OPTIMIZATION OF PYROLYSIS OF OIL PALM EMPTY FRUIT BUNCHES

MOHAMAD AZRI SUKIRAN*; NOR KARTINI ABU BAKAR and CHOW MEE CHIN***

ABSTRACT

In this study, pyrolysis of oil palm empty fruit bunches (EFB) was investigated using a quartz fluidized-fixed bed reactor. The effects of various pyrolysis temperatures, particle sizes and heating rates on the yields of the products were investigated. The temperature of pyrolysis and heating rate were varied in the range of 300°C-700°C and 10°C-100°C min^{-1}, respectively. The particle size was varied in the range of <90, 91-106, 107-125 and 126-250 µm. The products obtained from pyrolysis of EFB were bio-oil, char and gas. Under the experimental conditions, the maximum bio-oil yield was 42% obtained at 500°C, with a heating rate of 100°C min^{-1} and a particle size of 91-106 µm. The maximum yield of char was 42%, obtained at a pyrolysis temperature of 300°C, heating rate of 30°C min^{-1} and particle size of 91-106 µm. Meanwhile, the optimum yield of gas was 46%, which could be achieved at a pyrolysis temperature of 700°C, heating rate of 30°C min^{-1} and particle size of 107-125 µm.

Keywords: empty fruit bunches (EFB), pyrolysis, bio-oil, char.

Date received: 12 September 2008; **Sent for revision:** 18 September 2008; **Received in final form:** 7 January 2009; **Accepted:** 30 July 2009.

INTRODUCTION

Biomass is mainly derived from the agriculture or forestry sector. Today, various forms of biomass are used all over the world for energy generation. Biomass provides a clean, renewable energy source that could dramatically improve the environment, economy and energy security. The use of these materials will depend on a safe state of the art, economics and technologies that are used to transform them into manageable products (Sensoz *et al*., 2006).

Empty fruit bunches (EFB) of oil palm are one of the major solid wastes from the oil palm industry in Malaysia besides fibre and shell. EFB are another valuable source of biomass that can be readily converted into energy. Fresh oil palm bunches processed in an oil mill generate between 20% and 25% EFB, the ligno-cellulosic fibrous materials left after bunch stripping. A mill with a capacity of 60 t of fresh fruit bunches (FFB) per hour will thus produce almost 83 000 t EFB per year. These considerable volumes of organic waste, which are produced on a continuous basis, require effective removal procedures adapted to the nature of the by-product.

Pyrolysis is one of the most promising technologies for biomass utilization (Bridgwater *et al*., 1999; Kawser *et al*., 2004), which converts biomass to bio-oil, char and gases depending on the pyrolysis conditions. Pyrolysis may be described as a thermal degradation of materials in the complete absence or inadequate presence of oxygen.

Yorgun *et al*. (2001a) studied slow pyrolysis of sunflower-extracted bagasse conducted under different pyrolysis conditions in order to investigate the optimum pyrolysis parameters giving maximum oil yield in a fixed-bed reactor. Apaydin-Varol *et al*. (2007) investigated the effect of pyrolysis temperature of pistachio shell on product yield using a fixed-bed reactor. The aim was to find out the final temperature that gave the maximum bio-oil yield. Acikgoz and Kockar (2007) carried out flash pyrolysis experiments which were performed on linseed in a tubular transport reactor. The effects of final temperature and particle size on the yields of the pyrolysis products were investigated. Yang

* Malaysian Palm Oil Board,
P. O. Box 10620,
50720 Kuala Lumpur,
Malaysia.
E-mail: azri@mpob.gov.my

** University of Malaya,
Department of Chemistry,
Faculty of Science, Lembah Pantai,
50603 Kuala Lumpur, Malaysia.

et al. (2006) investigated the pyrolysis of palm oil wastes using a countercurrent fixed-bed reactor under different operating conditions of temperature, residence time and adding a catalyst, in order to achieve an improved performance of palm oil waste conversion to energy with a higher yield of H_2 gas. Uzun *et al*. (2006) investigated the effect of temperature, nitrogen flow rate, heating rate and particle size, influencing pyrolysis product yields from soyabean cake. Sensoz *et al*. (2006) pyrolysed olive bagasse in a fixed-bed reactor and studied the effects of pyrolysis temperature, heating rate, particle size and sweep gas flow rate on the yields of the products.

In this study, pulverized EFB were pyrolysed under different conditions in a fluidized fixed-bed reactor to optimize the process for producing pyrolysis products.

