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Investigating the Potential of Biomass Pyrolysis as a Self-Sustaining Energy Source

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Abstract—*As the global demand for energy increases and as fossil fuel reserves continue depleting, the need for a green, renewable energy source such as biomass is becoming more and more apparent. In this study, pyrolysis of biomass was carried out at temperatures of 350°C, 450°C and 550°C, and the yield of biochar, bio-oil and gaseous products was measured. Basic characterisation of the products was performed, and the composition of the gaseous products was analyzed to determine if a self-sustaining system could be achieved solely through energy obtained from the gaseous products, thereby leaving the biochar and bio-oil to be used for other higher-value applications. Calculations based on gas composition showed that the pyrolysis process at each temperature could indeed be sustained just by energy obtained from combustion of the gaseousco-products, thereby demonstrating the potential of biomass pyrolysis as a self-sustaining energy source.*

Keywords*: Biomass, Self-sustaining, Pyrolysis, Biochar, Bio-oil, Bioenergy.*

1. INTRODUCTION

Energy plays a vital role in the developmental activities of any nation. The growing world population, coupled with industrialization and rapid technological advancement has caused a massive increase in the worlds energy demand. Today, over 80% of the worlds energy is supplied by the combustion of fossil fuels [1].As fossil fuel reserves continue depleting, and the damage they cause to the environment becomes more and more apparent, the need for alternate energy sources such as biomass that are both efficient as well as renewable is becoming increasingly evident.

Biomass refers to biological material derived from living, or recently living organisms, that can be converted to higher value products or energy [2]. It most often refers to plants or plant-derived materials, such as wood, crops and agricultural residue. Conversion of biomass into higher value products and energy, can be done by several thermo-chemical processes such as combustion, gasification and pyrolysis. Pyrolysis has an advantage over the other processes due to its low capital costs and lack of waste products.

Pyrolysis can be defined as the thermal decomposition of organic matter at elevated temperatures in the absence of oxygen [3]. It is an irreversible process involving the simultaneous change of both chemical composition and physical phase. The pyrolysis of biomass results in the formation of three co-products: biochar, bio-oil and pyrolysis gas. From these three products, both biochar and bio-oil can be considered medium to high-energy density materials [4], and have a host of other high value applications in addition to being used as biofuels. High value chemicals can be extracted from bio-oil for use in applications ranging from furnace oil to cosmetics. Furthermore, the biochar produced finds use an excellent soil amender due to its ability to improve the nutrient retention and water holding capacity of soil.

In this study, we test the feasibility of using the gaseous co-products as a source of fuel to run the pyrolysis system, thus freeing up the bio-oil and biochar co-products for use in other higher-value applications. In particular, we test whether the system is self-sustaining, i.e. whether the energy obtainable from the gaseous co-products is sufficient to run the entire pyrolysis process.

2. MATERIALS AND METHODS

2.1 Feedstock

All experiments were performed using biomass collected around the ICT campus. General garden waste such as leaves, stalk and branches were converted into pellets and used as feedstock for the pyrolysis.

2.2 Experimental set up

The pyrolysis set up used for the experiments is shown in Figure 2.1.

A standard mass of feedstock (100g) was loaded batch wise for each pyrolysis run. The system was heated at a constant rate of 5°C per minute. The condensable liquid product was collected through the measuring cylinder (labelled Product Collector) and weighed. The gaseous products were collected in the Tedlar bag. After pyrolysis, the solid residue (char) left inside the reactor was weighed. The weight of the gaseous/volatile products was calculated from the material balance.

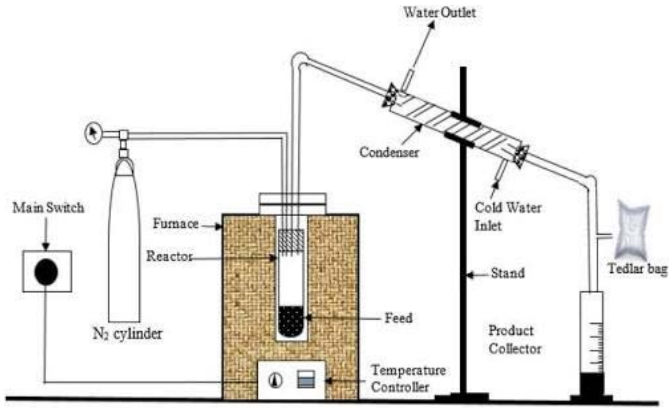

Figure 2.1: Pyrolysis experimental set up

The pyrolysis runs were performed at 350°C, 450°C and 550°C and the mass of the char, liquid products and gaseous products was measured at each temperature.

2.3 Characterization of Products

As this study focuses on the pyrolysis gas composition (and thus heating value), limited analysis was performed on the solid and liquid products.

2.3.1 Characterization of Bio-Oil

Ultimate Analysis was performed on the oil sample to determine the elemental composition of the material.

