The Potential of Coffee Husk and Pulp as an Alternative Source of Environmentally Friendly Energy

Weldemedhin Merete[1]*, Alemayehu Haddis[2], Esayas Alemayehu[3] and Argaw Ambelu[2]

[1]Environmental Protection Research Directorate, Ministry of Environment and Forest , P. O. Box 24536 Code 1000, Addis Ababa, Ethiopia
[2]Department of Environmental Health Sciences & Technology, Jimma University, Ethiopia
[3]Department of Water Resources and Environmental Engineering, Jimma University, Ethiopia

Abstract: In Ethiopia enormous amounts of coffee husk and pulp are generated anually from coffee processing industries. However, they have been poorly utilized or left to decompose or otherwise dumped in the environment. Therefore, this research was conducted at Teppi and Limu coffee farms in Ethiopia to produce briquettes from coffee husk and pulp. The objectives of the study were to evaluate the energy potential of briquette produced from coffee husk and pulp and characterize their fuel properties. The coffee husk and pulp were carbonized in an oxygen-deficient environment separately by using carbonizing kiln at Jimma Agricultural Mechanization Research Centre. Then the carbonized materials were ground to fine particles and mixed with a binder and converted to briquettes by using a briquette extruder machine. Triplicate samples of the briquettes were sent to Geological Survey of Ethiopia for analysis. The calorific value of the briquettes produced from coffee husk and pulp ranged between 5041.1±168.60 and 4037.6±219.39cal/g, respectively. Further analysis showed that through conversion of the coffee husk and pulp in to briquette, annually the two farms could generate 1.3×10^{13}cal of energy and substitutes 5,284.35 m^3 of firewood or save 52.84 to 66.05 ha of tropical forests from deforestation. The results of the study have shown that briquettes produced from coffee husk have more positive attributes than briquettes produced from coffee pulp at both farms. It is concluded that briquettes produced from coffee husk and pulp could be used as an alternative source of energy and waste management option.

Keywords: Briquette; Carbon Sequestration; Coffee Husk; Coffee Pulp

1. Introduction

In Ethiopia, enormous amounts of coffee husk and pulp are generated from coffee processing industriesannually. Nevertheless, these materials have been poorly utilized and managed or are left to decompose or burned in open fields (Yisehak, 2009) or dumped in the environment including water bodies (Alemayehu and Rani, 2007). Yet, these activities cause and aggravate pollution of air, the environment, and water (Abebe *et al*., 2011) potentially underminig coffee certification since environmental considerations and sound coffee production systems are among the criteria and code of conduct required for the certification (Volkmann, 2008).

On the other hand, utilization of coffee husk and pulp is an option to alleviate the problems (Yared *et al.,* 2010). For example, in different regions of Ethiopia, this biomass has been consumed by households in place of firewood with inefficient open fire stoves. However, direct utilization of this type of biomass as a source of energy is not suitable because it has low density, high smoke, and low energy intensity (Abakr and Abasaeed, 2006). Moreover, smoke released from the biomass causes acute respiratory infections (Taylor and Nakai*,* 2012).

Alternatively, converting such agricultural residues into briquettes addresses these problems (Abakr and Abasaeed, 2006) because briquette production is environmentally friendly, socially acceptable, and provides a smokeless source of fuel (Akowuah *et al.,* 2012). Besides, briquette production requires low cost (Wessapan *et al.,* 2010), offers a significant advantage over firewood in that it has greater heat intensity (Wondwossen, 2009). It also realizes zero waste production (Suhartini *et al.,* 2011) and improves the calorific value of the biomass (Aina *et al.,* 2009).

However, briquettes produced from different biomass have different characteristics (Sayakoummane and Ussawarujikulchai, 2009). Therfore, before using briquettes for consumption, their moisture content (MC), volatile matter (VM), ash content (AC), fixed carbon content (FC), calorific value (CV), bulk density (BD) and sulfur content (SC) must be studied and characterized (Oladeji, 2010).

Despite ample availability, coffee husk and pulp have never been used in Ethiopia as an effective source of energy, but have been dumped into nearby rivers (Alemayehu and Rani, 2007). Therefore, the objectives of this study were to produce briquettes from coffee husk

*Corresponding Author. E-mail: weldemedhinm@yahoo.com

ISSN 1992-0407

and pulp and, evaluate their energy potential and characterize their fuel property.

