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Drying, burning and emission characteristics of beehive charcoal briquettes: An alternative household fuel of Eastern Himalayan Region

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Abstract

Beehive charcoal briquettes were produced from powdered charcoal in which soil was added as binder. It was found to be an eco-friendly, clean and economic alternative source of household fuel for the people of Eastern Himalayan Region. Experiments were conducted to determine natural drying behaviour, normalised burn rate, temperature profile and emission of CO, CO_2, UBHC (unburnt hydrocarbons) and NO_x of beehive briquettes prepared from 60:40; 50:50 and 40:60 ratios of charcoal and soil. It was observed that under natural drying conditions (temperature, humidity) briquettes took 433 hr to reach equilibrium moisture content of 5.56–10.29 %. Page's model was found suitable to describe the drying characteristics of all three combinations. Normalised burn rate varied between 0.377–0.706 % of initial mass min^{-1}. Total burning time of briquette ranged between 133–143 min. The peak temperature attained by briquettes ranged from 437 ºC to 572 ºC. All the briquette combinations were found suitable for cooking and space heating. Emission of CO, CO_2, UBHC, NO and NO_2 ranged between 68.4–107.2, 922–1359, 20.9–50.8, 0.19–0.29 and 0.34–0.64 g kg^{-1}, respectively which were less than firewood.

Key words

Beehive briquette, Burn rate, Emission, Natural drying, Renewable fuel, Temperature profile

Introduction

The rural people of Eastern Himalayan Region use traditional cook stoves for cooking and space heating. Wood and coal are the most common fuel for these stoves. Thermal efficiency of these traditional stoves is very low (lesser than 15% for most of the stoves), and cause significant air pollution (Bhattacharya *et al.*, 2002). Direct burning of biomass emits substantial amount of pollutants including respirable particles, carbon monoxide, nitrogen and sulphur oxides which may cause health hazards and increase green house gas emission (Bruce *et al.*, 2000). Densified biomass, also known as briquette, has been found to be a solution to these problems. It can provide an alternative household solid clean fuel and is eco-friendly (Grover and Mishra, 1996).

Charcoal briquettes are produced from charcoal with some binding agent. In beehive briquettes, charcoal in certain proportion is used with soil as binder. In general, the ratio of charcoal and soil is 70:30 by volume. These briquettes are made cylindrical with 21 parallel holes due to which they look like beehive. Preliminary study showed that dried beehive briquettes produced smokeless blue flame with an average burning time of 2.5 hr (Mandal *et al.*, 2012).

Utilization of agricultural residue for production of bio-coal (briquetted charcoal) is a novel procedure for the simultaneous disposal and partial substitution of biomass-derived charcoal for other energy sources (Demirbas, 1999). In Eastern Himalayan Region, 37 million tonnes of biomass is produced annually from agriculture and forestry (Anonymous, 2010). This biomass can be used to produce charcoal for making beehive briquettes which can mitigate the demand of clean household fuel with reduced health hazards of rural women and provide small scale business opportunity to entrepreneurs.

Evaluation of drying and burning characteristics of this briquette is necessary to find out the suitable combination of charcoal and soil. An understanding of natural drying behaviour will help to decide the production capacity based on storage space available. The parameters like fuel density, moisture content, size and geometry as well as raw material properties have been shown to significantly effect the biomass burn rate (Chaney *et al*., 2008). Temperature profile of burning briquette helps in understanding the suitability of fuel for cooking/heating purposes (Smit and Meincken, 2012). Emission is an important factor in using briquettes as high amount of harmful gases in emission will be hazardous for health. Therefore, this study was conducted with the objective of standardizing the ratio of charcoal and soil in beehive charcoal briquettes, to understand the natural drying mechanism, to determine the burn rate, temperature profile and emission behaviour of different pollutants during burning of briquette.

Materials and Methods

Making of briquettes : Beehive briquettes were made using powdered charcoal (<5mm) and soil (<0.5 mm). Three ratios of charcoal and soil *viz.,* 60:40 (S_1); 50:50 (S_2) and 40:60 (S_3) on dry weight basis were considered as 50:50 is the commonly used ratio. After mixing charcoal and soil thoroughly, 300 ml of water was added to prepare the dough of required consistency suitable for moulding the briquette. A beehive briquetting mould was used to make the briquettes (Fig. 1) which consisted of a cylinder, a base plate with 21 rods and a cover plate. The mixture was put into the cylinder and the whole unit was beaten 20 times on a wooden plank to increase compaction level. The cylinder and cover plate were then pulled out of the base plate along with the briquette. It was placed upside down on ground and pressed to release the briquette. Each briquette was 146 mm in diameter and 85 mm in height.

