Use of Refuse Derived Fuel as Renewable Energy Source via Pyrolysis

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ABSTRACT

The present paper focuses on characterization of solid waste from Chiang Mai, Thailand to generate refuse derived fuel (RDF) and its pyrolysis products. Slow pyrolysis experiments were conducted in an externally heated tube reactor. Effect of temperature on product yields and gas composition were evaluated. It was found that local solid waste contained high proportion of combustible mixture. The pyrolysis product distribution showed strong temperature dependence. RDF from local solid waste was found to release high yields of solid and gaseous products. Amount of tarry liquid was significant when pyrolyzed at 600 ^{o}C and 700^{o}C. Pyrolysis products from solid waste have a potential to be further utilized as fuels.

Key Words: *MSW, Product distribution, Pyrolysis, RDF, Renewable energy*.

1. INTRODUCTION

Solid waste management is growing in importance with population, industrialization and urbanization. Solid waste is mainly generated from residential and commercial refuse in vast quantity and its disposal is problematic in many areas largely because of limited landfill space and rising public concern with environmental problems. Thailand's rapid growth in the past several years has led to a pattern of high consumption. According to the Pollution Control Department, total municipal solid waste (MSW) throughout the country was 13.5 million tons in 1997 and increased to 13.8 and 14.4 million tons in 2000 and 2003, respectively. The increasing trend in per capita generation is expected and has placed a tremendous pressure on the government and local authorities to manage it effectively. In most countries, emphasis has been placed on utilizing solid waste for the generation of electricity as an attractive alternative to landfills [1, 2].

Waste-to-energy (WTE) conversion in modern facilities with adequate and careful environmental monitoring has been shown to be a safe and cost effective technology. WTE conversion has a worldwide adoption and is becoming popular in Asia [3, 4, 5]. One of the options suggested by solid waste management planners is energy generation through production of a refuse derived fuel (RDF) [6]. RDF production process starts with separation and sorting of solid waste to remove recyclable or potentially hazardous materials from the waste stream. The remaining combustible material is crushed and passed to a dryer to remove excess moisture. It is eventually compacted into small pellets. RDF is predominantly composed of paper, plastic and woody materials. The proportion varies, depending on local conditions and recycling programs. It has a number of advantages over untreated solid waste which are the higher heating value, the homogeneity of physico-chemical composition, the ease of storage, handling and transportation and the lower pollutant emissions [7].

A proper thermal pyrolysis method may be adopted to convert RDF into a useful renewable energy source. Pyrolysis is an endothermic thermal decomposition process either with the complete absence of oxidizing agent, or with such a limited supply of oxidizing agent that extensive gasification is avoided and the production of gaseous, solid and liquid products can occur in significant portions [8]. Pyrolysis technology has been widely studied and applied for biomass feedstocks including solid waste. Yan et al. [9] presented their work on pyrolysis of household garbage collected in China, showing product yield as a function of temperature. Li et al. [10] performed similar investigation but focusing on effects of heating rate, moisture content and size of solid waste. Demirbas [11] described pyrolysis of common plastic waste materials including polystyrene, polyethylene and polypropylene while Day et al. [12] examined pyrolysis of mixed plastics from electronic equipment. Sorum et al. [13] investigated pyrolysis characteristics of 11 different components representing dry cellulosic fraction and plastics of MSW to obtain detailed information on chemical kinetics of MSW components. Similar work was carried out by Lin et al. [14] reporting pyrolysis kinetics of RDF.

Nonetheless, there are relatively few studies regarding pyrolysis of solid waste based RDF. Previous studies revealed large variation in pyrolysis product distribution. This discrepancy may be attributed to difference in RDF composition, experimental setup and conditions. The scatter and lack of data regarding pyrolysis of RDF have motivated this work. The present paper describes the characteristics of solid waste in Chiang Mai, Thailand and its possible use as energy source, with emphasis on RDF. Experimental investigation of RDF pyrolysis is also carried out in a laboratory scale to evaluate its gaseous, liquid and solid product yields.

