Journal of Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 12 (24): 2574-2579, 2012
ISSN 1812-5654 / DOI: 10.3923/jas.2012.2574.2579

Downdraft Gasification of Oil Palm Frond: Effects of Temperature and Operation Time

M.N.Z. Moni and Shaharin A. Sulaiman
Department of Mechanical Engineering, Universiti Teknologi PETRONAS,
Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

Abstract: The last years saw a sharp increment in the interest laid on the renewable and the alternative energy sector, mainly due to the depletion of fossil fuel throughout the world for industrial and commercial use. Malaysia is the second largest producer of palm oil, currently holding up to 4.5 million hectares of palm oil plantation in its land. Currently produced at more than 40 million tons a year, only a small portion of Oil Palm Frond (OPF) is used as domestic animals forage and as raw material in small-scale furniture industry, while the rest is left at the plantation floor to naturally decompose. This study introduces OPF as a solid biomass fuel for gasification to produce synthesis gas that can be utilized for heat and energy generation in a cleaner and more efficient manner than direct combustion. OPF was gasified in the downdraft gasifier at 700-1000°C reactor temperature with a controlled air supply of 180 to 200 L min^{-1}. The effects of reactor temperature and operation time to the quality of syngas produced from OPF downdraft gasification were investigated. At a calorific value at around 18 MJ kg^{-1}, OPF was found to produce synthesis gas that sustainably burnt in air with a higher heating value of around 5 MJ Nm^{-3}. OPF was found to be optimally producing syngas with desired energy content at a reactor temperature range of 700-900°C and within the first 45 min of gasifier operation.

Key words: Biomass, fuel, downdraft gasification

INTRODUCTION

Until the petroleum industry was introduced in the late 1800 sec, mankind has exploited biomass as the main energy source for heat and power generation since the beginning of time. However, the recent years saw a quick depletion of the global petroleum resources while demands for heat and power increase steadily by the year. With the petroleum resources estimated to disappear completely in less than 50 years of so, scientists and researchers worldwide introduced several renewable and alternative energy sources; one of them is biomass. While biomass is most common as solid fuels to the large energy facilities, its exploitation in small scale application can be even more fascinating mainly for the higher prospect for heat recovery, less complexity in raw materials supply and much lower impacts to the environment. Moreover, small plants are applicable to a wider range of industry and consumer users than large plants, adding up to its generous versatility as a renewable source for heat and power generation. As in Malaysia, a tropical country located close to the equator, biomass supply is in abundance. Being currently the second largest palm oil producer responsible for 43% of the world's supply, Malaysia utilized more than 4.5 million hectares of its land for the cultivation of oil palm trees (Malaysia Palm Oil Board, 2011). With increasing trend in the awareness of biomass potential as alternative energy resource, the palm oil industry has emerged to be an attractive platform for continuous and large biomass supply as depicted by Abdullah and Yusup (2010). Common examples of biomass from oil palm industry are Palm Oil Mill Effluent (POME), Empty Fruit Bunch (EFB), fiber, shells, kernels, trunks and Oil Palm Fronds (OPF) as widely discussed by Faizal *et al.* (2010), Wan Asma *et al.* (2010), Abdullah *et al.* (2011) and Razuan *et al.* (2010). OPF was not given much attention to unlike other biomasses produced by the oil palm tree. Other than being utilized as ruminant feedstock for cattle as reported by Atil (2004) and as a raw material in small-scale wood and furniture industry, a large amount of OPF would normally be left on the plantation floor as a natural fertilizer once pruned or used as nutrient sources for the cultivation of young palms according to Haron *et al.* (2007). Recent studies on OPF as a raw material for ethanol production as reported by Yutaka (2007) and biomass briquette by Nasrin *et al.* (2008) have been presented and discussed. This realization of OPF as a biomass source led to a few studies including this one to have been established to introduce alternative endings to OPF as a biomass with potential values. With biomass gasification re-emerging popularity among researchers and enthusiasts worldwide in the

Corresponding Author: M.N.Z. Moni, Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

pursuit to create and promote the awareness in green technology, OPF is seen to be a potential candidate based on its abundant supply and considerable energy content to be processed as a solid fuel for gasification. Efforts in studying OPF gasification by simulation and experiment approaches was reported by Atnaw *et al.* (2011), bearing a potential result where OPF might be a prospective biomass fuel for heat and energy generation. Similarly, a torrefaction attempt on OPF was reported by Sulaiman and Anas (2012).

