

SOME PHYSICAL AND COMBUSTION CHARACTERISTIC OF *LEUCAENA LEUCOCEPHALA* PELLET

*Amrit SHRESTHA¹, Wanphut SAECHUA¹ and Panmanas SIRISOMBOON¹

¹*Agricultural Engineering Curriculum, Department of Mechanical Engineering, Faculty of Engineering, King MoQJNXW๑V IQVWLWXWH RI THcKQRORΛ Ladkrabang Chalongkrung Road, Ladkrabang, Bangkok, Thailand 10520*

Corresponding author: Amrit SHRESTHA. E-mail: shresthamrit329@gmail.com

ABSTRACT

Leucaena leucocephala pellet can be a superior green fuel for Thailand by taking the advantage of such economic and environmental beneficial plant by establishing good rules and regulations toward afforestation of energy crops without altering the food chain. Before selling the biomass or its pellet, commercially, combustion characteristics must be recognized in advance so that it will get its actual monetary value instead of random cost per unit weight. For this purpose, thermogravimetric analysis (TGA) was performed to determine the ignition temperature, ignition index, burnout index and combustion performance index and found to be 261.7°C, 6.10×10^{-4} , 8.20×10^{-3} and 2.19×10^{-7} respectively and higher heating value (HHV) was found to be 18.65 MJ/kg. In addition, bulk density and solid density of pellet was found to be 578.13 kg/m³ and 1151.10 kg/m³ respectively.

Keywords: *Leucaena leucocephala* pellet, Combustion characteristics, Thermogravimetric analysis (TGA)

INTRODUCTION

Current fossil fuel crisis, increasing cost of fuel and rising environmental air pollution concerns has fostered the development of biomass resources as an alternative energy source [1, 2]. Biomasses in term of agricultural resources supply energy in two forms from energy crops and residue of crops [3, 4]. So, a fast growing energy crops are needed which can mitigate the current crisis having less impact on environmental pollution. In such case, *Leucaena leucocephala* can be a crucial plant as it is one of the most fast growing, productive and versatile multipurpose tree which can be grown in wide range of soil and tolerate drought [5-9].

The energy plays a vital role in a country economy [10] and, also, one of the most essential needs for human being. Thailand falls under tropical zone where the average temperature is 27 °C and annual rain fall of 1,200-1,600 mm/year [11]. *Leucaena leucocephala* is found naturalized in most tropical and subtropical areas of the world [12]. It is advantageous for both energy and environment because biomass is considered as CO₂ neutral [13]. In general, pelletization of biomass produce the pellet which has high density and high heating value in compare to

raw of same kind [14]. Meanwhile, it easier to store and transport and has greater economic value in the share market [15]. Therefore, Thailand government can take advantage of such economic and environmental benefit energy crops by establishing good rule and regulation toward afforestation of energy crops without altering the food chain. However, the unplanned afforestation and clearance of cultivated land for plantation of energy crops may lead to the food deficiency.

The knowledge of the combustion performance is essential parameters for the design of reactor and optimization of product [16-18]. Lignocellulosic biomass mainly consists of the hemicellulose, cellulose and lignin [19]. Combustion of biomass can be divided into four processes: moisture removal, devolatilization stage, char oxidation, and remaining stage [20]. The decomposition of the biomass begins with the moisture evolution followed by the devolatilization. Devolatilization takes place by releasing gaseous and volatile products that leads to the formation of the tar and char [21]. Hemicellulose shows the early decomposition followed by the cellulose and lignin. Hemicellulose has random amorphous structure and rich with the branches while cellulose has long polymer molecules without

branches and orderly crystalline structure which make cellulose more thermally stable than the hemicellulose [22]. In addition, highest thermal stability of the lignin is constantly reported due the strong structure background from the highly branched polysaccharides and the heavy crossed linked aromatic compounds [23].

However, up to date, the study of the *Leucaena leucocephala* biomass pellet has not yet been reported. Nevertheless, Barneto et al. [24] studied the thermal degradation of a *Leucaena leucocephala* biomass and its compost, and composting effect on hydrogen production. So, the aim of this work was to perform the primary study on the combustion behavior of ligno-cellulosic biomass pellet by the means of the TGA technique. The combustion characteristics i.e. the ignition temperature (T_i), ignition index (D_i), burnout index (D_f) and combustion performance index (S) were studied. In addition, some physical and energy properties including higher heating value (HHV), bulk density and solid density of the pellets were investigated.

