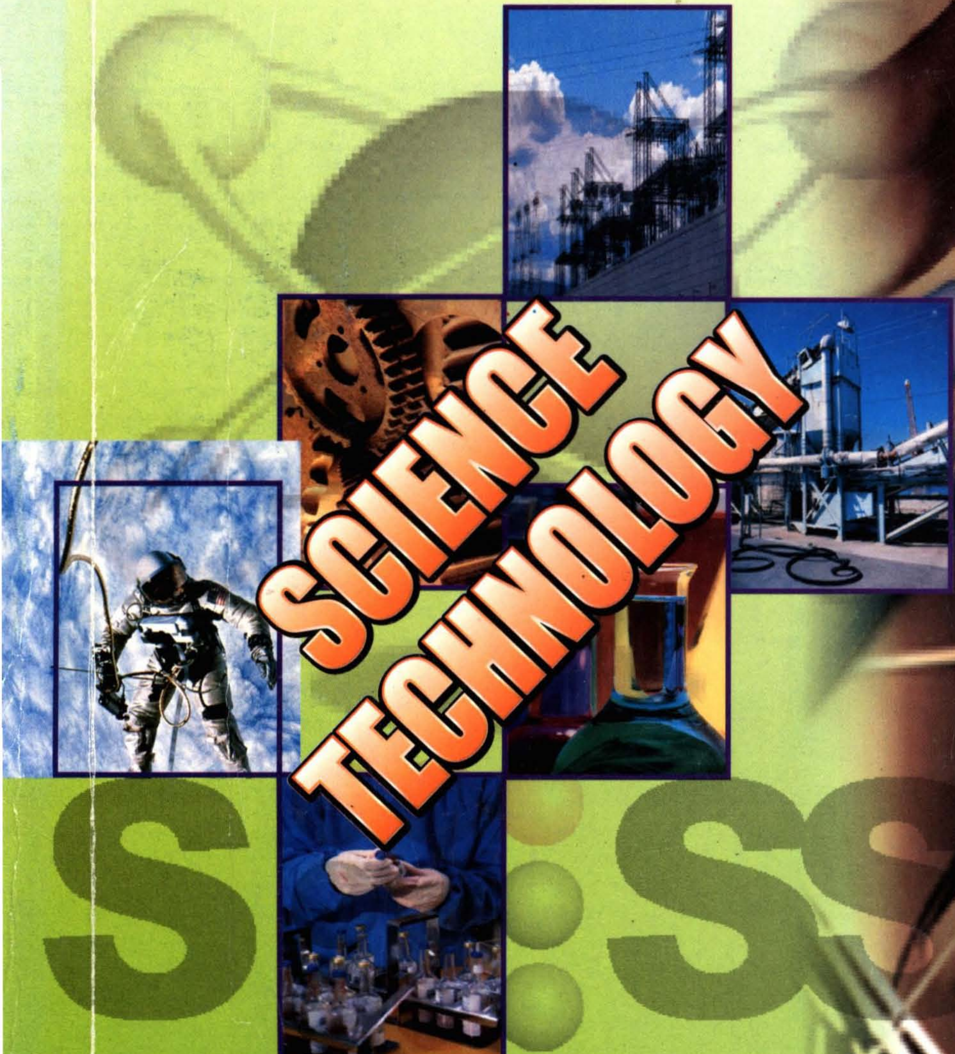
UNIVERSITI TEKNOLOGI MARA

ISO 9001:2000 No Sijil :0500132

Globalising Knowledge and Information

NATIONAL SEMINAR ON SCIENCE TECHNOLOGY & SOCIAL SCIENCES 2006



30-31 May 2006

Swiss Garden Resort & Spa

Kuantan, Pahang

Pyrolysis of Refuse Derived Fuel (RDF)

Raja Razuan Raja Deris
Changkook Ryu
V.N Sharifi

ABSTRACT

Refuse Derived Fuel (RDF) was pyrolysed at temperature ranges from 300°C to 800°C with heating rate of 10°C/min. The char yield decreased with increasing pyrolysis temperature up to 500°C, from 68.19% to 36.76%. Above 500°C, the char yield was almost constant. However, the gas yield (includes the loss of fine oil droplets) shows an opposite trend, with increasing pyrolysis temperature. The oil production was almost stable above temperature 500°C. Liquid yield was very low which was below temperature 400°C because of the temperature was not sufficient enough for the RDF to pyrolyse. However, at temperature above 400°C, most of the oil produced has broken to yield more gas product. The analysis of pyrolysis gas showed that CO and CO_2 are dominant in the early stage of pyrolysis. Hydrocarbon, H_2 starts to appear at temperature above 500°C.