2. Materials and Methods

2.1. Description of the study sites

According to the farm's officials,Teppi coffee farm is found in Gambella Regional State in Majangir Zone and it is an expanse of 6,400ha of land covered by coffee. Geographically, it is located at $7^0$18' N latitude, $35^0$14' E longitude, and at an altitude of 1,330m above sea level. Limu coffee farm is located in Oromia Regional State in Jimma Zone and covers an an expanse of 7,800ha of land. Geographically it is located at $7^0$58' N latitude, $36^0$54' E longitude, and at an altitude of 1,800meters above sea level.

2.2. Sampling technique

The two coffee farms (Teppi and Limu) were selected purposively as a source of coffee husk and pulp. This helped to obtain enough amounts as well as homogenous type of coffee husk and pulp. The experimental study and the laboratory analysis were conducted using the facilities of Jimma Agricultural Mechanization Research Center and Geological Survey of Ethiopia, respectively.

2.3. Conversion of coffee husk and pulp into carbonized material

The coffee husk and pulp were allowed to dry before carbonization to remove the moisture and facilitate the carbonization process. For each treatment, 19 kg sample of coffee husk and pulp was carbonized separately in an oxygen-scarce environment. This was repeated three times. The conversion efficiency of raw coffee husk and pulp into carbonized material was calculated according to Pari *et al.,* (2004) as follows:

$$\textbf{Carbonization efficiency of coffee husk}\ (\%) = \frac{\textbf{weight of carbonized coffee husk}}{\textbf{weight of raw coffee husk}} \times \textbf{100} \quad 1$$

$$\textbf{Carbonization efficency of coffee pulp}\ (\%) = \frac{\textbf{weight of carbonized coffee pulp}}{\textbf{weight of raw coffee pulp}} \times \textbf{100} \quad 2$$

2.4. Procedure of briquette production

The carbonized materials were ground in to fine particles and mixed with a binder[a] in the ratio of 3:1 *i.e.* every three kg of ground carbonized material was mixed with one kg of the binder (Yisehak, 2009). Then the mixture was converted in to briquettes by using a briquette extruder machine. This was done by pouring the mixture into the briquette extruder machine and rotating the handle of the fly wheel to transport the mixture to the end of the machine (Wondwossen, 2009) with the help of an auger. Finally, the briquettes were placed on a suitable material for drying under the sun.

2.5. Data collection and Analysis

Data were collected from the carbonization process and the laboratory analysis of briquettes. Descriptive statistics such as mean and standard deviation were calculated using Microsoft Excel application.

2.6. Data quality control

During collection of the feedstock (coffee husk and pulp) extraneous materials like leaves, grasses, sand, soil, wood branches etc were carefully excluded. After production, the briquettes were packed and kept in a dry and clean environment and subjected to laboratory analysis. The laboratory analysis was done after calibration of the instrument such as Carbolite Oven, Carbolite Furnaces and Parr Adiabatic Oxygen Bomb calorimeter following standard procedure of the American Society for Testing and Materials (ASTM).

2.7. Laboratory analysis

From each treatment, triplicate samples of the dried briquettes were brought to Geological Survey of Ethiopia (GSE) for determination of moisture content (MC), volatile matter (VM), ash content (AC), fixed carbon content (FC), calorific value (CV), bulk density (BD) and sulfur content (SC).

2.7.1. Proximate analysis

2.7.1.1. Moisture content

The moisture content of the briquette was determined by heating a sample of 1g briquette to 105 ^oC to a constant mass and the moisture was computed on weight basis according to the following equation:

$$\text{MC}(\%) = \frac{\text{Weight of sample}^{b}(\text{g}) - \text{Oven dried Weight of sample}^{c}(\text{g})}{\text{Weight of briquette sample (g)}} \times 100 \quad 3$$

2.7.1.2. Volatile matter

The volatile matter of the briquette was determined by heating an oven-dried sample in absence of oxygen at 950^{o}C for six minutes. The volatile matter was computed as the difference between the initial weight and final weight of the sample to the ratio of weight of the briquette sample as follows.

$$\text{VM}(\%) = \frac{\text{Weight of sample at 105 °C(g)} - \text{Weight of sample (g) at 950 °C}}{\text{Weight of briquette sample(g)}} \times 100 \quad 4$$

2.7.1.3. Ash content

Ash content of the briquette was determined by heating the briquette sample in a crucible at 750^{o}C for three hours in the oven. The ash content was calculated as the proportion of the weight of the ash in the briquette to the weight of briquette sample as follows:

$$\text{AC}(\%) = \frac{\text{Weight of sample at 950 °C} - \text{Weight of sample (g) at 750 °C}}{\text{Weight of briquette sample (g)}} \times 100 \quad 5$$

[a]Prepared from clay soil and water in 1:2 ratios *i.e.*For every one kg clay soil, two litre of water was used to prepare the binder.

