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PYROLYSIS FOR SOLID WASTE MANAGEMENT AND BIOFUEL PRODUCTION

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Abstract
Solid wastes, agricultural waste (biomass) inclusive are generated daily in the course of human activities. Their management poses serious challenges to sustainable environmental management. These wastes, however, hold promise in the generation of biofuels through a thermal degradation process of pyrolysis especially fast (flash) pyrolysis. By this process, products composition include solid components (bio-char), liquid components (bio-oil) and gaseous components (syngas) with liquid products making up over 60%, though actual product distribution depends on operating conditions such as temperature, heating rate, biomass composition. These can be formulated to make the biofuel to be used in internal combustion engines. Unlike conventional fossil fuel, utilization of bio-fuel from pyrolysis of biomass does not contribute to carbon dioxide (green house gas) emission into the atmosphere. Therefore, biomass energy is an emerging alternative to the depleting fossil fuels which are great source of greenhouse gases and are non-renewable. This paper highlights the prospects of pyrolysis of solid wastes (biomass) as a source of energy and other valuables thus constituting a valuable and additional option in solid waste management.
Keywords: Pyrolysis, agricultural wastes, bio-fuel, biomass

Introduction
Solid wastes are discards or ‘throw aways’ or rejects of solid composition which are generated in the course of man’s daily activities. At home they are domestic wastes, in the farm they are agricultural wastes, in the markets they are commercial solid wastes while industrial wastes are generated in industries. It is natural that wastes are end products which man generates in the course of his activities. They differ from the regular products of human activities in that they are usually not found to be useful materials in the course of these activities; they are therefore the unwanted end products of these activities. There are many types of solid wastes depending on their nature, composition, source and use. While some of these solid rejects are metallic or plastic, others are organic and biodegradable. Solid wastes are rapidly generated in the course of human activities; as such they occupy valuable space at the detriment of other valuable production inputs. In many developing countries, commonly used disposal options for solid and general wastes are usually of the end of pipe technic considering these items as spent and useless components of the environment that are to be thrown away. Their disposal is usually done without detailed planning and most litter the environment creating nuisances. These create additional challenges to the sustainable management of these wastes and the environment. Renewable energy is of growing importance due to the impact of environmental pollution; as well as issues of the depletion of fossil fuels. The main renewable energy sources are solar, wind, hydroelectric, biomass and geothermal power. Nowadays, biomass is considered as a renewable resource with high potential for energy production (Isa *et al*, 2009). Biomass is available as a potential resource for energy generation and for chemicals (Demirbas, 2007). Furthermore, it is the only renewable source of carbon and can be converted into convenient solid, liquid and gaseous fuels (Isa *et al*, 2009). Biomass contains stored chemical energy, originally derived from the energy of sunlight. Photosynthesis involves the use of energy in sunlight to convert CO_2 and water (from air) in to carbohydrates which are a source of chemical energy (Rolando, 2001).

Photosynthesis is a process by which plants use solar energy to transfer the low energy CO_2 into energy rich organic compounds. Thus, solar energy is captured and stored in the form of chemical energy. The energy, which is stored in plants and animals (that eat plants or other animals), or in the wastes that they produce is called biomass energy. This energy can be recovered by burning biomass as a fuel. Biomass energy is derived from plant and animal material, such as wood from natural forests, wastes from agricultural and forestry processes and industrial, domestic, human or animal wastes. Large quantities of agricultural plant residues are produced annually worldwide and are vastly underutilized (Isa *et al,* 2009). The energy obtained from agricultural wastes or residues is a form of renewable energy and, in principle, utilizing this energy does not add carbon dioxide, which is a greenhouse gas, to the atmospheric environment, in contrast to fossil fuels. This is because the carbon dioxide that is emitted in the utilization of biomass energy is the same carbon dioxide that is captured during photosynthesis. Due to the lower content of sulfur and nitrogen in the biomass waste, its energy utilization also creates less environmental pollution and health risks than fossil fuel combustion (Kendry, 2002).

Pyrolysis of Biomass: Pyrolysis is thermal degradation either in the complete absence of oxidizing agents, or with such a limited supply that gasification does not occur to an appreciable extent or may be described as partial gasification. Relatively, low temperature of 500 to 800°C is employed compared to 800 to 1000°C in gasification (Energy, 2012). Pyrolysis is the basic thermochemical process for converting biomass to a more useful fuel (Demirbas, 1998). Biomass is heated in the absence of oxygen or partially combusted in a limited oxygen supply, to produce a hydrocarbon rich gas mixture, an oil-like liquid and a carbon rich solid residue (Isa *et al*, 2009). Utility of biomass as feedstock depends on the general information about the organic components (hemicellulose, cellulose, lignin), proximate analysis (moisture, volatile, fixed carbon, ash), ultimate analysis (carbon, hydrogen, oxygen) and heating value. Biomass contains varying amounts of cellulose, hemicellulose and lignin. Cellulose is a straight and stiff molecule with a polymerization degree of approximately 10,000 glucose units (C6 sugar). Hemicelluloses are polymers built of C5 and C6 sugars with a polymerization degree of about 200 sugar units. The chemical and thermal stability of hemicellulose is lower than that of cellulose. Lignin is a three dimensional branched polymer composed of phenolic units. Due to the aromatic content of lignin, it degrades slowly on heating and contributes to a major fraction of the char formation. In biomass, cellulose is generally the largest fraction followed by hemicellulose, lignin, ash (Bridge, 1999). The pyrolysis processes can be categorized into slow and fast pyrolysis. Fast pyrolysis is currently the most widely used pyrolysis system. Slow pyrolysis takes several hours to complete and results in biochar as the main product. On the other hand, fast pyrolysis yields 60% bio-oil and takes seconds for complete pyrolysis. In addition, it gives 20% biochar and 20% syngas (Salman, 2009). Fast or flash pyrolysis is used to maximize either gas or liquid products according to the temperature employed (Energy, 2012).

