EFFECT OF REACTION TEMPERATURES ON YIELDS AND PROPERTIES OF BIO-OIL PRODUCED BY FAST PYROLYSIS OF NAPIER PAK CHONG 1 GRASS (*Pennisetum Purpureum Schum*)

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ABSTRACT

Napier Pak Chong 1 grass is a renewable energy sources in Thailand. Bio-oil from Napier Pak Chong 1 grass was produced using a bench-scale fluidized-bed reactor. The aim of this work was to investigate the influence of reaction temperature on product yield and properties. The temperature range studied was between 350°C and 550°C. The results showed that the optimal reaction temperature for the production of pyrolysis oil was between 450°C and 500°C. The highest pyrolysis oil yield was 66.3 wt.% on a dry basis of biomass. The bio-oil produced was separated into two phases, i.e., upper and lower phase. The basic properties of the lower phase bio-oil products were determined. The results showed that water and ash contents of this pyrolysis oil were 9.4 wt.% and 0.01 wt.%, respectively. In addition, the densities, pH value and fresh viscosity were found to be 1,101 kg/m^3, 4.22 and 48.3 cSt, respectively.

KEYWORDS: *Napier Pak Chong 1 grass, fast pyrolysis, reaction temperature, bio-oil, fluidized-bed reactor*

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INTRODUCTION

Fast pyrolysis or rapid pyrolysis of biomass is thermal decomposition occurring in the absence of oxygen. It has a very high heating rate and a short hot vapor residence time [1]. In fast pyrolysis, biomass degradations very rapidly to generate primarily vapors and aerosols with some gas and charcoal. After cooling and condensation, a dark brown liquid is formed that has a heating value of approximately half that of heavy oil [2]. This liquid is called “bio-oil or pyrolysis oil”. Many researchers have studied the pyrolysis oil production from various types of biomass using a variety rapid pyrolysis reactor configurations. Bio-oil can be used as an alternative fuel in furnaces and engines to produce heat and/or power [3]. Additionally, bio-oil can be used as a raw material for chemical production.

Napier grass or elephant grass is *Pennisetum purpureum* [4]. It is a renewable resource. Typically, Napier grass is able to grow with little water and few nutrients. Its use for grazing has made productive use of arid lands for food production. Through application of fast pyrolysis technology, Napier grass can be used for bio-oil and biogas production. These can serve as valuable fuels, and also have positive impacts upon the environmental. Studied production of bio-oil from elephant grass via slow pyrolysis at two heating rates, 10 and 50˚C/min, in an infrared furnace [4]. They found that bio-oil primarily consisted of organics acids, phthalate esters, benzene compounds and amides.

In this work, Napier Pak Chong 1 grass was converted into liquid product by rapid pyrolysis process to increase the value of energy crops. Experiments were conducted in a fluidized-bed reactor to investigate the influence of reaction temperatures on yields and properties of pyrolysis oil produced.

MATERIALS AND METHODS

Feed material

Napier Pak Chong 1 grass harvested in Northeastern Thailand was sundried, ground and sieved to collect a sample with a biomass sample size range of 0.25-0.425 mm. Napier Pak Chong 1 grass samples were tested to determine their basic properties, including proximate and ultimate analyses, as well as their heating values. Proximate analysis was used to determine the moisture, volatile matter, fixed carbon, and ash contents according to ASTM standard methods. The ultimate analysis was to determent carbon, hydrogen, nitrogen, sulfur, and oxygen contents. The ultimate analysis was conducted using a Carbon Hydrogen Nitrogen & Sulfur Analyzer Model Carbon 628, 628 S. The heating values on a dry basis of biomass sample were calculated based on the elemental analysis data. The higher heating value (HHV_{dry}) of Napier Pak Chong 1 grass was calculated from a correlation developed by sheng et al. [5] as given in equation (1). The lower heating value (LHV_{dry}) of Napier Pak Chong 1 grass was calculated from higher heating value and the hydrogen content using equation (2) [6].

