Bull. Chem. Soc. Ethiop. **2016**, 30(3), 465-472. ISSN 1011-3924
Printed in Ethiopia
DOI: http://dx.doi.org/10.4314/bcse.v30i3.15

CHARACTERIZATION OF DATE PALM FRONDS AS A FUEL FOR ENERGY PRODUCTION

S.A. Sulaiman[1*], H.S. Bamufleh[2], S.N.A. Tamili[1], M. Inayat[1] and M.Y. Naz[3]

[1]Department of Mechanical Engineering, Universiti Teknologi Petronas, 32610 Bandar Seri Iskandar, Perak, Malaysia
[2]Department of Chemical & Materials Engineering, Faculty of Engineering, King Abdulaziz University, P.O. Box 80204, Jeddah 21589, Saudi Arabia
[3]Department of Physics, University of Agriculture, 38040 Faisalabad, Pakistan

(Received July 1, 2015; revised August 9, 2016)

ABSTRACT. This study investigated the characteristics of date palm fronds (DPF) for their use as a feedstock for fuel and energy production. The calorific values and elemental contents of the DPF samples were measured through proximate analysis, ultimate analysis and energy dispersive X-ray spectroscopy. For proximate analysis, thermo-gravimetric analysis technique was used to identify the moisture content, volatile matter, fixed carbon and ash content. Ultimate analysis was used to determine the weight percentage of carbon, hydrogen and nitrogen. In line with this, X-ray fluorescence was used to determine the percentage of sulfur in the tested samples. The results of the conducted study were compared with other biomass reported in the past literature. The fixed carbon content of DPF was found lower than the other biomass except rice husk. Ajwah DPF exhibited the highest carbon content of 14.1%, while Jeddah DPF showed lowest carbon content of 5.2% among all the tested samples. However, presence of the metallic elements in the samples, such as Mg and Na can cause problems in the thermo-chemical processing systems.

KEY WORDS: Date palm fronds, Biomass, Proximate analysis, Ultimate analysis, Calorific value, Elemental content

INTRODUCTION

Biomass wastes have high potential to be used as a source of energy. An attractive aspect of biomass utilization is its renewability which can ensure that the sources will not be depleted. The energy in plants and plant derived materials are obtained by photosynthesis in the process of plant growth [1]. Utilization of biomass wastes as energy resource has various economic and environmental advantages. Date palm (*Phoenix dactylifera*) is one of the most cultivated palms in arid and semi-arid regions. Currently, there are about 105 million date palm trees being grown around the world [2]. The origin of date palm is still uncertain but there are several claims that it is originated from Babel in Iraq, from Dareen or Hofuf in Saudi Arabia or Harqan and also from an island on the Arabic Gulf in Bahrain. The oldest radio-carbon discovery of date seeds was on Dalma Island, part of the Abu Dhabi Irelands Groups. In 2006, the top 10 palm date producing countries were Egypt, Saudi Arabia, Iran, United Arab Emirates, Pakistan, Algeria, Sudan, Oman, Libya and Tunisia [3]. In addition to fruits, date palm also provides a large number of other by-products [4].

Nowadays, with the development of the technology the date palm is used for many applications. Date palm leaves are the important natural sources of fibers where it can be used as an input for many industrial applications in almost all fields [2]. Date palm age may reach over 100 years [3] and an average of 12-15 new fronds are being grown every year. The same amount of fronds is pruned for maintenance of the palm in the same year [4]. The global production of dates has grown from 7,429,811 tons in 2009 to 8,267,335 tons in 2014 and the amount of wastes generated from the fruit production is also increasing every year. The date palm wastes can be used for many applications, such as in production of paper pulp and composite materials, and preparation of activated carbon [5]. However, with regard to energy application, using date

*Corresponding author. E-mail: shaharin@petronas.com.my

palm wastes only, very few studies were conducted in the past. Therefore in this research, the characteristics of date palm fronds (DPF) were investigated for their potential as an effective feedstock for different energy conversion processes, such as gasification, pyrolysis and torrefaction.

