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THERMOCHEMICAL BEHAVIOUR OF EMPTY FRUIT BUNCHES AND OIL PALM SHELL WASTE IN A CIRCULATING FLUIDIZED-BED COMBUSTOR (CFBC)

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ABSTRACT

Circulating fluidized-bed (CFB) technology is considered to be one of the most suitable techniques to thermally convert fuels into useful energy. However, practical experience is available for only a limited number of fuels and conditions. This paper describes the results from a bench-scale circulating fluidized-bed combustor (CFBC), installed at SIRIM Berhad, Shah Alam, for gasification and combustion of different biomass materials. The purpose of the tests was to investigate the suitability of the selected fuels for energy production using CFBC while taking care of the flue gas emissions. The experiments gave sufficient information on the main process and flue gas characteristics. The measurements for temperatures and emissions were done for four different biomass samples of empty fruit bunch (EFB) of palm shell and palm shell waste powders of 210-300, 425 and 600 microns. The concentrations of CO, NOx and CO_2 in the flue gas were measured continuously. The combustion performances were evaluated by varying the primary gas flow through the CFBC tubular furnace to identify the optimum operating conditions for the CFBC. The NOx content was from 20-164 ppm while the CO emissions were high for some operating conditions.

Keywords: biomass, circulating fluidized-bed, oil palm solid wastes, emission characteristics, temperature profiles.

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INTRODUCTION

Biomass was the world's first fuel and source of energy, but when coal became widely available, to be followed later by bio oil and natural gas, its use declined. However, in recent years interest in it has been renewed, much of being focused on its efficient conversion for energy. The importance of biomass energy in developing countries today is indisputable. However, in many countries, wood supply (as fuel) can no longer meet the demand and very few countries have excess wood for gasification or charcoal production without serious impact on their natural resources (Kate *et al.*, 1997).

With respect to the global issues of sustainable energy and reduction in greenhouse gases, biomass is getting increased attention as a potential source of renewable energy. However, biomass is not yet competitive with fossil fuels. Fossil fuels contribute to the major part of world's total energy consumption. According to the World Energy Assessment report, 80% of the world's primary energy consumption is contributed by fossil fuels, 14% by renewable energy (out of which biomass contributes 9.5%) and 6% by nuclear energy (Rogner *et al.*, 2000; Devi *et al.*, 2003).

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Different biomass conversion processes produce heat, electricity and fuels. Biomass integrated gasification / combined cycle systems are of prime importance as modern technologies (Bui *et al.*, 1994). Among all biomass conversion processes, gasification is one of the promising ones. The energy efficiency in the case of gasification is higher than that of combustion. One of the major issues in biomass gasification is how to deal with the tar formed in the process.

Among the proven combustion technologies (such as grate-fired systems and suspension-fired systems, fluidized bed systems), the fluidized bed is reported to be the most efficient and suitable for converting agricultural and wood residues into energy (Bridgwater, 1994). The emissions from biomass combustion systems, including the products of complete (CO_2) and incomplete combustion (CO, char particles, tar, polycyclic aromatic hydrocarbons and other organic compounds), as well as NOx, SO_2, HCl and ash particles, are affected by the combustion method as well as by the operating conditions and fuel properties (Dornburg *et al.*, 2001). In order to control the emissions effectively (especially to minimize the emissions of incomplete combustion products), one has to know the effects of the operating parameters on the emission behaviour. In this research, experiments have been done, under different operating conditions, to estimate the emissions behaviour.

In the very near future, it will be necessary to work more intensively on the replacement of fossil fuels by high hydrogen content fuels and to shift to natural gas and biogas. As we prepare for a world of diminishing fossil fuel reserves, with increasing demand for the protection of our environment, the combustion community has two major goals to fulfill: enhancement of combustion efficiency and reduction of pollutant emission. However, it is to be realized that the combustion phenomena are very complex, multi-dimensional, unsteady and multi-disciplinary.