Keywords: *pyrolysis; refuse derived fuel*

Introduction

The pyrolysis and gasification processes, are the two technologies that widely applied for the treatment of special refuse such as rubber, exhausted oils and plastics, can constitute a valid alternative to incineration of the fraction of municipal solid waste (MSW) which can be utilized as a fuel, known as refuse derived fuel (RDF). Three products are usually obtained from pyrolysis: gas, liquid and char. The proportion of which depend very much on the pyrolysis parameters and process conditions such as temperature, heating rate, and gas flow rate. The liquid product from pyrolysis has a moderate heating value, is easily transported and can be burnt directly in thermal power stations. It can possibly be injected into the flow of a conventional petroleum refinery, burnt in a gas turbine, or upgraded to obtain light hydrocarbons for transport fuel (Islam et al. 1999). The solid char can be upgraded to activated carbon. Also, char can be mixed with water and stabilizer to produce slurry fuel. However, the gas produced from pyrolysis process has a high colorific value (CV), that is sufficient to be used for the total energy requirements of the pyrolysis plant (Islam et al. 1999). Much work has been done on MWS especially on incineration and gasification technologies, but not many researchers have focused their work on pyrolysis of material related to MSW especially RDF. This study focuses on optimization of products produced from pyrolysis of RDF material. Palletised Desified-RDF was pyrolysed in fixed bed reactor (130 mm in diameter and 300 mm height) at 300°C to 800°C. The influences of the process conditions on the product yields were studied.

Materials and Methods

RDF material

The RDF sample was supplied by CIVIC Environmental Technology, UK. The sample was made from common municipal solid waste (MWS), which was, palletised of average diameter about 5 mm and length 10 mm to 25 mm. Table 1 shows the proximate and ultimate analyses of the RDF material pyrolysed.

Pyrolysis reactor

The experimental system used was a fixed bed pyrolysis unit. Fig. 1 shows the schematic diagram of the pyrolysis unit. The reactor size was 130 mm in diameter and 300 mm in height, constructed of stainless steel with temperature control. The reactor was heated externally and nitrogen gas flow rate was 2 l/min. The RDF sample of 0.3 kg was loaded on wire mesh in the reactor vessel and slightly tapped to ensure good packing. The furnace control was set to the desired temperature as follows:

Setting Temperature °C	332	360	440	550	645	740	840
Final temperature °C (approx.)	300	350	400	500	600	700	800

The solid and liquid products were removed after the rector cooled to room temperature and quickly weighed to obtain the yield. Gas sample was collected at the outlet of the gas analyser by using gas-sampling bottle. The composition of the gas was measured by gas chromatography.

