# Thermochemical Conversion of Municipal Solid Waste to Produce Fuel and Reduce Waste

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## ABSTRACT

A 250 $dm^3$ pyrolysis reactor was designed, fabricated and tested for performance. The feedstock for the reactor was 12kg dried household refuse (a mixture of food waste, fruits/vegetable, paper, plastic and textile materials). The experiment was replicated four times each with the same percentages of waste components in the household refuse. The experiments were performed between $500^0$C and $650^0$C. A waste volume reduction of about 65% on the average was achieved after the experiments and pyrolytic oil of between 5.27kg and 6.85kg was obtained. The residues obtained were mainly char (25%) which showed that the process has a potential for the treatment of municipal solid waste and is a good technology for resource recovery.

**Keyword:** Municipal solid waste; pyrolysis; volume reductions, pyrolytic oil.

## 1. INTRODUCTION

The annual generation of Municipal Solid Wastes (MSW) in Nigeria is 29.78 x $10^9$kg (Ojolo et al., 2004). The main components of these are putriscible materials, paper, plastics/rubbers, textiles, and metals (Ojolo, 2004). These wastes are stored and transported in and through the society's living space and have a great potential of adversely affecting the hygiene of the people living in the areas concerned. It also has a potential for affecting the aesthetic of the environment.

Since the global energy crises of the 1970s, there has been a trend towards use of alternative energy sources to replace fossil fuel worldwide (Czernik et al., 1995). The fuel potential of many waste is a valuable resource and considerable interest has been devoted to it recently to exploit its potential. However, it has been found out that the energy content that could be practically recovered from the wastes would be a small percentage of the total energy required in any nation (Jackson, 1985). This suggests that energy recovery from wastes will only serve as a supplement to the total energy required.

Over the years, different waste management, treatment and disposal methods have been adopted apart from the traditional options of landfill and incineration. Emphasis is now shifting to technologies that will be acceptable to the end users. One of such technologies is pyrolysis (Piechura, 1998; Eugene, 1998). Pyrolytic technology among other methods is a way of harnessing the energy in these wastes, providing a good method of disposing the wastes without affecting the ecological system (John et al., 1980; Robert, 1998).

For many metropolitan areas in Nigeria, disposal of MSW often involves the delivery to a transfer station followed by the transportation to a remote landfill. This process is often capital intensive and the costs are likely to increase in the future due to escalating transport costs, as acceptable landfill sites become more remote. Most of these wastes on landfill sites or in other dumping sites are usually incinerated, thereby constituting a source of environmental pollution leading to depletion of the ozone layer. Concerns about $CO_2$ emission may discourage widespread dependence on fossil fuel and encourage the development and utilization of renewable energy technologies including energy from MSW. The key point here is that the use of biosources adds no net $CO_2$ to our environment. As fossil fuels are increasingly replaced by biofuels, the addition of $CO_2$ to the atmosphere will be slowed down dramatically.

The products of pyrolysis of MSW are carbonaceous char, oils, and combustible gases. The product yield during the thermochemical conversion of MSW depends on temperature, pressure, time, reaction conditions, and added reactants or catalysts (Paul, 1982; Demirbas and Kucuk, 1997).