EXPERIMENTAL

Samples of date palm fronds were received from Madinah Al Munawwarah and Jeddah Cities, and dried under natural conditions for 2 to 4 days in order to remove the moisture content. The fronds were three types altogether, which are Sukariah, Ajwah and Jeddah as shown in Figure 1. Then the samples were ground and sieved to a particle size of 250 µm by using a mechanical granulator.

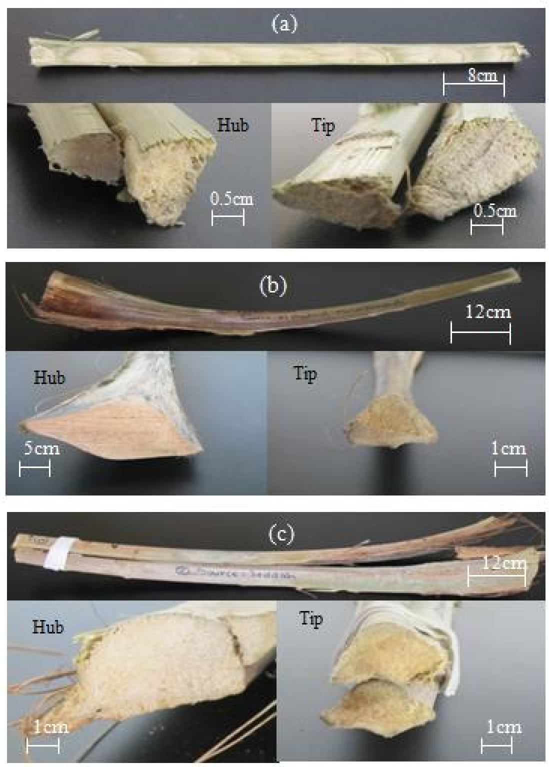

Figure 1. Typical date palm fronds sample; (a) Sukariah, (b) Ajwah and (c) Jeddah.

Proximate analysis

The moisture content, volatile matter, ash and fixed carbon of DPF were determined using proximate analysis, which is an empirical technique [6]. The proximate analysis was carried out using Thermo-gravimetric Analyzer (Pyris 1 TGA). During proximate analysis, the mass of substance was heated at a controlled rate and the mass loss was recorded as a function of time and temperature [7]. The ASTM E1131-08 standard test method was used to set up for the parameters. During the analysis, the moisture content and volatile matter were removed by heating the sample up to 850 ^{o}C in an inert gas environment.

Ultimate analysis

Ultimate analysis is important in determining the basic composition of a feedstock to know the suitability of the feedstock for energy production. The chemical composition in percentage, i.e. carbon, hydrogen, nitrogen and sulfur were identified using ultimate analysis. Series II CHNS/O Analyzer was used to determine carbon, hydrogen and nitrogen weight percentage. A S8 Tiger Bruker X-ray Fluorescence equipment was used for the determination of sulfur content. A feedstock with lower sulfur content is preferred in order to avoid formation of acidic compounds during its reaction with oxygen, water and oxidants.

Heating value

There are two ways of expressing the heating value of a biomass sample. The higher heating value is obtained when the product of the heat of combustion of the sample is determined relative to liquid water, whereas we call lower heating value when the heat of combustion of the sample is determined relative to the gaseous water. The difference of the two values is the latent heat of the product water. In the given study, Leco AC-350 Bomb Calorimeter was used for the determination of heating values.