[b]Weight of sample= Weight of crucible + weight of briquette sample

[c] Oven dried weight of sample=Weight of sample at 105 ^{o}C

2.7.1.4. Fixed carbon

The percentage of fixed carbon content of the briquettes was computed by subtracting the sum of volatile matter (VM), ash content (AC), and MC (moisture content) from 100.

$$FC(\%) = 100 - [MC\% + VM\% + AC\%] \quad 6$$

2.7.2. Determination of bulk density, sulfurcontent and calorific values

2.7.2.1. Bulk density

The bulk density of the briquette was expressed as the ratio of the mass of the briquette to the volume of the briquette.

$$BD\left(\frac{g}{cc}\right) = \frac{\text{mass of briquette sample}}{\text{volume of briquette sample}} \quad 7$$

2.7.2.2. Sulfur content

Sulfur content was measured using Parr (1241) Adiabatic Oxygen Bomb calorimeter through calorimetric combustion of the briquette sample according to the as follows:

$$SC(\%) = \frac{[\text{Weight difference}^{d} - \text{Blank}^{e}] \times 13.73}{\text{Weight of briquette sample}} \quad 8$$

2.7.2.3. Calorific Value

The calorific value of the briquette was measured using Parr (1241) Adiabatic Oxygen Bomb calorimeter as follows:

$$CV(cal) = \frac{\Delta T^{f} \times 2420 - [\text{wire burn} \times 2.3 + \text{Titration} + \text{Sulfur}^{g}]}{\text{Weight of briquette sample}} \quad 9$$

3. Results and Discussion

3.1. Input and output of carbonization of coffee husk and pulp

The conversion efficiency of feedstock (uncarbonized coffee husk and pulp) into carbonized material ranged from 31.02±0.84% for that of coffee pulp in Limu to 32.61±1.60% for coffee husk in Teppi. The average of the conversion efficiency mean value of the carbonized coffee husk from Teppi and Limu coffee farms is 32.39% *i.e.* from 100 kg of raw coffee husk net average carbonized coffee husk is amounted to 32.39 kg. Similarly the average of the conversion efficiency mean value of the carbonized coffee pulp from Teppi and Limu coffee farms is 31.18% *i.e.* from 100 kg of raw coffee pulp net average carbonized coffee pulp amounted to 31.18 kg (Table 1).

Annually, from the two farms, 3,676,088 and 3,535,224 kg of coffee husk and dry coffee pulp were generated (Personal communication with the farm officials and calculated result from compiled annual report of the farms). Based on this finding, if these farms carbonized their coffee husk and pulp, they could annually produce 1,190,685 and 1,102,283 kg of carbonized coffee husk and pulp, respectively.

[d]Weight difference = Weight at 825^{0}C - Weight of crucible,

[e] Blank = 0.0002

[f] Final temperature – Initial temperature

[g]Sulfur = SC* Weight of briquette sample*13.378

Table 1. Input and output of carbonization of coffee husk and pulp, Teppi&Limu, south-western Ethiopia.

Sample of feed stock	Input (Mass of uncarbonized feed stock) in kg	Treatment	Output (Mass of carbonized feed stock) in Kg	Conversion Efficiency of feedstock into carbonized material in %	Net average mass of carbonized material from both farms in kg
*Teppi*coffee husk (TCH)	19	TH_1	6.50	34.21	Net average mass of carbonized material produced from coffee husk 1/2(TCH+LCH) =1/2(32.61+32.17) is 32.39
		TH_2	5.89	31.00	
		TH_3	6.20	32.63	
		Mean ± SD	6.20±0.31	32.61±1.60	
*Teppi*coffee pulp (TCP)	19	TP_1	5.95	31.31	
		TP_2	6.08	32.00	
		TP_3	5.84	30.73	
		Mean ± SD	5.95±0.12	31.34±0.64	
Limu coffee husk (LCH)	19	LH_1	32.36	32.36	Net average mass of carbonized material produced from coffee pulp1/2(TCP+ LCP)= 1/2(31.34+31.02) is 31.18
		LH_2	32.63	32.63	
		LH_3	31.53	31.53	
		Mean ± SD	6.11±0.11	32.17±0.57	
Limu coffee pulp (LCP)	19	LP_1	5.90	31.05	
		LP_2	6.05	31.84	
		LP_3	6.00	30.16	
		Mean ± SD	5.98±0.07	31.02±0.84	