MATERIALS AND METHODS

Empty Fruit Bunches

An EFB of about 5 kg was collected from a palm oil mill located in Padang Jawa, Klang. The bunch was dried at 100 ± 5°C and cut into smaller pieces. It was then milled, sieved and separated into fractions using a test sieve shaker (Endecotts EFL 2000). The separated portion level particle sizes were < 90 μm, 91-106 μm, 107-125 μm and 126-250 μm.

Pyrolysis Experiments

Pyrolysis of the oil palm EFB was carried out using a quartz fluidized fixed-bed reactor. A weighed sample of the pulverized biomass was introduced into the reactor. The reactor of dimensions 135 mm length and 40 mm internal diameter was introduced into an electric furnace. The temperature of the reactor was determined by inserting a thermocouple as near to the upper fritz as possible.

The whole experimental rig that consisted of the volatiles and gas collection system is illustrated in *Figure 1*. A fluidized bed was generated using argon at a rate 1.5 litre min^{-1}, on 160 g zircon sand of 180-250 μm. For each experiment, 2 g of EFB feedstock was introduced into the sand bed.

The whole experiment was held for either a minimum of 10 min or until no further significant release of gas was observed. The connection tubes between the reactor and the cooling system were heated using heating tape to avoid condensation of the pyrolysis vapors.

Before a run, the reactor was weighed. After a run, the cooled reactor was weighed again and the char yield was calculated from the difference. The char remaining in the reactor was elutriated by introducing argon into the sand bed. The bio-oil was collected in a series of flasks placed in a cold trap containing ice. The bio-oil accumulated in the flasks was transferred into a small bottle and the remaining liquid product in the flasks, including all connection tubes, was dissolved with ethanol.

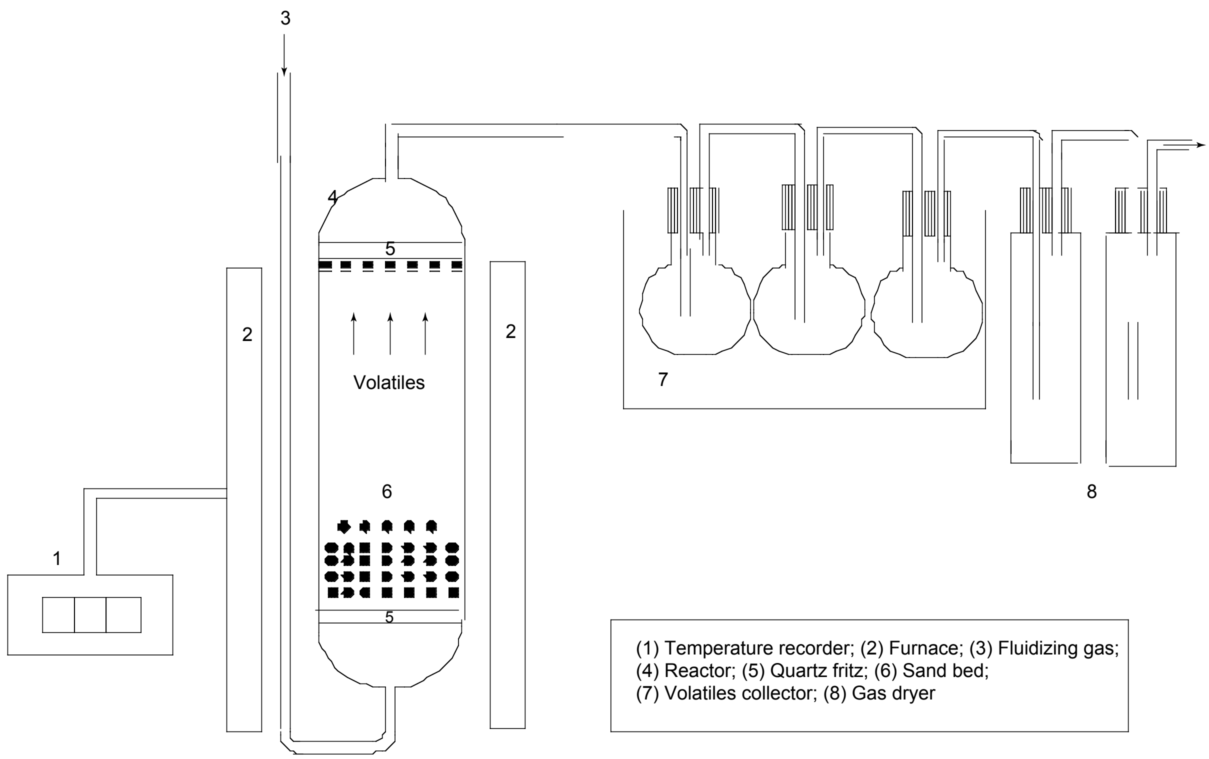

Figure 1. Schematic diagram of the pyrolysis system.