FESEM microstructures and EDX analysis

A SUPRA 55VP model Field Emission Scanning Electron Microscope (FESEM) analyzer in combination with Energy Dispersive X-ray Spectroscopy (EDX) in non-conducting specimens mode was used for the study of microstructures of each sample [8]. SUPRA 55VP allows studying the surface of the samples examination with nanometer scale in either high vacuum or in Variable Pressure (VP) Model. FESEM was used to visualize very small topographic details on the surface of the samples. Electrons which are produced by the field emission source accelerate in a high electrical field gradient. A narrow scan beam is produce within the high vacuum column by primary electrons. Secondary electrons are emitted from each spot on the sample. The secondary electrons were caught by a detector and produce an electronic signal. Finally, the signal is amplified and transformed to video scan image that can be seen on the screen.

RESULTS AND DISCUSSION

Proximate analysis

Table 1 shows the proximate analysis of DPF. Figure 2 shows the percentage weight loss of DPF with temperature. The moisture content, volatile matter, fixed carbon and ash content measurements were based on weight loss versus temperature plots, as shown in Figure 2.

The characteristic of biomass may be affected by many factors such as weather, nature of the soil, method of harvesting, season of harvesting and the humidity of the environment. From Table 1, for DPF samples, Jeddah has the highest value of volatile matter which is 83%, while Ajwah has the lowest value which is 78.2%. When compared with other parts of the date palm, Ajwah and leaf part of the date palm showed almost similar results for volatile matter with very small difference of 0.01%. Among the date palm biomass, leaf stem has the lowest value for volatile matter, which is only 55.3%. By considering the past literature on biomass, DPF are comparable with those which have higher content of volatile matter, such as sugar cane bagasse, oil palm frond and western hemlock [9-11].

When the content of fixed carbon was compared, Ajwah showed the highest value among the DPF samples which is 14.1%, while Jeddah has the lowest value of 5.2%. A big difference of 8.9% was observed between Ajwah and Jeddah. When compared with the other part of the date palm, leaf part and Jeddah samples showed the same value of carbon content, which was measured about 5.2%. Bituminous coal had the highest value for the fixed carbon, which was approximated about 57%. Ajwah and sugar cane bagasse revealed very small difference of 0.2%. Generally, the fixed carbon content of DPF is lower as compared to that of other biomass except to rice husk, and higher than date palm biomass except for Jeddah DPF.

Table 1. Proximate analysis comparison of DPF with other biomass (dry basis).

Sample	Type of biomass	Volatile matter (%)	Fixed carbon (%)	Ash content (%)	Reference
DPF Samples	Ajwah	78.2	14.1	7.7	Present result
	Sukariah	82.5	13.6	3.6	Present result
	Jeddah	83.0	5.2	11.7	Present result
Date palm biomass	Seed	76.6	7.7	10.8	[11]
	Leaf	78.1	5.2	11.7	[11]
	Leaf stem	55.3	7.8	19.2	[11]
Other biomass	Sugar cane bagasse	82.3	14.3	3.3	[13]
	Oil palm fronds (OPF)	83.5	15.2	1.3	[7]
	Wood (*Acacia mangium)*	45.5	45.5	9.0	[13]
	Rice husk	75.4	12.3	13.2	[7]
	Rice straw	66.5	16.9	16.6	[9]
	Wheat straw	70.0	16.4	16.6	[9]
	Corn straw	69.0	16.4	14.5	[9]
	Sesame stalk	72.2	17.0	6.6	[9]
	Western hemlock	84.8	15.0	0.2	[10]
Coal	Bituminous coal	35	57	8	[11]