3.2. Evaluation of the Energy Potential of the Briquette Produced from Coffee Husk and Pulp

The average of the calorific mean values of the briquettes produced from coffee husk at both farms *i.e.* net average calorific value of the briquettes produced from Teppi and Limu coffee husk amounted to 5041.1 cal/g (Table 2). As a result, if 1,190,685 kg carbonized coffee husk was mixed with the specified proportion of the binder, the two farms could possibly produce 1, 488,356.25 kg of briquettes, which would have a calorific value of 7,502,952,691,875 as total energy. Accordingly, the average of the calorific mean values of the briquettes produced from Teppi and Limu coffee pulps was 4037.6 cal/g (Table 2). Thus, if 1,102,283 kg of carbonized coffee pulp was mixed with the specified proportion of the binder, the farms could possibly produce 1,377,853.75 kg briquettes, which would amount to a total energy of 5,563,222,301,000 calorie.

Therefore,these farms could generate 1.3×10^{13}cal of energy from briquettes.

One kg of fuel wood gives 13.8 MJ of energy, which is equal to 3,296.82 cal/g of energy and one cubic meter of fuel wood equals to 750 kg (FAO, 1999). Therefore, through production of briquettes, the farms could possibly substitute energy obtained from 5,284.35 m^3 of firewood. Tropical high forest could give 80 to 100 m^3 of firewood per hectare (FAO, 1987). Based on this conversion, these farms could save 52.84 to 66.05 ha of tropical forest from deforestation annually.

Correspondingly, the aboveground carbon sequestration of tropical rain forest (at Ton Mai Yak station) is 137.73 tons of carbon per hectare (Terakunpisut *et al.*, 2007). Accordingly, these farms could save forests which have the potential to sequestrate 7.28 to 9.1 kilo tons of carbon annually.

Table 2. Characterization of briquette produced from coffee husk and pulp through determination of BD (Bulk density), SC (Sulfur content) and CV (Calorific value).

Samples of briquette	Treatment	Laboratory result of BD, SC & CV			Net average CV in cal/g from both farms
		BD in g/cc	SC in%	CV in cal/g	
Briquette produced from *Teppi*Coffee Husk (TCH)	TH$_1$	0.65	0.09	4916.02	Net average CV of briquette produced from coffee husk = 1/2(CVTCH+CVLCH) =1/2(5132.98+4949.17) is 5041.1
	TH$_2$	0.73	0.04	5182.54	
	TH$_3$	0.58	0.04	5300.39	
	Mean ± SD	0.65±0.07	0.06±0.03	5132.98 ±196.92	
Briquette produced from *Teppi* Coffee Pulp (TCP)	TP$_1$	0.47	0.22	3719.46	
	TP$_2$	0.41	0.05	4003.57	
	TP$_3$	0.45	0.21	3864.33	
	Mean ± SD	0.44±0.03	0.16±0.09	3862.45±142.06	
Briquette produced from *Limu* Coffee Husk (LCH)	LH$_1$	0.58	0.08	4868.68	Net average CV of briquette produced from coffee pulp = 1/2(CVTCP+CVLCP) =1/2(3862.45+4212.80) is 4037.6
	LH$_2$	0.56	0.07	5035.20	
	LH$_3$	0.55	0.04	4943.63	
	Mean ± SD	0.56±0.01	0.06±0.02	4949.17±83.28	
Briquette produced from *Limu* Coffee Pulp (LCP)	LP$_1$	0.52	0.12	4148.83	
	LP$_2$	0.51	0.06	4173.91	
	LP$_3$	0.51	0.07	4315.67	
	Mean ± SD	0.51±0.01	0.08±0.03	4212.80±89.96	

3.3. Fuel property characterization of briquettes produced from coffee husk and pulp

3.3.1. Moisture content

The moisture content of the briquettes produced in this research (Table 3) is much smaller than the moisture content of briquettes produced from rice husk and corncob which were 12.67% and 13.47%, respectively (Oladeji, 2010). The quality specification of charcoal usually limits the moisture content between 5 to 15% (FAO, 1987). Therefore, the moisture content of briquettes obtained in this research is in line with this specification. However, to facilitate heat transfer, moisture content should be as low as possible (USAID, 2010).