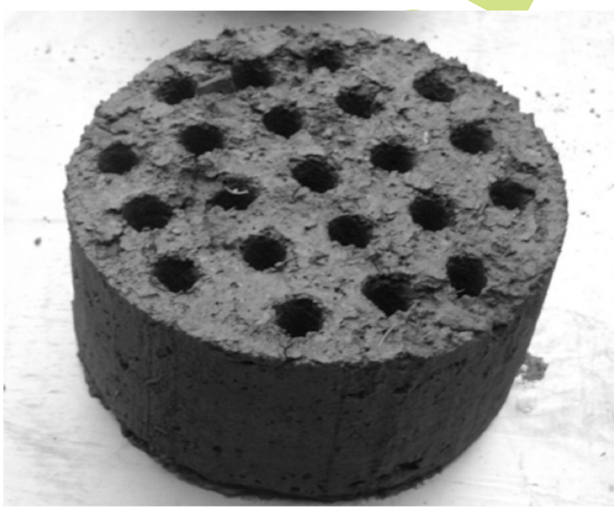

Fig. 1 : Beehive charcoal briquette

Wet briquettes were allowed to dry in open air as well as in sunlight during day time from September – October, 2011. The data on mass reduction was recorded two times in a day, in morning at 9 AM and in afternoon at 4 PM. Mass reduction was recorded by a digital balance with accuracy of 0.1 g. Ambient temperature and relative humidity were also recorded at same time interval. Initial moisture content of briquettes on dry and wet basis was determined using standard method by drying in a convective oven at 105 °C for 24 h.

Meisami-asl and Rafiee (2009) model was used to describe the drying characteristics of beehive briquettes in natural drying. The statistical parameters, such as the coefficient of determination (R^2), root mean square error (RMSE) and chi-square (χ^2) were used to determine the goodness of fit.

Proximate analysis : Proximate analysis is the characterization of coals and other solid fuels. It separates the products into four groups: (1) moisture, (2) volatile matter, consisting of gases and vapors driven off during pyrolysis, (3) fixed carbon, the nonvolatile fraction of fuel, and (4) ash, the inorganic residue remaining after combustion (ASTM, 2007). Moisture content was determined by same method described earlier. BSI standard method (BSI, 2009) was followed to determine volatile matter. The sample was kept in a muffle furnace at 900 °C for 7 min in a covered crucible. The ash content was determined by heating dry sample of briquettes in open crucible in a muffle furnace at 900 °C for 30 min.

Determination of burning rate : Single briquette was placed at the centre of a steel wire mesh. The whole unit was placed on an electronic digital balance with least count of 0.1g to record the mass loss in every two minute interval. Each briquette was ignited by placing firelighter just below the mesh and allowed to burn until the temperature declined to lesser than 100 °C which is considered too less for cooking purpose. Smoke of burning was extracted following the extraction hood method (Ballard and Jawurek, 1999). Reduction in mass in every two minute interval was normalised by initial briquette mass. A graph of normalised mass was plotted against time. There are three distinct phase of burning. Phase -1 is the ignition phase, Phase -2 the steady state flaming combustion phase and Phase -3 when the flame dies (Chaney *et al*., 2008). The gradient of Phase -2 is the normalised steady-state combustion rate which is referred here as the normalised burn rate (NBR). For each briquette burnt, the graph was plotted and NBR was calculated.

Temperature was recorded in every two minutes by a digital temperature indicator connected with a K-type thermocouple (accuracy of ±1 °C) placed 50 mm above the base of the fire. Height of a cooking pan over an oven does not exceed this height.

Measurement of pollutants : The hood method was used for sampling of emission from burning briquettes (Bhattacharya *et* *al*., 2002). Whole testing unit was placed under an extraction hood through which the flue gas escaped. Concentration of pollutants like CO_2, CO, UBHC (Unburnt hydrocarbons), NO and NO_2 were measured from the escaping flue gas. To determine the CO_2 and CO content, the exhaust gas samples were collected in 20 ml syringe and analyzed using a Nucon–5700 gas liquid chromatograph. Estimation of UBHC, NO and NO_2 in the flue gas was done using a Nucon–4900 hydrocarbon analyzer, Nucon 500–NO analyzer and Nucon 500–NO_2 analyzer, respectively. Flue gas samples were fed into analyzers through suction pump having an inlet pipe diameter of 3 mm without affecting combustion rate. Readings were taken at an interval of 10 min. Emission of each pollutant was calculated following the method of Bhattacharya *et al*. (2002).

