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Fast pyrolysis of sugarcane residues in a fluidised bed reactor with a hot vapour filter

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ABSTRACT

Sugarcane residues – leaves (SL) and tops (ST) from Thailand were pyrolysed in a fluidised bed reactor incorporated with a hot filter. The aim was to investigate the effects of reaction temperatures and hot filtration on pyrolysis products. The bio-oils were characterised by water, solids and ash contents, density, heating value, pH, viscosity and stability. The optimum pyrolysis temperatures for SL and ST were 429 °C and 403 °C, which gave maximum bio-oil yields of 52.5 wt% and 59.0 wt%, respectively. Using the hot filter reduced bio-oil yield by 7–8 wt%. However, the filtered bio-oils had better viscosity, solids and ash contents and stability.

1. Introduction

It is generally accepted that the fuel shortage and the environmental problems are one of the major crises that need urgent attention. A solution to these problems is the exploitation of renewable energy technology such as fast pyrolysis. Fast pyrolysis is mostly applied to biomass to convert it to a liquid form, termed “bio-oil”. Many researchers studied the production of bio-oil from various types of biomass by many fast pyrolysis reactor configurations. The bio-oil yield could be as high as 80 wt% on dry biomass feed [2] depending on the type of biomass and the reactor unit. The lower heating value (LHV) of bio-oil is typically about 14–18 MJ/kg [2]. Bio-oil can be used as an alternative fuel in furnaces and engines to produce heat and power. In addition, bio-oil can be a raw material for chemical production. Recently, bio-oil has been proposed as a feed for biorefineries to optimise the production of fuels and chemicals to get the highest value out of the bio-oil in social, environmental and economic aspects [1].

Sugarcane is a perennial plant of the genus *Saccharum*. The main sources of sugarcane are Brazil, India, China, Thailand, Pakistan and Mexico. Typically, sugarcane is grown for sugar production. Lately, sugarcane has become an ethanol production feedstock. The demand for sugar and ethanol is increasing. Therefore, it is expected that the residues will increase accordingly. Residues from sugarcane plantations include bagasse, leaves and tops. The bagasses are traditionally used as a fuel in the sugar factories to generate electricity for their own use. The leaves and tops are mostly burnt in the fields and are not efficiently used for energy. In Thailand, some farmers burn the leaves before harvesting the crops, leading to air pollution. Only a small portion of the leaves and tops are used as a compost and animal feed. Globally, sugarcane production is ~2×10^9 Tonnes per year, whereas in Thailand the production is ~1×10^8 Tonnes per year, or 5% of the global production [6]. Assuming a crop to residue ratio of 0.302 for sugarcane residues (leaves and tops) [15], the residues would be ~6×10^8 Tonnes per year or 96 MTOE (Million Tonnes of Oil Equivalent). This would cost ~$US75,000 million based on a $107/barrel crude oil price. Therefore, fast pyrolysis technology applied to sugarcane leaves and tops for bio-oil production would have two advantages – the fuel value and the environmental impact.

Recently Xu et al. [21], investigated bio-oil production by flash pyrolysis of sugarcane residues using a bubbling fluidised bed pyrolyser with a focus on the post treatments of the aqueous phase. They studied the effect of pyrolysis temperature and vapour residence time and