The development of new combustion technologies and their transfer to large plants or factories are on the way, because the competition has already became a worldwide issue in the international economic actors. The transfer of these novel technologies to small- and mid-sized manufacturing industries could be essential for the economies of developing countries. According to recent developments in fundamental research, the design of energy systems and the implementation of the operations feedback will mainly rely on progress on the conception of more reliable materials (optimization of heat transfer, thermal and mechanical resistance, lengthening of life time), efficiency and reliability of energy production and energy saving (reduction of fuel consumption, alternate fuel, reduction of pollutant emissions) and the control of combustion processes (Pierre, 2004).

Over the last 8-10 years, interest in large scale biomass gasification for power generation has been growing steadily. Efficiency well over 40% has been predicted for such plants in the near future. For capacity range lower than 5-10 MWe, new designs and catalytic gas cleaning may make a new generation of biomass power gasifier feasible in the near future (Bhattacharya, 1997).

MATERIALS AND METHODS

This paper deals with the experimental study of combustion of different biomass fuels, namely, oil palm shell waste and empty fruit bunch (EFB) in a circulating fluidized-bed combustor (CFBC) using alumina particles of 200 microns as inert material. The main objectives of this work were to study the formation and reduction of the major gaseous pollutants (CO and NOx) in the CFBC when firing the selected biomass fuels, and to study the combustion performance when fired with different fuels for different operating conditions.

Biomass Materials Used for Experimental Work

Biomass, as a fuel, is characterized by high moisture and volatile content, low bulk density, low specific energy and normally low ash content. The proximate and ultimate analysis of oil palm shell are shown in *Tables 1* and *2* (Ani, 1992).

TABLE 1. PROXIMATE ANALYSIS OF OIL PALM SHELL WASTE

Solid waste	Proximate analysis %			
	Moisture	Volatile	Fixed carbon	Ash
Palm shell	9.7	67	21.2	2.1

TABLE 2. ULTIMATE ANALYSIS OF OIL PALM SHELL WASTE

Solid waste	Ultimate analysis %					GCV
	C	H	N	O	S	MJ kg^{-1}
Palm shells	47.62	6.2	0.7	43.38	-	19.1

The ultimate and promimate analysis of EFB was also done. The results are being tabulated in *Tables 3* and *4*.

TABLE 3. PROXIMATE ANALYSIS OF EMPTY FRUIT BUNCH (EFB)

EFB	Proximate analysis %			
	Moisture	Volatile	Fixed carbon	Ash
Palm shell	6.8	77.4	19.3	3.3

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TABLE 4. ULTIMATE ANALYSIS OF EMPTY FRUIT BUNCH (EFB)

EFB	Ultimate analysis %						GCV
	C	H	N	O	S	Cl	MJ kg^{-1}
Palm shells	49.5	5.9	0.5	40.6	0.10	0.20	18.1

The EFB was shredded and in this state it contained fibrous EFB several centimetres long as shown in *Figure 1a*. These fibrous EFB were easily entangled and formed into lumps, which jammed the screw feeder. It was found that such EFB could not be dropped smoothly from the screw feeder to the sample supply port. In order to remove the fibrous EFB causing such a problem, the shredded EFB were sieved through a 5 mm mesh screen. The appearance of EFB after sieving is shown in *Figure 1b*. Sieving of EFB improved the transfer of EFB from the screw feeder.

Experimental

The experiments were carried out in SIRIM Berhad, Shah Alam. The system was developed by JFE, Japan under a joint-venture programme between the Japanese Government and SIRIM Berhad. The experimental apparatus consisted of a circulating fluidized-bed (CFB) type experimental gasifier, experimental sample supplying unit, secondary combustion furnace, gas cooler, dust collector, blower and control panel. A schematic diagram of the test rig is shown in *Figure 2*.