Products of Biomass Pyrolysis: The primary products may be gaseous, liquid or solid depending on the process employed; or the operating conditions. Mostly, interest is in the liquid products due to their ease of storage, transportation, handling in combustion engines and potential for oil substitution (Energy, 2012). The oils (liquid products) from biomass pyrolysis are dark brown viscous liquids (Demirbas, 2007). The liquid is composed of a very complex mixture of oxygenated hydrocarbons. The complexity arises from the degradation of lignin, and a broad spectrum of phenolic compounds. The liquid is often called oil, but is more like tar. This also can be degraded to liquid hydrocarbon fuels (Energy, 2012). Bio-oil is not suitable for direct use in standard internal combustion engines. Alternatively, the oil can be upgraded to either a special engine fuel or through gasification, to a syngas and then bio-diesel (Salman, 2009). Water constitutes 15-30%. Other major classes of components are sugar and anhydro-sugar, alcohol, carbonyl and hydroxycarbonyl compounds, monocarboxylic acids, and phenolic compounds mainly derived from lignin (Demirbas, 2007). In addition, bio-oil is also a vital source of a wide range of organic compounds and specialty chemicals (Salman, 2009). The solid product from pyrolysis is char. Besides being a solid fuel, biochar can also be utilized as a useful, commercialized material, such as filter medium or activated carbon, oil adsorbent, a building material component, fertilizer (Thailand, 1984). The gas products from pyrolysis include CH_4, C_2H_4, C_2H_6, CO, CO_2, H_2, H_2O (Jeno, 2001). Pyrolysis gases should be utilized on or near the site of production. However, the gas is extremely useful for drying crops, water pumping, and heating boilers. The dry and clean gas can also be used for powering internal combustion engines (Thailand, 1984).

Factors affecting Product Distribution of Biomass: The distribution of products depends mainly on the biomass composition and rate and duration of heating. Other factors include; reactor type, catalyst, residence time and presence of reactive gases such as air (oxygen) and hydrogen.

***Temperature and heating rate*:** Table 1 shows the effect of temperature and heating rate on product distribution (Jeno, 2001). Suneerat *et al*, (2008) in their study on the effect of temperature (200-800^{o}C) on the pyrolysis of biomass, observed that significant weight loss occurred at temperatures between 200-400^{o}C after which the weight loss rate was much lower. This is more likely due to the impact of decomposition of cellulose which decomposes quickly at 200-400^{o}C. The decomposition of lignin which is slower but spans over the entire temperature range is thought to be responsible for additional weight loss (400-800^{o}C). Ronaldo, (2001) reported that a rapid heating increases volatile yield and decreases char yield and also leads to a fast decomposition of the biomass to primary volatiles. Rapid pyrolysis of biomass shows that char yield remains constant above a certain temperature and further increase in heating rate because of additional increase of temperature does not affect the char yield.

***Biomass composition*:** Suneerat *et al*, (2001) investigated the relationship between the chemical components (Table 2) and the pyrolysis weight losses of the three biomass samples; rice husk, rice straw and corncob at 850^{o}C. In the experiment, pyrolysis rates were found to be influenced by the proportion of the chemical components of the biomass. The higher the lignin content which normally corresponds to the lower content of cellulose, the lower the pyrolysis weight loss (i.e., lower volatile products). Corncob, which contains the highest cellulose content, gave the highest total volatile yield. Ronaldo (2001) also reported that biomass with higher cellulose content gives more volatile and less char products. Higher yields of char are favoured by high carbon content, low oxygen content, low hydrocarbon content and high content of coke forming component such as lignin.

Table 1: Effect of Temperature and Heating Rate on Product Distribution of Biomass Pyrolysis.

Pyrolysis	Heating rate (k/s)	Residence time (s)	Temperature (^{o}C)	Product
Slow	<1	300-1800	400	Char
			600	Gas/oil/char
Fast	500-10^5	0.5-5	500-650	70% oil; 15% char; 15% gas
Flash	>10^5	<1	<650	Oil
		<1	>650	Gas
		<0.5	1000	Gas

Table 2: Chemical Composition of Selected Biomass

Biomass	Hemicellulose	Cellulose	Lignin
Rice husk	28.6	28.6	24.4
Rice straw	35.7	32.0	22.3
Corncob	31.0	50.5	15.0

Conclusion

Pyrolysis of biomass is a process for the conversion of biomass to solid, liquid and gaseous products, with the liquid products making up over 60%, though product distribution depends on operating variables such as temperature, heating rate, biomass composition. Solid wastes as feed stock for the process of pyrolysis have immense potentials. Pyrolysis of biomass is a source of renewable energy and chemicals. Among the products are biochar, bio-oil and syngas. Bio-oil has comparative advantage because of its ease in storage, transportation and handling in combustion engines. Therefore, as a potential source of energy and chemicals, bio-oil is an emerging alternative to the depleting fossil fuels which are great source of greenhouse gases and are non-renewable. Accumulated deposits of agricultural wastes like rice husks, maize cobs, and other biodegradable solid wastes of organic origin which litter backyards, street corners and threshing floors in our communities can support biofuel production facilities (through pyrolysis) thereby opening up additional frontiers for the management of these solid wastes.

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