohols, aldehydes, amines, esters, ethers, and ketones. Some of them are represented in the Hansens solubility parameter (HSP) sphere in Fig. 2a. The center of the sphere represents the polymer (PHB) and the radius of the sphere is its interaction radius ($R_{0,PHB}=8.5$). The most suitable solvents are shortlisted based on the relative energy difference (RED) between the solvents and PHB. Subsequently, these solvents were further screened based on certain parameters like SH&E criteria (Safety, Health, and Environment), process constraints, and experimental solubility trials with standard PHB. Finally, anisole, cyclohexanone, and hexanol were chosen to perform experimental extraction trials with biomass. In order to decide the temperature and concentration range for the Design of Experiments (DoE), trials were conducted at different points and the results are presented below in Fig. 2b. It is indicative that at high temperature (120-140) °C, the PHB extraction yield is higher since as temperature increases the solubility of PHB also increases.

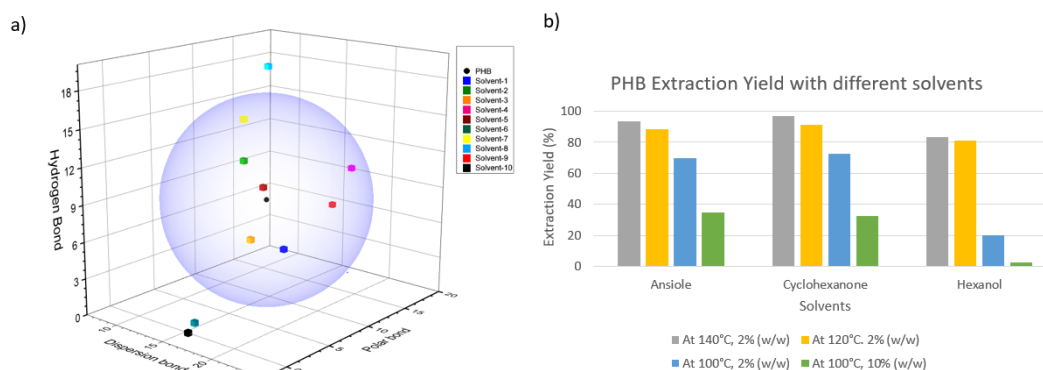


Figure 2: a) HSP Sphere for PHB b) PHB Extraction yield at different operating conditions

4. Future Prospects

A predictive DoE will be performed on extraction of PHB from the PHB-enriched biomass to understand the effect of different solvents and various parameters like temperature of extraction, and solid to liquid (S/L) ratio. The developed process will be optimized and a response equation with interaction terms will be developed to describe the relationship between the different factors.

5. References

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