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

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

$$LHV_{dry}\left(\frac{MJ}{kg}\right) = HHV_{dry} - 2.442 \times 8.936\left(\frac{H}{100}\right) \quad (2)$$

The Napier Pak Chong 1 grass analysis results are summarized in Table 1.

Fast pyrolysis apparatus

The fast pyrolysis of Napier Pak Chong 1 grass was completed in a fluidized-bed reactor. Fig. 1 shows a schematic diagram of the fast pyrolysis apparatus.

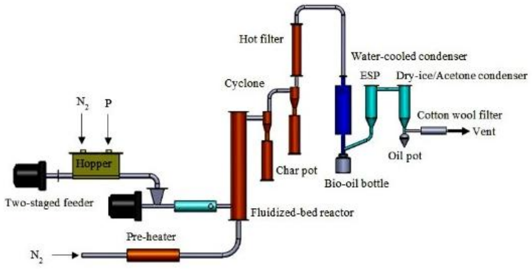

Fig. 1. Schematic diagram of the rapid pyrolysis plant

Table 1. Characteristics of Napier Pak Chong 1 grass

Characteristics	Napier Pak Chong 1 grass	Sugarcane bagasse [a]
Proximate analysis (wt.%, dry basis)		
Volatile matter	85.19±0.20	75.85
Fixed carbon*	9.37±0.20	20.01
Ash	4.99±0.04	4.14
Ultimate analysis (wt.%, dry basis)		
Carbon	47.41±0.14	48.67
Hydrogen	6.44±0.04	6.70
Nitrogen	0.66±0.01	0.45
Sulfur	0.09±0.01	0.08
Oxygen*	40.39±0.13	44.10
Heating value (MJ/kg, dry basis)		
HHV	19.33±0.03	16.81
LHV	17.92±0.03	N/A

[*] Calculated by difference.

[a] Islam et al. [7]

Fast pyrolysis conditions

Table 2 gives the different pyrolysis conditions for each experiments. There were five temperature levels examined, 350°C, 400°C, 450°C, 500°C and 550°C.

Table 2. Reaction conditions

Parameters (Run)	Napier Pak Chong 1 grass 1	2	3	4	5
Reaction temperatures (°C)	350	400	450	500	550
Particle size (mm)			0.25-0.425		
Feed rate (g/hr.)			200-300		
Hot nitrogen flow rate (L/min)			6		
Input (g)			300		
Duration (hr.)			1		

Bio-oil analysis

The pyrolysis oil samples were collected from the water-cooled condenser and electrostatic precipitator. Water content of pyrolysis oil was measured using a Karl-Fischer Moisture Titrator (MKC-520). Ash content of pyrolysis oil was measured as the amount of residue remaining after heating pyrolysis oil to 775°C, for 24 hr. in air [8]. Density of pyrolysis oil was determined using a density bottle at room temperature. The pH of pyrolysis oil was determined with a pH meter (AMT620 Lab PH meter). The pyrolysis oil kinematic viscosity was determined using a ViscoClock Viscometer with a SI Analytics viscosity bath (CT 72/P) according to ASTM D 445 standard methods.

RESULTS AND DISCUSSION

Effect of reaction temperatures on the product distribution

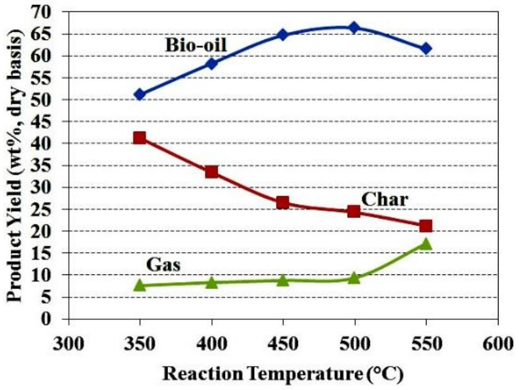

Fig. 2. Effect of reaction temperatures on product yields obtained from fast pyrolysis of Napier Pak Chong 1 grass