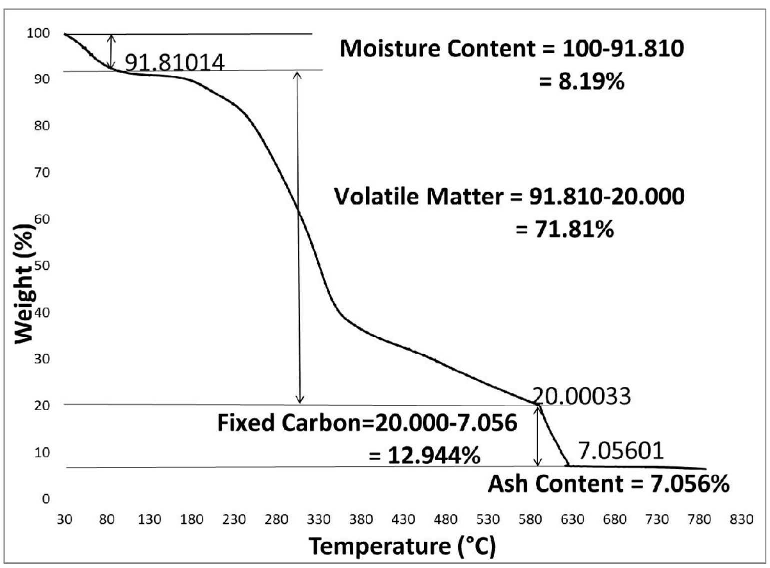

Figure 2. Percentage weight loss of DPF with temperature.

The investigations on ash content DPF samples revealed highest value of 11.7% in Jeddah while lowest value of 3.6% in Sukariah. However, Jeddah's sample and leaf part of the date fronds showed the same values of ash content. From other date palm biomass, leaf stem exhibited the highest value of 19.2%. DPF has lower ash content as compared to the agricultural wastes, i.e. rice husk, rice straw, wheat straw and corn straw. Ajwah and bituminous coal revealed 0.3% difference for the ash content. Biomass with higher volatile matter would have better combustion [12], while biomass with higher ash content would have poor combustion.

Ultimate analysis

Table 2 shows the results of ultimate analysis of DPF, date palm biomass, other biomass and coal samples. A minimal difference among the carbon contents of DPF samples was noticed in these studies. However, when compared with date palm biomass, the carbon content of all DPF samples was found significantly low except to leaf steam. Comparing with the other biomass, bituminous coal has the highest carbon content of 73.1%. Similarly, the other biomass also found better than DPF in terms of carbon content. For the hydrogen content, Sukariah showed the highest value of 5.70% while Ajwah exhibited the lowest value of 5.38% among all the tested DPF samples. Comparing with the date palm biomass, there was a small difference for all DPF samples, which is around 0.1% to 0.06%. For the nitrogen content, Jeddah has the highest value of 0.47% while Ajwah has the smallest value of 0.28% among the tested DPF samples. On comparison with the date palm biomass, all date biomass have higher value than DPF samples. Bituminous coal has 1.40% nitrogen, which is the highest value compared to all the biomass [7, 11, 13].

Table 2. Ultimate analysis comparison of DPF with other biomass.

Sample	Type of biomass	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulfur (%)	Reference
DPF samples	Ajwah	36.3	5.38	0.28	0.33	Present result
	Sukariah	38.9	5.70	0.32	0.66	Present result
	Jeddah	37.9	5.66	0.47	0.60	Present result
Date palm biomass	Seed	45.3	5.6	1.0	0.8	[11]
	Leaf	49.4	5.8	1.2	1.3	[11]
	Leaf stem	36.1	5.2	0.7	0.7	[11]
	Sugar cane bagasse	42.0	4.01	1.28	0.74	[13]
	Oil palm fronds (OPF)	44.6	4.53	0.71	0.07	[7]
	Oil palm fronds (OPF)	44.6	4.53	0.71	0.07	[7]
Other biomass	Wood (*Acacia mangium)*	43.5	3.59	1.00	0.16	[13]
	Rice husk	39.8	4.18	1.35	0.06	[7]
	Rice straw	39.2	5.10	0.60	0.10	[9]
	Wheat straw	42.1	6.53	0.58	0.32	[9]
	Corn straw	42.7	6.16	0.99	0.21	[9]
	Sesame stalk	41.3	6.57	0.81	0.29	[9]
Coal	Bituminous coal	73.1	5.50	1.40	1.70	[11]