Material

The *Leucaena leucocephala* pellet, which was pelletized for commercial purpose were obtained from the factory of Thailand. The pellet, 100 g, was sent to Intertek Testing Service (Thailand) Ltd. for proximate analysis and ultimate analysis which were conducted following the ASTM methods.

Solid density and bulk density measurement

Random twenty pieces of pellet was selected. The length and diameter were measured using digital vernier caliper (Digimatic caliper, Mitutoyo, Japan) and weight by electric balance (ARC120, Adventurer, OHAUS, USA. Resolution of 0.01 g) of each pellet was measured. While measuring length and diameter, ten measurements were taken on different surface-positions and average was taken.

For the measurement of the bulk density, either volume or weight of pellet was fixed. Firstly, pellet was filled in a cylindrical can of volume 983.69 cm³ and the respective weight was measured using the same electric balance. On the other hand, pellet of 2 kg was weighted and volume was measured. Each process was

repeated for ten times and average of the whole process was taken to calculate the bulk density.

Higher heating value determination

The higher heating value was obtained by oxygen bomb calorimeter (C 2000 Basic, IKA, Germany). The sample subjected to the calorimeter was prepared as follows: first, the pellet was undersized into small pieces with mortar and pestle, then was grounded through 2 mm diameter sieve (SM100, Retsch, Germany) and was again grounded using miller (Pulverisette 14, Fritsch, Germany) through 0.2 mm diameter sieve. These samples were kept in zipped plastic bag prior to the testing. The experiment was run for three replications and the average was taken. The sample size was fixed around 0.5 g.

The ground sample left from higher heating value determination was subjected for thermogravimetric analysis. The combustion characteristic of biomass pellet was performed in the thermogravimetric analyzer (TG 209 F3 Tarsus, Netzsch, Germany, 0.1 µg resolution, heating rate ranges from 0.001 to 100 Kmin⁻¹, 6.8 mm diameter aluminum oxide (AL₂O₃) crucible) in a room temperature of 25°C and the thermogravimetric (TG) profile and differential thermogravimetric (DTG) profile were analyzed using Proteus 6.0.0. (Netzsch Software, Germany). At the heating rate of 10°Cmin⁻¹, the temperature of furnace was increased from 30°C to 900°C in an air flux (O₂) of 20 mLmin⁻¹. The mass of the sample was monitored continuously as a function of temperature and time. The experiments were performed for two replications to determine their repeatability. The sample size was kept constant at around 6 mg.

The ignition index (D_i) is determined by the equation as follows:

$$D_i = \frac{(dw/dt)_{max}}{t_p t_i} \quad \dots(1)$$

Where $(dw/dt)_{max}$ =maximum combustion rate, t_p = corresponding time of $(dw/dt)_{max}$ and t_i = ignition time.

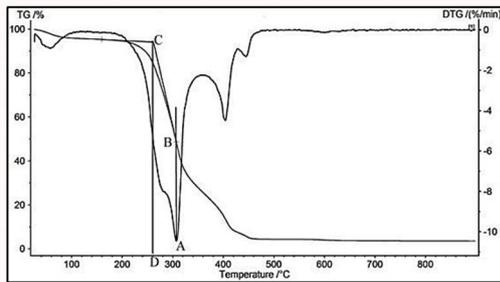


Fig. 1 Ignition temperature determining process

Burnout index (D_f)

Burnout temperature was identified as the corresponding temperature of no further weight loss in TG and DTG curves. Burnout temperature is the temperature on TG and DTG curves that shows the constant mass after the char combustion during the process and the corresponding time is known as burning time [25, 28, 29]. The burnout index (D_f) is defined as:

$$D_f = \frac{(dw/dt)_{max}}{\Delta t_{1/2} t_p t_f} \quad \dots(2)$$

Where $\Delta t_{1/2}$ = time zone of $(dw/dt)/-(dw/dt)_{max} = 1/2$ and t_f = burnout time.

Combustion performance index (S) A higher combustion index represents better combustion reactivity of the fuel which was calculated as [30-33]:

$$S = \frac{(dw/dt)_{max}(dw/dt)_{mean}}{T_i^2 T_f} \quad \dots(3)$$

Where, $(dw/dt)_{mean}$ = average combustion rate, T_i = ignition temperature and T_f = burnout temperature.