Fig. 2 shows the effect of reaction temperatures on the product distribution. Bio-oil yield was maximal in the reaction temperatures range of 450-500°C. The highest pyrolysis oil yield was 66.3 wt.% on a dry basis of biomass. Gas yield increased with increasing reaction temperatures however the yield of charcoal decreased. The higher non-condensable gas yields at higher temperatures were postulated to secondary cracking of the fast pyrolysis vapour and charcoal into non-condensable gas, depending on the reaction temperatures. [9]. This result is consistent with the results of Islam et al. [7] in which pyrolysis oil yield of 56 wt.% was attained for sugarcane bagasse pyrolysis in a fixed-bed fire-tube heating pyrolysis at 475°C.

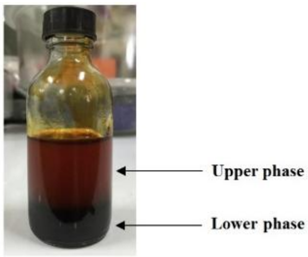

Fig. 3. Bio-oil produced from fast pyrolysis of Napier Pak Chong 1 grass

Characterization of bio-oil

The pyrolysis oil produced from fast pyrolysis of Napier Pak Chong 1 grass were separated into two phase, i.e., upper and lower phase (see Fig. 3). Table 3 shows the water contents of Napier Pak Chong 1 grass bio-oil lower phase was 8.06-9.40 wt.%, which meets the ASTM burner fuel standards [10]. Ash content of pyrolysis oil was around 0.01–0.02 wt.%. The density of pyrolysis oil from the lower phase was 1,101-1,231 kg/m^3. This is a typical value for a fast pyrolysis liquid. The pH of pyrolysis oil in this study was 2.85-4.47. The viscosity of pyrolysis oil from the lower phase was 47.67-52.02 cSt.

Table 3. Characteristics of bio-oil derived from rapid pyrolysis of Napier Pak Chong 1 grass

Properties	Reaction temperatures					ASTM burner fuel standard [a]
	350	400	450	500	550	
Water content(wt.%)						
Upper phase	80.04±4.43	79.01±10.1	77.79±10.5	73.32±19.3	75.46±11.5	30 max
Lower phase	8.72±1.32	8.93±1.40	8.06±0.97	9.40±0.65	8.47±0.93	
Ash content(wt.%)						
Upper phase	<0.01±0.002	<0.01±0.002	<0.01±0.001	<0.01±0.003	<0.01±0.002	0.25 max
Lower phase	0.02±0.004	0.02±0.006	0.01±0.003	0.01±0.004	0.01±0.002	
Density (kg/m^3)						
Upper phase	1,014±2.02	1,017±6.68	1,001±0.43	993±2.21	992±4.43	1,100-1,300
Lower phase	1,231±14.1	1,211±9.11	1,193±12.5	1,101±2.07	1,101±0.59	
PH value						
Upper phase	2.95±0.01	2.64±0.04	4.18±0.03	4.42±0.02	4.78±0.02	Report
Lower phase	2.97±0.01	2.85±0.03	4.12±0.02	4.22±0.02	4.47±0.11	
Viscosity (cSt)						
Upper phase	3.25±0.98	3.44±0.71	2.79±0.12	2.98±0.30	3.07±0.30	125 max
Lower phase	50.70±5.18	47.67±2.80	48.37±1.35	48.29±1.72	52.02±2.30	

[a]Oasmaa et al. [10]

CONCLUSION

In this study, fast pyrolysis experiments using Napier Pak Chong 1 grass were conducted in a fluidized-bed plant. Results showed that the maximum yields of pyrolysis oil occurred at a reaction temperature of 450-500°C, which resulted in a maximal pyrolysis oil yield of 66.3 wt.% on a dry basis of biomass. The non-condensable gas yields increased with increasing reaction temperatures, although the charcoal yields decreased. The bio-oil produced from fast pyrolysis of Napier Pak Chong 1 grass were separated into two phase, i.e., upper and lower phase.

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