

Effects of Biomass Types, Biomass Pretreatment, and Pyrolysis Temperature on Pyrolytic Product Yields

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ABSTRACT

This research studied the effects of temperatures on decomposition of fast biomass pyrolysis as well as the effects of biomass compositions on the quantity of pyrolytic products. The biomass used were sawdust, unwashed sugar cane bagasse, and washed bagasse (with warm water). The biomass particle sizes were less than 0.425 mm and the pyrolysis process was a continuous process with feeding time around 30-45 minutes. The temperatures studied here were in the range of 450-600°C. The preliminary study of the decomposition of these biomass were obtained by thermogravimetric analysis (TGA) and the results showed that the decomposition temperatures of the three biomass are similar and in a narrow range of 272-373°C. The lowest decomposition temperature of the unwashed-bagasse might be due to the highest amount of hemicelluloses from sugar. On the other hand, sawdust which has the highest amount of cellulose decomposes at the highest temperature. As the pyrolysis temperature increases, the amount of ash decreases while the amount of gas product increases. The highest quantity of bio-oil was achieved at the temperature of 500°C. Among the three biomass, it is likely that unwashed-bagasse results in the highest bio-oil and hence, the lowest amount of gas products. According to GC investigation, it can be observed that the majority of the gas product are methane (60-70%) and ethane (20-30%).

Keywords: pyrolysis, renewable energy, sawdust, sugar cane bagasse

I. INTRODUCTION

Due to the depletion of fossil fuel, renewable energy has drawn significant attention from researchers around the world. Biomass has become one of the interesting renewable energy sources as it is in large supply especially in agricultural areas like

Thailand. Not only is biomass economically beneficial, but also plays an important role in terms of environmental issues. Biomass is a CO₂ neutral resource as growing plants and trees can contribute to sequestration of CO₂, liberating greenhouse effect. There are several means of biomass utilisation as an energy source. From way back biomass was traditionally used as firewood for domestic usage which is an inefficient method as well as causing air pollution such as CO₂ and fine particulates from combustion of biosolids [1, 2]. Fermentation of waste biomass to obtain biogas especially methane have been studied widely [3, 4] and recently studies have attempted to generate bioethanol and hydrogen [5,6]. Other forms of energy such as biodiesel and bio-oil have also been extensively investigated [7-9].

Among these energy sources, hydrogen is recognised as a promising future energy carrier since it is a clean fuel containing a high combustion heat value. Currently, hydrogen is produced mainly via steam reforming of natural gas at oil refineries; however, greenhouse gas emission from the process and insecurity of the resources are major problems. Biomass-derived hydrogen has shown a potential to overcome these shortcomings.

There has been a number of research studies carried out aiming for biomass gasification process development and eventually scale up for commercially use. One of the critical drawbacks of the process is the transportation of biomass to gasification plants. Biomass can be bulky and transportation of biomass not only consumes large amounts of energy and operating costs, but also causes pollution. Up to 75% by weight of bio-oil can be obtained from biomass pyrolysis [10]. As a result, if the biomass is converted into bio-oil at the harvesting site, the handling, distribution, and storage problems of biomass can be resolved. Badger and Fransham [11] compared handling costs between bio-oil, loose biomass, and biomass pellet by considering capital costs for required equipment and instruments and economic analysis showed that although the estimate construction costs for handling systems of bio-oil is comparable to those of biomass, significant savings for bio-oil are derived from land usage, operating costs and maintenance costs. Thus, the two-step utilization (biomass → biomass-derived fuels → hydrogen) is more favorable before the technologies of hydrogen

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storage and transportation are mature enough for cost-effective industrial use [12].

