

INITIAL STUDY ON THE COMBUSTION OF PALM WASTES IN A SPOUTED BED

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ABSTRACT

Malaysia produces more than 35 million tonnes of palm wastes annually. These wastes, such as palm shells, palm fibers, and empty fruit bunches (EFB), which have high calorific values, could in turn be used for power and steam generation for plant usage. Palm wastes have a great potential as a renewable energy source to complement the national strategy of 5% total national electricity from renewable energy sources (Eighth Malaysia Plan, 2001-2005). Thus, research was carried out to investigate the use of palm wastes as feed for combustion process in a spouted bed. Improper design and operating conditions of the combustor have detrimental effects on the boiler efficiency besides posing environmental problems. It was expected that spouted bed would demonstrate more efficient combustion of palm wastes. Investigations on the optimum combustion parameters in a SB included the determination of optimum bed height, amount of excess air ratio, and combustion temperatures. Results from this research showed that the secondary air was needed to improve the efficiency of the combustion process. Spouted bed demonstrated a very good mixing pattern of the sand and the palm wastes. At the bed height of 1.5 Dc and minimum spouting velocity of $2U_{ms}$, the optimum air factor for good combustion characteristic would be 1.6.

Keyword: Spouted bed, palm wastes, efficiency

INTRODUCTION

Incineration of palm wastes is an important option for disposal of waste besides generating electricity and steam for the plant usage. However, improper design and operating condition of the combustor have detrimental effect on the boiler efficiency and pose environmental problems. DOE found that incineration of EFB would cause emission of excessive "white smoke". Therefore, incineration of EFB is not allowed for new establishment. However, ash from EFB contains high nutrients for plant in particular potassium (Table 1)[1].

Table 1: Composition of EFB ash (Dry basis, % wt)[1]

Potassium (K ₂ O)	Phosphorus (P ₂ O ₅)	Magnesium (MgO)	Calcium (CaO)
41.4	3.7	5.8	4.9

Furnaces are used to incinerate palm wastes in palm oil mill in Malaysia. However, furnace incineration showed a poor mixing pattern, which could cause incomplete combustion and consequently pose environmental problems. In contrast, spouted bed has very good mixing pattern, which could induce efficient combustion. Mathur and Gishler first introduced the spouted bed technology in 1955. Palm wastes would burn efficiently in spouted bed because this technique permits agitation of solid materials that are too coarse and uniform in size for good fluidization [2].

In this study, both modeling and experimental works were carried to investigate the efficiency of palm wastes combustion in SB. Experiment were conducted with continuous feeding of palm wastes. Temperature profiles across the SB column were determined.

EXPERIMENTAL

Figure 1 showed the schematic diagram of the bench scale spouted bed combustor. The combustor consisted of a carbon steel cylinder with an internal diameter of 80 mm and a cone with an angle of 60°. A section of the cylinder made of glass enabled the observation of the combustion process. The top end of the combustor was connected to a cyclone. Feeding was through a screw feeder located at the side wall of the column.

Air was supplied by a compressor and metered by a rotameter before being fed into the bed through the cone section. LPG was also fed into the bed through the cone section. Ignition of the pre-mixed LPG/air mixture was achieved using an electrical spark ignition system mounted on the inner side of the combustor wall.

Type-K thermocouples were used to measure the temperature at the bottom of the bed (T_{sand}), the temperature at the freeboard (T_F), and the temperature of the cyclone (T_{cyclone}). T_{sand} , T_F , and T_{cyclone} were continuously read and recorded from the temperature readers.

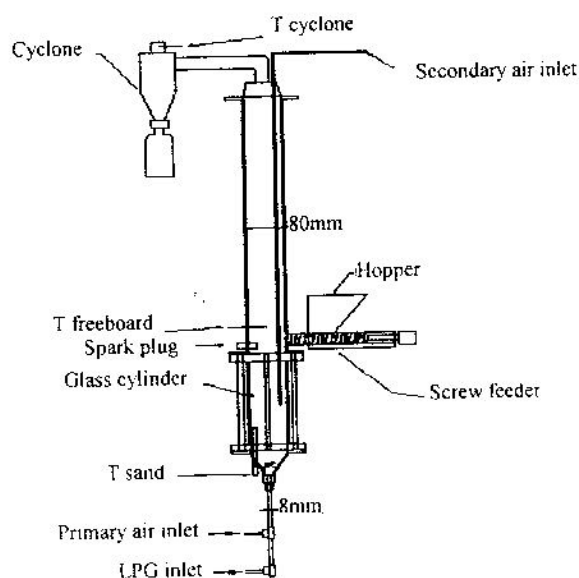


Figure 1: Schematic diagram of spouted bed

Palm Wastes

Palm wastes such as palm shell, palm fiber, and EFB were collected from a palm oil mill in Kulai. These wastes were ground into small pieces before they could be incinerated in the spouted bed. Table 2 showed the composition (dry basis) of these palm wastes.