Results and Discussion

Drying characteristics : Temperature and relative humidity throughout the drying period ranged between 22 – 31 ºC and 65 – 81%, respectively. There was no significant difference in rate of moisture loss of three combinations of briquettes in natural drying condition (Table 1). The initial rate of moisture loss was high for all three combinations (Doymaz *et al.,* 2004; Moreno *et al*., 2004; Phanphanich and Mani, 2009). Unlike hot air drying, rate of moisture loss in natural drying of briquettes was slow. Similar kind of result was obtained by Basunia and Abe (2001) for drying of rough rice under natural convection. Two third of total drying time was taken to remove 90% of initial moisture content. The final moisture content of each briquette combination after a drying period of 433 hr was considered as equilibrium moisture content (EMC) as there was no change in moisture content after this time period (Fig. 2). The highest EMC of 10.29% db was observed in case of 60:40 charcoal-soil ratio (S_1), whereas the lowest EMC of 5.56% db was observed with 40:60 charcoal-soil ratio (S_2). Higher EMC of S_1 may be due to high charcoal content which is hygroscopic in nature.

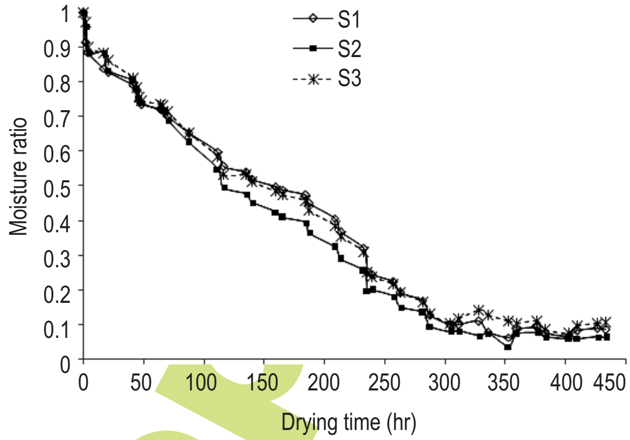

Fig. 2 : Natural drying curves of beehive briquettes made from charcoal-soil ratio of 60:40 (S1), 50:50 (S2) and 40:60 (S3)

The R^2 values in all the cases were higher than 0.96 (Table 2) which showed good fit of the Page's model. The lower values of χ^2 and RMSE also indicated better goodness of fit of the measured data in the Page's model. However, the values were higher than those reported earlier in drying of solid by-products of olive oil extraction (Doymaz *et al*., 2004).

Burning rate and temperature : In all three combinations, Phase-1 of burning was not so distinct (Fig. 3). As a benchmark, loss of 10% of initial mass, which took 15 min, was considered as beginning of Phase-2. In all three combinations, Phase-2 did not last for same duration and also there was not equal mass loss. In S_1, loss of initial mass up to 50% was considered the start of Phase-2, whereas in S_2 and S_3 this value was 60% and 70%, respectively. The NBR of Phase-2 of S_1 was 0.706% of initial mass min^{-1} which was higher than both S_2 (0.477% of initial mass min^{-1}) and S_3 (0.377% of initial mass min^{-1}). The highest NBR of S_1 might be due to higher charcoal content and lower soil content. Low burn rate of S_3 was due to higher soil content and also due to high

Table 1 : Combinations of charcoal and soil in Beehive briquettes and their proximates

Briquette sample	Charcoal (%)	Soil (%)	Dry density (kg m^{-3})	Moisture content (% wb)	Volatile matter (% wb)	Fixed carbon (% wb)	Ash content (% wb)
S_1	60	40	417.83	9.33	11.97	37.54	41.16
S_2	50	50	490.66	5.43	10.40	32.63	51.54
S_3	40	60	583.63	5.29	8.33	26.14	60.24

Table 2 : Coefficients and errors for the Page's model for different briquette composition

Briquette sample*	Coefficient (K)	Coefficient (N)	Coefficient of determination (R^2)	Chi-square (χ^2)	Root mean square error (RMSE)
S_1	5.98E-06	1.310	0.963	0.00626	0.0772
S_2	4.56E-07	1.601	0.981	0.00593	0.0751
S_3	1.08E-06	1.491	0.980	0.00607	0.0760