Regarding sulfur content, Sukariah exhibited the highest value among the tested samples, which is 0.66%, while Ajwah has the lowest value of 0.33%. There was a small difference of 0.06% between Sukariah and Jeddah. The other date palm biomass has a higher value of sulfur compared to that of DPF samples, and bituminous coal has the highest value of 1.7% as compared to all tested biomass. The higher value for carbon content shows that the feedstock has a higher calorific value, since carbon-carbon bond has higher energy level compared to carbon-hydrogen and carbon-oxygen bonds [14]. The higher content of the nitrogen and sulfur may give harmful effect to the environment and there need additional treatment during the conversion process.

Heating value

For heating value of DPF samples, as shown in Table 3, Sukariah exhibited the highest value of 16,809 kJ/kg while Jeddah sample revealed the lowest value of 16,418 kJ/kg. Seed showed the highest value of 18,970 kJ/kg among all the date palm biomass samples. When Ajwah was compared with the other biomass, the calorific value was found quite closer to the corn straw with very small difference of 30 kJ/kg. Bituminous coal showed the highest value of 34,000 kJ/kg. In general, HHV of DPF was found bit higher than the agricultural biomass wastes except corn straw, and lower than sugar cane bagasse, oil palm frond and wood. However, overall HHV difference of agricultural biomass wastes and other biomass wastes was not significantly high and therefore DPF can be used as an alternative feedstock for different energy conversion processes such as gasification, pyrolysis and torrefaction [9-11].

Table 3. Heating value of DPF.

Sample	Type of biomass	Heating value (kJ/kg)	Reference
DPF samples	Ajwah	16670	Present result
	Sukariah	16809	Present result
	Jeddah	16418	Present result
Date palm biomass	Seed	18970	[11]
	Leaf	17900	[11]
	Leaf stem	10900	[11]
Other biomass	Sugar cane bagasse	17485	[13]
	Oil palm fronds (OPF)	17280	[7]
	Wood (*Acacia mangium)*	17525	[13]
	Rice husk	15300	[7]
	Rice straw	15800	[9]
	Wheat straw	16500	[9]
	Corn straw	16640	[9]
	Sesame stalk	15920	[9]
Coal	Bituminous coal	34000	[16]

Elemental analysis

Microstructure of each sample was determined using field emission scanning electron microscope (FESEM) at different magnifications (Figure 3). The weight percentage of each element was determined using energy dispersive X-ray spectroscopy (EDX). The observed elements in the spectra of the samples are shown on the left side of Figure 3. For Ajwah, the elements such as Cl, Ca, C, K, O, Mg, Na and Si were detected in the area. Cl showed the

Table 4. Elemental composition of DPF and other biomass.

Samples Elements	DPF						OPF		Rice husk	
	Ajwah		Sukariah		Jeddah					
	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %
C	40.7	49.6	38.6	46.7	37.4	44.9	47.0	54.3	37.9	47.3
O	51.0	46.7	55.9	50.9	60.2	54.2	52.5	45.5	48.2	45.2
Na	0.73	0.47	0.67	0.42	-	-	-	-	-	-
Mg	0.49	0.30	-	-	-	-		-	-	-
Si	1.21	0.63	0.57	0.29	-	-	-	-	13.99	7.48
Cl	3.35	1.39	1.98	0.81	0.99	0.40	0.56	0.22	-	-
K	1.93	0.72	0.97	0.36	1.37	0.50	-	-	-	-
Ca	0.57	0.21	1.33	0.48	-	-	-	-	-	-

highest peak as compared to other elements. Except for Mg, all elements detected in Ajwah sample were also found in Sukariah. For Jeddah sample only Cl, K, C and O were detected in the spectrum area and Cl showed the highest peak for all the samples. Table 4 shows the elemental compositions of different biomass feedstock obtained from EDX analysis. The carbon content in DPF, obtained from EDX analysis of Ajwah sample, was found higher than the carbon content obtained from CHNS Analyzer. From CHNS, the carbon content of Ajwah sample was measured about 36.3% while EDX analysis predicted the carbon content about 40.7%.