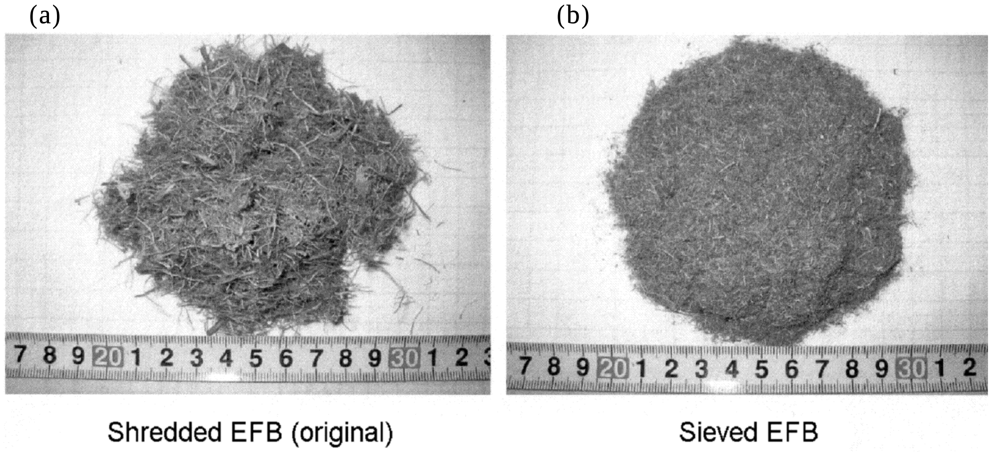

Figure 1. Appearance of empty fruit bunches (EFB).

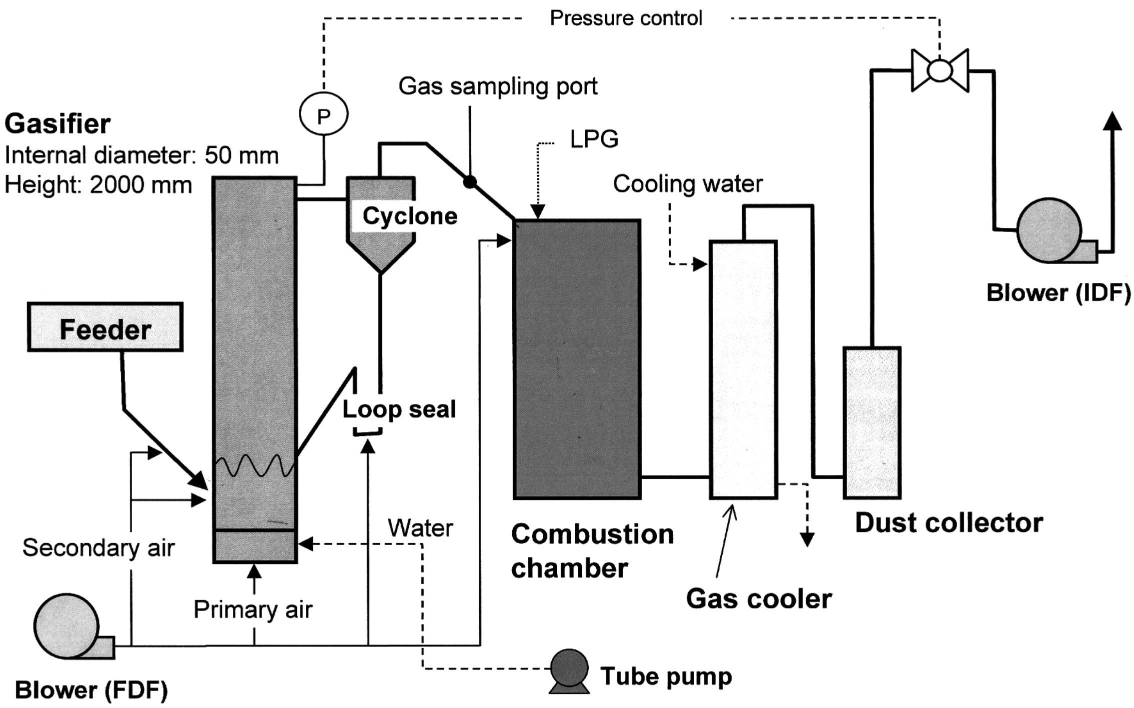

Figure 2. Layout of the experimental circulating fluidized-bed (CFB) gasifier at SIRIM.

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The CFB experimental gasifier is a vertical tubular furnace having an inner diameter of about 50 mm and a height of 2000 mm. The fluidizing air is supplied from the bottom and the circulating particles are separated from air by a cyclone and the particles returned to tubular furnace through the loop seal downstream of the furnace. The gasifier is provided with three external electric heaters (upper, centre and lower) to allow internal control the temperature. A heater is installed on the air supply line to pre-heat the air.