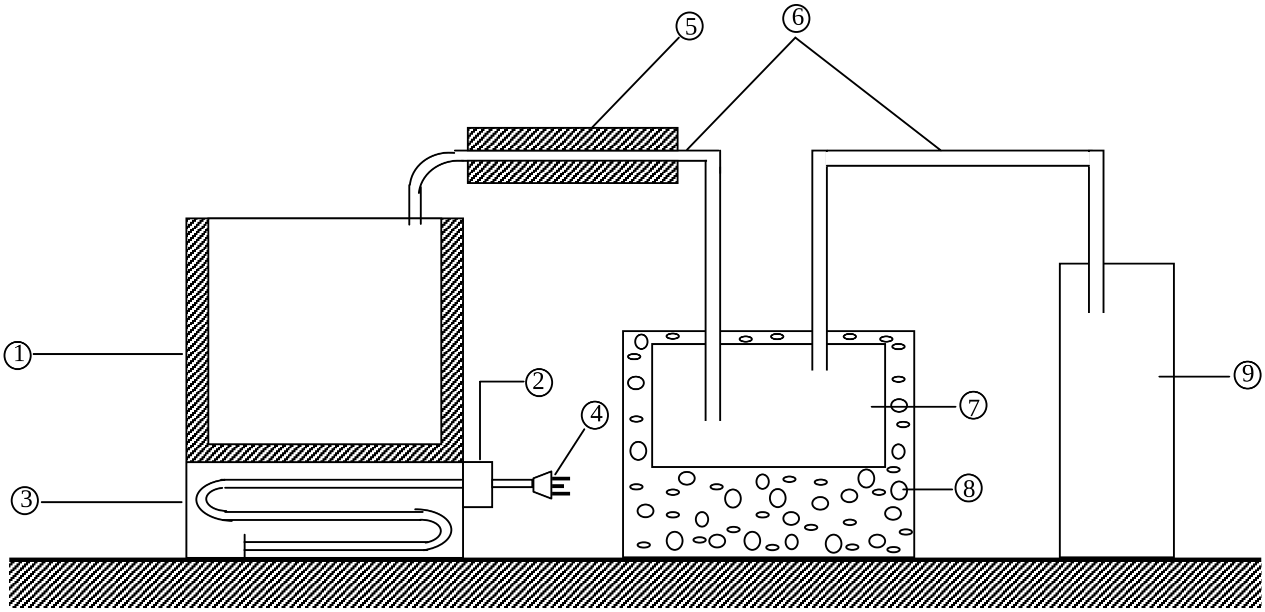
The products of pyrolysis have different chemical and fuel properties. The heating value of char generally was between 25.52MJ/kg and 30.16MJ/kg (Barner and Gerald, 1983). The heating value of tar oil was said to be about 24.7MJ/kg (Anon, 1983); while the heating value of pyrogas was given as 1.51MJ/kg (Anon, 1987).

Pyrolytic processes have been studied previously in other countries using several different types of equipment such as fluidized beds (Kaminsky, 1993; Rajvanshi, 1986; Paul, 1982), rotary kilns (Li *et al*., 1999; Foley, 1986), and rotating reactors (Westerhout *et al*., 1998). Some studies have been conducted using MSW or other sources of wastes (Kaminsky *et al*., 1996; Williams and Williams, 1997; Fink, 1999). The recent works on pyrolysis in Nigeria available for review are the pyrolysis of shredded plastic waste (Ojolo *et al*., 2004), corncobs (Oniya, 2000), and wood (Kucha, 1990 and Fapetu, 1994). Pyrolysis of MSW has not been reported in Nigeria. Therefore, this work is of immense benefit and contribution to the development of MSW pyrolysis technology in Nigeria. The objectives of this work are to thermochemically convert MSW into fuel and to manage wastes through volume reduction.

## 2. EXPERIMENTAL EQUIPMENT AND PROCEDURES

### 2.1 The Equipment

The pyrolytic reactor consisted of a furnace which enclosed a retort, a gas holder, and the condensate receiver (Figure 1). The retort was connected to the condensing unit with copper pipes for easy handling. The cylindrical retort was constructed from 1.6mm thick mild steel. It was sealed at the bottom and had an air- tight cover to prevent emission of gases to the atmosphere and air entrance. A 3500W capacity heating element was placed at bottom of the retort. The heating compartment was well lagged with fibre glass to prevent heat loss to the atmosphere. A $1200^0$C thermostat was used to control the temperature. The thermostat determines the feedstock residence time and the rate of heating. The connecting copper pipes used for the flow of the pyrogas were adequately lagged to ensure that the products were well condensed. The feedstock used in the experiment was household refuse.



1 – Fibre glass; 2 – Temperature control unit; 3 – Heating element; 4 – Power source;
5 – Lagging; 6 – Copper pipes; 7 – Condensate receiver; 8 – Ice; 9 – Gas holder.

Figure 1. The thermochemical experimental setup

### 2.2 Experimental Procedures

The feedstock (MSW) were collected from five waste dumpsites at the University of Lagos, Nigeria. The MSW were dried under the sun for 4-6 hours per day for a period of 8 days to reduce the moisture content. The moisture contents of the dried wastes were between 8-10%. The dried MSW were then pulverized to reduce the particle sizes. The reactor was loaded each time with about 12kg dried MSW from each dumpsites and allowed to operate for 4 hours at a temperature range of $400^0$C-$650^0$C. The average rate of heating was 1.00s/g in all the experiment. The pyrolytic oil produced was collected by distillation in a container embedded in an ice container. The experiment was repeated four times each for the different MSW loadings. The weight and the volume of liquid produced in the container was measured and recorded. The gas produced during the experiment was collected by water displacement in the gas measuring unit. The weight and the volume of the char left in the retort were measured and recorded. The pyrogas produced was tested for combustibility by connecting the gas storage unit to a Bunsen burner. When the gas has built up sufficient pressure inside the gas holder, the burner was ignited. The energy content (heating values) of the pyrolytic oil, char and pyrogas produced were calculated using Doulong Peti's formula as in Sawayama *et al*. (1996).