This study intended to utilize OPF for downdraft gasification process, in which the effects of the reactor temperatures and operation time to the quality of the produced syngas were studied. The outcome of this study would enable OPF to be utilized as a solid biomass fuel for gasification at a larger scale where its practicality can be further observed and studied for actual application. The public awareness about gasification and its benefit may be increased mainly due to the heightened interests in green technology and the world's fuel crisis. The promising potential of OPF as gasification fuel would be one of the biggest solution to Malaysia's yearly energy expenses on coal and other fossil fuels for heat and energy generation when applied. The outcomes of this present research would also generate a few more studies of OPF as a biomass fuel for other applications, if not for gasification, thus promoting more intellectual awareness of OPF as a new hope as a biomass fuel source.

GASIFIER SETTINGS

Gasifier specification: The gasifier used for the experiment was a laboratory-scale stationary, batch-operated 50 kWth fixed-bed downdraft type. The arrangement of the gasifier system is shown in Fig. 1. Air was supplied into the gasifier by means of blowing using a 250 W vortex blower and the amount of supplied air was controlled using a ball valve and a bypass point and monitored using a pitot tube and a water manometer. The full capacity of the gasifier was 12 kg for 2.5-5.0 cm cubic OPF blocks with 70% compact factor.

Feedstock specification: Pre-processed OPF fuel in block form was prepared and utilized in the experiment. Every part of OPF was utilized except for the leaflets in order to maintain a uniform fuel particle size and morphology. Averagely, the dimension of each fuel block was 2.5-5.0 cm in cubic shape. The fuel was processed from green OPF and was pre-dried to achieve the desired moisture content of 12±2%. The calorific value of OPF fuel was found to be 17.65 MJ kg^{-1} by average on dry basis.

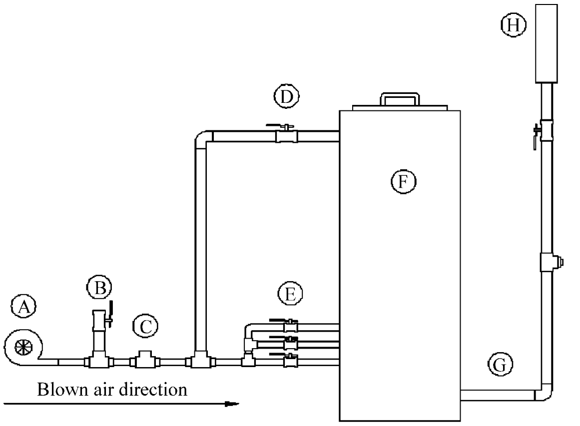

Fig. 1: Downdraft gasifier assembly, A: Vortex air blower, B: Air bypass outlet, C: Pitot tube point, D: Primary air route, E: Secondary air route, F: Downdraft glassifier, G: Gas exhaust pipe and H: Gas flare point

Gasification setting: The downdraft gasification of OPF was conducted within a known operation range for OPF fuel. The supplied air into the gasifier was controlled in the range of 180-200 L min^{-1} to keep the reactor temperature in between 700-900°C. Conducted studies have shown that this setting was the most optimal for the gasification of OPF fuel as described previously. The reactor temperature was controlled by means of regulating the air supply into the gasifier. The intended gasifier operation time was 1 h before refueling was required.

Preheating procedure: Prior to each test, the reactor was first preheated to prepare for gasification. Preheating was done by burning a pilot fuel that comprised of shredded paper, garden refuse and rejected OPF fuel from the fuel processing stages in the gasifier to bring up the reactor temperature to more than 500°C. This process was important to form a layer of char bed above the reactor grate. With preheating, syngas was produced at a shorter time (5-10 min) than without (15-20 min) and the combustion of OPF fuel was found to be steadier and less problematic. The positive effects of gasifier preheating can be explained by considering the autoignition temperature of woody biomass including wood that is around 250-300°C as thoroughly discussed by Baker (1983), Boonmee and Quintiere (2002) and Cao *et al.* (2006). Following preheating, thermochemical reactions occurred almost as instantly on freshly-loaded OPF fuel blocks due to rapid heating of fuel, resulting into a quicker transition from instantaneous drying to pyrolysis. Such transition made syngas to produce faster than without preheating. Additionally, excess tar deposits on the internal reactor and pipe walls from previous operations were discovered to be consumed in the heat, showing another advantage of preheating in the caretaking of the gasifier system. This was due to the thermal cracking of tar at a temperature of 700 to above 1000°C according to Milne *et al.* (1998).