A gas sampling port is provided in the middle of the duct leading to combustion chamber. Flue gas, tar and moisture generated by the gasification can be sampled through the port. For monitoring the gasification condition, the concentrations of CO, CO_2 and O_2 in the gas produced were measured with a gas analyser.

The biomass sample to be gasified was supplied to the gasifier through the screw feeder and rotary valve. The feed rate from the screw feeder can be adjusted by changing the rotational speed of the driving motor through inverter control. A photograph of the experimental gasifier is shown in *Figure 3*. The rotary valve is located after the screw feeder to seal off the gasifier. The chute downstream side of the rotary valve is cooled by aeration to prevent fusing of the biomass sample by overheating.

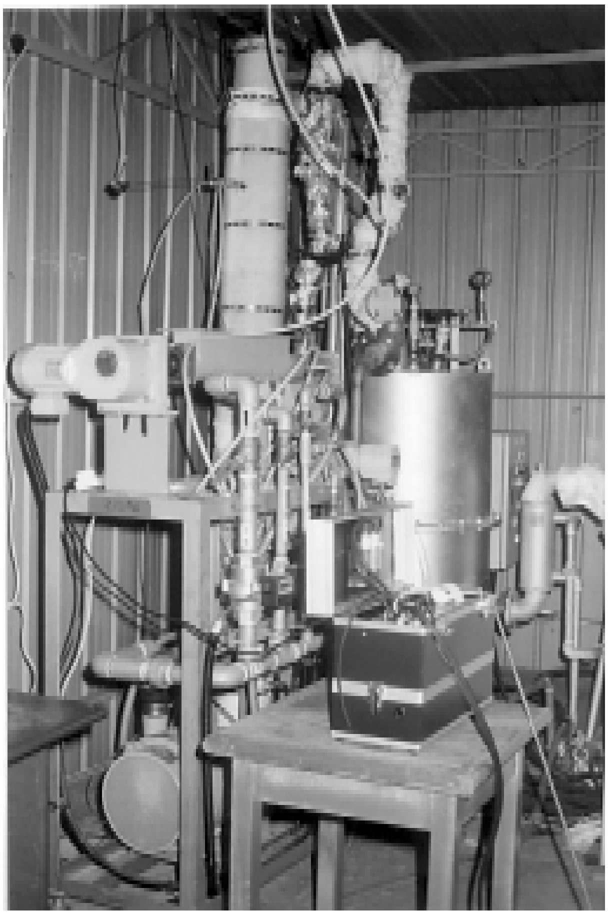

Figure 3. Photograph of the experimental gasifier.

The secondary combustion furnace is designed to completely burn the combustible gases, such as CO and H_2, in the gas produced by gasification. A mixture of the gas produced and air is burnt constantly in a LPG burner. The gas cooler after the secondary combustion furnace cools the exhaust combustion gas with water to protect the equipment on the downstream side. However, in this paper, the combustible gases were not burned in the LPG; rather they were diluted and discharged through the stack. The gases discharged were monitored for the emissions.

Immediately before the induction fan (IDF), an automatic valve is connected to the differential pressure gauge that measures the pressure in the gasifier. The valve controlled the pressure in the furnace during the experiment. In case of any excessive pressure build up in the gasifier, the pressure control valve can relieve the pressure. The operation of these devices, heater temperatures, air pre-heat temperature, in-gasifier pressure and sample feed rate is via the main control panel. The secondary combustion chamber is controlled via the auxiliary control panel on the equipment side.

The temperatures at various locations in the CFB rig were continuously monitored and recorded using a Yokogawa Hybrid Recorder (HR 1300). The furnace pressure, supply air flow rate were also monitored. The concentrations of CO, CO_2 and O_2 in the produced gas were also recorded using a calibrated Madur Flue Gas Analyser (GA-40 plus). The resolution for measurement of O_2 and CO_2 was 0.01%, and for the measurement of CO and NO, 1 ppm.

Method

Approximately 200 g of the circulating alumina powder were loaded into the gasifier (height of static bed: approximately 100 mm), and a CFB formed by pumping in air and increasing the in-furnace temperature. Formation of the CFB was observed by monitoring the change in the temperature of the loop seal. It took about 3-4 hr before the CFB attained the pre-set temperatures. The pre-set temperatures were selected using thermogravimetric analysis (TGA) of the devolatization behaviour of EFB and palm shell waste powders. After the CFBC temperature reached the specified temperatures, constant feeding of biomass can be started with in-furnace temperature and the gas composition (CO, CO_2 and O_2) monitored.

