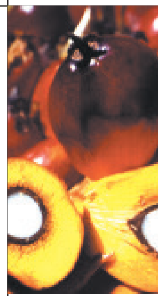

Pyrolysis of Oil Palm Biomass to Multiple Fuels and Products: Experiences of MPOB

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INTRODUCTION

Energy has always played an important role, be it for survival or the continued development of mankind. Biomass has long been utilised in supplying energy since the beginning of civilisation and still so in prospering the economies of developing countries. It has received renewed attention recently mainly as a consequence of high and volatile oil prices and climate change caused by increased fossil fuel consumption. The focus now is on producing biomass energy as an alternative renewable energy source using matured and readily applicable conversion technologies. Oil palm biomass from the Malaysian palm oil industry poses great potential for energy application, which is abundantly available from the palm oil milling activities (*e.g.* empty fruit bunches (EFB), palm kernel shell (PKS) and mesocarp fibres) and oil palm pruning/replanting activities from the plantations (*e.g.* oil palm frond (OPF) and oil palm trunk (OPT)). Thus, oil palm biomass is advantageous to be converted into useful and profitable bioproducts (*e.g.* fuel, chemical and material).

Among the potential energy conversion system, pyrolysis is considerably a more promising pre-commercialisation technology for biomass to bioenergy production. Pyrolysis is the thermal degradation of biomass materials in the complete absence of oxygen. Relatively low temperatures of 350°C to 600°C are employed, compared with 800°C to 1200°C in gasification (Basu, 2013). In general, pyrolysis of biomass produces liquid products (bio-oils) and gas leaving behind a solid residue richer in carbon *i.e.* bio-char. The yields and compositions of the final pyrolysed products are dependent on various parameters, including temperature, residence time, feedstock used, type of reactor, heating

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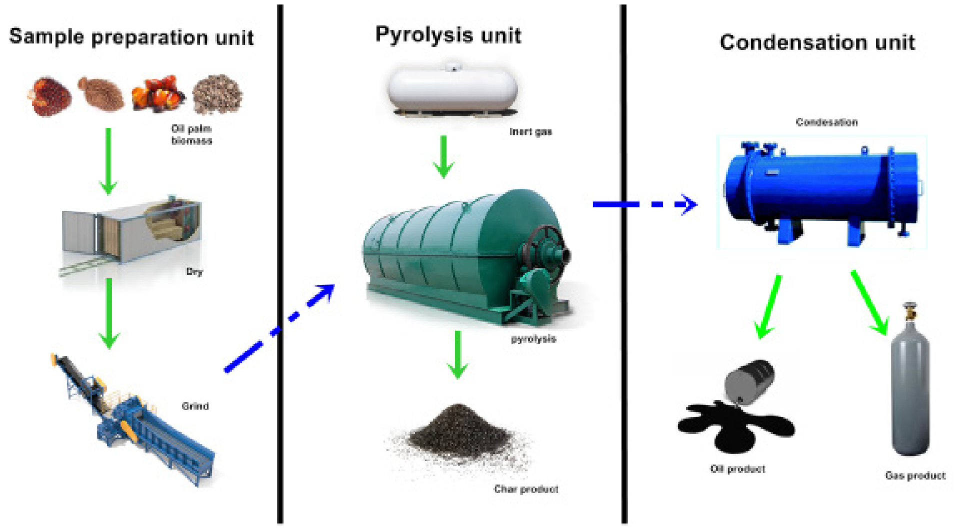


Figure 1. Reactor components in pyrolysis of oil palm biomass.

rate and addition of catalyst (Kong *et al.*, 2014). Pyrolysis is attractive because the biomass wastes which are difficult and costly to manage can be readily converted into liquid products. These liquids have advantages in transport, storage, distribution, combustion and retrofitting, and flexibility in production and marketing.

Pyrolysis Technology

Generally, pyrolysis is performed in a closed reactor system with moderate operating temperatures. The feedstock does not combust, as oxygen or air is absent. The reactor is indeed the 'heart' of the process. Various pyrolysis reactors, such as the fluidised bed, rotating cone, vacuum reactor, entrained flow and simple batch reactor have been designed mostly at laboratory scale (Mazlan *et al.*, 2015). Pyrolysis could be categorised into slow, intermediate, fast and flash. The classification is based on the heating rates and residence times during the process. It can be divided into three stages, i.e. preparation of feedstock, pyrolysis process and product collection (*Figure 1*). Prior to pyrolysis, the samples should be dried and ground to get fine biomass particles for optimum exposure to the process. Nitrogen (N_2) - an inert gas - is commonly used to accelerate vapours sweeping from the hot zone (pyrolysis zone) through the cool zone (condenser). Condensation is an important pyrolysis step for oil production. Without this, only the biochar and gas products can be obtained from the process.