2. SOLID WASTE IN CHIANG MAI, THAILAND

According to the Pollution Control Department, the total solid waste production in the country is over 35 kilotons/day. The per capita generation of MSW in Thailand was approximately 0.5 – 1.0 kg/day, with average value of 0.65 kg/day. Chiang Mai is the second largest city in Thailand. The city accommodates government offices, shopping complexes, medical, agricultural and educational institutions, industrial units and residential areas and is a major tourist destination. The population is around 400,000 with more than three millions visitors a year. The current solid waste collected in Chiang Mai is amounted to about 400 tons/day. The composition of the Chiang Mai solid waste is shown in Table 1, in comparison with different regions in the country. Organic waste is the single major component for the whole country.

For Chiang Mai, combustible and organic components were found to account for about 46% and 35%, respectively. At present, recycling and landfills are practiced for waste disposal and waste incineration is being discussed and planned. Alternatively, with proper pretreatment processes including screening, shredding, size reduction, classification, separation, drying, densification, and storage, approximately 150 tons/day of RDF may be generated. The RDF is mainly composed of paper and paperboard, plastics and woody matter. Fuel value of one energy source is greatly dependent upon its heating value. The heating value of materials may be estimated from formula developed in previous literature [15] as a function of the chemical content:

$$HHV\ (\text{MJ/kg}) = 33.5(C) + 142.3(H) - 15.4(O) - 24.5(N) \quad (1)$$

where *HHV* is the higher heating value of fuel. *C*, *H*, *O* and *N* are carbon, hydrogen, oxygen and nitrogen contents (% by weight of fuel), respectively. The chemical of each RDF component has been evaluated [16] and listed in Table 2. For the Chiang Mai RDF, its heating value is in the range of 18 – 25 MJ/kg.

Table 1 Component of solid waste collected in Thailand in the year 1997.

Component	Fraction by weight (%)				
	Chiang Mai	Bangkok	Central	Northeast	South
Organic waste	34.5	35.5	50.0	53.0	48.8
Paper	14.5	11.6	4.1	10.4	12.0
Plastic	14.9	19.9	15.5	11.1	14.5
Wood	8.6	14.5	8.9	2.1	6.6
Glass	9.2	4.2	1.9	2.0	1.3
Metals	3.9	2.0	6.1	7.9	5.7
Leather, rubber	4.0	0.7	4.7	2.0	3.0
Textile	4.6	3.7	3.3	2.8	1.7
Other	5.8	7.9	5.5	8.8	3.4

Table 2 Chemical composition of main RDF components.

	C (%)	H (%)	O (%)	N (%)	S (%)	Cl (%)	Water (%)	Ash (%)
Paper	34.4	4.7	32.4	0.2	0.21	0.24	21.0	4.6
Plastic	56.4	7.8	8.1	0.9	0.29	3.00	15.0	8.6
Wood	41.2	5.0	34.5	0.02	0.07	0.09	16.0	2.8

3. MATERIALS AND METHODS

The solid waste samples were derived from shredded waste paper, waste plastics and woody materials with average size of 5 mm, according to combustible composition of Chiang Mai solid waste with moisture, organic and incombustibles such as glass, metal and ceramic removed. The pyrolysis experiments were carried out in a laboratory scale, externally heated reactor set up, shown in Fig. 1. The apparatus includes a heating furnace, a pyrolysis reactor, a condenser, temperature probes, a temperature controller, a flow meter and a data acquisition system. The reactor is of cylindrical-shaped, made of 3 mm thick stainless steel, 200 mm in diameter and 350 mm in height. The experimental runs were performed for different temperatures between 400 – 700^{o}C. Temperatures were measured with thermocouples and controlled to within ± 5^{o}C during pyrolysis experiments. RDF was pyrolyzed for a reaction period lasting about 120 minutes. The gaseous products were analyzed in a Shimadzu gas chromatography model GC-8A for HC, CO, H_2 and CO_2.