3.3.2. Volatile matter

The volatile matter of briquettes obtained from this research (Table 3) is lower than the volatile matter of briquettes produced from rice husk which was 67.98 (Oladeji, 2010). However, the volatile matter of charcoal can vary from 5 to 40% but good commercial charcoal has net volatile matter content of about 30% (FAO, 1987). Hence, the volatile matter of all briquettes obtained from this research is in line with this criterion. Briquettes containing large amounts of volatile matter are highly combustible.However, highly volatile charcoal is easy to ignite but may burn with a smoke flame. Low volatile charcoal is difficult to ignite but delivers very clean heat (Sotannde *et al.*, 2010).

3.3.3. Ash content

The ash content of the briquettes in this research (Table 3) is higher than the ash content of briquettes produced from Hazelnut shell which was 7% (Haykiri-Acma and Yaman , 2010). Yet, a typical ash content of fine quality lump charcoal is about 3% (FAO, 1987). However, the ash content of the briquettes produced in this study was greater than the specified range. This might be due to the effect of the binder used to bind the ground carbonized material which was non combustible (clay soil). This suggestion is consistent with the proposition that using anon-combustible binder results in the production of more ash than using a combustible binder (Onchieku *et al.,* 2012). The ash content is an indicator of slugging behavior of the biomass. Hence, the larger the ash content, the larger will be the slugging behavior. However, this is not always true sincea slugging behavior can also depends on the temperature of operation, the mineral compositions and their percentage (Grover & Mishra, 1996).

Table 3.Characterization of briquettes produced from coffee husk and pulp through determination of proximate analysis.

Samples of briquette	Treatment	Laboratory result of proximate analysis			
		MC in %	VM in %	AC in %	FC in %
Briquette produced from *Teppi* Coffee Husk (TCH)	TH_1	6.37	24.89	12.54	56.20
	TH_2	6.29	22.77	12.08	58.86
	TH_3	5.90	19.29	13.01	61.80
	Mean ± SD	6.18± 0.25	22.32±2.83	12.54±0.47	58.95±2.80
Briquette produced from *Teppi*Coffee Pulp (TCP)	TP_1	13.81	22.40	22.82	40.97
	TP_2	10.64	24.57	20.95	43.84
	TP_3	9.55	25.40	22.66	42.39
	Mean ± SD	11.33±2.21	24.12±1.55	22.14±1.03	42.4±1.42
Briquette produced from *Limu* Coffee Husk (LCH)	LH_1	6.24	28.05	10.63	55.08
	LH_2	7.39	20.29	14.07	58.25
	LH_3	5.97	22.54	11.69	59.80
	Mean ± SD	6.53±0.75	23.63±3.99	12.13±1.76	57.71±2.41
Briquette produced from *Limu* Coffee Pulp (LCP)	LP1	10.78	23.01	19.52	46.69
	LP2	7.83	26.00	18.92	47.25
	LP3	7.77	31.56	18.48	42.19
	Mean ± SD	8.79±1.72	26.86±4.34	18.97±0.52	45.38±2.77

3.3.4. Fixed carbon content

The fixed carbon content of the briquettes obtained from this research (Table 3) is much less than the fixed carbon content of briquettes produced from sawdust which was a fixed carbon content of 78.68% (Sayakoummane and Ussawarujikulchai, 2009) and greater than carbon content of briquettes produced from Hazelnut shell which was a fixed carbon content of 21% (Haykiri-Acma and Yaman, 2010).

3.3.5. Bulk density

The bulk density of the briquettes obtained from this research is greater than the bulk density of briquettes produced from elephant grass, which hadacorresponding value of 0.319 g/ cc (Onuegbu *et al.*, 2012).