The solvent part of the bio-oil which dissolved in ethanol was extracted in a rotary evaporator and the quality of the bio-oil was thus established. The bio-oil comprising a dark liquid was weighed. The gas yield was calculated from the material balance. Three series of experiments were carried out throughout the study.

Effect of temperature. The first series of experiments were to determine the effect of the final pyrolysis temperature on the pyrolysis products. The temperature of pyrolysis was set at 300°C, 400°C, 500°C, 600°C and 700°C in this study. The heating rate was maintained at 30°C min^{-1} and the particle size of the EFB used was in the range of 91-106 μm.

Effect of particle size. The second series of experiments were to determine the effect of particle size on the pyrolysis products. Four different particle sizes ranging from <90 μm, 91-106 μm, 107-125 μm to 126-250 μm were pyrolysed at a heating rate of 30°C min^{-1}. The final temperature was maintained at 500°C.

Effect of heating rate. The third series of experiments were to determine the effect of heating rate on the pyrolysis products. The heating rates of 10°C, 30°C, 50°C and 100°C min^{-1} were studied. The final pyrolysis temperature was maintained at 500°C and the particle size of the EFB was in the range of 91-106 μm.

RESULTS AND DISCUSSION

Effect of Temperature

As shown in *Figure 2*, at the lowest pyrolysis temperature of 300°C, the decomposition process was relatively slow and char was the major product. As the temperature increased from 300°C to 500°C, the amount of condensable liquid product increased to a maximum value in the range of 33%-35%. At higher pyrolysis temperatures of 600°C and 700°C, the bio-oil yield decreased to 30%-32%. Studies by Yorgun *et al*. (2001b) and Acikgoz and Kockar (2007) on pyrolysis of sunflower oil cake and linseed, respectively, indicated the same trend. The higher treatment temperature led to more bio-oil cracking, resulting in higher gas yield and lower bio-oil yield (Zanzi *et al*., 2002; Chen *et al*., 2003; Ji-lu, 2007). The results obtained from the first series of experiments showed that the maximum bio-oil yield obtained was 35% at the pyrolysis temperature of 500°C. The lowest of bio-oil yield was 27% at the temperature of 300°C.

The char yield significantly decreased as the final pyrolysis temperature was raised from 300°C to 700°C. The highest char yield was 42% obtained at the temperature of 300°C, while the lowest char yield was 23% obtained at the temperature of 700°C. In other words, the pyrolysis conversion was increased as the temperature was raised (Onay *et al*., 2001; Ozcimen and Karaosmanoglu, 2004; Tsai *et al*., 2006). The decrease in char yield with an increase in temperature could either be due to the greater primary decomposition of the EFB at higher temperatures or through secondary decomposition of the char residues.

The highest and lowest of gas yields were 46% and 31% at the temperatures of 700°C and of 300°C, respectively. The gas yield increased with an increase in pyrolysis temperature. An increase in gas products is thought to occur predominantly because of the secondary cracking of the pyrolysis vapours at higher temperatures. However, the secondary decomposition of the char at higher temperatures may also produce other non-condensable gas products (Horne and William, 1996).