For DPF samples, Ajwah showed the highest value of carbon weight percentage (40.7%) while Jeddah revealed the lowest value of 37.4%. When compared with other biomass, OPF reflected the highest carbon content of about 47.0%. Rice husk, on the other hand, exhibited

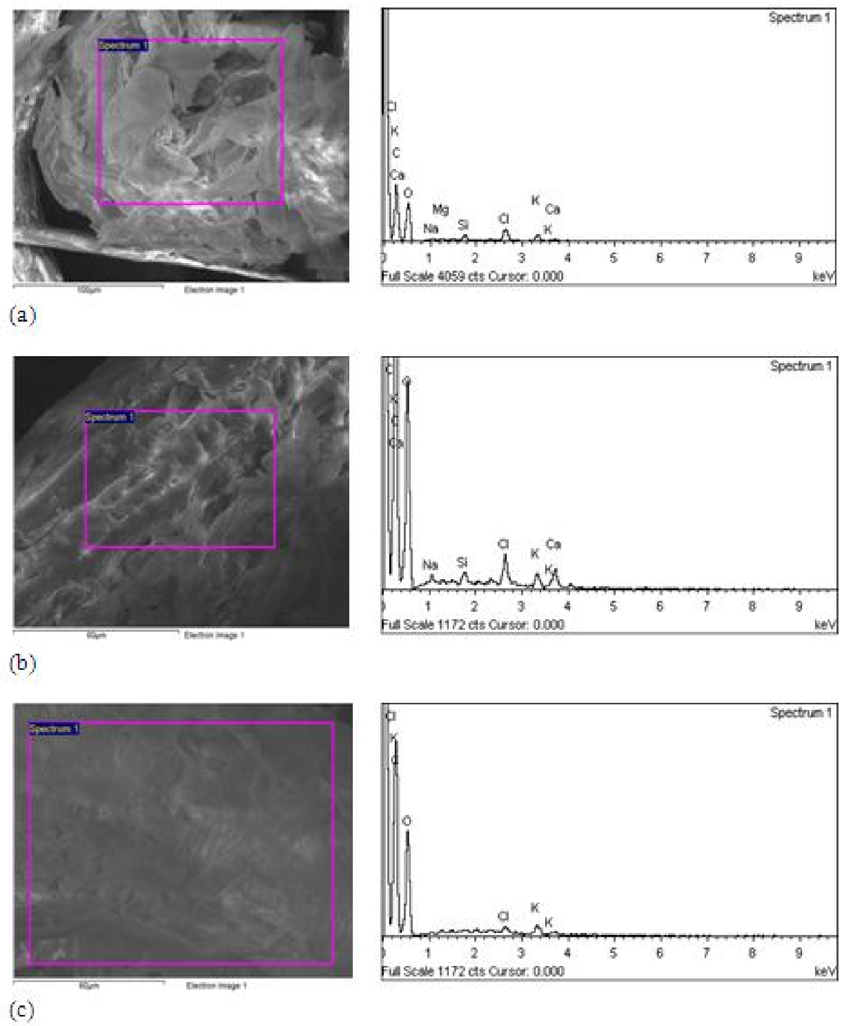

Figure 3. EDX images and elemental composition of (a) Ajwah, (b) Sukariah and (c) Jeddah.

almost similar values as Jeddah sample. Jeddah showed the highest oxygen content of 60.2% when compared to other samples, while rice husk showed the lowest value of 48.2%. Na was detected only in Ajwah and Jeddah. Mg was detected only in Ajwah and Si was detected only in Ajwah and Sukariah. Ajwah had the highest contents of Cl and K, which are 3.35% and 1.93%, respectively. Ca was detected only in Ajwah and Sukariah samples. Metallic elements, such as Mg, Na, Si, K and Ca should be in the samples to be considered as thermos-chemical processing systems [15]. However, higher content of some of elements in a feedstock can cause critical problems while handling the ash and downstream equipment.