After the temperatures had stabilized, the primary air flow rate of the fluidizing air was varied and the produced gas analysed from the sampling port after the cyclone and as well as from the exhaust. The biomass feed rate varied depending on the biomass used. Using the 5 mm EFB particles the flow

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was not so smooth as when using to palm shell particles. The EFB gave a pulsating flow while the palm shell produced a smooth flow. However, the different palm shell particle sizes showed different flow behaviour through the screw feeder as shown in *Figure 4*. The experimental conditions are being summarized in *Table 5*.

RESULTS AND DISCUSSION

Combustion of EFB Particles

The 5 mm EFB particles were fed through the screw feeder and rotary valve. The temperature at the top of the CFB was about 650°C. At this temperature, the gas was sampled and its properties analysed using gas chromatography. It was found that the sampled produced gas contained about 5% H_2, 10% CO, several % CH4 and other hydrocarbon (HC) components and its heating value exceeded 1000 kcal m^{-3}. Based on these results, it was realized that a usable gas containing H_2, CO and CH4 can be obtained by CFB gasification of EFB. The concentrations of H_2 and CH_4 increased as the in-furnace temperature became higher. However, the gas heating value and carbon conversion ratio did not change so much with in-furnace temperature. Although the gas heating value exceeded 1000 kcal m^{-3} with the lower air ratios, the carbon conversion was less than 40%. The carbon conversion ratio was low perhaps because a large quantity of EFB remained unreacted owing to the dimensional restrictions of the experimental apparatus and char and soot were over generated.

Combustion of Palm Shell Waste Particles of 212-300 microns

Oil palm shell waste was obtained from Kulai Palm Oil Mill of the Federal Land Development Authority (FELDA), Johor, Malaysia. It was crushed,

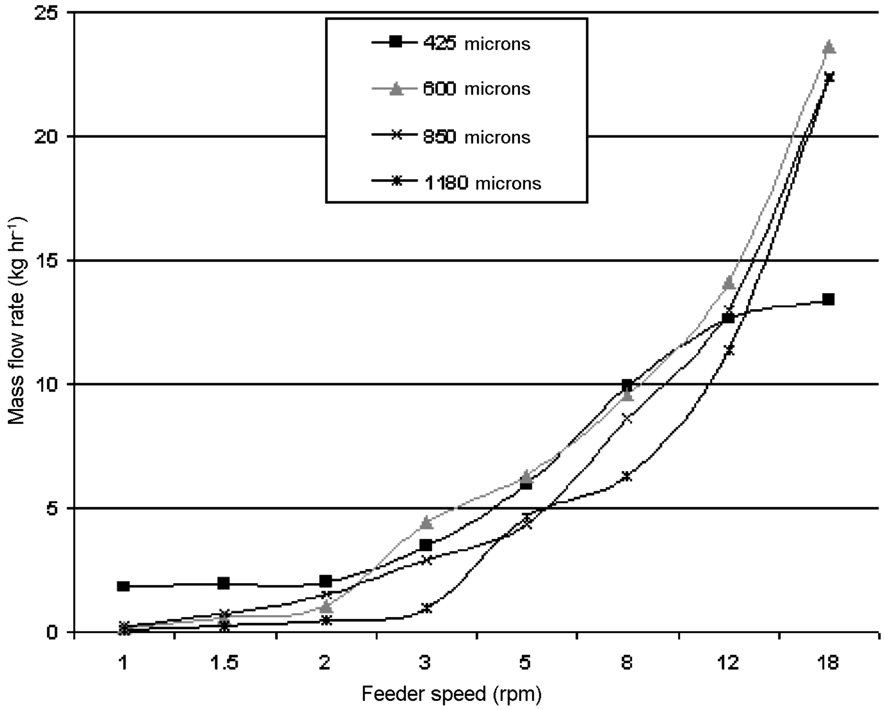

Figure 4. Flow behaviour of feeder for different palm shell waste particles.