Among the thermochemical technologies, pyrolysis has been widely used for converting biomass resource into combustible gas, bio-oil and char. Pyrolysis as a first stage in a two-stage gasification plant for straw and other agricultural materials deserve consideration and development. Flash pyrolysis gives high oil yields, but the technical efforts needed to process pyrolytic oils mean that this energy generating system does not seem very promising at the present stage of development. Fast pyrolysis using a fluidizing-bed has proven to be effective as it allows efficient heat transfer as well as good temperature control [13-15]. Recently the technology was further proved because the yield of liquid product increased at its processing conditions of (1) very high heating rate ($>100^{\circ}\text{C}/\text{min}$), (2) finely ground biomass feed ($<1 \text{ mm}$), (3) carefully controlled temperature (around 500°C), and (4) rapid cooling of the pyrolysis vapors to make the bio-crude products [16-18]. For the utilization of pyrolytic products from biomass resource, the gas can be considered as gas fuel, whereas the non-aqueous bio-oil can be used either as liquid fuel or as raw material for chemicals. With this regard, pyrolysis has been considered as an available alternative technology that converts sewage sludge into biofuels and valuable chemicals [19, 20].

Bio-oil can be separated into two fractions by water extraction, i.e. an organic fraction with lignin derived materials that can be used for the production of more valuable chemicals such as phenolic resins and a water soluble fraction that can be catalytically steam reformed to produce hydrogen. Although steam reforming of the hydrophobic phase is difficult due to coke formation and catalyst deactivation, direct steam reforming of whole bio-oil is more beneficial as the separation process is not necessary. The successful steam reforming of bio-oil through both simulation predictions [6, 7] and experiments [8-10] has drawn great interest for commercial applications. A fluidised-bed reactor has proven to be effective as it allows efficient regeneration of catalysts that are quickly deposited by carbon from non-volatile materials in bio-oils [9, 11, 12]. Generally, most commercial Ni-based catalysts as well as noble metal catalysts (Pt, Rh, and Ru) were found to be effective for bio-oil's tar elimination [9, 13-15].

In order to achieve high hydrogen production yields from the gasification of bio-oil, it is necessary to fully understand the bio-oil compositions and properties as well as their effects on the process. This research aims to characterise and relate the oil compositions and properties to biomass source and pyrolysis conditions. These oils and information obtained will be used for further gasification process to ultimately obtain hydrogen as a clean renewable energy source.

II. EXPERIMENT

A. Biomass Preparation

Sugar cane bagasse and sawdust were wastes obtained from local sugar cane juice shop and a furniture factory, respectively. Pretreated biomass was the sugar cane bagasse that was soaked in warm water for 2 hours to remove the remaining sugar and hereafter called 'washed bagasse'. The raw materials were sun dried to get rid of the moisture and then milled and sieved to different sizes prior to performing thermogravimetry analysis (TGA) to determine decomposition temperatures.

B. Pyrolysis

The pyrolysis system composed of a vertical pyrolyzer connected to a screw feeder and condenser system as shown in Fig. 1. The pyrolyzer was 4 in. in diameter and 12 in. long, and made of stainless steel. The condenser system was $\frac{1}{4}$ in. stainless steel tube, 1.2 m in length and shaped as shown in the figure followed by three Allihn condensers maintained at -15 to -25°C using a mixture of ice and salt. At the end of the condenser, a gas bag is connected to collect gas at certain time (10, 20 and 30 min.). Prior to starting the experiment, the furnace was set at a desired temperature. Once the temperature reached the set point, nitrogen gas at a rate of 1L/min. was purged through the pyrolyzer for 15 min. The biomass was then fed to the system at a desired feeding rate controlled by the screw feeder. Once the experiment finished, the biomass feeding was stopped and the furnace was turned off. The system was left to cool down for about 1 hr and bio-oil and char were collected and weighed.