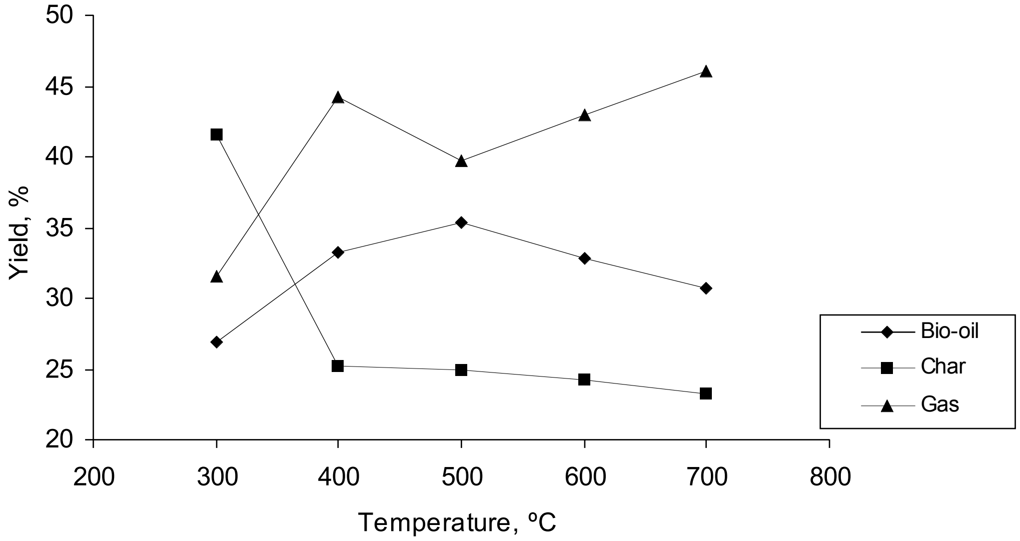

Figure 2. Yield of pyrolysis products at various final pyrolysis temperatures with a heating rate of 30°C min^{-1} and a particle size of 91-106 μm.

Effect of Particle Size

The effect of particle size on the product yields is illustrated in *Figure 3* at the temperature of 500°C and the heating rate of 30°C min^{-1}. The smallest particle size of < 91 μm produced a bio-oil yield of 33%, which was only about 2% higher compared to the yield with the highest particle size. Meanwhile, the char and gas yields were 28% and 39%, respectively. The largest particle size of 126-250 μm produced a bio-oil yield of 31% with a char yield of 28% and gas yield of 41%. The maximum bio-oil yield (35%) was obtained at the particle size of 91-106 μm, while the lowest bio-oil yield (30%) was obtained at the particle size of 107-125 μm. The highest char yield was 29% obtained at the particle size of <90 *μ*m, while the lowest char yield was 25% obtained at the particle size of 91-106 *μ*m. The highest (43%) and lowest (37%) gas yields were obtained at the particle size of 107-125 *μ*m and <90 *μ*m, respectively.

Encinar *et al*. (2000) who pyrolysed cardoon (*Cynara cardunculus* L.) with particle sizes ranging from 0.43-2.00 mm hypothesized that an increase in particle size causes greater temperature gradients inside the particle so that at any given time the core temperature is lower than that of the surface, which possibly gives rise to an increase in the char yields and a decrease in the yields of liquids and gases. Particle size is known to influence pyrolysis product yields. If the particle size is sufficiently small it can be heated uniformly, as shown by the results obtained which are consistent with earlier studies (Seebauer *et al*., 1997).

However, in this work it was observed that the particle size had no significant influence on the production of bio-oil during pyrolysis. Only small differences were obtained, probably due to experimental error. These results were also in agreement with those of Sensoz *et al*. (2006), who reported that particle sizes of olive bagasse below 5 mm did not exert any influence on the process rate.

Effect of Heating Rate

The effect of heating rate on the product yields is given in *Figure 4* at the temperature of 500°C and the particle size of 91-106 μm. The results obtained in this study show that an increase in the heating rate led to an increase in the yield of bio-oil. It was noted that the higher the heating rate, the lower the effect on mass transport limitations (Sensoz, 2003). The bio-oil yield reached a maximum value of 42% with the highest heating rate of 100°C min^{-1}. The lowest bio-oil yield (30%) was obtained at the heating rate of 10°C min^{-1}.

The highest char yield (26%) was obtained at the heating rate of 10°C min^{-1}, while the lowest char yield (21%) was obtained at the heating rate of 50°C min^{-1}. It was observed that an increase in heating rate led to a decrease in char yield. This may be related to the fact that rapid heating leads to a fast depolymerization of the solid materials to primary volatiles, whilst at a lower heating rate dehydration is more stable and an anhydrocellulose is too slow and is limited in occurrence (Chen *et al*., 1997).

The highest and lowest gas yields obtained were 43% and 36% at the heating rates of 10°C min^{-1} and 100°C min^{-1}, respectively.