TABLE 5. EXPERIMENTAL CONDITIONS IN THE CIRCULATING FLUIDIZED-BED (CFB) TEST RIG

EFB feed rate		2.4-60 kg hr^{-1}
Palm shell powder feed rate		3.0-7.0 kg hr^{-1}
Gasifying agent flow rates	Primary air	1.0-3.5 $m^3 hr^{-1}$
	Secondary air	1.0-1.5 $m^3 hr^{-1}$
	Loop seal air	0.1-0.75 $m^3 hr^{-1}$
	Combustion air	10-28 $m^3 hr^{-1}$
Gas velocity		1.0-2.0 m s^{-1}
Gas residence time		1.1-2.0 s
In furnace temperature		700°C-850°C

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grinded and sieved to different size samples. The conditions for this experiment were similar to those for the previous experiment. However, the particles were too small and too easily pushed by the screw feeder even at a low speed. This overfed the furnace.

The temperature at the top of the CFB increased rapidly as the feeding started to reached about 709°C in a very short time as shown in *Figure 5*. In order to evaluate the effect of the primary air flow through the CFB, the flow rate was varied and the system stabilized before any data were recorded. The emission and experimental data are shown in *Table 6*.

Due to increased particle flow rate, the circulating particle formed a dense bed. The palm shell particles fed to this layer got into contact with the high temperature circulating particles and were quickly pyrolyzed. When a palm shell particle (PSP) came into contact with a circulating particle at a higher temperature, the heat conductance to the PSP improved, and it was more quickly pyrolyzed. As shown in *Table 6*, as the primary air flow was increased, the CO concentration increased rapidly. This was probably due to the very fine particle size and low residence time in the CFB furnace. This resulted in poor combustion and a high concentration of CO was found near the CFB top. The emission was a heavy white smoke representing incomplete and enhanced CO formation.

Combustion of Palm Shell Waste Particles of 425 microns Particles

Keeping in view the inadequacy of the screw feeder to control the feed rate of the 212-300 micron particles, it was decided to feed bigger PSP of 425 and 600 microns. The 425 micron particles had a satisfactory feeding behaviour. A typical heating behaviour at the top of the CFB rig for 425 microns particles is shown in *Figure 6*.

The feeding was started after about 60 min of stabilization with the temperature at 790°C. As soon as the feeding started the devolatisation began and temperature of the bed started to rise rapidly. In about 30 min the temperature at the top of the furnace had risen to about 864°C. The effects of variation in the primary air flow rate on emissions are shown in *Table 7*.

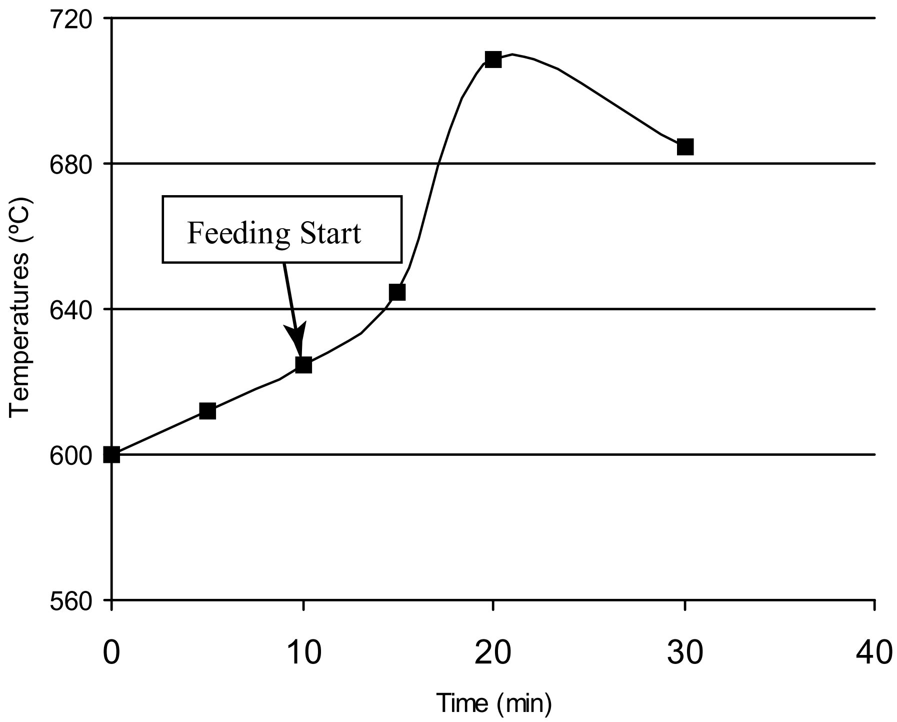

Figure 5. Variation of circulating fluidized-bed (CFB) temperature with time.