RESULT AND DISCUSSION

Proximate analysis and the ultimate analysis

The proximate analysis and the ultimate analysis results are presented in Table 1. They are the easiest and most widely used method to characterize a biomass fuel. Proximate analysis represents moisture, volatile matter (VM), ash and fixed carbon (FC) on weight percent basis of a biomass whereas ultimate analysis signify weight percentage of carbon(C), hydrogen(H), nitrogen(N), sulfur(S), oxygen(O) that is present on a biomass. In addition, proximate and ultimate analysis correlates the heating value of fuel. Heating value of the fuel highly depends upon FC, VM, C, and H whereas heating value decrease with higher content of

ash and oxygen [45]. Nitrogen and sulfur leads to the formation of harmful emission. Fixed carbon is responsible for the formation of char [14].

Proximate analysis	Method	Result (wt %)
Moisture	ASTM E 871-82 (R06)	7.59
Volatile matter	ASTM E 871-82 (R06)	72.91
Ash	ASTM D 1102-84 (R07)	1.96
Fixed carbon	Calculation	17.55
Ultimate analysis		
Carbon	CHN Analyzer	44.98
Hydrogen	CHN Analyzer	6.20
Nitrogen	CHN Analyzer	0.52
Sulfur	ASTM E 775-87 (R086), B-IPC	0.04
Oxygen	Calculation	46.31
Chloride	ASTM E 776-87 (R09)	Less than 0.01

Solid density and bulk density measurement

Bulk density and solid density of pellet was found to be 578.13 kg/m³ and 1151.10 kg/m³ respectively. The solid density was found almost double the bulk density. This may be due to the void spaces between the pellets as the orientation, shape and size of the pellet effect on the bulk density.

Higher heating value

The experimental higher heating value (HHV_e) was found to be 17.23 kJ/kg. This experimental higher heating value includes heat of condensation released from the water vapor during the combustion process. So, this value was converted into anhydrous higher heating value as [45, 46]:

$$HHV = \frac{HHV_e}{1-MC} \quad \dots(4)$$

Where, HHV = higher heating value, HHV_e = experimental higher heating value and MC = moisture content in decimal.

The anhydrous higher heating value (HHV) was found to be 18.65 kJ/kg. This value was in range of higher heating value for hard wood [45].

Combustion performance

The ignition temperature, ignition index, burnout index and combustion index with the peak temperature and respective mass loss are listed in Table 2. Ignition temperature

determines the easiness to ignite the fuel. A fuel with high ignition temperature is more difficult to ignite and vice versa [34]. The higher value of combustion performance of fuel is desired for better combustibility, whereas higher burnout temperature defines the difficulty to burn and thus requires longer time while lower value indicates the reduced presence of unburnt [30]. The value of Df was found higher and Di lower than that of coal [25], while the S was found higher than coal [32]. The higher value of Df and S and lower value of Di signify that L. leucocephala pellet is easier to burn than coal, which connotes the possibility for the future fuel.

Table 2 Combustion characteristics of L. leucocephala

Parameter	value
(dw/dt) _{max} (%min ⁻¹)	10.45
(dw/dt) _{mean} (%min ⁻¹)	1.11
T _{max} (°C)	307.5
t _{max} (min)	28.0
T _i (°C)	261.7
t _i (min)	23.6
T _f (°C)	776.25
t _r (min)	74.95
Δt _{1/2} (min)	23.42
D _f (10 ⁻⁰³)	8.20
D _i (10 ⁻⁰⁴)	6.10
S (10 ⁻⁰⁷)	2.19

Thermogravimetric analysis of Leucaena leucocephala pellet

The combustion profile of wood pellet, Leucaena leucocephala, is shown in the Figure 2. The combustion profile can be categorized into four stages: moisture removal (<110 °C); devolatilization (197-350 °C); char combustion (360-600 °C) and residue decomposition (>600 °C). The peak temperature associates with different stages with peak mass loss are shown in Table 3. L. leucocephala consist mainly holocellulose (hemicellulose, cellulose) and lignin [24]. When the moisture is removed from the sample, the pellet started to degrade slowly. After 195 °C, volatilization of volatile soared up, which leads to formation of char [16, 21].

The combustion begins with the volatilization of hemicellulose and cellulose and partial decomposition of lignin [35, 36]. Hemicellulose shows the early decomposition [2, 23] followed by cellulose [2, 22] and lignin, which

showed the wide range of decomposition [2, 23]. The sharp peak at 308.1 °C in the temperature range of 200 °C to 355 °C was associated with cellulose and a very small shoulder peak at 284.6 °C to the left was of hemicellulose [37, 38].