CONCLUSION

The study on the effect of temperature on product yields has shown that a temperature of 500ºC was optimum for producing the bio-oil product, 300ºC was the best temperature to produce the char product and 700ºC was the best for producing the maximum gas yield under the same conditions of particle size and heating rate. In this study, the particle size was

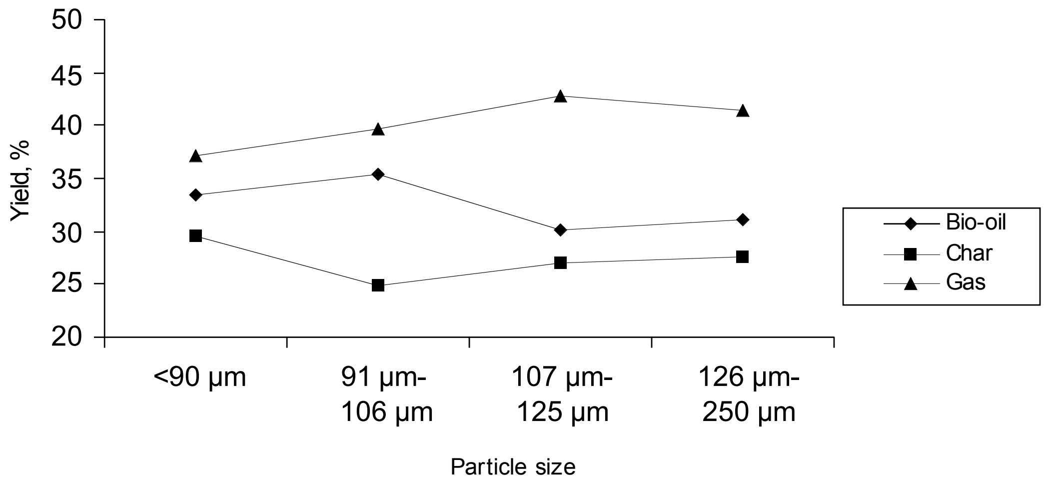

Figure 3. Yield of pyrolysis products at various particle sizes with a final temperature of 500°C and a heating rate of 30°C min^{-1}.

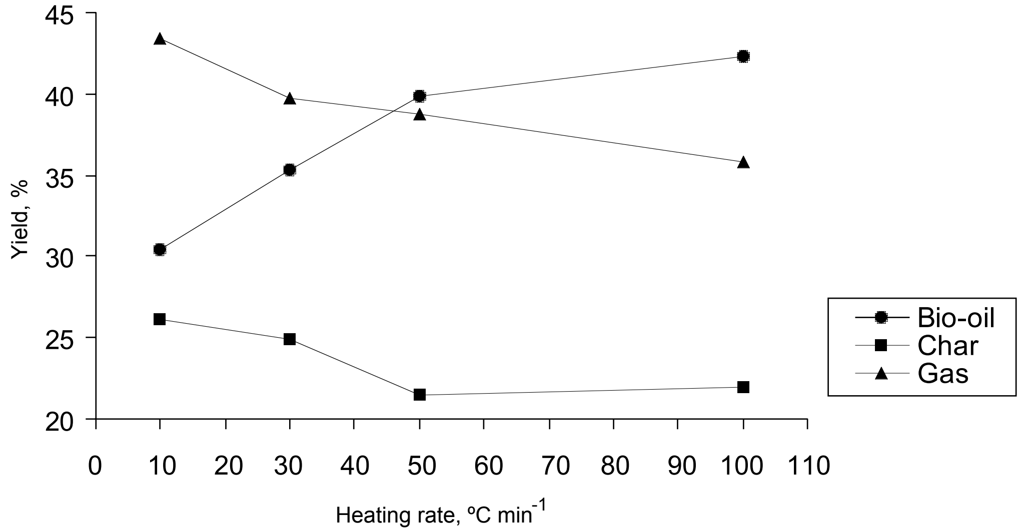

Figure 4. Yield of pyrolysis products at various heating rates with a final temperature of 500°C and a particle size of 91-106 μm.

observed to be optimum in the range of 91-106 μm for producing bio-oil and char products, and a particle size within the range of 107-125 μm was optimum for producing the gas product at the same temperature (500ºC) and heating rate (30ºC min^{-1}). A heating rate of 100ºC min^{-1} was optimum for producing bio-oil and a rate of 10ºC min^{-1} was optimum for producing the char and gas products.

It can be concluded that the optimum bio-oil yield of 42% was obtained at 500ºC, with a heating rate of 100ºC min^{-1} and a particle size of 91-106 μm. The maximum product yield of char of 42% was obtained at the pyrolysis temperature of 300ºC, heating rate of 30ºC min^{-1} and particle size of 91-106 μm. Meanwhile, the optimum gas yield of 46% could be achieved at a pyrolysis temperature of 700ºC, heating rate of 30ºC min^{-1} and particle size of 91-106 μm.