*S_1, S_2, S_3 are 60:40; 50:50 and 40:60 ratio of charcoal and soil, respectively

Table 3 : Emission of pollutants from briquettes of different composition

Briquette sample	Emission rate (g kg^{-1} of briquette burnt)				
	CO	CO_2	UBHC	NO	NO_2
S_1	107.2	1359	50.8	0.29	0.62
S_2	79.9	1158	26.6	0.26	0.49
S_3	68.4	922	20.9	0.19	0.34

*S_1, S_2, S_3 are 60:40; 50:50 and 40:60 ratio of charcoal and soil, respectively

density (Chaney *et al*., 2008). There was not much difference in total burning time of three briquettes. Briquettes with 60% soil burnt 10 min longer than briquettes with 40% soil. Phase-3 of all three briquette combinations lasted for about 60 min.

In the present study with beehive charcoal briquettes, no distinct drop in temperature was observed in preheating phase of burning for all three combinations whereas, degassing and charcoal phases showed steady rise and decline with time (Fig. 4).

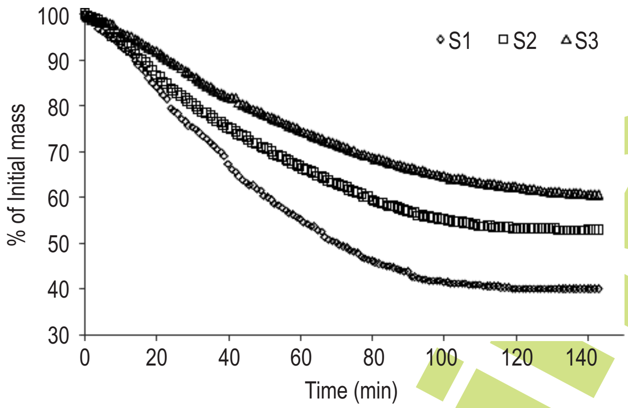

Fig. 3 : Burning characteristics of beehive briquettes made from charcoal-soil ratio of 60:40 (S1), 50:50 (S2) and 40:60 (S3)

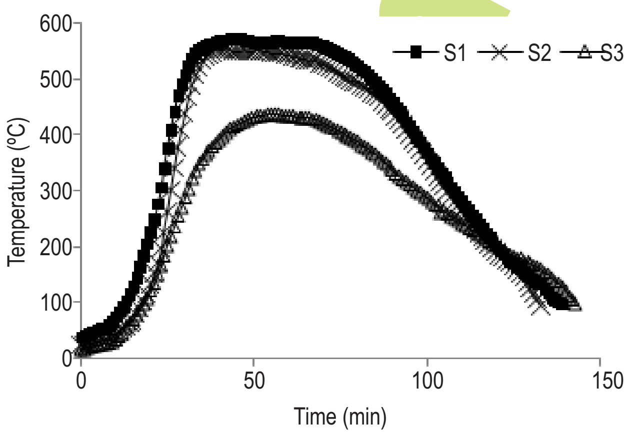

Fig. 4 : Time/temperature profile of beehive briquettes made from charcoal-soil ratio of 60:40 (S1), 50:50 (S2) and 40:60 (S3)

This may be due to the fact that these briquettes were made of charcoal which burned less vigorously than wood (Kumar *et al*., 1992). The highest temperature was reached by S_1 (572ºC) after 44 min, followed by S_2 (553ºC) after 42 min and S_3 (437ºC) after 55 min.

Good combustion temperature in degassing phase and slow rate of temperature decline at the carbonization phase is ideal for cooking and heating purposes (Smit and Meincken, 2012). Briquette samples S_1 and S_2 showed good combustion temperature in degassing phase and slow decline in charcoal phase which showed their suitability for cooking and space heating. The combination S_3 can be adopted when economy is concerned as it needs 50% less amount of charcoal than combination S_1.

Pollutants characteristics : There was no significant difference in emission of four gases from all three combinations of beehive briquettes (Fig. 5a-e). The highest CO emission (0.11%) was observed in case of composition S_1, followed by S_2 (0.1%) and S_3 (0.09%). NO emission was highest in S_2 (1.70 ppm), followed by S_1 (1.56 ppm) and S_3 (1.40 ppm). NO_2 emission from three briquette combinations S_1, S_2 and S_3 was 3.51, 3.20 and 3.10 ppm, respectively. Emission of UBHC was highest in S_1 (0.03%) and almost equal in S_2 and S_3 (0.02%).