3.3.6. Sulfur content

Briquettes produced in this research have lower sulfur content than briquettes produced from rice husk which had a sulfur content of 0.82% (Oladeji, 2010). The lower sulfur content in the briquettes produced from coffee husk and pulp is promising interms of minimal potential to release sulfur, which would reduce indoor air pollution and the formation of acid rain (Ciubota-Rosie *et al*, 2008).

3.3.7. Calorific value

The calorific value of the briquettes obtained in this research is greater the calorific value of briquettes produced from elephant grass which was 3817.6 cal/g (Onuegbu *et al.*, 2012). All briquettes produced in this research have higher calorific values than wood which has a calorific value of 3,296.82cal/g (FAO, 1999).

3.4. Comparison of briquettes produced from coffee husk and pulp

At both farms, the briquettes produced from coffee husk have lower values of moisture content, ash content, volatile matter, and sulfur content but higher values of fixed carbon content, calorific value, and bulk density than the briquettes produced from coffee pulp (Tables 2 and 3).When the moisture content of the briquette increases, there will be a requirement for higher amounts of energy for evaporation during combustion (Aina *et al.,* 2009) and the lower the moisture content of the briquette, the higher will be the calorific value (Akowuah *et al.,* 2012). Low volatile matter content of the briquettes shows that it burns without smoke and deliversa clean flame during combustion. Conversely, high volatile matter content indicates that the briquette burns with smoke (Sotannde *et al.*, 2010). The higher the ash content, the higher will be the emission of micro aerosols and fumes as well as formation of slag (Livinngston and Babcock, 2006) and the lower will be the calorific value due to combustion remnants (Sotannde *et al.*, 2010). Therefore, the results of the analysis indicated that briquettes produced from coffee husk have more positive attributes than briquettes produced from coffee pulp at both farms. Among the positive features are low moisture content, high density, low ash content, and high calorific value (Oladeji, 2010).

4. Conclusion

This research has demonstrated that briquette produced from coffee husk and pulp have high potential as a source of environmentally friendly energy, which is that reduces pollution as well as provides a sound coffee waste management option. This can also play a role in acquiring coffee certification. Moreover, production of briquettes from coffee husk and pulp helps to increase the mechanism of carbon sequestration through reducing the deforestation rate as a result of providing renewable, clean, and sustainable energy as a substitute for fuel wood and charcoal.

5. Acknowledgements

The authors are very grateful to Jimma University research project and Graduate Study office for the financial support. They are also thankful to Teppi and Limu coffee farms, Jimma Agricultural Mechanization Research Center, and Geological Survey of Ethiopia for providing the laboratory room to perform the analysis.

6. References

Abakr, Y. A. and Abasaeed, A. E. 2006. Experimental evaluation of a conical-screw briquetting machine for the briquetting of carbonized cotton stalks in Sudan. *Journal of Engineering Science and Technology* 1: 212 – 220.

Abebe Beyene, Yared Kassahun, Taffere Addis, Fassil Assefa, Aklilu Amsalu, Worku Legesse, Helmut Kloos and Ludwig Triest. 2011. The impact of traditional coffee processing on river water quality in Ethiopia and the urgency of adopting sound environmental practices. *Environ Monit Assess* 184:7053 - 7063.

Aina O, Adetogun A, and Iyiola K. 2009. Heat Energy from Value-Added Sawdust Briquettes of Albiziazygia.*Ethiopian Journal of Environmental Studies and Management* 2: 42 - 49.

Akowuah, O.A. Francis, K and Stephen, J. M. 2012. Physico-chemical characteristics and market potential of sawdust charcoal briquette. *International Journal of Energy and Environmental Engineering* 3:20.

Alemayeu Haddis and Rani Devi. 2007. Effect of effluent generated from coffee processing plant on the water bodies and human health in its vicinity. *Journal of Hazardous Materials* 152: 259 - 262.

Ciubota-Rosie, C. Gavrilescu, M. and Macoveanu, M. 2008. Biomass – An important renewable source of energy in Romania. Environmental Engineering and Management Journal 5: 559 - 568.

FAO (Food and Agriculture Organization). 1987. Simple technologies for charcoal making. FAO Forestry Paper 41, Rome, Italy.

FAO (Food and Agriculture Organization). 1999. The role of wood energy in Africa. Definitions, Conventions and Conversion Factors Applied, Appendix 1, Rome, Italy. http://www.fao.org/docrep/x2740e/x2740e05.htm (Accessed on August 21, 2013).