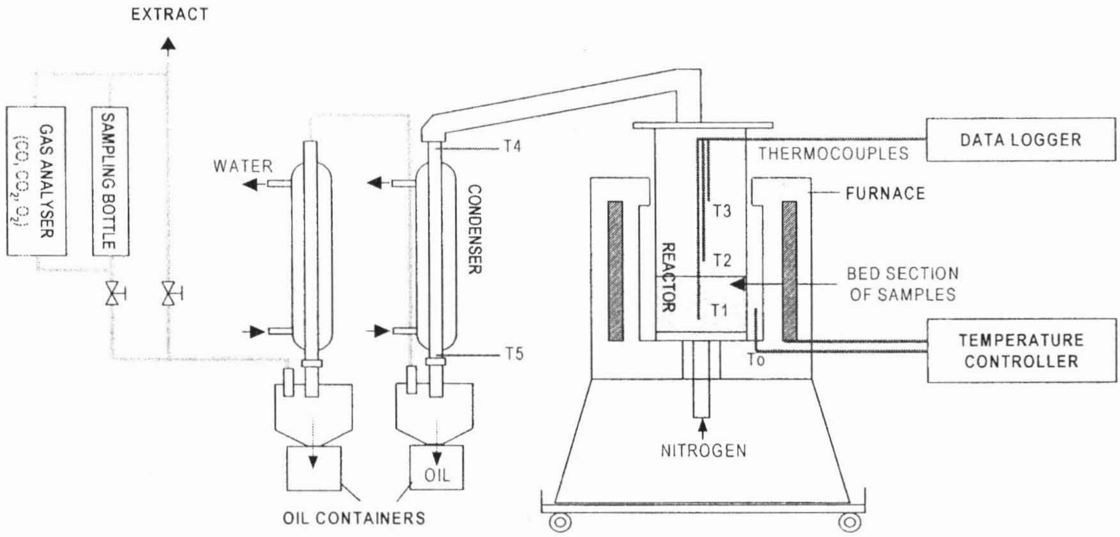


Fig. 1: Schematic illustrations of experimental apparatus for RDF pyrolysis

Table 1: Proximate and Ultimate Analysis of Raw Material (RDF).

Proximate analysis		Ultimate analysis	
Test Parameters	(%)	Test Parameters	(%)
Moisture Content	3.7	Carbon	47.0
Ash Content	13.5	Hydrogen	4.1
Volatile Content	70.0	Oxygen	31.8
Fixed Carbon	13.3		
Calorific Value (MJ/Kg)	20.5		

Results and Discussion

Pyrolysis test - Product yields

Fig. 2 shows the solid (Char) yield decreased rapidly from 68.19% (at temperature of 300°C) to 36.76% (at temperature of 500°C) Above temperature of 500°C the char yield is almost constant with the values from 36.03%, 33.98% and 33.23% at temperature of 600°C, 700°C and 800°C respectively. Liquid yield revealed a consistent result for almost all stage of temperature tested from 14.32% (at temperature 300°C) to 13.79% (at temperature 800°C). Except for the value at 400°C and 700°C the results are slightly higher 19.49% and 16.11% respectively. Below temperature of 400°C, the liquid yield was very low, and this is because below such temperature of 400°C pyrolysis of RDF does not occur or just started to occur. Above 400°C the temperature is high enough to breakdown the high molecules of the RDF materials and converted them into a gas form. The gaseous produced are condensed by the condensers to form liquid. However, above 400°C the temperature is too high which then caused the oil products to quickly breakdown to yield mainly gas product. The gas (includes the loss of fine oil droplets) result shows an opposite trend of solid yield. It shows a rapid increased from 17.49% (at temperature of 300°C) to 50.02% (at temperature of 500°C). Above 500°C the oil yield is almost stable with the value of 50.16%, 49.19% and 52.98% at temperature of 600°C, 700°C and 800°C respectively. For this type of RDF materials, temperature of 500°C is a maximum temperature for the high molecular substances especially plastics materials to breakdown to a smaller form or gas. Further increased on the temperature does not affect the gas yield because there is no more reaction to breakdown the high molecular compounds.

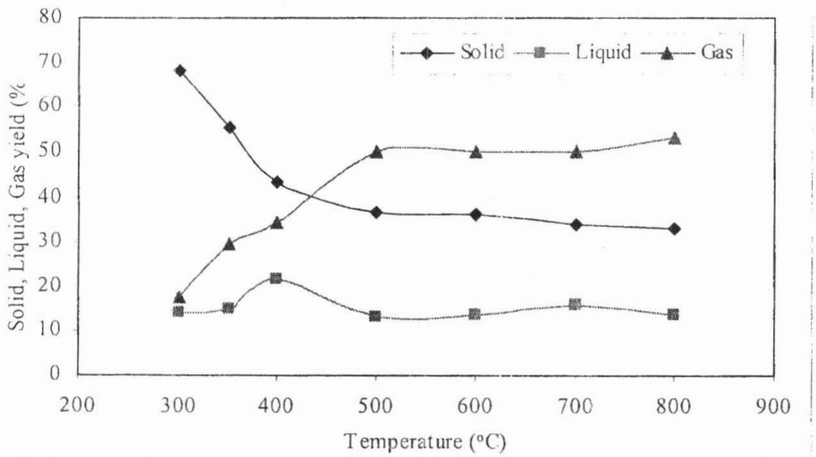


Fig. 2: Effect of temperature on solid, liquid and gas yield

Pyrolysis test - Gas composition

Fig. 3 shows that the percentage of H_2 in the pyrolysis gas increases with the temperature because larger molecules are easier to break into small molecules with increasing temperature. Large molecule contents of CH_4 and C_3H_8 started to form at 400°C and increased steadily up to temperature of 600°C. Above temperature of 600°C CH_4 and C_3H_8 decrease with increasing temperature; however CO increases steadily below temperature of 600°C. The CO_2 gas increases rapidly when the temperature is below 500°C, and then drops sharply with the temperature above 600°C. Nitrogen (N_2) gas is not important in this study. It was used as a sweep gas for pyrolysis process. N_2 gas decreases steadily up to temperature 600°C. It is because the pyrolysis gas increases with increasing temperature. Above temperature 600°C, N_2 gas increased due to decreases in pyrolysis gas.