The Malaysian Palm Oil Board (MPOB) Experiences

The Energy and Environment Unit of MPOB has set up a small-scale pyrolysis experimental rig (*Figure 2*). The rig can accommodate 5 g to 10 g of biomass feedstock for each pyrolysis experiment. It can be divided into two components *i.e.* (1) pyrolysis component - fluidised–fixed bed reactor, furnace, fluidising gas (argon gas), thermocouple and sand bed and (2) condensation component - bio-oil collector, gas dyer (silica gel) and water-ice bath. MPOB has conducted both the slow and fast pyrolysis studies for the effects of different temperatures, particle sizes, residence times, heating rates and type of oil palm biomass on pyrolysis products. The studies were conducted at varying temperatures and heating rates from the range of 300°C to 700°C and 10°C min^{-1} to 100°C min^{-1}, respectively. Moreover, the particle sizes and residence times varied in the

Figure 2. The pyrolysis experimental rig available at MPOB.

TABLE 1. DISTRIBUTIONS OF THE PYROLYSIS PRODUCTS FROM VARIOUS TYPES OF OIL PALM BIOMASS

Type of palm biomass	Pyrolysis products[a] (wt.%)		
	Bio-oil	Biochar	Gas[b]
Empty fruit bunches	47.4 ± 2.1	22.3 ± 1.8	30.3 ± 2.2
Palm kernel shell	19.0 ± 3.3	55.1 ± 2.4	25.9 ± 2.1
Oil palm frond	25.7 ± 2.7	42.6 ± 3.4	31.7 ± 3.2
Oil palm trunk	29.4 ± 2.5	16.8 ± 1.8	53.8 ± 1.6

Note: [a]Obtained at temperature of 500°C and particle size of 107–125 μm.
[b]Calculated by difference.
Source: Mohamad Azri *et al.* (2016).

range of <90 to 250 μm and 10 min to 60 min, respectively. In fact, temperature and residence time of the reactor in pyrolysing oil palm biomass are the two most important parameters that determine the type of final product. Four types of oil palm biomass, *i.e.* EFB, PKS, OPF and OPT, were successfully tested using this pyrolysis rig; with final products distribution as shown in *Table 1*. In pyrolysing oil palm biomass at the optimum conditions, *i.e.* temperature of 500°C and particle size of 107-125 μm, the EFB gave rise to the maximum bio-oil yield (47 wt.%), whereas the PKS and OPT led to the most char (55 wt.%) and gas (54 wt.%). Based on these optimum conditions, 1 t of EFB can produce approximately 470 kg bio-oil, 220 kg biochar and the rest are gas products.

CHARACTERISTICS OF THE PYROLYSIS PRODUCTS

The final products of the pyrolysed oil palm biomass include bio-oil, bio-char and gases (*Figure 3*). Bio-oil is dark brown, free-flowing liquid that comprises mainly the oxygenated organic compounds. Chemically, bio-oil is a complex mixture of water, guaiacols, catechols, syringols, vanillins, furancarboxaldehydes, isoeugenol, pyrones, acetic acid and formic acid. Other major groups of compounds present are hydroxyaldehydes, hydroxyketones, sugars, carboxylic acids and phenolics. The important bio-oil fuel properties are viscosity, water content, acidity, density, chemical composition, ash content, calorific value (CV), solvability, ageing and combustion temperature. Examples of bio-oil properties

(a) (b)

Figure 3. Pyrolysis products: (a) bio-oil and (b) bio-char.

TABLE 2. CHARACTERISTICS OF BIO-OILS DERIVED FROM EMPTY FRUIT BUNCHES (EFB) AT DIFFERENT PYROLYSIS TEMPERATURES

Property	Temperature (°C)		
	450	500	550
Calorific value (MJ kg^{-1})	20.5 ± 0.07	21.5 ± 0.02	21.6 ± 0.01
Total ash (wt.%)	0.41 ± 0.01	0.55 ± 0.01	0.38 ± 0.03
pH	3.0 ± 0.02	2.4 ± 0.01	2.2 ± 0.01
Water content (wt.%)	30.1 ± 1.2	27.5 ± 2.4	34.2 ± 2.7
Total acid (mg KOH g^{-1})	84.1 ± 1.5	72.6 ± 2.3	69.0 ± 1.8
Density (g cm^{-3})	0.88 ± 0.01	0.95 ± 0.01	0.90 ± 0.03
Ultimate analysis (wt.%)			
Carbon	35.3 ± 0.14	47.8 ± 0.06	56.3 ± 0.09
Hydrogen	5.67 ± 0.08	6.69 ± 0.02	6.77 ± 0.04
Oxygen[a]	57.6 ± 0.06	43.9 ± 0.04	35.4 ± 0.06
Nitrogen	1.41 ± 0.06	1.68 ± 0.06	1.56 ± 0.02