OPF DOWNDRAFT GASIFICATION

Influence of reactor temperature: The influence of reactor temperature on the quality of syngas from the downdraft gasification of OPF was investigated by comparing the components and the calorific values of syngas produced at various reactor temperatures. Figure 2 shows the production trends of CO, CO_2, CH_4 and H_2 while Table 1 and 2 shows their average values at different reactor temperature ranges. CO and H_2 were found to produce in an increasing manner with increasing reactor temperature. CO_2 production showed a dropping pattern as the reactor temperature rose. H_2 was increasingly produced as the reactor temperature reached 850°C but dropped following that point. CH_4 production however was found to be slightly increasing with increasing temperature, although with very less significance.

The lower calorific value of syngas (LCV_{syngas}) and the H_2:CO ratio are shown in Fig. 3. The experimental results showed that H_2:CO ratio decreased while LCV_{syngas} increased with increasing reactor temperature.

The reason behind the increment of LCV can be explained using the following correlation:

$$LCV_{syngas} = |(LCV_n \times Vol.\%) \qquad (1)$$

where, LCV_{syngas} is the total lower calorific value of syngas while LCV_n is the specific lower calorific value of a gas component species i.e., CO and CO_2. The summation of the lower calorific values of all gas component species (CO, CO_2, H_2 and CH_4) will bear LCV_{syngas}. The typical LCV for each gas component is as shown in Table 3.

The increment in LCV_{syngas} with increasing reactor temperature was speculated due to the increasing concentration of CO in syngas, where the LCV of CO is slightly higher than that of H_2, hence also explained why LCV_{syngas} still increased even when with reducing H_2 amount in syngas: the superiority of energy content of CO at increasing concentration overcame the loss in syngas energy due to the reduction of H_2 in syngas as the reactor temperature rose to above 1000°C. While this may be beneficial to increase LCV_{syngas}, the combustibility of syngas may be compromised due to the high CO concentration for the fact that CO, although combustible,

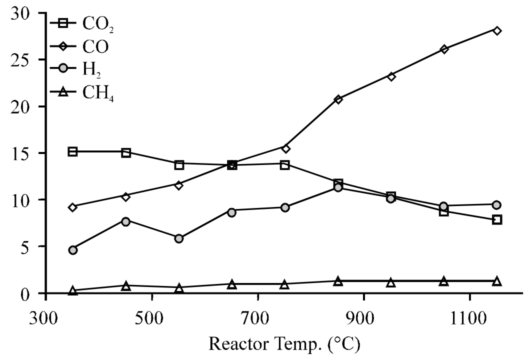

Fig. 2: Production trends of gas components in syngas produced from downdraft gasification of OPF chips as a function of reactor temperature at 180 to 200 L $min^{-1}$of air

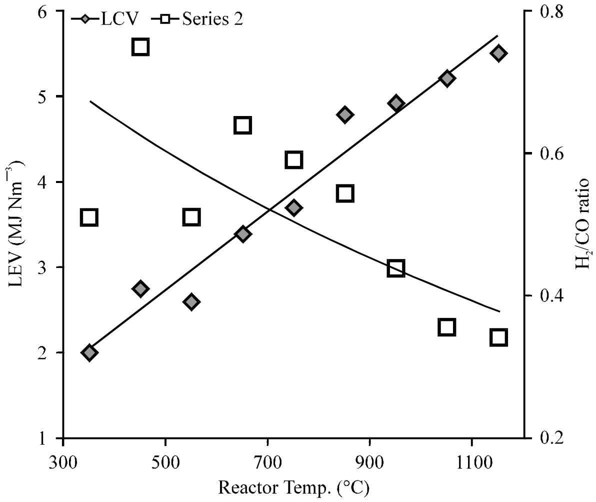

Fig. 3: Lower calorific value and H_2:CO ratio of syngas produced from downdraft gasification of OPF chips as a function of reactor temperature