4. RESULTS AND DISCUSSION

Non-condensable fraction of volatiles released from the pyrolysis process is referred to as pyrolysis gas while the condensed fraction is known as pyrolysis liquid. Solid product is derived from carbon-contained residues remaining in the reactor. The liquid fraction is a complex mixture of water and organic chemicals while the solid fraction contains carbonaceous residue, unconverted organic solid and inorganic ash. Fig. 2 shows variations of mass distribution of pyrolysis products in terms of gas, liquid and solid with temperature. They were reported as a percentage of the initial dry mass (% by weight). The mass balance was very good, close to 100%. It was found that solid product fraction was higher than gas and liquid at all temperatures considered. Solid yield of about 66% was highest at 400^{o}C and appeared to decrease with a further increase in temperature. Gaseous yield was the second highest after solid. It was found to be around 25% initially at 400^{o}C, then undergo no significant change at 500 ^{o}C, and rise slightly to about 32% at 700^{o}C. Meanwhile, pyrolysis liquid yield was observed to increase with a rise in temperature at the beginning, reach the maximum at 600°C, then reduce slightly in spite of a further increase in temperature.

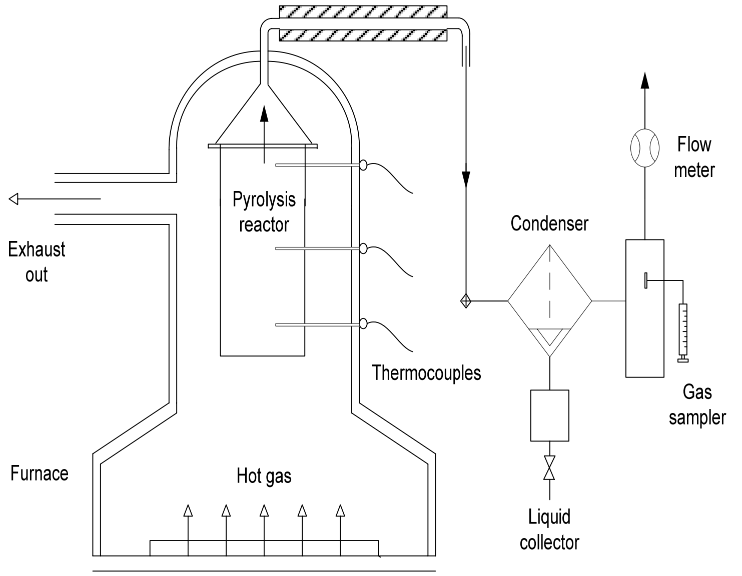

Fig.1 Experimental test setup for pyrolysis.

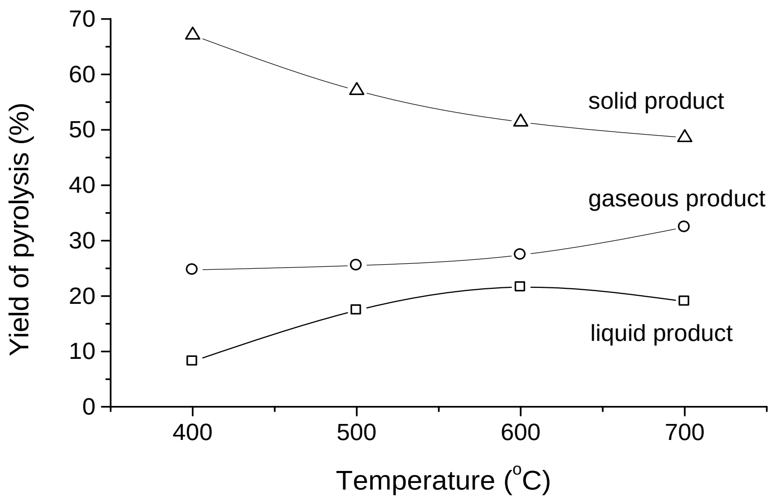

Fig. 2 Yields of pyrolysis products from Chiang Mai RDF.