2.3.2 Characterization of Biochar

The solid residue (biochar) derived from the biomass pyrolysis was characterised using Scanning Electron Microscopy (SEM) with an acceleration voltage of 20kV at magnifications of 400X, 500X and 1000X to obtain a clear view of the surface morphology of the char.

2.3.3 Characterization of Gaseous Products

Gas samples were collected during each pyrolysis run using Tedlar bags, and were then analysed for the concentration of H_2, CO, CH_4, CO_2, C_2H_4, C_2H_6 and C_3H_8 gases using Gas Chromatography (GC). The composition of the gaseous products was analysed at various temperatures and was used to calculate the amount of energy that could be obtained from combustion of the gases.

3. RESULTS AND DISCUSSION

3.1 Product Distribution

The yield of products from the pyrolysis of biomass at various temperatures is shown in Figure 3.1.

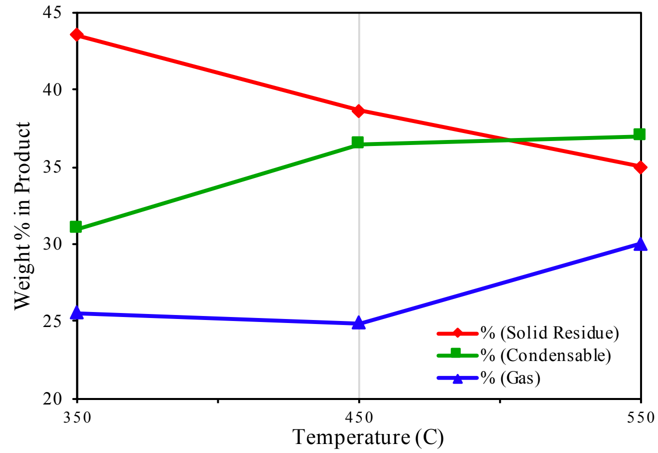

Figure 3.1: Variation of the % yield of products with temperature

As evident from the figure, increasing the temperature from 350°C to 550°C causes a decrease in the yield of char (from 43.48% to 35.00%) and an increase in the yield of the condensable liquid fraction (from 31.00% to 37.00%). The yield of the gaseous fraction first decreases (from 25.52% to 24.88%) as the temperature increases from 350°C to 450°C and then increases (from 24.88% to 30.00%) as the temperature rises to 550°C.

The results of this analysis are summarised in table 3-1.

Table 3-1: Distribution of solid, liquid and gaseous products from the pyrolysis of biomass

Feed quantity (g)	Product yield (wt %)	Pyrolysis Temperature (°C)		
		350°C	450°C	550°C
100	Char	43.48	38.64	35.00
100	Liquid	31.00	36.48	37.00
100	Gas	25.52	24.88	30.00

3.2 Ultimate Analysis of Bio-Oil

The results of the Ultimate Analysis of the bio-oil product are summarised in Table 3-2.

Table 3-2: Elemental Composition of Bio-Oil

Element	Weight %
Carbon	10.943
Nitrogen	0.883
Hydrogen	10.416
Oxygen	77.758

Additionally, the theoretical calorific value of the sample was determined to be 1461.8 cal/g.

3.3 SEM Analysis of Char

SEM analysis was performed to determine the surface morphology of the char. Figures 3.2, 3.3 are 3.4 are SEM images taken at 400X, 500X and 1000X magnification respectively.