ACKNOWLEDGEMENT

The authors wish to thank the Director-General of the MPOB for permission to publish this article. We would like to acknowledge all staff of the Energy and Environment Unit, MPOB, for their valuable assistance throughout the implementation of the projects. Thanks are also due to MPOB for its Graduate Students Assistantship Scheme to the first author enabling him to pursue his postgraduate study.

REFERENCES

ACIKGOZ, C and KOCKAR, O M (2007). Flash pyrolysis of linseed (*Linum usitatissimum* L.) for production of liquid fuels. *J. Analytical and Applied Pyrolysis, 78*: 406-412.

APAYDIN-VAROL, E; PUTUN, E and PUTUN, A E (2007). Slow pyrolysis of pistachio shell. *J. Fuel, 86*: 1892-1899.

BRIDGWATER, A V; MEIER, D and RADLEIN, D (1999). An overview of fast pyrolysis of biomass. *J. Organic Geochemistry, 30*: 1479-1493.

CHEN, G; YU, Q and SJOSTROM, K (1997). Reactivity of char from pyrolysis of birch wood. *J. Analytical and Applied Pyrolysis, 40-41*: 491-499.

CHEN, G; ANDRIES, J; LUO, Z and SPLIETHOFF, H (2003). Biomass pyrolysis/gasification for product gas production: the overall investigation of parametric effects. *J. Energy Conversion and Management, 44*: 1875-1884.

ENCINAR, J M; GONZALEZ, J F and GONZALEZ, J (2000). Fixed-bed pyrolysis of *Cynara cardunculus* L. Product yields and compositions. *J. Fuel Processing Technology, 68*: 209-222.

HORNE, P A and WILLIAMS, P T (1996). Influence of temperature on the products from the flash pyrolysis of biomass. *J. Fuel, 75*: 1051-1059.

JI, L Z (2007). Bio-oil from fast pyrolysis of rice husk: Yields and related properties and improvement of the pyrolysis system. *J. Analytical and Applied Pyrolysis, 80*: 30-35.

KAWSER, J; HAYASHI, J and LI, C Z (2004). Pyrolysis of a Victorian brown coal and gasification of nascent char in CO_2 atmosphere in a wire-mesh reactor. *J. Fuel, 83*: 833-843.

ONAY, O; BEIS, S H and KOCKAR, O M (2001). Fast pyrolysis of rapeseed in a well-swept fixed-bed reactor. *J. Analytical and Applied Pyrolysis, 58-59*: 995-1007.

OZCIMEN, D and KARAOSMANOGLU, F (2004). Production and characterization of bio-oil and biochar from rapeseed cake. *J. Renewable Energy, 29*: 779-787.

SEEBAUER, V; PETEK, J and STAUDINGER, G (1997). Effects of particle size, heating rate and pressure on measurement of pyrolysis kinetics by thermogravimetric analysis. *J. Fuel, 76(13)*: 1277-1282.

SENSOZ, S (2003). Slow pyrolysis of wood barks from *Pinus brutia* Ten. and product compositions. *J. Bioresource Technology, 89*: 307-311.

SENSOZ, S; DEMIRAL, I and GERCEL, H F (2006). Olive bagasse (*Olea europea* L.) pyrolysis. *J. Biomass and Bioenergy, 97*: 429-436.

TSAI, W T; LEE, M K and CHANG, Y M (2006). Fast pyrolysis of rice straw, sugarcane bagasse and coconut shell in an induction-heating reactor. *J. Analytical and Applied Pyrolysis, 76*: 230-237.

UZUN, B B; PUTUN, A E and PUTUN, E (2006). Fast pyrolysis of soybean cake: product yields and compositions. *J. Bioresource Technology, 97*: 569-576.

YANG, H; YAN, R; CHEN, H; LEE, D H; LIANG, D T and ZHENG, C (2006). Mechanism of palm oil waste pyrolysis in a packed bed. *J. Energy and Fuels, 20*: 1321-1328.

YORGUN, S; SENSOZ, S and KOCKAR, O M (2001a). Characterization of the pyrolysis oil produced in the slow pyrolysis of sunflower-extracted bagasse. *J. Biomass and Bioenergy, 20*: 141-148.

YORGUN, S; SENSOZ, S and KOCKAR, O M (2001b). Flash pyrolysis of sunflower oil cake for production of liquid fuels. *J. Analytical and Applied Pyrolysis, 63:* 1-12.

ZANZI, R; SJOSTROM, K and BJORNBOM, E (2002). Rapid pyrolysis of agricultural residues at high temperature. *J. Biomass and Bioenergy, 23*: 357-366.