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Techno-economic analysis of biooil production process from palm empty fruit bunches

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ABSTRACT

Empty fruit bunches (EFB), a main residue of the palm oil industry, are one of the most recent renewable energy resources and they promise a high yield of liquid with low gas and char. The objective of this study is to evaluate the economic feasibility of the biooil production process from EFB via fast pyrolysis using the fluidized-bed. A comprehensive model of a biooil production plant was developed utilizing a commercial process simulator. The total capital investment (TCI) was estimated for five different plant sizes. The EFB biooil plant was analyzed in terms of the specific capital cost (SCC), payback period (PBP), return on investment (ROI), and the product value (PV). The minimum profitable plant size was found to be 20 kton-dry EFB/yr at a PV of 0.47 $/kg of biooil including 39% of water. Sensitivity analysis was performed on the basis of the minimum plant size to identify key variables that have a strong impact on the PV. The plant size and the biooil yield showed a major influence on the PV. In the most optimistic scenario investigated in this study, biooil can be produced at a PV of 0.27 $/kg.

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1. Introduction

Renewable energy is of growing importance in satisfying environmental concerns over fossil fuel usage and its contribution to the Greenhouse Effect [1]. Empty fruit bunches (EFB), a main residue of the palm oil industry, are one of the most recent renewable energy resources and they promise a high yield of liquid from 50% to 70% with low gas and char [2–7]. Both the need for non oil-producing countries to have secure energy and worldwide climate change imperatives are driving the effort to replace petroleum-derived fuels with bio-fuels [8]. Biomass fast pyrolysis is a cellulosic conversion technology that can contribute to renewable fuels by producing naphtha and diesel range stock fuel [9].

The energy transform technology based on the thermal chemical reaction of EFB is still in the beginning stages of the laboratory or pilot scales [7,10]. There are two kinds of thermal chemical transforming technology: the biooil and syngas productions via fast pyrolysis and gasification, respectively. Biooil from pyrolysis is produced in the fixed- or fluidized-bed with or without a catalyst. The pyrolysis reactor is operated at about 500 °C without a catalyst, and at 300–350 °C with a catalyst [11–15]. With the pyrolysis technology, the fast heating rate normally gives a higher biooil yield than the slow one. It is a high temperature process in which the feedstock is rapidly heated in the absence of oxygen. Volatiles vaporize and condense to a dark brown mobile liquid, having about half the heating value of conventional fuel oil [4,5]. Biooil can be used for diesel engines and boiler fuels, as well as feedstock for fine chemicals and renewable rubbers [11].

Liu et al. (2012) modeled the pyrolysis of biooil aqueous fraction into three stages: volatilization of volatile fractions, decomposition of heavy fractions and char combustion [16]. Matzing et al. (2011) presented a biomass thermal kinetics model consisting of five global decomposition steps [17]. They predicted gas, char and biooil compositions with respect to the reaction temperature and the heating rate. Dufour et al. (2011) developed a new model of biomass pyrolysis that accounted for a simplified multi-step chemical decomposition with the formation of tars at liquid phase inside the particle [18]. Abdullah et al. (2007) reported that 50% and 72% of biooil were produced at 500 °C in a bench-scale fluidized-bed for unwashed EFB (ash content = 5.29 wt%) and washed EFB (ash content = 1.03 wt%), respectively. This experiment showed that over 70% of the yield could be achieved in the biooil production from EFB, when EFB ash was sufficiently removed [3].

Several oxygenated compounds were found in the EFB biooil such as acetic acid, phenol and derivations of phenol, aldehydes, ketones and a small percentage of polyaromatic hydrocarbons [19–21]. Wu and Liu (2010) selected m-cresol (C_7H_8O) as a model

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Nomenclature

ASR	annual sales revenue ($/yr)
BPR	biooil production rate (kg/yr)
CF	cash flow ($/yr)
DC	depreciation cost ($/yr)
EFB	empty fruit bunches
FCI	fixed capital investment ($)
GP	gross profit ($/yr)
i	interest rate
IC	indirect cost ($)
NP	net profit ($/yr)
NPV	net present value ($)
Q_{ex}	excess heat flow rate (kJ/yr)
PBP	payback period (yr)
PC	project contingency ($)
PFD	process flow diagram
P_{biooil}	biooil product price ($/kg)
P_{heat}	excess heat price ($/10^6 k J)
ROI	return on investment (%)
PoS	plot of sensitivity
SCC	specific capital cost ($/(kg/yr))
TCI	total capital investment ($)
TDIC	total direct and indirect cost ($)
TIC	total installed cost ($)
TPC	total production cost ($/yr)
TPEC	total purchased equipment cost ($)
WC	working capital ($)
φ	corporation tax rate (%)

compound of biooil in steam reforming for hydrogen production [22]. Xie et al. (2011) chose methanol, acetic acid, and ethylene glycol for the thermodynamic analysis in aqueous phase reforming of biooil [23]. Ashcraft et al. (2012) defined biooil and pyrolysis gas properties using phenol and ethylene as the respective model compounds to determine the temperature-dependent thermal conductivity, viscosity, and heat capacity [12].

