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ORIGINAL PAPER

Delignification kinetics of empty fruit bunch (EFB): a sustainable and green pretreatment approach using malic acid-based solvents

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Abstract
Recently, the development of efficient and environmentally benign solvents has received great attention to replace current harsh organic solvents. In this context, low-transition-temperature mixtures (LTTMs) have emerged as favorable green solvents for biomass delignification. Palm oil biomass, empty fruit bunch (EFB) was pretreated with commercial L-malic acid and microwave hydrothermally extracted cactus malic acid-derived LTTMs at 60, 80, and 100 °C. The LTTMs applied in this study were derived from malic acid–choline chloride–water and malic acid–monosodium glutamate–water with a molar ratio of 2:4:2 and 3:1:5, respectively. Three first-order reactions were used to express the delignification kinetic model of EFB. The first term was based on the initial stage and assigned as infinite due to the fast rate of delignification which could not be detected. The second and third terms were proportional to bulk and residual delignification stages. A good agreement was obtained between the kinetic model and the experimental data obtained in this study with $R^2 \geq 0.91$. The activation energies for the delignification reactions using L-malic acid and cactus malic acid-based LTTMs in the bulk and residual stages were approximated as 36–56 and 19–26 kJ/mol and 34–90 and 47–87 kJ/mol, respectively.

Keywords Delignification · Lignin · Empty fruit bunch · Kinetics · Green solvents

Introduction

Worldwide attention has been attracted for research and development in biorefinery in response to environmental issues such as CO_2 emissions and demand for integrated production of biopolymers, biochemical, and biofuels as alternatives to fossil fuels through the conversion of biomass (John et al. 2011). Lignocellulosic biomass has been widely used to replace fossil-based resources due to its abundant supplies on the earth. In terms of biorefinery, conversion of lignocellulosic has the capability to supply future society with environmental-friendly energy and chemicals while optimizing biomass utilization, economics, and sustainability (Rasmussen et al. 2017). Oil palm (*Elaeis guineensis*) is currently one of the leading crops grown widely in Southeast Asian countries, and Malaysia is one of the largest palm oil exporters in the world. Empty fruit bunches (EFBs) are one of the most abundant lignocellulosic biomass which accounts for 20% of fresh fruit weight (Mohammad et al. 2012) with the production of about 15.8 million tonnes per year (Tye et al. 2014). Oil palm EFB contains 23.7–65.0% of cellulose, 20.6–33.5% of hemicellulose, and 14.1–30.5% of lignin (Chang 2014). Nonetheless, the complex structure of plant-based biomass due to the intricate intermolecular arrangements of cellulose, hemicellulose, and lignin leads to a drawback on the biomass digestibility (Singh et al. 2014).

Lignin is an abundant natural polymer with phenolic polymer present in large quantities in wood tissues and plant cells. Recalcitrance arises from the lignin and lignin–carbohydrate complexes not only restricting the accessibility of cellulose microfibrils to microorganisms and enzymes

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