Table 1: Gas components in syngas produced from downdraft gasification of OPF chips as a function of reactor temperature range

	Gas components (Vol.%)			
Reactor Temp. (°C)	CO	CO_2	CH_4	H_2
300-400	9.23	15.19	0.39	4.71
400-500	10.39	15.08	0.84	7.78
500-600	11.70	13.80	0.67	5.95
600-700	13.79	13.70	1.03	8.79
700-800	15.61	13.80	1.03	9.19
800-900	20.80	12.06	1.35	11.29
900-1000	23.33	10.38	1.23	10.20
1000-1100	26.12	8.81	1.32	9.30
1100-1200	28.21	7.82	1.29	9.59
300-400	9.23	15.19	0.39	4.71
400-500	10.39	15.08	0.84	7.78

Table 2: Characteristic of syngas produced from downdraft gasification of OPF chips as a function of reactor temperature range

Reactor Temp. (°C)	LCV (MJ Nm^{-3})	H_2:CO ratio	CGE (%)
300-400	1.99	0.51	27.65
400-500	2.73	0.75	37.96
500-600	2.59	0.51	36.03
600-700	3.39	0.64	47.11
700-800	3.68	0.59	51.15
800-900	4.77	0.54	66.27
900-1000	4.91	0.44	68.19
1000-1100	5.19	0.36	72.12
1100-1200	5.49	0.34	76.28

Table 3: Typical LCV of syngas main gas components

Gas species	CO	CO_2	CH_4	H_2
LCV (MJ Nm^{-3})	13.1	0	37.1	11.2

Table 4: Characteristic of syngas produced from the downdraft gasification of OPF chips at a reactor temperature range of 700 to 900°C

Reactor temperature (°C)	700-900
CO concentration (Vol. %)	15.61-20.80
CO_2 concentration (Vol. %)	12.06-13.80
CH_4 concentration (Vol. %)	1.03-1.35
H_2 concentration (Vol. %)	9.19-11.29
LCV (MJ Nm^{-3})	3.68-4.77
H_2:CO ratio	0.54-0.59
CGE (%)	51.15-66.27

is also a non-supporter of combustion. Higher H_2 concentration in syngas is therefore still favorable for this reason. This increasing amount CO compared to decreasing H_2 with increasing reactor temperature also caused the H_2:CO ratio to radically drop.

The cold gas efficiency of syngas (CGE_{syngas}) is shown in Fig. 4. The experimental CGE_{syngas} values were calculated using the following correlation:

$$CGE - \frac{(V_{syngas} \times LCV_{syngas})}{(m_{OPF} \times LCV_{OPF})} \quad (2)$$

where, V_{syngas} is the flow rate of syngas leaving the reactor, m_{OPF} is the mass feed rate of OPF fuel in the reactor and LCV_{syngas} and LCV_{OPF} are the lower calorific values of syngas and OPF, respectively. Due to the inability to measure the actual V_{syngas} owing to the incapability of the existing measuring instrument, it was estimated that every kilogram of OPF produced 2.5 m^3 of gas by average amount of gas produced from 1 kg or biomass according to the GEK developers (AllPowerLabs, 2010) while m_{OPF} was estimated to be 10 kg h^{-1}. LCV_{syngas} were calculated from syngas compositions while LCV_{OPF} was defined to be 18 MJ kg^{-1} by average.

It was observed that CGE_{syngas} increased with increasing reactor temperature, mainly due to the increment in syngas energy as attributed to the rising concentration of CO (Table 4). The highest CGE_{syngas} value was found to be 76.28% at a reactor temperature range of 1150±50°C. This observation was related to the increasing amount of CO in syngas as discussed previously and to note that CGE_{syngas} was mostly in between 50 to 70%, it showed a good indication that the pyrolysis process inside the reactor was good enough to extract volatiles from OPF fuel as concluded by Kennedy and Lukose (2006).