The third stage was associated with the char oxidation which depicted two separate peaks. The first char oxidation peak (stage H), which elevated at 405.6 °C with higher decomposition rate 4.57 %min⁻¹, was associated with the oxidation of holocellulose [24]. However, cellulose contributes less to the char formation as most of its mass loss during the volatilization [39-44]. Therefore, this peak is mainly associated with the hemicellulose. In addition, a second separate peak (stage L) which rose at 443.7 °C is mainly associated with the lignin oxidation [16, 24]. Similar lignin curve was evolved during combustion of lignocellulosic biomass, pine bark, at lower heating rate [1]. The profile above 600 °C was defines as the remaining char residue and inorganic compound decomposition. A very insignificant peak was observed above the temperature of 605 °C which was mainly associated with the combustion of inorganic matter [16, 24].

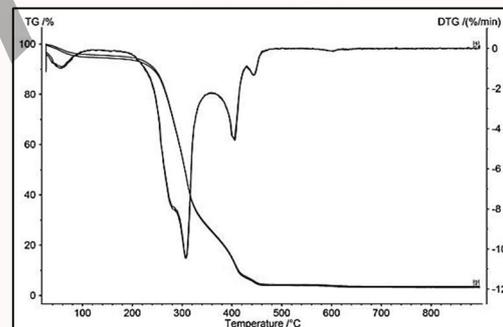


Fig. 2 TG and DTG profile of L. leucocephala

Table 3 Combustion performance

Parameters		Value	
Devolatilization	T _{peak} (°C)	308.1	
	(dw/dt) _{max} (%min ⁻¹)	10.44	
Char oxidation	Stage H	T _{peak} (°C)	405.6
		(dw/dt) _{max} (%min ⁻¹)	4.57
	Stage L	(dw/dt) _{max} (%min ⁻¹)	443.7
		(dw/dt) _{max} (%min ⁻¹)	1.34
Residue (%)		3.37	

CONCLUSION

The combustion characteristic of L. Leucocephala pellet was analyzed by the means of TGA. The main combustion profile depicted two different stages. Firstly, the combustion of volatile matter takes place from 197 °C to

350°C. The second stage was related with char combustion which depicted two separate peaks mainly associated with hemicellulose and lignin. As L. Leucocephala pellet has higher combustion index compared to coal, it can be a good source of fuel which might help to mitigate the energy crisis and lessen the air pollution. In future, biomass can be a good source of fuel for combustion.