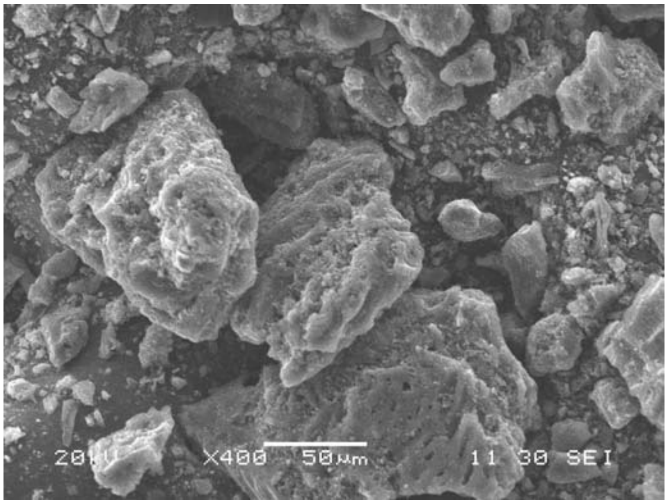

Figure 3.2: SEM image of char at 400X magnification

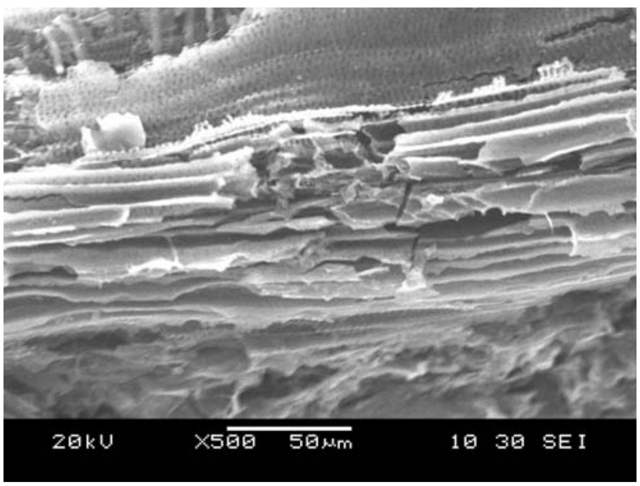

Figure 3.3: SEM image of char at 500X magnification

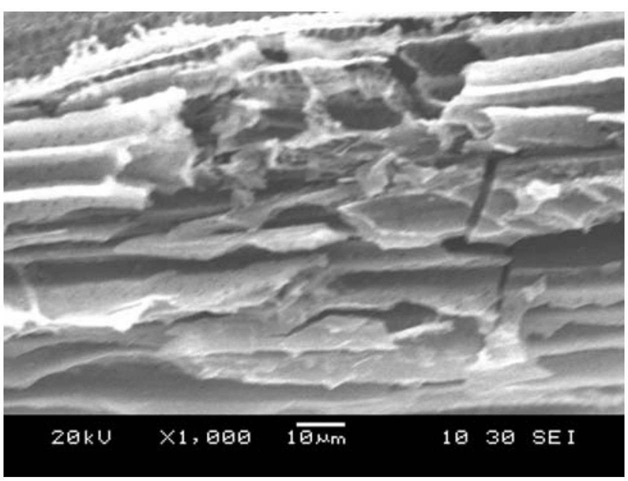

Figure 3.4: SEM image of char at 1000X magnification

3.4 GC Analysis of Gaseous Products

The results of the Gas Chromatography are summarised in Table 3-3.

Table 3-3 Composition of gaseous products for pyrolysis at different temperatures

Temperature(℃)	350	450	550
H_2	0	2.61	3.97
CO	18.22	73.28	72.26
CH_4	6.44	7.45	1.27
CO_2	6.96	1.06	0.35
C_2H_4	0	15.5	21.69
C_2H_6	5.10	0	0
C_3H_8	63.2	0	0

3.5 Self-Sustaining System

The following calculation was performed using data for the pyrolysis at 550°C.

Mass of feedstock = 100g = 0.1kg

Specific heat capacity of biomass ≈ 0.478kcal kg^{-1} K^{-1}[5]

Initial temperature of the system = 30°C

Initial temperature of the system = 550°C

The energy required to heat the biomass pellets from 30°C to 550°C is determined by the formula:

$Q = mC_p\Delta T$

where:

m = mass of feedstock

C_p = specific heat capacity of biomass

ΔT = change in temperature

Hence, the energy needed for the pyrolysis Q = 0.1×0.478×(550-30) = 24.86 kcal (Energy Input)

Mass of gaseous product = 30g

Proportion of CH_4 = 1.27%

Proportion of H_2 = 3.97%

Proportion of CO = 72.26%

Calorific value of CH_4 = 13.28 kcal g^{-1}[6]

Calorific value of H_2 = 33.89 kcal g^{-1}[6]

Calorific value of CO = 2.41 kcal g^{-1} [6]

Energy obtained from CH_4 = 1.27×0.3×13.28 = 5.06 kcal

Energy obtained from H_2 = 3.97×0.3×33.89 = 40.36 kcal

Energy obtained from CO = 72.26×0.3×2.41 = 52.24 kcal

Total energy available in pyrolysis gases = Energy from CH_4 + Energy from H_2+ Energy from CO

= 5.06 + 40.36 + 52.24 = 97.66 kcal (Energy Output)

Net Energy Return = Energy Output – Energy Input = 97.66 – 24.86 = +72.80 kcal

A positive value for Net Energy Return indicates that the system produces more energy than is required to operate it.

Similar calculations performed for the pyrolysis at 350°C and 450°C, also yield positive values for Net Energy Return (13.17 kcal and 89.12 kcal).

Thus, the pyrolysis of biomass is a self-sustaining system.

4. CONCLUSION

The pyrolysis of biomass at 350°C, 450°C and 550°C was shown to produce gaseous products having sufficient energy to maintain the pyrolysis process. It was thus shown that the pyrolysis of biomass is a self-sustaining energy source with only the gaseous products being used to sustain the system. This lowers the carbon footprint of the process, while allowing the other co-products, bio-oil and biochar, to be used for other higher-value applications. Further study could be performed to determine the temperature for pyrolysis which would allow the maximum yield of bio-oil and biochar, while still producing sufficient gas to power the system.

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