CONCLUSIONS

This study investigated the characteristics of date palm fronds (DPF) of three samples, Ajwah, Sukariah, and Jeddah. The results were compared with other biomass feedstock. The volatile matter content in DPF samples was found comparable with other biomass, such as sugar cane bagasse and oil palm fronds (OPF). The fixed carbon content of DPF was lower as compared to other biomass except rice husk. The ultimate analysis revealed that DPF has lower carbon content than the other biomass. The HHV difference measured from agricultural biomass wastes and other biomass wastes was not notable therefore DPF can be used as an alternative feedstock for different energy conversion processes. The significance presence of metallic elements in samples can cause problems in the thermo-chemical processing systems and therefore require proper handling and treatment during process. Conclusively, DPF has the potential to be used as renewable energy source by using appropriate energy conversion technologies, such as gasification, pyrolysis and torrefaction.

ACKNOWLEDGEMENTS

The authors would like to acknowledege Uinversiti Teknologi Petronas for providing the fund for this research work.

REFERENCES

1. Lee, S.; Speight, J.G.; Loyalka, S.K. *Handbook of Alternative Fuel Technologies*, CRC Press: Baca Raton; **2007**.
2. Agoudjil, B.; Benchabane, A.; Boudenne, A.; Ibos, L.; Fois, M. *Energy and Buildings* **2011**, 43, 491.
3. Bhansali, R.R. *Date palm cultivation in the changing scenario of Indian arid zones: challenges and prospects* in *Desert Plants*, Springer: Online publication; **2010**; p 423.
4. Barreveld, W. *Date palm products: Agricultural Services Bulletin No. 101*, Food and Agriculture Organisation of the United Nations (FAO): Rome; **1993**.
5. El May, Y.; Dorge, S.; Jeguirim, M.; Trouvé, G.; Said, R. *Aerosol Air Qual. Res.* **2012**, 12, 814.
6. Faghihi, K.; Asghari, A.; Hajibeygi, M. *Bull. Chem. Soc. Ethiop.* **2013**, 27, 95.
7. Guangul, F.M.; Sulaiman, S.A.; Raghavan, V.R. *The 4th International Meeting of Advances in Thermofluids (IMAT 2011)*, **2012**, 1197.
8. Njoya, D.; Hajjaji, M.; Nkoumbou, C.; Elimbi, A.; Kwekam, M.; Njoya, A. *Bull. Chem. Soc. Ethiop.* **2010**, 24, 39.
9. Cuiping, L.; Chuangzhi, W.; Haitao, H. *Biomass & Bioenergy* **2004**, 27, 119.
10. Reed, T.; Reed, T.B.; Das, A. *Handbook of Biomass Downdraft Gasifier Engine Systems*, Biomass Energy Foundation: USA; **1988**.
11. Sait, H.H.; Hussain, A.; Salema, A.A.; Ani, F.N. *Biores. Technol.* **2012**, 118, 382.
12. Demirbas, A. *Prog. Energy Combust. Sci.* **2004**, 30, 219.
13. Inayat, M.; Sulaiman, S.A.; Hussain, S.B.; Fiseha, M G.; Atnaw, S.M.; Jamil, A.A. Proceedings of the International Conference on Global Sustainability and Flare in Co-gasification of Biomass Feedstock in Throated Downdraft Gasifier, Singapore, **2015**, 203.
14. Nguyen, T.L.T.; Gheewala, S.H.; Garivait, S. *Applied Energy* **2008**, 85, 722.
15. Horsfall, Jnr, M.; Vicente, J. *Bull. Chem. Soc. Ethiop.* **2007**, 21, 349.
16. McKendry, P. *Biores. Technol.* **2002**, 83, 37.