Table 2: Elementary analysis of palm wastes (Dry basis, % wt)

Waste sample	Ash	Volatile	Fixed C	C	O	H	N	S	GCV (MJ/kg)
Palm shell	1.96	79.22	18.82	47.978	45.781	5.487	0.714	0.040	21.3
Palm Fiber	3.63	84.78	11.59	50.091	41.147	6.247	2.385	0.130	19.6
EFB	5.74	85.79	8.47	50.099	40.618	7.164	2.052	0.068	19.2

Moisture content: Palm shell – 12.15%, Palm fiber – 13.95%, EFB – 24.63%

Bed Material

Silica sand granules with a mean diameter of 0.67mm were used as the bed material. At ambient temperature, the minimum air flow rate needed to spout the bed material of 12cm height (1.5Dc) was approximately 68 L/min, which gave the spouting velocity of 0.23 m/s.

Experimental Procedures

The height of static sand bed utilized for incineration experiment was 12cm (1.5Dc). The required amount of sand was charged into the bed. First, an air flow rate of 40 L/min was introduced into the bed. Then the supply of LPG was gradually introduced into the bed. The pre-mixed LPG/air mixture was ignited using an electric sparker. The air and LPG flow rates were adjusted to achieve the desired spouting velocity and temperature. In LPG combustion, the desired bed temperature was achieved less than 12 minutes. When the bed temperature reached 720°C, the LPG supply was cut off and palm wastes feeding was initiated. A specific amount of palm wastes was fed continuously onto the bed through the screw feeder. The feeding period was 40 minutes.

RESULTS AND DISCUSSION

Modeling of palm wastes combustion

The adiabatic flame temperature, CO, and O₂ concentration for different air factors were calculated using the FLAME program v1.3 (J.M. Taylor, University of Leeds). Table 3 showed the adiabatic flame temperature and concentration of various gaseous products.

Table 3: Concentration of CO, and O₂ and adiabatic temperature (Dry basis, % wt)

Air Factor	Palm Shell				Palm Fiber				EFB			
	T _{ab} , K	CO	O ₂	CO, mg/Nm ³	T _{ab} , K	CO	O ₂	CO, mg/Nm ³	T _{ab} , K	CO	O ₂	CO, mg/Nm ³
0.8	2413	7.280	0.2	108069	2155	6.5600	0.007	98213	2060	5.8800	0.002	91646
0.9	2422	4.600	0.6	67684	2236	3.4500	0.103	51368	2157	3.0100	0.040	46687
1.0	2394	2.750	1.2	40072	2237	1.4400	0.657	21228	2176	1.0300	0.495	15799
1.1	2342	1.540	2.1	22228	2175	0.5656	1.720	8244	2110	0.3444	1.600	5207
1.2	2275	0.815	3.1	11660	2091	0.2226	2.920	3210	2025	0.1256	2.840	1873
1.3	2199	0.410	4.1	5812	2004	0.0893	4.080	1275	1941	0.0486	4.010	716
1.4	2120	0.200	5.1	2813	1922	0.0367	5.150	520	1862	0.0196	5.060	286
1.5	2043	0.096	6.0	1344	1846	0.0155	6.100	218	1789	0.0080	6.000	116
1.6	1969	0.046	6.8	644	1776	0.0066	6.950	92	1723	0.0035	6.840	49
1.7	1900	0.022	7.6	310	1712	0.0029	7.700	40	1662	0.0015	7.590	22
1.8	1836	0.011	8.3	148	1653	0.0013	8.390	18	1606	0.0007	8.260	10
1.9	1776	0.005	8.9	74	1599	0.0006	9.000	8	1555	0.0003	8.870	4
2.0	1721	0.003	9.5	37	1549	0.0003	9.560	4	1507	0.0001	9.420	2

Incineration of palm wastes are subjected to the requirement of EC Directives 89/369/EEC and 89/429/EEC [5,6] to prevent air pollution. According to these directives, combustion gases shall be maintained at a temperature of 850°C in the presence of 6% oxygen, for a period of 2 seconds after the last injection of combustion air. From Table 3, the concentration of oxygen in the flue gas at an air factor of 1.6 was more than 6%, which was greater than the standard value. The higher the air factors the lower the adiabatic flame temperature due to the transfer of heat to the excess air. The concentration of CO decreased

as the air factor was increased. Excess air to the combustion system ensured complete combustion of the wastes.