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REFERENCES

- [1] López-González, D., Fernandez-Lopez, M., Valverde, J.L. and Sanchez-Silva L. Thermogravimetric-mass spectrometric analysis on combustion of lignocellulosic biomass. *Biore-source Technol.* 143: 562-574 (2013)
- [2] Sivasangar, S., Taufiq-Yap, Y.H., Zainal, Z. and Kitagawa, K. Thermal behavior of lignocellulosic materials under aerobic/anaerobic environments. *Int. J. Hydrogen Energ.* 38: 16011-16019 (2013)
- [3] Liu, T., McConkey B., Huffman T., Smith S., MacGregor B., Yemshanov D. and Kulshreshtha S. "Potential and impacts of renewable energy production from agricultural biomass in Canada. *Appl Energ.* 130: 222-229 (2014)
- [4] Stern N. *The economics of climate change: the stern review*, Cambridge University press, Cambridge, (2007)
- [5] Prasad, J. V. N. S., Korwar, G.R., Rao, K.V., Mandal, U.K., Rao, G.R., Srinivas, I., Venkateswarlu, B., Rao, S.N. and Kulkarni H.D. Optimum stand density of *Leucaena leucocephala* for wood production in Andhra Pradesh, Southern India. *Biomass Bioenerg.* 35: 227-235 (2011)
- [6] Meelu, O.P. and Morris R.A. Green manuring research in the Philippines e a review. *Philipp. J. Crop Sci.* 11:153-159 (1989)
- [7] Savale, S.R., Sanglikar, R.V., Sthool, V.A. and Kadam, J.R. Effect of *Leucaena leucocephala* barriers and bund on erosion losses and yield of pearl millet + mothbean. *Asian J. Soil Sci.* 2: 142-145 (2007)
- [8] Shelton, H.M. and Jones, R.J. Opportunities and limitations in *Leucaena*, pp. 16-23, in H.M. Shelton, C.M. Piggan and J.L. Brewbaker (Eds.) *Leucaena opportunities and limitations: proceedings of a workshop held in Bangor, Indonesia, ACIAR Proceedings*, Canberra (1995)
- [9] Gutteridge, R.C. The potential of nitrogen fixing trees in livestock production system, pp. 1-16, in J.N. Daniel and J.M. Roshetko (Eds.) *Nitrogen Fixing Trees for Fodder Production: Proceedings of an International Workshop. Forest, Farm, and Community Tree Research Reports*, Winrock International Institute, Morrilton (1998).
- [10] Ramage J. and Scurlock J. Biomass, in G. Boyle (Ed.) *Renewable energy-power for a sustainable future*, Oxford University Press, Oxford, (1996)
- [11] Thai Meteorological Department. Thailand weather, Meteorological knowledge. [Online]. Available: <http://www.tmd.go.th/info/info.php?FileID=22>. 2014
- [12] Lim, T.K. *Edible Medicinal and Non-Medicinal Plants: Volume 2, Fruits*. Springer, New York (2012)
- [13] Demirbas, A. Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues. *Prog. Energ. Combust.* 31: 171-192 (2005)
- [14] Poddar, S., Kamruzzaman, M., Sujan, S.M.A., Hossain, M., Jamal, M.S., Gafur, M.A. and Khanam, M. Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties: Higher heating value. *Fuel* 131:43-48 (2014)
- [15] Vinterback, J. Pellets 2002: the first world conference on pellets. *Biomass and Bioenergy* 27: 513-520 (2004)
- [16] López-González, D., Fernandez-Lopez, M., Valverde, J. L. and Sanchez-Silva, L. Thermogravimetric-mass spectrometric analysis on combustion of lignocellulosic biomass. *Bioresource Technol.* 143:562-574 (2013)
- [17] Yorulmax, S. Y. and Atimaya, A. T. Investigation of combustion kinetics of treated and untreated waste wood samples with thermogravimetric analysis. *Fuel Process. Technol.* 90: 939-946 (2009)
- [18] Cordero, T., Rodriguez-Maroto, J. M., Rodriguez-Mirasol, J. and Rodriguez, J. J. On the kinetics of thermal decomposition of wood and wood components. *Thermochim. Acta* 164: 135-144 (1990)
- [19] El-Sayed, S. A. and Mostafa, M. E. Pyrolysis characteristics and kinetic parameters determination of biomass fuel powders by differential thermal gravimetric analysis (TGA/DTG). *Energ. Convers. Manage.* 85: 165-172 (2014)
- [20] Qing, W., Hao, X., Hongpeng, L., Chunxia, J. and Jingru, B. Thermogravimetric analysis of the combustion characteristic of oil shale semi-coke/biomass blends. *Oil Shale* 28: 284-295 (2011)

