Combustion/Pyrolysis of Oil Palm Stones and Palm Kernel Cake

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Introduction/Main Objective

Biomass is important for new energy sources because it is an indigenous, considerably cheap and, above all, renewable fuel. By-products or waste from the palm oil mills are generated in significant amounts and mainly consists of Empty Fruit Bunches (EFB), Oil Palm Stones (OPS), Oil Palm Shell (OPSh), Palm Kernel Cake (PKC) and Palm Oil Mill Effluent (POME). These waste are currently not fully utilised as a fuel. Pelletisation of PKC is very important in order to utilise it as a fuel. The loose PKC raw material need to be densified and form a homogeneous product before it can be burnt.

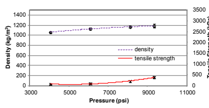
The main objective of this PhD study is to investigate the main characteristics of the thermo-chemical conversion of OPS and PKC. A series of combustion and pyrolysis tests were carried out by using OPS and PKC as the raw materials in two fixed bed reactors. In addition, the FLIC code was used to predict the key parameters, such as for theoretical solid temperature and gas composition. These parameters were used to validate the experimental results. The main parameter investigated in the combustion tests was the effect of air flow rates on the thermal characteristics of OPS material.

Experimental Programmes

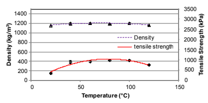
Pelletiser

Experimental conditions

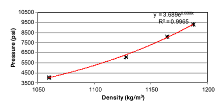
Properties	Test conditions						
Moisture (%)	15	7.9	5				
Pressure (MPa)	27.58	34.47	41.37	48.26	55.16	62.05	
Temperature (°C)	20	40	60	80	100	120	
Binders	wt%						
Caustic soda	0.5	1.0	1.5	2.0	2.5		
Calcium carbonate	0.5	1.0	1.5	2.0	2.5	3.5	5.0
Maize starch	5.0	10.0	15.0	20.0			
Tapioca satrch	5.0	10.0	15.0	20.0			
Potato starch	5.0	10.0	15.0	20.0			



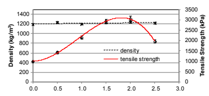
Effect of pressure on PKC pellet density and tensile strength



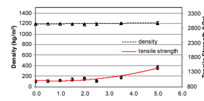
Effect of temperature on PKC pellet density and tensile strength



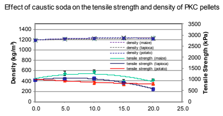
Relationship between pelletisation pressure and PKC pellet density



Effect of caustic soda on the tensile strength and density of PKC pellets



Effect of calcium carbonate on the tensile strength and density of PKC pellets



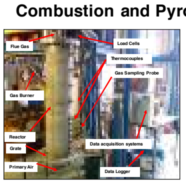
Effect of different starch binders on the tensile strength and density of PKC pellets

Pellet produced at different moisture contents: (a) 15%, (b) 7.9%, and (c) 5%.

The optimum conditions for the production of PKC pellets were found at moisture content of 7.9 % (as received), pressure of 64.38 MPa and temperature of 80-100°C.

Small additions of caustic soda improved quality of PKC pellets in terms of tensile strength and density by 61% and 20% respectively.

Combustion and Pyrolysis Tests: Results and Discussion



Fixed Bed Reactor (Pot Burner)

Combustion:

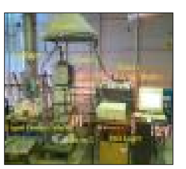
The combustion tests were conducted in a counter-current fixed-bed reactor.

Reactor:
interior tube: Iconel 600 nickel alloy tube (8 mm thickness)

Dimensions of the reactor:
ID: 200 mm
H: 1500 mm

Maximum temperature : 1250°C.

The grate was a stainless steel perforated plate with approximately 700 holes of 2 mm in diameter.



Fixed Bed Pyrolyser

Pyrolysis:

The pyrolyser unit consists of:
Two furnaces
Temperature controller
condenser

Reactors:
Made from 316 stainless steel.

Dimensions:
ID: 125 mm
H: 300 mm

Maximum temperature : 1000°C.

Gas outlet hole of 36 mm at the top of the reactor .