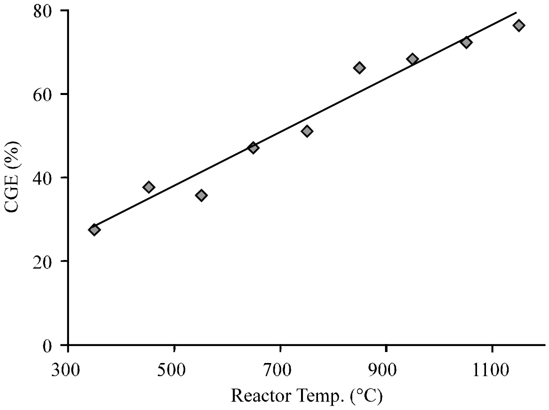

Fig. 4: Cold gas efficiency (CGE) of syngas produced from downdraft gasification of OPF chips as a function of reactor temperature

INFLUENCE OF OPERATION TIME

The influence of operation time to syngas characteristic has been an important interest to this study in order to determine the maximum operation time until the gasifier needs to halt the supply of syngas for refueling mainly due to decreasing syngas quality. The characteristic of syngas was monitored by the concentration of its gas components, lower calorific value (LCV_{syngas}), H_2:CO ratio and CGE_{syngas}. The values were the average of five repeated operations and are shown in Table 5 and 6.

Figure 5 shows the concentration of the gas components in syngas as a function of gasifier operation time. The highest-in-concentration gas component, CO, was observed to peak at minute 75 at 21.69% after a steady climb before experiencing a sharp drop towards the end of operation. H_2 showed almost the same pattern where its concentration peaked at minute 85 before experiencing a drop following that period. CO_2 however, experienced very less change in concentration except at minute 55 where it suddenly peaked before stabilizing again and then gently increased after minute 75 towards the end of operation. CH_4 experienced relatively almost no change at all in concentration along the gasification period and was observed to reduce in concentration after 95 min of operation.

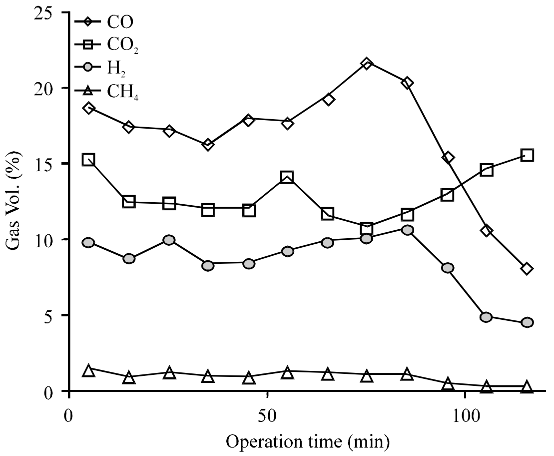

Fig. 5: Production trends of gas components in syngas produced from downdraft gasification of OPF chips as a function of gasifier operation time

Table 5: Gas components in syngas produced from downdraft gasification of OPF chips as a function of gasifier operation time

	Gas components (Vol.%)			
Time (min)	CO	CO_2	CH_4	H_2
5	18.73	15.34	1.49	9.87
15	17.49	12.52	0.98	8.83
25	17.27	12.43	1.32	10.00
35	16.30	12.00	1.09	8.41
45	17.95	12.02	0.99	8.53
55	17.73	14.20	1.39	9.25
65	19.36	11.72	1.27	9.94
75	21.69	10.84	1.19	10.18
85	20.43	11.81	1.22	10.77
95	15.45	13.02	0.64	8.22
105	10.74	14.73	0.37	4.97
115	8.16	15.60	0.40	4.63

Table 6: Characteristic of syngas produced from downdraft gasification of OPF chips as a function of gasifier operation time

Time (min)	LCV (MJ Nm^{-3})	H_2:CO ratio	CGE (%)
5	4.37	52.58	60.71
15	3.86	50.65	53.64
25	4.13	64.57	57.30
35	3.69	64.12	51.31
45	3.89	53.78	53.98
55	4.62	73.77	64.19
65	4.37	69.38	60.70
75	4.67	47.22	64.90
85	4.60	52.83	63.92
95	3.37	52.56	46.84
105	2.22	46.36	30.79
115	1.84	56.76	25.60