TABLE 6. EMISSION QUALITY WITH PRIMARY AIR FLOW RATE

Sr. No.	Primary air flow rate (m^3 hr^{-1})	Exhaust temperature (°C)	CO (ppm)	NOx (ppm)	CFB top temp. (°C)
1	1.0	185	2 950	75	709
2	1.5	160	4 819	49	685
3	2.0	150	7 000	38	680

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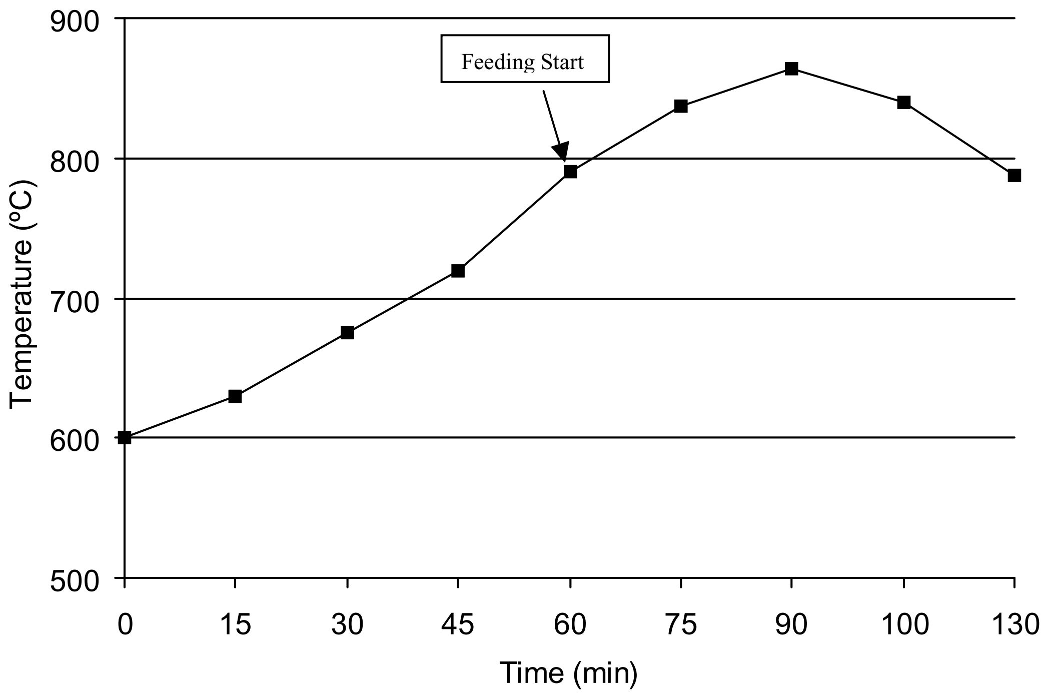

Figure 6. Variation of circulating fluidized-bed combustor (CFBC) temperature with time.

TABLE 7. EMISSION QUALITY WITH PRIMARY AIR FLOW RATE

Sr. No.	Primary air flow rate (m^3 hr^{-1})	Exhaust temperature (°C)	CO (ppm)	NOx (ppm)	CFB top temp. (°C)
1	1.0	105	1 094	38	752
2	1.5	193	6 092	127	837
3	2.0	150	4 420	90	864
4	2.5	143	8 500	52	842
5	3.0	150	5 354	40	809

It can be inferred from *Table 7* that the primary air flow rate of 1 m^3 hr^{-1} was good for the 425 micron particles. Increasing the flow rate above that reduced the particle residence and resulted in incomplete combustion and hence, high CO emission. A similar trend was also shown by the 600 micron particles fluidization. However, the temperature at the top of the CFB rose to about 888°C and the CO emissions was about 7000 ppm.