## 3. RESULTS AND DISCUSSIONS

The result of the pyrolytic experiment is presented in Table 1. From the table, the products of the pyrolysis are char, tar oil and pyrogas in varying proportions. The MSW contain more lignin than animal waste resulting in more oil yield (Zalin *et al*., 1997). Since the MSW have been pulverized, they have less air spaces and smaller particle sizes for the thermochemical reactions. This leads to increased products yield with increasing feedstock weights. The average weights of char and pyrolytic oil per kg MSW are 0.25kg and 0.52kg respectively; the average volume of pyrogas produced is 1.09 l.

As can be inferred from Table 1, the average yield of char produced during the pyrolysis of MSW expressed as a percentage of feedstock was 24.23%. This result is lower than 30-40% obtained by Abe (1988) for wood pyrolysis. Tar oil yield is 52.19%. This result is slightly lower than 53.8% obtained by He *et al*. (1999) for raw swine waste pyrolysis. This could be traced to more oxygen content in MSW as compared to swine waste (Li et al., 1999). The average yield of pyrogas was 22.58% of feedstock. This is higher than 20% obtained by He *et al*. (1999) and lower than 33.82% obtained by Oniya (2000) from dry corncobs.

Table 2 shows the energy contents in the product of pyrolysis. It is observed that energy content in the tar oil is 151.66MJ; this is 59.61% of the energy in the MSW. This shows that tar oil produced from MSW can be used more efficiently as energy and if distilled it can yield some useful petroleum products. This result is higher than 34.56% obtained by Oniya (2000) and 30.5MJ obtained by He *et al* (1999). The energy content in char produced was 89.89MJ. This is 35.33% of the energy in the MSW. This is lower than 53.31% obtained by Bamgboye and Oniya (2004) for corncorbs char. This shows that the char produced from pyrolysis of MSW cannot be efficiently used for energy as compared with corncobs char, the MSW contains less cellulose than corncobs this results in less energy from its char (Antal and Varhegyi, 1995).

Table 1. Products of MSW pyrolysis

| *Exp. No.* | *Wt. of MSW Ww (kg)* | *Wt. of char Wc (kg)* | *Wt. of tar oil Wt (kg)* | *Vol. of pyrogas Vg (l)* | *Operating temp. ($^oC$)* |
|---|---|---|---|---|---|
| 1 | 10.0 | 2.5 | 5.27 | 0.92 | 500 |
| 2 | 11.0 | 2.8 | 5.92 | 0.96 | 550 |
| 3 | 12.0 | 3.0 | 6.25 | 1.05 | 600 |
| 4 | 12.5 | 3.1 | 6.45 | 1.20 | 600 |
| 5 | 13.5 | 3.5 | 6.85 | 1.30 | 650 |
| Ave. | 11.8 | 2.98 | 6.15 | 1.09 | |

Table 2. Energy content in the products of pyrolysis, MJ

| *Exp. No.* | *Energy cont. in char (MJ)* | *Energy cont. in Tar oil (MJ)* | *Energy content in pyrogas (MJ)* |
|---|---|---|---|
| 1 | 75.40 | 130.17 | 3.37 |
| 2 | 84.45 | 146.22 | 3.44 |
| 3 | 90.48 | 153.38 | 4.15 |
| 4 | 93.50 | 159.32 | 4.45 |
| 5 | 105.56 | 169.20 | 4.76 |
| Ave. | 89.89 | 151.66 | 4.034 |

Operating temperature is the most important parameter in the thermochemical conversion process. When the temperature was below $500^0$C, there were intermittent drops of pyrolytic oil in the condensate receiver in all experiments. As the temperature increased from 500$^0$C to 650$^0$C the oil product yield increased (Figure 2). When the temperature was further increased to 700$^0$C, the oil product yield decreased by 11.8%. It was observed that at temperature above 650$^0$C more char was formed which led to the decrease in oil yield. The residence time for all the experiments was set at 4 hours.

