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Research Article

Design and Synthesis of Conducting Polymer Bio-Based Polyurethane Produced from Palm Kernel Oil

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Polyurethane (PU) is a unique polymer that has versatile processing methods and mechanical properties upon the inclusion of selected additives. In this study, a freestanding bio-based polyurethane film the screen-printed electrode (SPE) was prepared by the solution casting technique, using acetone as solvent. It was a one-pot synthesis between major reactants, namely, palm kernel oil-based polyol and 4,4-methylene diisocyanate. The PU has strong adhesion on the SPE surface. The synthesized bio-based polyurethane was characterized using thermogravimetry analysis, differential scanning calorimetry, Fourier-transform infrared spectroscopy (FTIR), surface area analysis by field emission scanning electron microscope, and cyclic voltammetry. Cyclic voltammetry was employed to study electrocatalytic properties of SPE-polyurethane towards oxidation of PU. Remarkably, SPE-PU exhibited improved anodic peak current as compared to SPE itself using the differential pulse voltammetry method. Furthermore, the formation of urethane linkages (-NHC(O) backbone) after polymerization was analyzed using FTIR and confirmed by the absence of peak at 2241 cm^{-1} attributed to the sp-hydridized carbons atoms of C≡C bonds. The glass transition temperature of the polyurethane was detected at 78.1°C.

1. Introduction

Conducting polymers (CPs) are polymers that can release a current [1]. The conductivity of CPs was first observed in polyacetylene, nevertheless owing to its instability, and the invention of various CPs has been studied and reported such as polyaniline (PANI), poly(*o*-toluidine) (PoT), polythiophene (PTH), polyfluorene (PF), and polyurethane (PU). Furthermore, natural CPs have low conductivity and are often semiconductive. Therefore, it is imperative to improve their conductivity for electrochemical sensor purposes [2–4].

The CPs can be produced from many organic materials and they have several advantages, such as having an electrical current, inexpensive materials, massive surface area, and small dimensions, and the production is straightforward. Furthermore, according to these properties, many studies have been reported by researchers to study and report the variety of CPs applications such as sensors, biochemical applications, electrochromic devices, and solar cells [1, 5]. There is scientific documentation on the use of conductive polymers in various studies such as polyaniline [6], polypyrrole [7], and polyurethane [8–11].

Polyurethane productions can be obtained by using several materials as polyols such as petroleum, coal, and crude oils. Nevertheless, these materials have become very rare to find and the price is very expensive at the same time required a sophisticated system to produce it. The reasons such as price and time consuming to produce polyols have been considered by many researchers; furthermore, finding utilizing plants that can be used as alternative polyols should be done immediately [12]. Thus, to avoid the use of petroleum, coal, and crude oils as raw materials for a polyol, vegetable oils become a better choice to produce polyol in order to obtain a biodegradable polymer. Vegetable oils that are generally used for polyurethane synthesis are soybean oil, corn oil, sunflower seed oil, coconut oil, nuts oil, rapeseed, olive oil, and palm oil [12, 13].

It is very straightforward for vegetable oils to react with a specific group to produce a PU such as epoxy, hydroxyl, carboxyl, and acrylate owing to the existence of (-C=C-) in vegetable oils. Thus, it provides appealing profits to vegetable oils compared to petroleum considering the toxicity, price, and harm to the environment [14, 15]. Palm oil becomes the chosen in this study to produce PU owing to it being largely cultivated in South Asia particularly in Malaysia and Indonesia. It has several profits compared to other vegetable oils such as the easiest materials obtained, the lowest cost of all the common vegetable oils, and recognized as the plantation that has a low environmental impact and removing CO_2 from the atmosphere as a net sequester [16, 17].

The application of bio-based polymer has appealed much attention until now. Global environmental activists have forced researchers to discover another material producing polymers [18]. PUs have many advantages that have been used by many researchers, they are not merely versatile materials but also have the durability of metal and the flexibility of rubber. Furthermore, they can be promoted to replace rubber, metals, and plastics in several aspects. Several applications of PUs have been reported and studied such as textiles, automotive, building and construction applications, and biomedical applications [19, 20]. Polyurethanes are also considered to be one of the most useful materials with many profits, such as possessing low conductivity, low density, absorption capability, and dimensional stability. They are a great research subject due to their mechanical, physical, and chemical properties [21–24].

PU structure contains the urethane group that can be formed from the reaction between isocyanate groups (-NCO) and hydroxyl group (-OH). Nevertheless, several groups can be found in PU structure such as urea, esters, ethers, and several aromatic groups. Furthermore, PUs can be produced from different sources as long as they contain specific materials (polyol and methylene diphenyl diisocyanate (MDI)), making them very useful for specific applications. Thus, according to the desired properties, PUs can be divided into several types such as waterborne, flexible, rigid, coating, binding, sealants, adhesives, and elastomers [25].

PUs are lighter than other materials such as metals, gold, and platinum. The hardness of PU also relies on the number of the aromatic rings in the polymer structure [26, 27], majorly contributed by the isocyanate derivatives. PUs have also a conjugate structure where electrons can move in the main chain that causes electricity produced even the current is low. The current of conjugated linear (π) can be elaborated by the gap between the valence band and the conduction band, or called high energy level containing electrons (HOMO) and lowest energy level not containing electrons (LUMO), respectively [28, 29].

In the recent past, several conventional methods have been developed such as capillary electrophoresis, liquid, and gas chromatography coupled with several detectors. Nevertheless, although chromatographic and spectrometric approaches are well developed for qualitative and quantitative analyses of analytes, several limitations emerged such as complicated instrumentation, expensive, tedious sample preparations, and requiring large amounts of expensive solvents that will harm the users and environment [22–24, 30–33]. Therefore, it is imperative to obtain and develop an alternative material that can be used to analyze a specific analyte. Electrochemical methods are extremely promising methods in the determination of an analyte in samples owing to the high selectivities, sensitivities, inexpensive, requirements of small amounts of solvents, and can be operated by people who have no background in analytical chemistry. In addition, sample preparation such as separation and extraction steps are not needed owing to the selectivity of this instrument where no obvious interference on the current response is recorded [34]. Few works have been reported on the electrochemical methods for the determination of analyte using electrodes combined with several electrode modifiers such as carbon nanotube, gold, and graphene [34, 35]. Nevertheless, the materials are expensive and the production is difficult. Thus, an electrochemical approach using inexpensive and easily available materials as electrode modifiers should be developed [36, 37].

Nowadays, screen-printed electrodes (SPEs) modified with conducting polymer have been developed for various electrochemical sensing. SPE becomes the best solution owing to the electrode having several advantages such as frugal manufacture, tiny size, being able to produce on a large scale, and can be applied for on-site detection [38]. Conducting polymers (CPs) become an alternative to modifying the screen-printed electrodes due to several advantages such as their electrical conductivity, able to capture analyte by chemical/physical adsorption, and large surface area. Thus, CPs are very appealing materials from electrochemical perspectives [39]. Such advantages of SPE encourage us to construct a new electrode for electrochemical sensing, and no research reported on the direct electrochemical oxidation of histamine using a screen-printed electrode modified by bio-based polyurethane. Therefore, this research is the first to develop a new electrode using (screen printed polyurethane electrode) SPPE without any conducting materials.

The purpose of this work was to synthesize, characterize, and study the electrobehavior of polyurethane using cyclic voltammetry (CV) and differential pulse voltammetry (DPV) attached to the screen-printed electrode. To the best of our knowledge, this is the first attempt to use a modified