The results obtained were in qualitative agreement with those reported in the literature [for example 9, 14]. It was clearly seen that at above 500°C, both gaseous and liquid yields increased at an expense of solid product. As temperature changed from 600 to 700°C, while change in solid product yield seemed to be at smaller rate, rise in gaseous product was due mainly to a decline in liquid yield. These outcomes may be attributed to the fact that main reaction stages in pyrolysis of solid waste involve depolymerization, polymerization, decomposition and gasification. A great amount of volatiles is released and solid semi-char is produced. At higher temperature, secondary decomposition is more influential and occurs at higher rate than polymerization. A solid char yield tends to decrease only marginally as a result of secondary char decomposition but heavy volatile matters (both gas and liquid) undergo secondary cracking to form lighter gas [17], resulting in less liquid product. Higher temperature and/or longer residence time may promote gas production at the expense of the liquid produced from the pyrolysis reaction. A possible reaction path for pyrolysis process of the solid waste is illustrated in Fig. 3.

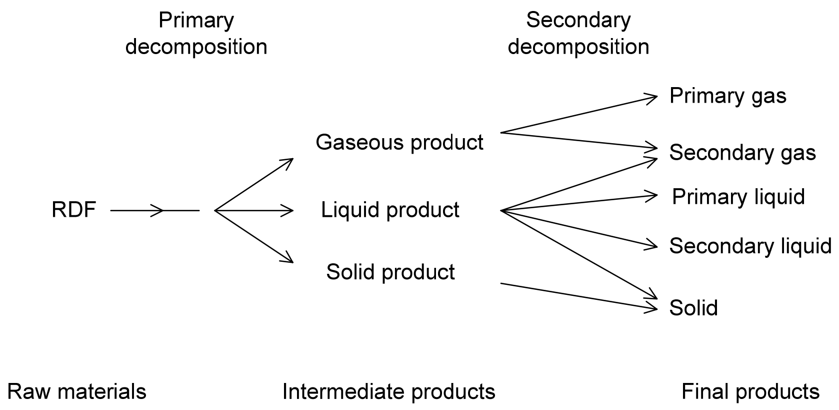

Fig. 3 A possible reaction path for pyrolysis process.

Table 3 Composition analysis of gas products.

Temperature (^oC)	HC (% v/v)	CO (% v/v)	CO_2 (% v/v)	H_2 (% v/v)	N_2 (% v/v)
400	3.5	4.9	42.5	0.0	49.1
500	25.5	11.0	30.0	0.1	33.4
600	18.7	9.6	32.4	0.2	39.1
700	6.1	20.2	57.5	0.0	16.2

Volatiles released from solid waste pyrolysis include CO, CO_2, H_2O, H_2, CH_4, light and heavy HC, and tars. While heavy fraction condenses into tarry liquid, the non-condensable fraction can be considered as a fuel gas. The composition of this fuel gas as a function of temperature is shown in Table 3. Gas content was found to vary considerably with temperature. The pyrolysis gas was found to consist mainly of CO_2, CO, light HC, with negligible amount of H_2. The gas analysis data showed high evolution of CO_2 for the temperature range considered. Low release of CO and HC was evident at low temperature (400^{o}C) but marked increases of CO and HC yields were observed at 500^{o}C. With increase in temperature to 600 and 700^{o}C, HC content appeared to decline while CO content was found to decrease slightly and jump sharply to its maximum value. The gases have a significant heating value. The heating values calculated from the gas analysis data from pyrolysis temperatures of 400 – 700^{o}C were in the ranges of 5 – 10 MJ/Nm^3. The gas obtained can be used as a low heating value gaseous fuel. The solid residues are carbon rich with high heating value and relatively pollution-free potential solid biofuel. The liquid product has a potential to be used as a fuel oil substitute. They may be used in current form which is better, compared to the untreated solid waste.

5. CONCLUSIONS

Local Thai solid waste was found to contain high combustible fraction that may be used to generate RDF. Experiments to investigate pyrolysis of the Chiang Mai RDF in a laboratory-scale, externally heated reactor at preheated temperatures of 400 – 700^{o}C were carried out. Yields of pyrolysis products in terms of gas, liquid and solid were observed to be a strong function of temperature. The solid yield decreased whereas the gas yield increased. The liquid yield increased at first, reached a peak around 600^{o}C and then declined. The slow pyrolysis process adopted in this work may be practical for application to solid waste treatment. Solid, gas and liquid were the three separate components of the pyrolysis products and may be utilized as a better form of fuel in combustion process than the untreated solid waste.

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