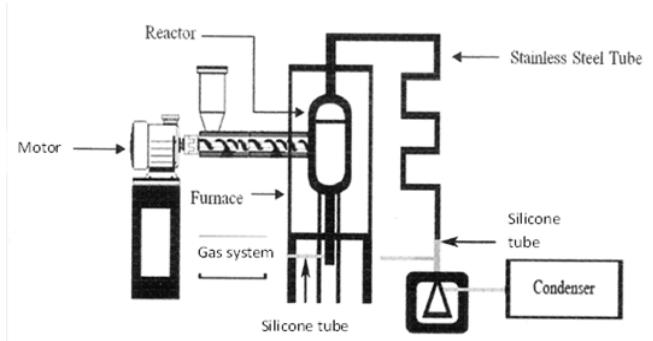


Figure 1 Pyrolysis system

III. RESULTS AND DISCUSSION

A. Thermogravimetry Analysis (TGA)

Decomposition temperatures of each biomass were investigated using TGA under nitrogen atmosphere. Mettler Toledo TGA850 was set with a heating rate of $10^{\circ}\text{C}/\text{min}$ for a temperature range of 30 - 1000°C . Fig. 2 shows that both unwashed and washed-bagasse had a two steps decomposition over the range of 270 - 370°C while there was only one decomposition step in

the range of 310-370°C for sawdust. This might be due to the sugar contents in the sugar cane bagasse which are small molecules that can decompose easily. The weight loss at around 100°C indicated that unwashed- bagasse had the highest moisture of around 11% whereas washed-bagasse contained about 2% and sawdust had the lowest moisture content of 1%. At a temperature higher than 400°C, all biomass degraded gradually. At 1000°C, sawdust decomposed almost 100% but both bagasse had about 5% ash remaining.

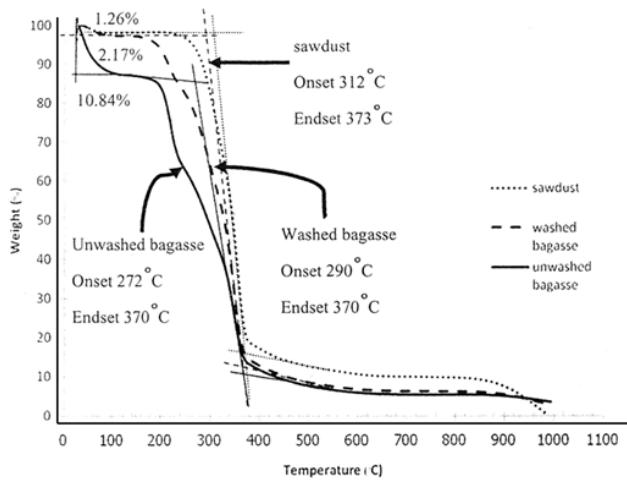


Figure 2 TGA of different biomass

B. Product Yields

Fig. 3-5 illustrate ash, bio-oil, and gas yields of the three biomass. Only washed-bagasse was carried out at 450°C. As the temperature increases, the amount of ash decreases whereas the amount of gas increases. As expected, unwashed-bagasse showed the highest amount of ash and bio-oil yields, resulting from the high sugar content. It was found that the pyrolysis temperature of 500°C seemed to be the best condition as the highest yield of bio-oil was obtained.