According to EC Directives 89/369/EEC and 89/429/EEC, the limit of CO concentration is 100 mg/Nm³. Modeling results showed that an air factor at 1.9 was the best air ratio for the present case to prevent air pollution.

Effect of Bed Height on the Temperature and Mixing Pattern

Figure 2 showed the temperature profile obtained from bed starting up processes in different bed heights. The sand was heated using LPG.

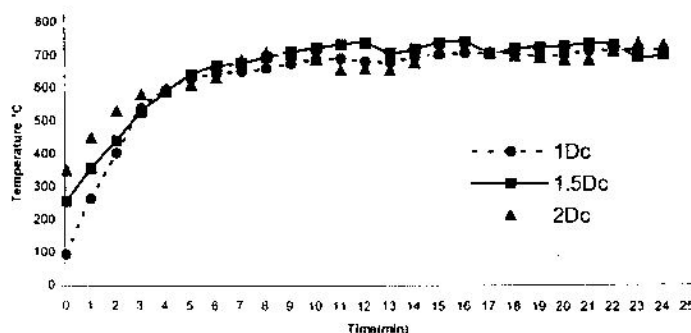


Figure 2: Temperature profile for bed heating up using different bed heights

From Figure 2, the maximum temperature of the sand was 720°C for a bed height of 1Dc. However the temperature could not be sustained for more than 1 minute if LPG was being cut off. The bed height of 1Dc exhibited good sand movement but the retention time in the bed was very short. Consequently, the wastes were not burned to completion and the heat generated from the wastes could not be retained in the sand.

At a bed height of 2Dc, instead of spouting the bed became a bubbling bed. Figure 2 showed that the temperature of the sand fluctuated between 660–740°C. This was caused by the eruption effect occurring in the bed. The sand temperature dropped tremendously as the eruption occurred, which was due to heat loss. The colour of the lower layer of the sand did not change although the top layer of the sand was glowing red. The sand in the bed with a height of 2Dc had to travel a greater distance from top to bottom of the bed compared to the cases of 1Dc and 1.5Dc. This would cause significant heat loss during the sand movement. Eventually resulting poor mixing in the bed with a height of 2Dc.

For bed height of 1.5Dc, the movement of the sand was very good leading to good mixing. The temperature of the sand could reach 740°C in less than 12 minutes. When the temperature achieved a steady state, the whole bed would become glowing red. This indicated that the movement in the sand was very good. With a higher volume of sand compare to the bed height of 1Dc, the bed height of 1.5Dc could retain more heat. The longer retention time for palm wastes in the sand would promote complete combustion.

From the observation above, the bed height of 1.5Dc was found to be the optimum bed height for the combustion study in the current SB rig.

Effect of U_{ms} on the temperature and Mixing Pattern

Figure 3 showed the temperature profile for a bed height of 1.5Dc at different U_{ms} . Burning at an air input of $1.6U_{ms}$ showed that the temperature difference between the sand and the freeboard was approximately 300°C. This was due to the burning of LPG in the sand. However, the movement of sand in $1.6U_{ms}$ was very slow. It could be observed from Figure 4 that the duration for the sand temperature to reach from 687°C to 705°C was 6 minutes. Experimental observation showed that the lower region of the sand was stagnant, leading the formation of dead zones. As the result, air input of $1.6U_{ms}$ had a poor mixing pattern.