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found that maximum liquid yields were for sugarcane bagasse – 58.1%, external – 52.6% and whole plant – 55.5% which were obtained at the pyrolysis temperature of 400 °C. Although Xu et al. [21] pyrolysed sugarcane residues in a fluidised bed reactor, they did not fully examine the properties of the liquid product. Only the heating value and water content were used to calculate the energy contained in the bio-oil. Subsequently, in 2012, our group reported the fast pyrolysis of sugarcane and cassava residues in a free-fall reactor [16]. The sugarcane residues bio-oils were measured for water content, solids content, pH, specific gravity, elemental composition, heating value and chemical composition by GC/MS. Nevertheless, one of the most important properties of bio-oil – its stability – was not mentioned due to the small quantity of bio-oil produced. Therefore, the current paper continues the investigation of fast pyrolysis of sugarcane agricultural residues by assessing the impacts of reactor types and in-situ upgrading by hot vapour filtration. Hot filtration can be achieved by candle, granular or fixed bed filters. Previous studies applied candle filters to fluidised bed reactor for production of bio-oil from rice straw [7,9], radiata pine [8,14], Bamboo sawdust [7] and Oriental white [13]. A granular filter is another type that has been tested for bio-oil upgrading [4,12,20]. A hot filter based on a fixed bed of glass wool was also tested with a fluidised-bed fast pyrolyser using rice straw and husk [17] and cassava rhizome [18] and found that the bio-oil solids content could be significantly reduced, although the filter design is relatively simple.

In this work, a fluidised bed reactor was used and the products yields and properties were compared with previously reported results using a free fall reactor [16]. This work also assessed the influence of a fixed-bed hot filter on bio-oil properties, especially the solids content, viscosity and storage stability.

2. Experimental

2.1. Biomass feedstock

Biomass samples were sugarcane leaves (SL) and tops (ST) from plantations in north-east Thailand. The samples were sundried, ground and sieved to a 250–425 μm range particle size. Prior to experiments, they were dried in an oven at 105 °C for 24 h to reduce the moisture content to below 10 wt%. Drying the samples also eased the feeding and could reduce the bio-oil water content.

SL and ST samples were tested for their basic properties including proximate and ultimate analyses as well as heating value. The proximate analysis determined the moisture, volatile matter, fixed carbon and ash contents according to ASTM (E1756-01, E872-82 and E1755-01). The ultimate analysis determined carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and oxygen (O) contents using a 'Leco CHN/S Determinator' analyser according to ISO/IEC Guide 22 and EN 45014 standards at the Laboratory Equipment Center, Mahasarakham University, Thailand. The heating values were calculated based on the ultimate analysis results and equations (1) and (2).

The higher heating value (HHV) of biomass was calculated from a correlation developed by Sheng and Azevedo [19]:

$$HHV\left(\frac{MJ}{kg}\right) = -1.3675 + 0.3137C + 0.7009H + 0.0318O^{*} \quad (1)$$

where C, H are percentages on dry basis of carbon, hydrogen, respectively and O* is 100-C-H-Ash.

The lower heating value (LHV) was calculated from HHV and the hydrogen content:

$$LHV\left(\frac{MJ}{kg}\right) = HHV - 21.82171\left(\frac{H}{100}\right) \quad (2)$$

The biomass analysis results are summarised in Table 1.

2.2. Fast pyrolysis apparatus

Fast pyrolysis of biomass was carried out in a fluidised bed reactor unit. The unit consisted of a pre-heater, a biomass hopper, a two-staged feeder, a fluidised bed reactor, two cyclone separators, a hot filter and a bio-oil product collection unit (see Fig. 1). The reactor

Table 1
Characteristics of agricultural residues from sugarcane plantations in Thailand.

Analysis	Sugarcane leaves	Sugarcane tops
Proximate[a] (wt%)		
Moisture	3.5	2.7
Volatile matter	76.5	78.5
Fixed carbon[b]	16.1	14.6
Ash	7.4	6.9
Ultimate (wt%, dry, ash-free basis)		
Carbon (C)	50.8	48.6
Hydrogen (H)	5.0	4.7
Nitrogen (N)	0.4	0.6
Sulphur (S)	0.2	0.2
Oxygen[b] (O)	43.6	45.8
H/C molar ratio	1.2	1.2
O/C molar ratio	0.6	0.7
Molecular formula	$CH_{1.19}O_{0.64}$	$CH_{1.16}O_{0.71}$
Heating value (MJ/kg, dry basis)		
HHV	17.8	17.2
LHV	16.8	16.2

[a] Moisture content is on wet basis, whereas volatile matter, fixed carbon and ash contents are on dry basis.
[b] Calculated by difference.

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