Grover, P. D. and Mishra, S. K. 1996. Biomass briquetting: technology and practices. Food and agriculture organization of the United Nations, regional wood energy development programme in ASIA GCP/RAS/154/NET. Field Document No.46 Bangkok, Thailand.

Haykiri-Acma, H. and Yaman, S. 2010. Production of Smokeless Bio-briquettes from Hazelnut Shell.Proceedings of the World Congress on Engineering and Computer Science Vol II, 20-22, October 2010, San Francisco, USA. (http://www.iaeng.org/publication/WCECS2010/ WCECS2010_pp739-741.pdf) (Accessed on August 21, 2013).

Livinngston, B. and Babcock, M. 2006. Work shop on Ash related issues in biomass combustion workshop, 21 September 2006, Marriot Hotel, Glasgow, Scotland.

Oladeji, J. T. 2010. Fuel Characterization of Briquettes Produced from Corncob and Rice Husk. *The Pacific Journal of Science and Technology* 11: 101 - 106.

Onchieku J. M., Chikamai B. N. and Rao M. S. 2012. Optimum Parameters for the Formulation of Charcoal Briquettes Using Bagasse and Clay as Binder. *European Journal of Sustainable Development* 1, 3, 477 - 492.

Onuegbu, T. U., Ogbu, I. M. and Ejikeme, C. 2012. Comparative analyses of densities and calorific values of wood and briquettes samples prepared at moderate pressure and ambient temperature. *International Journal of Plant, Animal and Environmental Sciences* 2: 40 - 45.

Pari, G., Hendra, D., Setiawan, D., Saepuloh, M., Soleh, D., Ali, M., Miyakuni, K. and Ishibashi, N. 2004. Charcoal production for carbon sequestration. Demonstration Study on Carbon Fixing Forest Management in Indonesia.

Sayakoummane, V. and Ussawarujikulchai, A. 2009. Comparison of the Physical and Chemical Properties of Briquette and Wood Charcoal in Khammouane Province, Lao PDR. *Environment and Natural Resources Journa*l 7: 12 - 24.

Sotannde, O.A., Oluyege A.O., and Abah, G.B. 2010. Physical and combustion properties of charcoal briquettes from neem wood residues.*Int. Agrophysics* 24:189-194.

Suhartini, S., Hidayat, N. and Wijaya, S. 2011. Physical properties characterization of fuel briquette made from spent bleaching earth. *Biomass and Bioenergy*. doi: 10.1016/j.biombioe.07.002.

Taylor, E. T and Nakai, S. 2012. Prevalence of Acute Respiratory Infections in Women and Children in Western Sierra Leone due to Smoke from Wood and Charcoal Stoves. *Int. J. Environ. Res. Public Health* 9: 2252 - 2265.

Wessapan, T. Somsuk, N. and Borirak, T. 2010. Design and Development of a Compact Screw-Press Biomass Briquetting Machine for Productivity Improvement and Cost Reduction. The First TSME International Conference on Mechanical Engineering, 20 - 22 October 2010, Ubon Ratchathani.

Terakunpisut, J., Gajaseni, N. and Ruankawe, N. 2007. Carbon sequestration potential in aboveground biomass of Thong PhaPhum National Forest, Thailand.Applied ecology and environmental research 5: 93 - 102.

United States Agency for International Development (USAID), 2010. Biomass Briquetting in Sudan: A Feasibility Study Women's Refugee Commission.

Volkmann, J. 2008. Assessment of Certification Options for Wild Forest Coffee in Ethiopia CoCE Project Report Sub-project 5.4.

Wondwossen Bogale. 2009. Preparation of charcoal using agricultural wastes. *Ethiopian Journal of Education & Science* 5: 77 - 91.

Yared Kassahun Kebede, Tesfu Kebede, Fassil Assefa and Aklilu Amsalu. 2010. Environmental impact of coffee processing effluent on the ecological integrity of rivers found in GommaWoreda of Jimma zone, Ethiopia. *Journal of Ecology and Hydrology* 10: 259 - 270.

Yisehak Seboka. 2009. Bio-carbon Opportunities in Eastern and Southern Africa, Charcoal production: Opportunities and barriers for improving efficiency and sustainability. United Nations Development Programme 1 UN Plaza, USA, New York.

.