There are several researches on economic analysis for biooil production via fast pyrolysis. Solantausta et al. (1992) evaluated technically and economically a direct thermal liquefaction process [24]. Gregoire and Bain (1994) performed a techno-economic analysis for biooil production from woodchips [25]. Cottam and Bridgwater (1994) assessed and compared economical and technical opportunities for upgrading crude pyrolysis liquids into higher quality fuels [26]. Islam and Ani (2000) carried out the techno-economic analysis of a primary pyrolysis process and pyrolysis process with catalytic treatment converting rice husk waste into pyrolysis oil and solid char [27].

Biooil production processes via fast pyrolysis have used woodchips, rice husk waste or other biomass sources. Very few have evaluated the process performance of biooil production from EFB. Additionally, the plant size in most of the studies was fixed and very big. The big plant size is appreciated regarding to economies of scale. However, it is hard to collect enough biomass feedstock in reality. The quantity of EFB depends on the capacity of existing palm oil factories and the local situation of biomass transportation is not favorable normally. This study focuses on the feasibility analysis of different plant sizes in order to find the smallest plant size that is still profitable. The sensitivity analysis of the plant size, biooil yield, total capital investment (TCI), return on investment (ROI), corporation tax, and the EFB purchasing cost on the product value (PV) is performed to look for key variables affecting economic feasibility.

The paper is organized as follows. Section 2 describes the EFB biooil production plant and the pilot-scale experiment. Section 3 presents the methodology of economic analysis of the biooil plant. The results are discussed in Section 4 and the conclusion is followed in Section 5.

2. Process description and pilot-scale experiment

The EFB biooil production plant consists of five main areas: (1) the pretreatment for EFB drying and size reduction; (2) the fast pyrolysis and solid–gas separation consisting of the fluidized-bed with a combustor, the cyclone and an electrostatic precipitator (ESP); (3) the quenching with an indirect heat-exchanger; (4) the storage of biooil, and (5) utilities including a cooling water system, as shown in Fig. 1.

The properties of EFB are listed in Table 1, which were measured by Daekyung Esco Co., LTD. (Korea). The EFB sample has a similar composition to that of Abdullah and Bridgwater (2006) [2]. The ultimate and proximate analyses are shown for dry EFB containing a moisture of 9.6 wt% and an ash of 5.9 wt%.

Daekyung Esco provided experimental data obtained from a pilot-scale EFB plant of 2 ton-dry EFB/day. EFB was ground into 1–2 mm particles and was fed into the fast pyrolysis reactor (fluidized-bed) kept at 450–550 °C. The heating rate was about 1×10^4 °C/min. The residence time of EFB was about 1.5 s inside the fluidized-bed. The compressed air velocity of the fluidized-bed was kept at 1.6 times of the minimum fluidization velocity. The composition of the three products is given in Table 2 at three different temperatures. The best biooil yield (60 wt%) including water was achieved at 500 °C in the pyrolysis reactor. The biooil yield excluding water was 35 wt% in this plant. The char separated from the cyclones was withdrawn and its yield was 24 wt%. The similar results of the pyrolysis yield were achieved by Kim et al. (2013), which were biooil of 36.6 wt%, water of 17.4 wt%, gas of 17.1 wt%, and char of 28.9 wt% [21]. Since the combustion of char was not integrated in this pilot plant, the exterior heat was supplied to the pyrolysis reactor.

2.1. Process description

The EFB biooil production plant is shown in Fig. 2. EFB is dried and ground prior to being fed into the fluidized-bed pyrolysis reactor. The fluidized-bed pyrolysis reactor was chosen due to its potential to scale up, as well as its operational flexibility. High efficiency cyclones remove solid matter, mostly sand and char, from the gas exiting the pyrolysis reactor. Vapor is sharply condensed by two indirect heat exchangers, thereby yielding biooil. Char from the cyclone and non-condensable gases recycled from the cooler 2 are sent to the combustor to provide heat for the pyrolysis process.

The utilities area consists of an electricity supplier and a cooling water (water storage, water pump, and cooling tower) system. Cooling water used to condense the hot pyrolysis vapor goes to a cooling tower before being recycled. 5% of the water flow (4000 kg/hr) is assumed to be lost in the cooling tower and the loss is about 200 kg/hr for the 1 kton-dry EFB/yr plant. The temperatures of hot and recycled water are about 42 °C and 32 °C, respectively. These assumptions are used to calculate the TCI and operating cost of the utilities area.

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