Combustion parameters

Material	Case	Weight (kg)	Bed Height (mm)	Air Flow Rate (l/min)	(-)	Equivalent Ratio (φ)
OPS	001	6.00	320	250	0.33	3.0
	002	6.00	350	450	0.60	1.67
	003	4.12	220	600	0.80	0.83
	004	6.00	320	650	0.87	1.16

Operating conditions for pyrolysis tests

Material	Weight (g)	Set Temp. (°C)	Heating Rate (°C/min)	N_2 flow rate (l/min)
OPS	250	500 and 700	5, 10 and 15	1.5
PKC	250	500 and 700	5, 10 and 15	1.5

Raw Materials

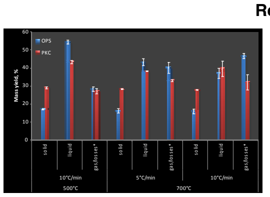
Oil Palm Stone (OPS)

Palm Kernel Cake (PKC)

Proximate and ultimate analyses of OPS and PKC samples

	Proximate analysis (%, as received)				Ultimate analysis (%,daf)					Cl (mg/kg)	CV (MJ/kg)
	M	VM	FC	Ash	C	H	O	N	S	Cl (mg/kg)	CV (MJ/kg)
OPS	4.71	86.50	6.55	2.24	72.54	9.11	16.24	1.73	0.37	300	27.46
PKC	7.92	71.84	16	4.28	59.81	6.43	30.48	3.26	0.03	550	18.67

Results from pyrolysis tests



Mass yields from the pyrolysis of OPS and PKC under different conditions.

Properties of the char samples from pyrolysis of the OPS and PKC

		OPS char		PKC char	
		500°C	700°C	500°C	700°C
Proximate analysis (%, as recieved)	Moisture	1.11 ± 0.24	1.18 ± 0.12	-	0.17 ± 0.11
	Ash	16.33 ± 1.68	13.10 ± 0.25	14.42 ± 0.18	14.95 ± 0.22
	Volatiles	14.08 ± 0.24	6.4 ± 0.73	12.49 ± 0.56	6.69 ± 1.20
	FC	68.48	79.31	73.08	78.18
Ultimate analysis (%daf)	C	80.27 ± 2.73	84.56 ± 2.29	62.78 ± 1.67	73.98 ± 1.59
	H	2.11 ± 0.40	1.33 ± 0.65	3.12 ± 0.15	0.79 ± 0.71
	O	13.15	10.17	30.05	21.7
	N	4.42 ± 0.20	3.79 ± 0.40	4.03 ± 0.11	3.49 ± 0.59
	S	0.04 ± 0.01	0.14 ± 0.15	0.02 ± 0.02	0.05 ± 0.04
Gross calorific value (MJ/kg)		27.6 ± 1.1	28.3 ± 0.40	28.1 ± 0.2	28.1 ± 0.10

The char yields obtained from the OPS were lower compared to those produced from the PKC, but the gas yields from the OPS were higher.

All char samples mainly consists of fixed carbon (FC).

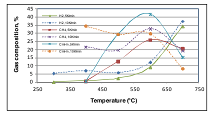
The calorific value (HHV) were approximately 28 MJ/kg (energy content as high as bituminous coal).

liquid derived from OPS formed a homogeneous mixture, while the liquid obtained from PKC consists of two distinct layers.

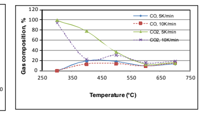
The calorific values of the liquid ranges from 21 to 38 MJ/kg.

Properties of the liquid products from pyrolysis of the OPS and PKC

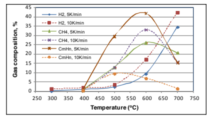
	OPS oil		PKC oil (light fraction)	
	500°C	700°C	500°C	700°C
CV (MJ/kg)	38.27	37.81	27.74	20.79
Viscosity @ 50°C (cSt)	-	9.9	-	1.5
Carbon	84.47	78.52	78.2	78.83
Hydrogen	10.53	10.64	8.97	8.13
Oxygen	3.23	8.95	8.96	8.84
Nitrogen	1.55	1.47	3.56	4.1
Sulphur	0.23	0.41	0.31	0.1
Empirical formula	$CH_{1.51}O_{0.17}$	$CH_{1.63}O_{0.09}$	$CH_{1.38}O_{0.09}$	$CH_{1.24}O_{0.08}$



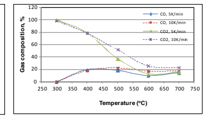
The concentration of H_2 and other hydrocarbons in the pyrolysis gases of OPS



The concentration of CO and CO_2 in the pyrolysis gases of OPS



The concentration of H_2 and other hydrocarbons in the pyrolysis gases of PKC



The concentration of CO and CO_2 in the pyrolysis gases of PKC

The gas consists mainly of CO_2, CO, H_2, CH_4 and other hydrocarbons.

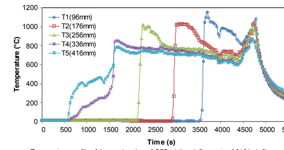
CO_2 and CO were mainly evolved at low temperatures (< 500°C).