It is important to understand that as the primary air flow rate is changed, the fluidization behaviour in the gasifier also changes abruptly, causing the devolatisation behaviour to change. This can be shown by plotting the average gasifier temperature with the height of the gasifier as shown in *Figure 7*. This shows a sudden jump in temperature after the middle section of the gasifier and which is expected to change the pyrolysis and emission behaviour.

The gas residence time in the furnace calculated from the air feed rate is short 1.1 to 2.0 s. The residence time is even shorter when the gas flow rate is increased by gasification of PSP. Particularly, under high temperature conditions, the residence time may be extremely short - less than 1 s. Although the sample was to be gasified by the quick heat decomposition, that is a feature of the CFB, the reaction did not advance much because of the insufficient resident time and soot and char were generated in quantity. Soot and char were also found in the duct of the apparatus. This proved insufficient residence time under the high temperature conditions

In a CFB furnace, heat decomposition of the matter fed into the furnace advances quickly. In addition, since the particle concentration in the furnace is high and the efficiency of contact of the circulating particles with the feedstuff and gas also high, high heat conductivity and the resultant high speed progress of the reaction can be expected. These features of the CFB are regarded as one of the factors for low tar generation. In this experiment, the PSP sizes 212-300 and 425 microns were sufficiently small for their quick heat decomposition. The palm shell

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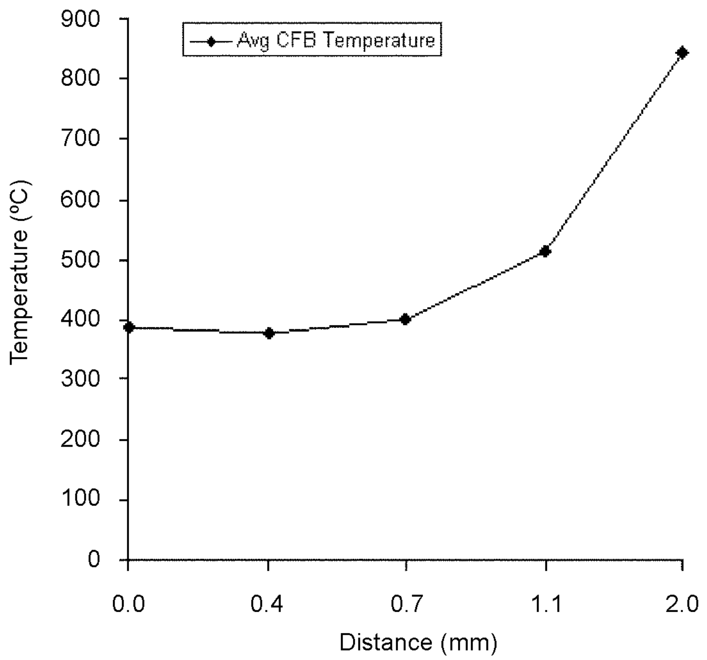

Figure 7. Variation of circulating fluidized-bed combustor (CFBC) average temperature with gasifier height.

powders used were therefore characterized by easy heat decomposition and low tar generation. However, excessive tar generation was found for the PSP of 600 micron. Reduced tar generation is one of major goals in biomass gasification systems. It is necessary to identify the optimum conditions for the experiments. Good heat transfer between the fluidizing particles and palm shell waste can be achieved by having the appropriate amount of alumina particles in the CFBC and using a low primary air flow rate. In order to reduce the tar formation, it is suggested to co-fire palm shell waste with coal.

CONCLUSION

The gasification experiment was successfully conducted using the CFB. Gas containing H_2, CO and CH_4 was produced with a heating value of 1000 kcal Nm^{-3} or more under proper conditions. The tar generation was low which may be due to quick heat decomposition of the EFB on the CFB. On the other hand, the generation of soot and char was high which may also be the cause of the low tar generation. The dependence of the emission quantity on the in-furnace temperature and primary air flow was identified and relationships between them derived. By this research, we have examined the gasification / combustion properties of palm shell waste powder which is found in abundance in Malaysia. Also fundamental data on gasification of palm shell waste has been obtained using a CFB.

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