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Optimization of levulinic acid from lignocellulosic biomass using a new hybrid catalyst

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ABSTRACT

Conversion of glucose, empty fruit bunch (efb) and kenaf to levulinic acid over a new hybrid catalyst has been investigated in this study. The characterization and catalytic performance results revealed that the physico–chemical properties of the new hybrid catalyst comprised of chromium chloride and HY zeolite increased the levulinic acid production from glucose compared to the parent catalysts. Optimization of the glucose conversion process using two level full factorial designs (2^3) with two center points reported 55.2% of levulinic acid yield at 145.2 °C, 146.7 min and 12.0% of reaction temperature, reaction time and catalyst loading, respectively. Subsequently, the potential of efb and kenaf for producing levulinic acid at the optimum conditions was established after 53.2% and 66.1% of efficiencies were reported. The observation suggests that the hybrid catalyst has a potential to be used in biomass conversion to levulinic acid.

1. Introduction

Due to depleting fossil resources, more attentions have been devoted for future transition of chemical industry from fossil raw materials to renewable feedstocks (Hongzhang et al., 2011). Lignocellulosic biomass feedstocks have been used widely in the biofuel and bio-based chemicals productions. Efb and kenaf are examples of the lignocellulosic wastes in Malaysia. Earlier, efb has been utilized for the biofuel production while kenaf has been used for the fiber board, particle board, textile and fuel productions (Abdullah and Gerhauser, 2008; Abdul Khalil et al., 2010;). Efb and kenaf seem to be potential feedstocks for the levulinic acid production. These biomass contain a large amount of cellulose and they can be fractionated to release the sugars before they can be further converted to produce levulinic acid (Rackemann and Doherty, 2011).

Biomass transformation to chemical products has a potential to replace those presently derived from petrochemical. Based on screening results for the top value added chemicals from biomass by Werpy and Petersen (2004), levulinic acid is one of the more recognized building blocks available from carbohydrates and has frequently been suggested as a starting material for a wide number of compounds. Levulinic acid can be produced from glucose, fructose, starch and lignocellulosic biomass (Hongzhang et al., 2011). Levulinic acid ($C_5H_8O_3$) is also known as 4-oxopentanoic acid, β-acetylpropionic acid and γ-ketovaleric acid. This compound is soluble in water, alcohol, ether and organic solvents with a ketone (CO) and carboxylic acid (COOH) groups giving it a wide range of functionality and reactivity (Fang and Hanna, 2002; Chang et al., 2007; Girisuta, 2007; Rackemann and Doherty, 2011). Extraction of levulinic acid from lignocellulosic biomass can be enhanced in presence of catalyst such as homogenous and heterogenous in the reaction system.

Homogeneous acids (H_2SO_4, HCl, etc.) were the popular methods for a long time to synthesize levulinic acid. These methods have been used in the first commercial-scale plant for the conversion of lignocellulosic biomass to levulinic acid. This plant was built in Caserta, Italy through a process developed by Biofine Renewables (Girisuta et al., 2008). Although these hydrolysis reactions were effective, the use of the mineral acid causes serious pollution and promotes equipment corrosion. Besides, it is difficult to recover acid from the reaction products for recycling purpose (Peng et al., 2010; Rackemann and Doherty, 2011). As an alternative, heterogeneous acid catalysts have been promoted since these catalysts can overcome the problems occurred in homogeneous catalysts (Hongzhang et al., 2011).

Heterogeneous acid catalysts such as LZY, HY and MFI type zeolites and $CrCl_3$ have been used previously for the synthesis of levulinic acid from fructose, glucose and cellulose (Jow et al., 1987; Lourvanij and Rorrer, 1993; Peng et al., 2010; Zeng et al., 2010). Performance testing over faujasite (LZY and HY) and mordenite (MFI) type zeolites revealed that acid sites, acidity, porosity and shape selectivity of the catalysts have significantly influenced the levulinic acid production. Peng et al., 2010 screened the catalytic performance of metal halides and they found that $CrCl_3$ effectively

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