At high temperature (> 500°C) H_2 and other hydrocarbons (C_1-C_3) were the dominant component in the gas products.

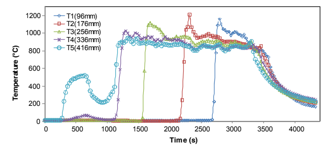
Most of the light HC gases start to evolve at temperature > 300°C.

The maximum H_2 concentration 35-45% was reached at the temperature of 700°C.

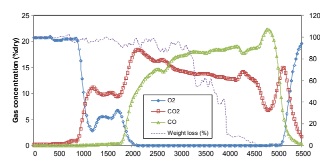
Results from combustion tests



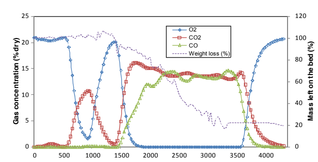
Temperature profile of the combustion of OPS at the air flow rate of 618 kg/m²h.



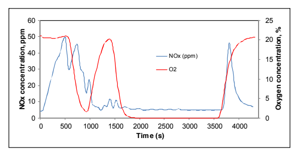
Temperature profile of the combustion of OPS at the air flow rate of 1113 kg/m²h.



Gas composition and residue mass for the OPS combustion at the air flow rate of 618 kg/m²h.



Gas composition and residue mass for the OPS combustion at the air flow rate of 1113 kg/m²h.



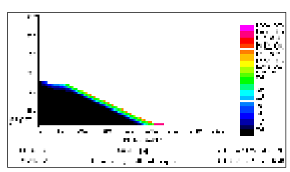
Oxides of nitrogen concentration from the combustion of OPS at an air flow rate of 1113 kg/m²h.

Increase in air flow rate increased the ignition front speed and burning rate.

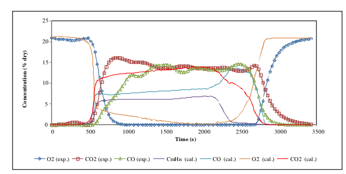
NOx concentration reached to a maximum value of about 47 ppm at the initial stage (t < 1000s)-due to the pilot burner.

NOx increased sharply to a peak value of 46 ppm at t= 3800s was due to the nitrogen in char converted to NOx with the present of oxygen during the char combustion.

Results from FLIC simulation



Temperature profile of the OPS at the primary air flow rate of 1113 kg/m²h obtained from FLIC simulation result .



Comparison of gas compositions between experiment and FLIC simulation results for OPS at the primary air flow rate of 1113 kg/m²h.

Major input conditions	
Model parameters	**Conditions**
Bed height (mm)	361
No. Of cells	300
Time step (s)	5
Fuel:	
Size	10 (100%)
Moisture	4.71
Volatile	86.5
Char	6.55
Ash	2.24
Oxidiser:	
Type	air
T (K)	298
N (Nm³/min)	0.434
Bed voidage fraction-ε	0.65
Pyrolysis:	
A (1/s)	5160000
E/R (K)	10700
Char gasification:	
A (kg/m2/s/kP(n)/K(m)	2.3
E/R (K)	11100

The predicted temperature profile during the ignition propagation stage was almost similar to the experimental results.

At this stage, the temperature increased to a maximum of 1400 K.

At approximately t = 2400-2500s, the ignition front reached the bottom of the bed.

In general, the predicted gas composition was in good agreement with the measured data.

Some minor discrepancies including the predicted concentrations of CO_2 and CO were slightly lower than the measured data.

Conclusions

The optimum conditions for the production of PKC pellets were found to be a moisture content of 7.9%, pressure 62.05 MPa and temperature 80 – 100°C.

Pyrolysis of the OPS and PKC at 700°C with a heating rate of 10°C/min gave maximum liquid yield of 57.92 and 42.84 wt% respectively.

The pyrolysis gases consists mainly of CO and CO_2, and evolved at lower temperature, below 500°C.

The main gases that evolved at the high temperature region (> 500°C) were hydrogen and other hydrocarbons gases (C_1-C_3).

The results of the combustion tests showed that an increase in air flow rate increased the ignition front speed and burning rate.

The FLIC modelling results were in good agreement with the experimental results.

Future work

The use of the binders should be investigated further in order to produce good quality of PKC pellets.

In order to compare the combustion characteristics between two different combustion systems, further experimental study is necessary to be carried out by using fluidised bed reactor.

Further investigation must be done on a broad range of combustion air flow rates for better understanding towards the combustion behaviour of the OPS and PKC materials.

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