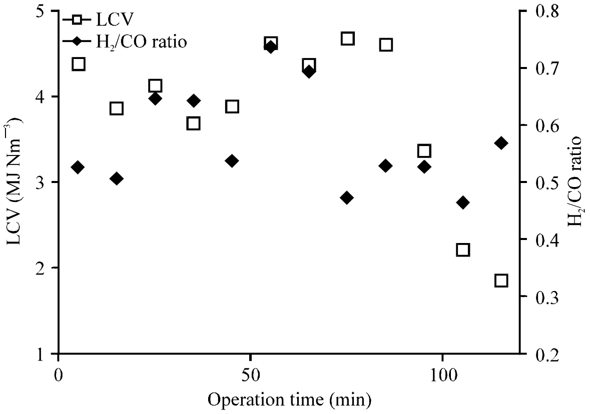

Fig. 6: Lower calorific value and H_2:CO ratio of syngas produced from downdraft gasification of OPF chips as a function of gasifier operation time

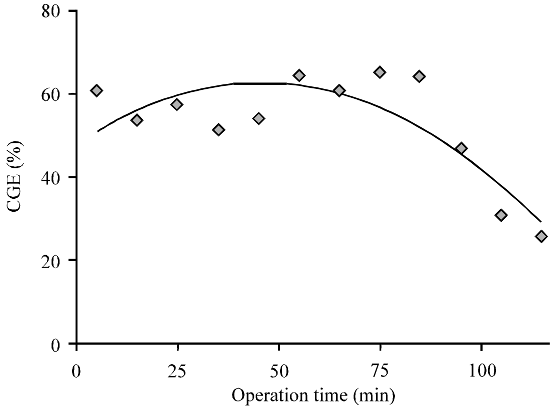

Fig. 7: Cold gas efficiency of syngas produced from downdraft gasification of OPF chips as a function of gasifier operation time

Figure 6 shows the trends of the lower calorific value of syngas, LCV_{syngas} and the H_2:CO ratio as functions of gasifier operation time. Both LCV_{syngas} and H_2:CO ratio showed a climbing trend before dropping towards the end of the gasifier operation. LCV_{syngas} experienced the most reduction after around 90 min of operation while the H_2:CO ratio did not give a very conclusive pattern of change along the gasification period, although the polynomial trend line suggested a smooth reduction following the 60th min of operation. The polynomial trend line for LCV_{syngas} showed a steep drop at nearly the same time frame. The reduction in LCV_{syngas} was mainly due to the decreasing amounts of CO and H_2 towards the end of the operation where as the OPF fuel has been consumed to a minimum level, the air-fuel ratio increased to nearly or more than 1.0, transitioning the otherwise substoichiometric gasification to complete combustion. This caused CO_2 to be produced instead of H_2 and CO, leading to the drops in LCV_{syngas} and H_2:CO ratio. Cao *et al.* (2006) discussed the similar observation, where LCV of syngas dropped mainly due to the decreasing amount of combustible components in syngas.

The cold gas efficiency of syngas (CGE_{syngas}) as a function of gasifier operation time is shown in Fig. 7. The plotted chart did not give a clear trending pattern albeit the polynomial trend line showed that CGE_{syngas} rose from the start of the operation and peaked at minute 55 (73.77%) before experiencing a steady reduction towards the end of the operation. By average, CGE_{syngas} was found to be 52.82% with a standard deviation of 12.82%.

CONCLUSION

The observations on the change in syngas characteristic due to the influence of reactor temperature critically contributed to the gasifier operation demands where, in order to produce good quality syngas from OPF gasification, the temperature of the reactor has to be kept in between the range of 700 to 900°C, which, in order to keep the H_2:CO ratio at above 0.5. At this temperature range, the characteristic of syngas is shown in Table 4. Although at a higher temperature LCV_{syngas} and CGE_{syngas} improved significantly, mainly attributable to the high concentration of CO, the ignitability of syngas was compromised due to the nature of CO as not a non-supporter of combustion. This was observed in the flare tests during operation where it was found that the flare, although still combustible, was harder to ignite and sustain combustion in air.