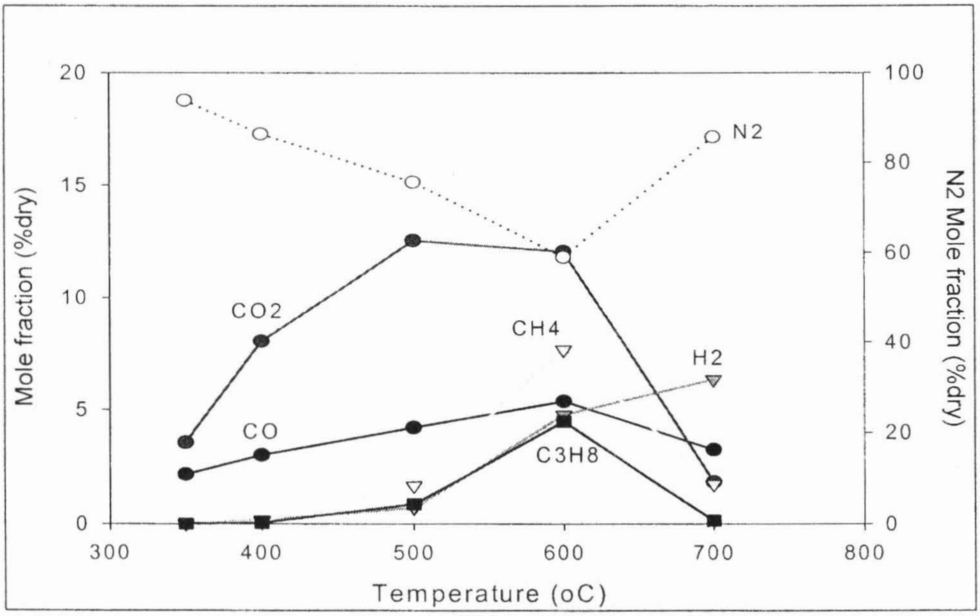


Fig. 3: Analysis of gases during pyrolysis of RDF at different temperatures

Char pyrolysed at 400°C and 700°C

Results of RDF pyrolysed at two different temperature, 400°C and 700°C, are shown in Table 2 and Table 3 as stated below. Such interesting result shown here is that an increase in pyrolysis temperature will increase the percentage of ash and fixed carbon content to around 50%, as for ash content from 31.7% (400°C) to 51.3% (700°C) and fixed carbon from 26.5% (400°C) to 44.3% (700°C). However, the volatile content and CV decrease with increases in pyrolysis temperature, but the CV on "Dry Ash Free Basis" are still very high for both temperatures. The CV of 35.3 MJ/kg (700°C) is similar to that of high rank coals. As for ultimate analysis the percentage of Carbon, Hydrogen and Oxygen content decrease with increases in temperature; 54.5% to 44.5% for Carbon content, 2.6% to 1.9% for Hydrogen content and 10.9% to 1.4% for Oxygen content. However, on "dry ash free basis" the Carbon content at 700°C (92.9%) is much higher then at 400°C (80.2%), therefore it is important to segregate (pre-treatment) the MSW in order to reduce the ash content.

Table 2: Proximate and ultimate analysis of char at 400°C.

Proximate analysis			Ultimate analysis		
Test parameters	(%)	Dry ash free basis (%)	Test parameters	(%)	Dry ash free basis (%)
Moisture Content	0.3	-	Carbon	54.5	80.2
Ash content	31.7	-	Hydrogen	2.6	3.8
Volatile content	32.6	47.9	Oxygen	10.9	16.0
Fixed carbon	26.5	39.0			
CV (MJ/kg)	22.6	33.2			

Table 3: Proximate and ultimate analysis of char at 700°C.