Note: [a] Calculated by difference.
Source: Mohamad Azri *et al.* (2016).

deriving from EFB at different temperatures are shown in *Table 2*. The produced bio-oil has moderate CV ranging from 21 MJ kg^{-1} to 22 MJ kg^{-1} and contains many chemical constituents, which are valuable as specialty chemicals. The potential applications of bio-oil are as fuel for (1) combined heat and power generation, (2) small stationary engines, (3) gas turbines and (4) boilers, also as chemicals feedstock and food flavouring agent.

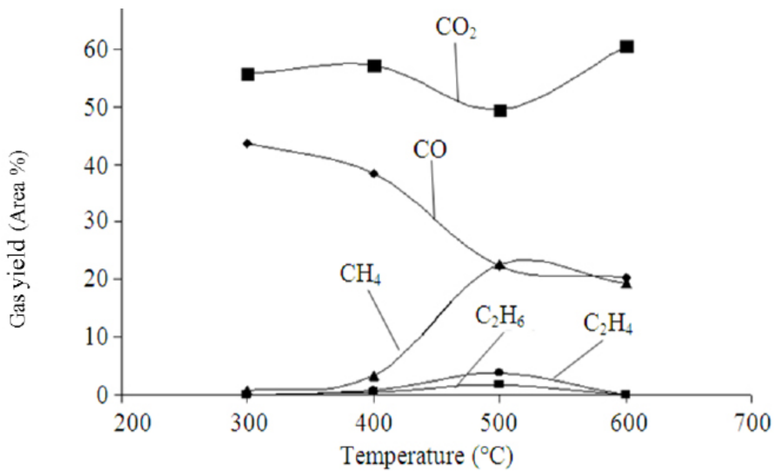
Bio-char (*Figure 3*) - an intermediate black solid residue - is also formed during the pyrolysis of EFB. The properties of bio-char (*Table 3*) are affected by the raw material used and the operating conditions, which are mainly the heating rate and temperature. The bio-char produced has higher CV (22–25 MJ kg^{-1}) than the bio-oil. The bio-char can be used as a solid fuel, char–oil or char–water slurries, activated carbon and soil enhancer.

In addition, the gases detected during pyrolysis were carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), ethane (C_2H_6) and ethylene (C_2H_4) (*Figure 4*). The gaseous product from pyrolysis

TABLE 3. CHARACTERISTICS OF BIOCHAR DERIVED FROM EMPTY FRUIT BUNCHES (EFB) AT DIFFERENT PYROLYSIS TEMPERATURES

Property	Temperature (°C)		
	450	500	550
Calorific value (MJ kg^{-1})	24.9 ± 0.09	22.8 ± 0.08	22.4 ± 0.05
Ultimate analysis (wt.%)			
Carbon	70.5 ± 0.02	69.7 ± 0.08	72.3 ± 0.04
Hydrogen	3.89 ± 0.08	4.11 ± 0.02	4.06 ± 0.02
Oxygen[a]	22.2 ± 0.05	23.3 ± 0.07	21.2 ± 0.10
Nitrogen	3.41 ± 0.01	2.95 ± 0.02	2.39 ± 0.02
Surface area (m^2 g–^{1})	5.21	4.74	3.52
Total pore volume (cm^3 g^{-1})	0.02	0.01	0.01

Note: [a] Calculated by difference.
Source: Mohamad Azri *et al.* (2016).



Source: Mohamad Azri *et al.* (2014).

Figure 4. The emitted pyrolysis gases at different temperatures.

usually has a high level of saturated and unsaturated hydrocarbons such as CH_4 and C_2H_4 from the complex thermal degradation processes. The produced gases may be used for feed drying, process heating and power generation or exported for sale.

Market Analysis

Given the limited reference of the existing pyrolysis oil production units, the commercial feasibility of such technology can only be estimated based on a number of variables, such as reactor type, feedstock, labour, utilities and maintenance costs. For example, a 400 t (bone dry) per day of greenfield (at RM 175 t^{-1}) pyrolysed using a rapid thermal processing unit, the production cost for bio-oil is ≈ RM 1.80 per gallon.

CONCLUSION

The produced valuable products such as bio-oil, bio-char and gas from oil palm biomass through thermal process such as pyrolysis provide co-benefits to the palm

oil industry in the form of renewable electricity, liquid and gaseous biofuels, large amounts of heat/low pressure steam and bio-chemicals. The multiple types of energy and chemicals generated have potential to contribute significantly to climate change mitigation.

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