The composition S_3 showed highest emission among all five pollutants due to highest charcoal content (Table 3). Emission of CO and CO_2 was less than burning charcoal and firewood (Zhang *et al*., 1999; Bhattacharya *et al.,* 2002) due to the fact that the fuel used here was not fully charcoal and a substantial amount of soil was present. However, the emission of UBHC and NO_x (NO and NO_2) were higher than charcoal (Bhattacharya *et al*., 2002).

Natural drying of beehive charcoal briquettes with final moisture content of lesser than 10% was accomplished in 18 days for all charcoal and soil combinations of 60:40, 50:50 and 40:60. The drying behaviour of briquettes followed the trend well described by Page model. Maximum temperature of more than 550ºC was attained and remained for 40 min during burning of briquettes with 60:40 and 50:50 charcoal and soil combinations. The total emission of pollutants in case of charcoal and soil ratio of 50:50 was 1265 g kg^{-1} which was 20% lesser than at 60:40 ratio. Briquettes with 50:50 ratio of charcoal and soil may be used to meet the rural household energy requirement.

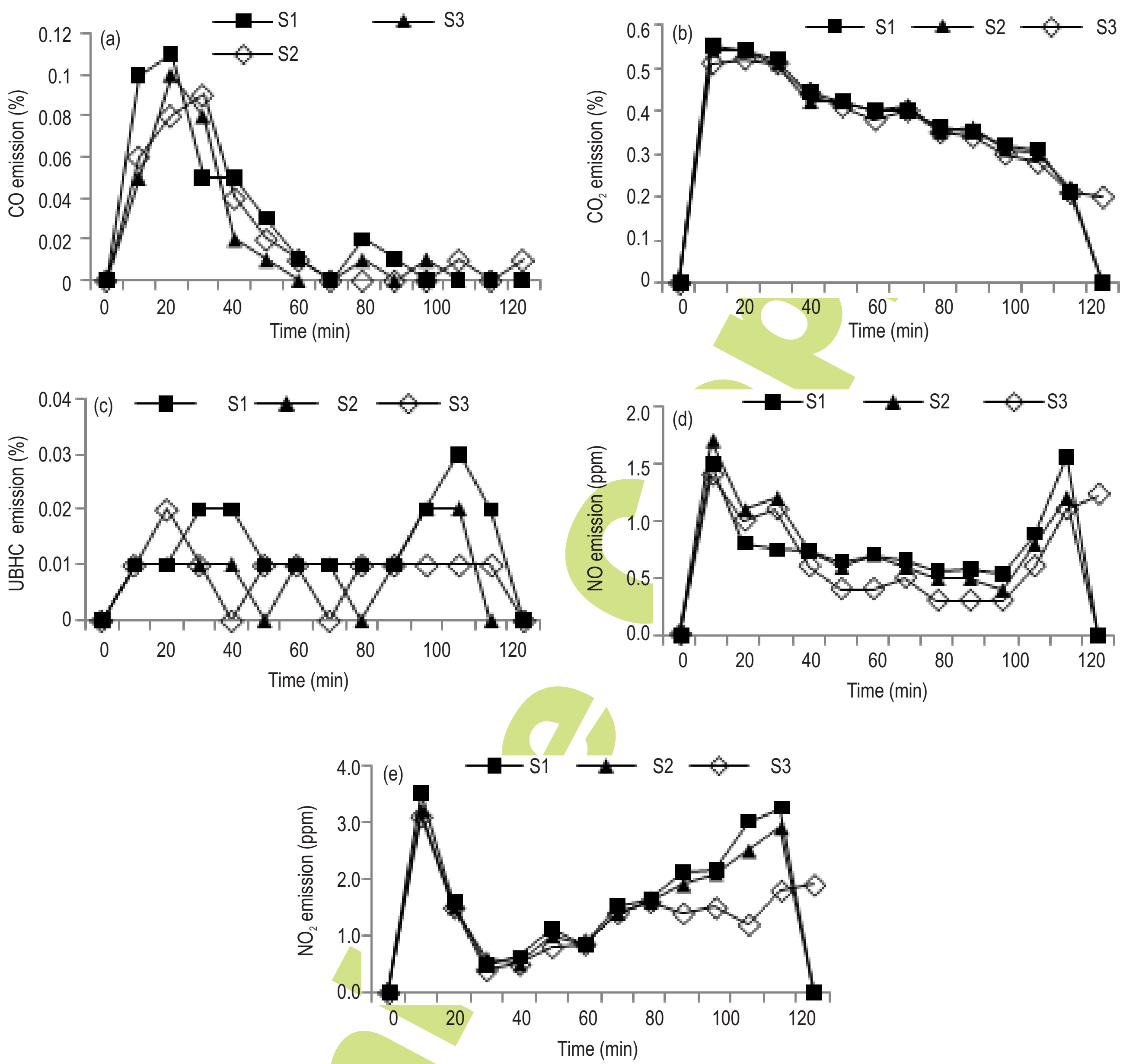

Fig. 5 : Emission of different gases: (a) CO, (b) CO_2, (c) UBHC, (d) NO and (e) NO_2 from burning beehive briquettes made from charcoal-soil ratio of 60:40 (S1), 50:50 (S2) and 40:60 (S3)

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References

Anonymous: Annual Report of ICAR Research Complex for NEH Region, Umiam, Meghalaya (India) (2010).

ASTM Standards and Engineering Digital Library, Proximate Analysis, SEDL/Manuals, Monographs and Data Series/MNL57-EB/MNL11271M, DOI: 10.1520/MNL 11271M (2007).

B.S. Institution.: "Solid biofuels: Method for the determination of the content of volatile matter." draft biomass standard, CEN/TS 15148 (2009).

Ballard-Tremeer, G. and H.H. Jawurek: The hood method of measuring emissions of rural cooking devices. *Biomass Bioenerg.*, **16**, 341–345 (1999).

Basunia, M.A., and T. Abe: Thin-layer solar drying characteristics of tough rice under natural convection. *J. Food Eng.,* **47**, 295-301 (2001).