Proximate analysis			Ultimate analysis		
Test parameters	(%)	Dry ash free basis (%)	Test parameters	(%)	Dry ash free basis (%)
Moisture Content	0.8	-	Carbon	44.5	92.9
Ash content	51.3	-	Hydrogen	1.9	4.0
Volatile content	3.5	7.3	Oxygen	1.4	2.9
Fixed carbon	44.3	92.5			
CV (MJ/kg)	16.9	35.3			

Conclusion

Pyrolysis test

1. The solid (Char) yield decreased rapidly as temperature rises from 300°C to 500°C. Above temperature of 500°C the char yield is almost constant with the values from 36.03%, 33.98% and 33.23% at temperature of 600°C, 700°C and 800°C respectively.
2. The liquid yield shows a consistent result for almost all temperature points. The maximum yield for liquid is at temperature of 400°C.
3. The maximum yield for oil production is at 500°C. Above temperature of 500°C production of oil is almost constant.
4. Increases in the temperature during pyrolysis of RDF cause the percentage of hydrogen to increase.
5. CH_4 and C_3H_8 start to appear at around 500°C. Above temperature of 600°C the amount of CH_4 and C_3H_8 decreases with increasing in temperature.
6. The maximum percentages of CO2 and CO gases were at the temperature of 500°C and 600°C respectively. The CO_2 was then stable until 600°C. Above 600°C both gases decreased with increases in temperature.

Raw material analysis

Based on RDF analysis it is concluded as follows:

1. Proximate and Ultimate analysis showed that RDF could be used as an alternative fuel for better environment. However, the main problem with RDF materials is that, it contains high ash content that can lead to corrosion and flue gas treatment problem.
2. Ash and fixed carbon content increased up to 50% with increases in pyrolysis temperature.
3. Calorific value (CV) (on a dry ash free basis) does not change very much as for the temperature of 400°C and 700°C.

Acknowledgements

The authors would like to thank University Teknologi MARA (UiTM), for giving the opportunity and financial support to carry out this study.

References

Brightwater, A.V. & Bridge, S.A. (1991) A Review of Biomass Pyrolysis and Pyrolysis Technologies. In: Bridgewater AV, Grassi,G, editors. Biomass Pyrolysis Liquids, Upgrading and Utilisation. *Elsevier Applied Science*:11-92.

Cozzani V. et al. (1995) A Fundamental Study on Conventional Pyrolysis of a Refused-Derived Fuel. *Ind. Eng. Chem. Res.* 34: 2006-2020.

Cozzani V. et al. (1996) Modelling and Experimental Verification of Physical and Chemical Processes during Pyrolysis of a Refuse-Derived Fuel. *Ind. Eng. Chem. Res.* 35: 90-98.

Cozzani Valerio et al. (1995) Devolatilization and pyrolysis of refuse derived fuels: characterization and kinetic modeling by a thermogravimetric and calorimetric approach. *Fuel.* 74(6): 903-912.

Islam, M.N. & Beg, M.R.A (2003) 'The Fuel Properties of Pyrolysis Liquid Derived from Urban Solid Waste in Bangladesh. *Bioresource Technology.*

Islam M.N. et al. (1999). Pyrolytic Oil from Fluidised Pyrolysis of Oil Palm Shell and Its Characterisation. *Renewable Energy.* 17: 73-84.

Rovatti M. et al. (1994). Pyrolysis of Refuse Derived Fuel: Kinetic Modeling from Product Composition. *Hazardous Materials.* 36: 19-36.

Royal Commission on Environmental Pollution, Eleventh Report – *Managing Waste: The Duty of Care* Presented to Parliament by Command of Her Majesty, December 1985.

Savage P.E. (2000). Mechanisms and Kinetics Models for Hydrocarbon Pyrolysis. *Analytical and Applied Pyrolysis.* 54: 109-126.

Shafizadeh (1982). Introduction to Pyrolysis of Biomass' *Analytical and Applied Pyrolysis.* 3: 283-305.

Williams P.T. (2000) *Waste Treatment and Disposal*: John Wiley & Sons.

Yang X. et al. (2001). Pyrolysis Behavior of Refused Derived Fuel. *Chemical Engineering of Japan.* 34: 91-94.

RAJA RAZUAN RAJA DERIS, Faculty of Applied Science, Universiti Teknologi MARA 40450 Shah Alam, Selangor. razuan@salam.uitm.edu.my

CHANGKOOK RYU & V.N SHARIFI, Department of Chemical & Process Engineering, University of Sheffield, Mappin Street, Sheffield. UK.