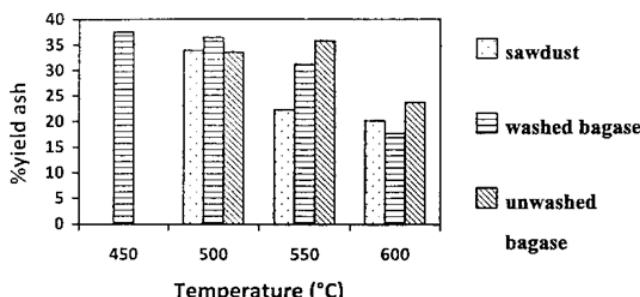


Figure 3 Ash yield

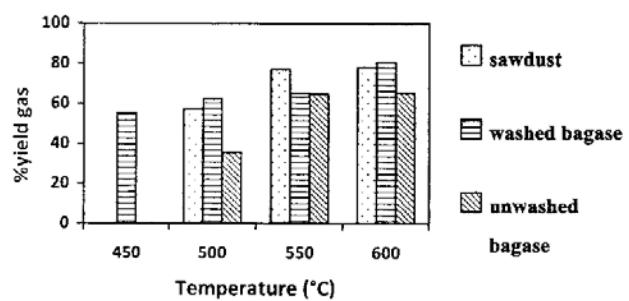


Figure 4 Gas yield

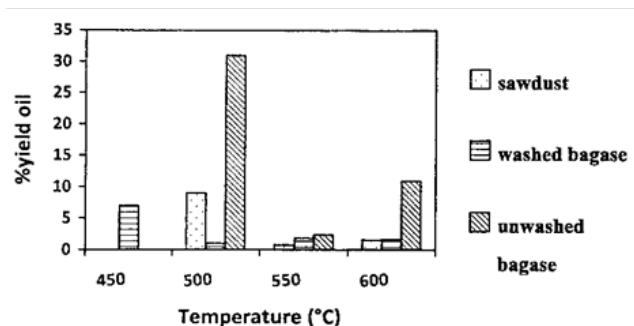


Figure 5 Bio-oil yield

C. Gas Chromatography (GC)

GC analysis as shown in Fig. 6-8 indicates that the majority of the gas products for all three biomass were methane with the approximated concentration of 1×10^{-6} to 1×10^{-5} mol/min and ethane at the concentration of 1×10^{-6} mol/min. It can be seen that different pyrolysis temperatures did not affect the gas yield except for washed-bagasse at 500 and 550°C.

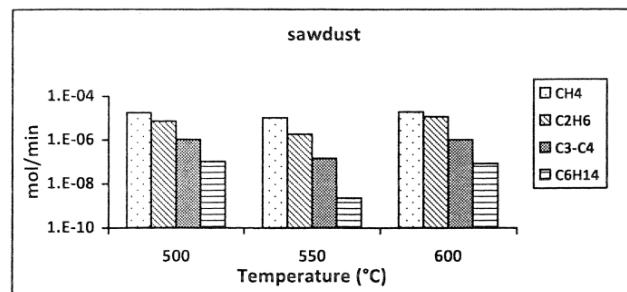


Figure 6 Gas yield from pyrolysis sawdust

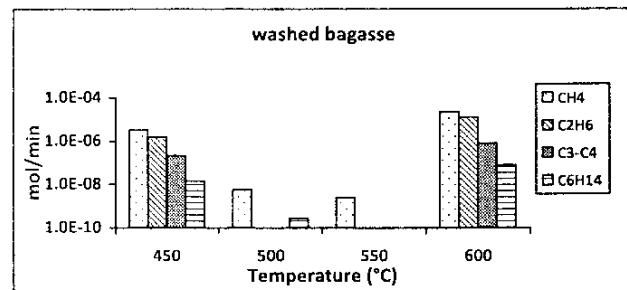


Figure 7 Gas yield from pyrolysis washed-bagasse.

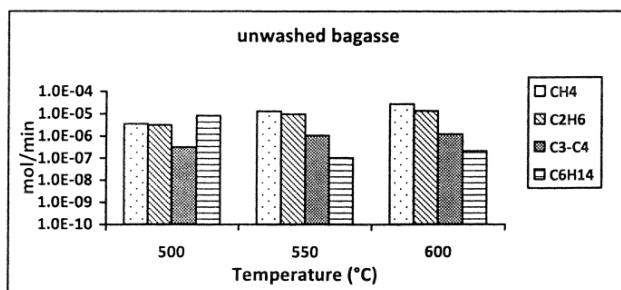


Figure 8 Gas yield from pyrolysis unwashed-bagasse.

IV. CONCLUSION

From both TGA and product yield analysis, decomposition temperatures and the product yields of the three biomass were not significantly different. Pretreatment of biomass (washed-bagasse) reduced the sugar content, hence reducing the bio-oil yield compared to untreated bagasse (unwashed-bagasse). The highest amount of bio-oil yield was 30% by the pyrolysis of unwashed-bagasse at 500°C.

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