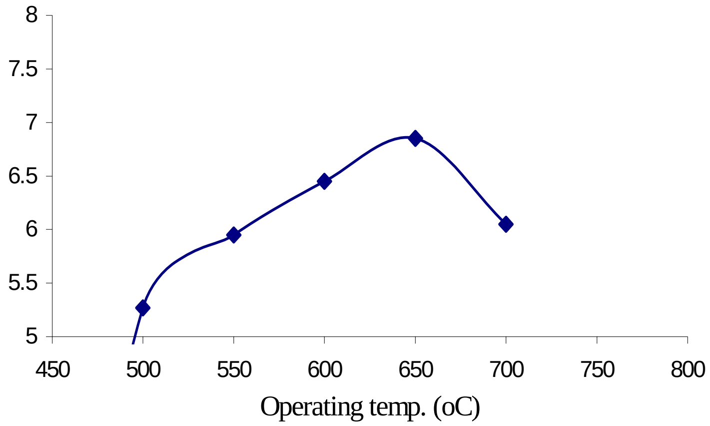


Figure 2. Effect of temperature on tar oil yield

Waste volume reduction decreased linearly with increase in feedstock weight (Table 3). This can be traced to the initial volume occupied by each feedstock. As the volume increases there is uneven and incomplete combustion of the feedstock leading to decreased in volume reduction. Also mass loss during pyrolysis depends on the source materials. Pyrolysis especially at high temperatures, not only reduces volume significantly, but also eliminates the original odour of the source materials (Yoshida, 2000; Shinogi and Kanri, 2003).

On the average there was 65.79% waste volume reduction in all the experiments. This shows that considerable MSW weight reduction can be achieved through pyrolysis and this is a means of MSW management. The char produced was about 25% of the MSW weight before each experiment. This char can be used as refuse- derived-fuel (RDF) similar to the uses of coal.

Table 3. MSW volume reduction after pyrolysis

| *Exp. No.* | *Duration (hr)* | *Operating temp. ($^0$C)* | *Quantity of MSW (kg)* | *Residence time per unit weight (s/g)* | *% waste vol. Red. (v/v)* |
|---|---|---|---|---|---|
| 1 | 4 | 500 | 10.0 | 1.44 | 66.67 |
| 2 | 4 | 550 | 11.0 | 1.31 | 66.35 |
| 3 | 4 | 600 | 12.0 | 1.20 | 65.72 |
| 4 | 4 | 600 | 12.5 | 1.15 | 65.76 |
| 5 | 4 | 650 | 13.5 | 1.07 | 65.02 |
| Ave. | | | | 1.00 | 65.79 |

Char formation increased with decreased heating rate (Figure 3). As temperature increased char yield increased for all materials. A large increase occurred between 550$^0$C and 600$^0$C. This increase may be due to the destruction of cellulose and hemi-cellulose that were present in the MSW.

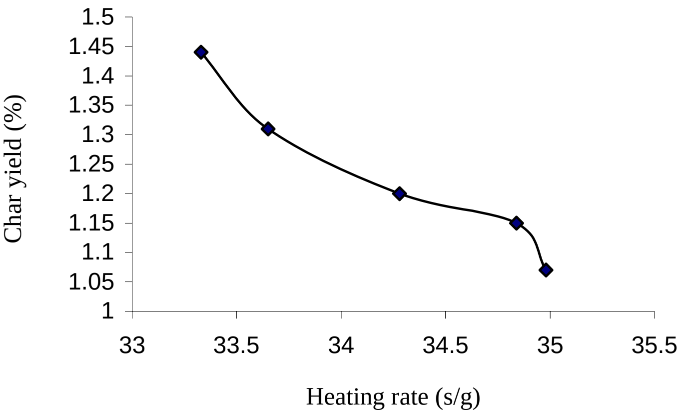


Figure 3. Char formation and heating rate

## 4. CONCLUSIONS

MSW pyrolysis has been investigated. The products of the pyrolysis were tar oil, pyrogas and char. The average yields of tar oil, char and pyrogas from MSW pyrolysis are 52.2%, 25.2% and 22.6% respectively. This shows that MSW can be completely converted into useful fuel products. The mean energy contents in char, tar oil and pyrogas are 89.89MJ, 151.66MJ and 4.03MJ respectively. The char produced can be used as RDF, which could provide heat for the pyrolysis reactions and could be used as fuel for domestic purposes. The tar oil can yield some petroleum products when distilled and could be used as fuel and for industrial purposes. Average waste volume reduction of about 66% was achieved through the pyrolysis of the MSW. This is an advantage over land filling.

Pyrolysis technology has the potential of being applied to the management of MSW which is a cost-effective supply of feedstock for renewable energy generation. Pyrolysis can greatly reduce the waste and odour emissions while producing energy.

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