Bhattacharya, S.C., D.O. Albina and P.A. Salam: Emission factors of wood and charcoal-fired cookstoves. *Biomass Bioenerg.,* **23,** 453–469 (2002).

Bruce, N., R. Perez-Padilla and R. Albalak: Bulletin of the World Health Organisation, **78**, 1078–1092 (2000).

Chaney, J.O., M.J. Clifford and R. Wilson: An experimental study of the combustion characteristics of low-density biomass briquettes. *Proc. 3rd Int. Conf. Appropriate Tech.*, Kigali, Rwanda, 12 – 15 (2008).

Demirbas, A.: Properties of charcoal derived from hazelnut shell and the production of briquettes using pyrolytic oil. *Energy,* **24**,141-150 (1999).

Doymaz, I., I. Gorel and N.A. Akgun: Drying characteristics of the solid by-product of olive oil extraction. *Biosyst. Eng.*, **88**, 213–219 (2004).

Grover, P.D. and S.K. Mishra: Biomass briquetting: Technology and practices, field document No.46, Regional Wood Energy Development Programme in Asia, Food and Agriculture Organization of The United Nations, Bangkok (1996).

Kumar, M., R.C. Gupta and T. Sharma: Effects of carbonisation conditions on the yield and chemical composition of *Acacia* and *Eucalyptus* wood chars. *Biomass Bioenerg.,* **6,** 411-417 (1992).

Mandal, S., Kumar Arvind, R.K. Singh and S.V. Ngachan: Evaluation of composition, burn rate and economy of beehive charcoal briquettes, *Int. J. Agric. Eng.*, **5**, 158-162 (2012).

Moreno, R., G. Antolin, A. Reyes and P. Alvarez: Drying characteristics of forest biomass particles of *Pinus* radiate. *Biosyst. Eng.*, **88**, 105-115 (2004).

Meisami-asl, E. and S. Rafiee: Mathematical modeling of kinetics of thin-layer drying of apple (var. Golab). *Agric. Eng. Int.*: the CIGR Ejournal., **11,** (2009).

Phanphanich, M. and S. Mani: Drying characteristics of pine forest residues. *Bioresources,* **5**, 108-121 (2009).

Smit, H.C. and M. Meincken: Time/temperature combustion profiles of various wood-based biofuels. *Biomass Bioenerg.*, **39,** 317-323 (2012).

Zhang, J., K.R. Smith, R. Uma, Y. Ma, V.V.N. Kishore, K. Lata, M.A.K. Khalil, R.A. Rasmussen and S.T. Thornneloe: Carbon monoxide from cookstoves in developing countries: Emission factors. *Chemosphere,* **1**, 353–366 (1999).