- [21] Gani, A. and Naruse, I. Effect of cellulose and lignin content on pyrolysis and combustion characteristics for several types of biomass. *Renew. Energ.* 32: 649-661 (2007)
- [22] Yang, H., Yan, R., Chen, H., Lee, D. H. and Zheng, C. Characteristic of hemicelluloses, cellulose and lignin pyrolysis. *Fuel* 86: 1781-1788 (2007)
- [23] Yang, H., Yan, R., Chen, H., Zheng, C., Lee, D. H. and Liang, D. T. In-depth investigation of biomass pyrolysis based on three major components: hemicellulose, cellulose and lignin. *Energ. Fuel* 20: 388-393 (2006)
- [24] Barneto, A. G., Carmona, J. A., Ferrer, J. A. C. and Balanco, M. J. D. Kinetic study on the thermal degradation of a biomass and its compost: Composting effect on hydrogen production. *Fuel* 89: 462-473 (2010)
- [25] Ma, B.-G., Li, X.-G., Wang, K. and Wang, X.-G. Investigation on catalyzed combustion of high ash coal by thermogravimetric analysis. *Thermochem. Acta*, 445: 19-22 (2006)
- [26] Nie, Q.-H., Sun, S.-Z. and Li, Z.-Q. Thermogravimetric study on the combustion characteristic of brown coal blends. *J. Combust. Sci. Technol.* 7: 72-76 (2001)
- [27] Li, X.-G., Ma, B.-G., Xu, L., Hu, Z.-W. and Wang, X.-G. Thermogravimetric analysis of the co-combustion of the blends with high ash coal and waste tyres. *Thermochim. Acta* 441 79-83 (2006)
- [28] Idris, S. S., Rahman, N. A. and Ismail, K. Combustion characteristics of Malaysian oil palm biomass, sub-bituminous coal and their respective blends via thermogravimetric analysis (TGA). *Bioresource Technol.* 123: 581-591 (2012)
- [29] Xie, J.-L. and He, F. Catalyzed combustion study of anthracite in cement kiln. *J. Chin. Ceram. Soc.* 26: 792-795 (1998)
- [30] Qing, W., Hao, X., Hongpeng, L., Chunxia, J. and Jingru, B. Thermogravimetric analysis of the combustion characteristics of oil shale semi-coke/biomass blends. *Oil shale* 28: 284-295 (2011)
- [31] Nie, Q. H., Sun, S. Z. and Li, Z. Q. Thermogravimetric analysis on the combustion characteristics of brown coal blends. *Combust. Sci. Technol.* 7: 71-76 (2001)
- [32] Xu, Y., Lin, S., Yuan, H., Zhu, K., He, X. and Chen, G. Thermogravimetric Analysis on the Combustion Characteristics for Blended Coals. *International Conference on Power Engineering-2007, Hangzhou*, pp. 153-156 (2007)
- [33] Xuexin, S. *The Experiment Technology and Method of Boiler Combustion [M]. Chinese Electrical Power Press, 2002. Beijing, China*
- [34] Idris, S. S., Rahman, N.A. and Ismail, K. Combustion characteristics of Malaysian oil palm biomass, sub-bituminous coal and their respective blends via thermogravimetric analysis (TGA). *Bioresource Technol.* 123: 581-591 (2012)
- [35] Shen, D. K., Gu, S., Luo, K. H., Bridgwater, A. V. and Fang, M. X. Kinetic study on thermal decomposition of woods in oxidative environment. *Fuel* 88: 1024-1030 (2009)
- [36] Liu, N. A., Fan, W., Dobashi, R. and Huang, L. Kinetic modeling of thermal decomposition of natural cellulosic materials in air. *J. Anal. App. Pyrol.* 63:303-325 (2002)
- [37] Kastanaki, E., Vamvuka, D., Grammelis, P. and Kakaras, E. Thermogravimetric studies of the behavior of lignite-biomass blends during devolatilization. *Fuel Process. Technol.* 77-78: 159-166 (2002)
- [38] Vamvuka, D., Kakaras, E., Kastanaki, E. and Grammelis, P. "Pyrolysis characteristic and kinetics of biomass residuals mixtures with lignite. *Fuel* 82: 1949-1960 (2003)
- [39] Raveendran, K., Ganesh, A. and Khilar, K.C. Pyrolysis characteristic of biomass and biomass component. *Fuel* 75: 987-998 (1996)
- [40] Moon, C., Sung, Y., Ahn, S., Kim, T., Choi, G. and Kim, D. Effect of blending ratio on combustion performance in blends of biomass and coals of different ranks. *Exp. Therm. Fluid Sci.* 47: 232-240 (2013)
- [41] Vamvuka, D. and Sfakiotakis, S. Combustion behavior of biomass fuels and their blends with lignite. *Thermochim. Acta* 26: 192-199 (2011)
- [42] Idris, S. S., Rahman, N. A., Ismail, K., Alias, A. B., Rashid, Z. A. and Aris, M. J. Investigation on thermochemical behaviour of low rank Malaysian coal, oil palm biomass and their blends during pyrolysis via thermogravimetric analysis (TGA). *Bioresource Technol.* 101: 4584-4592 (2010)
- [43] Vamvuka, D., Kakaras, E., Kastanaki, E. and Grammelis, P. Pyrolysis characteristics and kinetics of biomass residuals mixtures with lignite. *Fuel* 82: 1949-1960 (2003)
- [44] Safi, M. J., Mishra, I. M. and Prasad, B. Global degradation kinetics of pine needles in air. *Thermochim. Acta* 412: 155-162 (2004)
- [45] Telmo, C. and Lousada, J. Heating values of wood pellets from different species. *Biomass Bioenerg.* 35: 2634-2639 (2011)
- [46] DD CEN/TS 14918. Solid bio fuels – method for the determination of calorific value. *British Standards Institution, London* (2005)