The influence of operation time was found to be a crucial remark in operating the gasifier to produce good quality syngas from downdraft gasification of OPF. The designed operating duration for the gasifier was intended to be 60 min and it was discovered experimentally that the gasifier met the intended specification. Following the operation period of above 60 min, the quality of syngas in terms of composition and energy content reduced to which it became less effective to futile to be utilized to generate heat and power. For this reason, the operation of the gasifier has to be limited to only 60 min for each full capacity run until refueling is required.

REFERENCES

Abdullah, N., F. Sulaiman and H. Gerhauser, 2011. Characterization of oil palm empty fruit bunches for fuel application. J. Phys. Sci., 22: 1-24.

Abdullah, S.S. and S. Yusup, 2010. Method for screening of Malaysian biomass based on aggregated matrix for hydrogen production through gasification. J. Applied Sci., 10: 3301-3306.

AllPowerLabs., 2010. Gasifier experimenters kit. http://www.gekgasifier.com

Atil, O., 2004. Palm-based animal feed and MPOB's energy and protein centre. Palm Oil Dev., 40: 1-4.

Atnaw, S.M., S.A. Sulaiman and S. Yusup, 2011. A simulation study of downdraft gasification of oil-palm fronds using ASPEN PLUS. J. Applied Sci., 11: 1913-1920.

Baker, A.J., 1983. Wood fuel properties and fuel products from woods. Proceedings of the Fuelwood Management and Utilization Seminar, November 9-11, 1983, Michigan State University, East Lansing, pp: 14-25.

Boonmee, N. and J.G. Quintiere, 2002. Glowing and flaming autoignition of wood. Proc. Combust. Inst., 29: 289-296.

Cao, Y., Y. Wang, J.T. Riley and W.P. Pan, 2006. A novel biomass air gasification process for producing tar-free higher heating value fuel gas. Fuel Proc. Tech., 87: 343-353.

Faizal, H.M., Z.A. Latiff, M.A. Wahid and A.N. Darus, 2010. Physical and Combustion Characteristics of Biomass Residues from Palm Oil Mills. In: New Aspects of Fluid Mechanics, Heat Transfer and Environment, Mastorakis, N.E., V. Mladenov and Z. Bojkovic (Eds.). Wiley, New York, USA., ISBN: 978-960-474-215-8, pp: 34-38.

Haron, K., Z.Z. Zakaria and J.M. Anderson, 2007. Nutrient cycling in an oil palm plantation: The effects of residue management practices during replanting on dry matter and nutrient uptake of young palms. J. Oil Palm Res., 12: 29-37.

Kennedy, Z.R. and T.P. Lukose, 2006. Performance evaluation of a double-walled downdraft gasifier for energy applications. Adv. Energy Res., 2006: 307-316.

Malaysia Palm Oil Board, 2011. Oil palm planted area by states as At September 2011 (Hectare). http://econ.mpob.gov.my/economy/area/Area_state.pdf

Milne, T.A., R.J. Evans and N. Abatzoglou, 1998. Biomass gasifier tars: Their nature, formation and conversion. Report No. NREL/TP-570-25357, NREL. http://www.ps-survival.com/PS/Gasifiers/Biomass_Gasifier_Tars_Their_Nature_Formation_And_Conversion_1998.pdf

Nasrin, A.B., A.N. Ma, Y.M. Choo, S. Mohamad, M.H. Rohaya, A. Azali and Z. Zainal, 2008. Oil palm biomass as potential substitution raw materials for commercial biomass briquettes production. Am. J. Applied Sci., 5: 179-183.

Razuan, R., Q. Chen, X. Zhang, V. Sharifi and J. Swithenbank, 2010. Pyrolysis and combustion of oil palm stone and palm kernel cake in fixed-bed reactors. Bioresour. Technol., 101: 4622-4629.

Sulaiman, S.A. and M.I. Anas, 2012. Torrefaction of oil palm fronds for enhancement of fuel quality. Trends Applied Sci. Res., 7: 248-255.

Wan Asma, I., S. Mahanim, H. Zulkafli, S. Othman and Y. Mori, 2010. Malaysian oil palm biomass. Proceedings of the FRIM Regional Workshop on UNEP/DTIE/IETC, March 2-5, 2010, Osaka, Japan.

Yutaka, M., 2007. Potential of Oil Palm Trunk as a Source for Ethanol Production. Research Center for Agricultural Science, Japan.