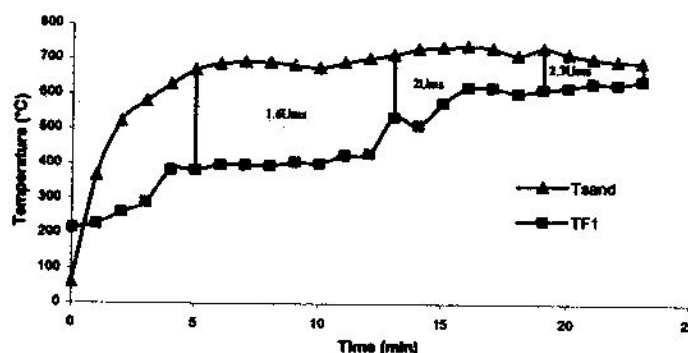


Figure 3: Temperature profile for different U_{ms}

Burning at $2U_{ms}$ and $2.3U_{ms}$ showed good mixing pattern, indicated by the whole bed turned glowing red when the bed reached a steady state. For an air input of $2U_{ms}$ the temperature difference between the sand and freeboard could be around 100°C . However, for air input of $2.3U_{ms}$ the temperature difference was approximately 50°C . The temperature of the sand was being cooled to below 700°C when burning was carried out at an air input of $2.3U_{ms}$ due to the cooling effect of the jet.

As the result, a primary air input of $2.0U_{ms}$ was the optimum air feed for the bed height of $1.5D_c$.

Palm Shell Combustion with Various Air Factors

The experiments were carried out at the feeding rate of 39.5 g/min with a primary air feed of $2U_{ms}$. Figure 4 showed the temperature profiles of the sand, freeboard and cyclone at various air factors. The temperature increased as the air factor was increased, as shown in Figure 4. This was due to the complete combustion process that was enhanced by increasing the air factor. However, the secondary air feed could not exceed 80 LPM . If the secondary air flow rate was increased to 80 LPM , the temperature would decrease. This was due to the formation of jet from the secondary air. As the result, it would cause cool and change the hydrodynamic to the sand bed.

As shown in Table 2, palm wastes contained a high percentage of volatile matters. These volatile matters would result in the combustion of volatiles at the top of the bed. However, Figure 4 showed that the temperature of the freeboard was lower than the sand. This result was due to the significant heat loss to the surrounding.

Conclusions

Conclusions derived from the study were as follows:

1. The quality of bed mixing was critical for palm wastes incineration in a spouted bed. A bed height of $1.5D_c$ and air spouting velocity of $2U_{ms}$ were the optimum parameters for good mixing pattern.
2. From the modelling of palm wastes combustion, the suggested optimum air factor for complete combustion was 1.9.
3. Heat loss through the glass and column was very significant. Insulation of the bed was needed to prevent heat this phenomenon.
4. The position of the secondary air inlet had an influence on the hydrodynamic of the SB.

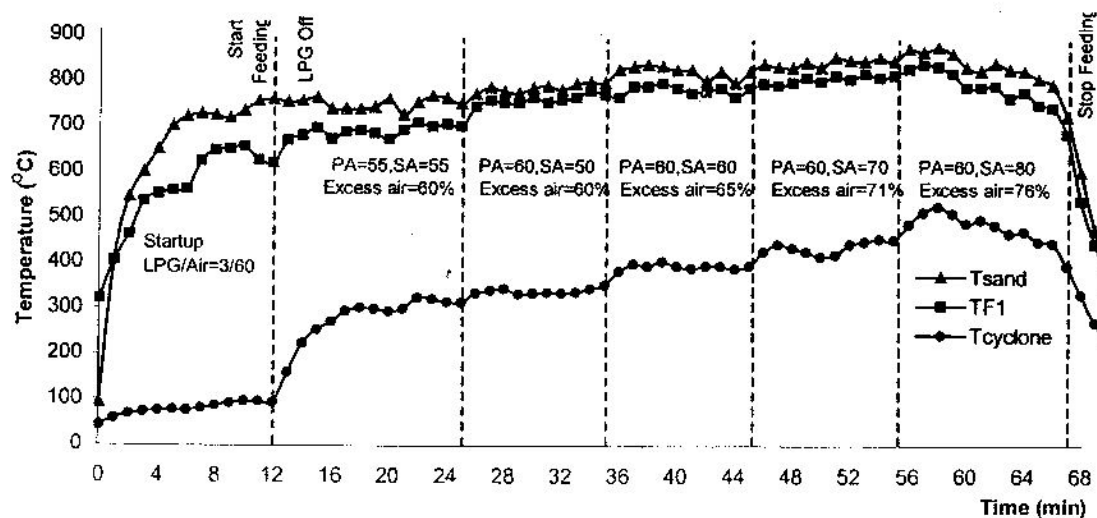


Figure 4: Temperature profile of sand, freeboard and cyclone at various air factors.

Notation

EFB	empty fruit bunches
Dc	diameter of the column
SB	spouted bed
U_{ms}	minimum spouting velocity
η_{ce}	combustion efficiency

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