Development of an Appropriate Briquetting Machine for Use in Rural Communities

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Abstract*— In this study, an appropriate commercial biomass briquetting machine suitable for use in rural communities was designed and constructed, and the performance evaluation carried out using sawdust. The physical and combustion properties of the briquette were determined at varying biomass-binder ratios of 100:15, 100:25, 100:35 and 100:45 using cassava starch as the binding agent. Both the physical and combustion properties of the briquette were significantly affected by the binder level (P < 0.05). The optimum biomass-binder ratio on the basis of the compressed density was attained at the 100:25 blending ratio having a compressed density of $0.7269 g/cm^3$ and a heating value of $27.17 MJKg^{-1}$ while the optimum blending ratio on the basis of the heating value was attained at the 100:35 blending ratio with a compressed density of $0.7028 g/cm^3$. It was concluded that the heating values at the optimum biomass-binder ratios were sufficient to produce heat required for household cooking and small scale industrial cottage applications. The biomass briquetting machine had a production capacity of about 43kg/hr.

***Keywords*—Appropriate technology, biomass, briquetting, binder level.**

I. INTRODUCTION

Briquetting of biomass is a relatively new technology in most African countries but there exist a number of different commercial briquetting technologies in Asia, America and Europe. The expansion of the use of biomass as an alternative source of energy for heating applications depends basically on three factors: residue availability for briquetting, adequate technologies and the market for briquettes [1]. [2] reported that although the importance of biomass briquette as a substitute fuel for wood is widely recognized, the numerous failures of briquetting machines in almost all developing countries have inhibited their extensive exploitation. The constraint in the advancement of biomass briquetting in Africa and in developing nations generally, is the development of appropriate briquetting technology that suits the local condition; both in terms of the briquetting press itself for local manufacture and the briquettes.

The failure of these machines have been attributed to some factors which include inappropriate or mis-match of technology; technical difficulty and lack of knowledge to adapt the technology to suit local conditions; excessive initial and operating cost of the machines; and the low local prices of wood fuel and charcoal.

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The more replicable, appropriate, cost effective, locally available, easy to make, environment friendly and culturally fitting a technology is for the briquetting of biomass, the higher its chance of success [3]. There currently exist a number of machines developed for the production of biomass briquettes in developing nations. Some of the existing machines in the rural areas are either gender unfriendly, or having poor production capacity and briquette quality, and depends on direct human strength for densification. The need at the moment in the densification of biomass in developing countries is the development of an appropriate briquetting machine suitable to the local communities. For biomass to make a significant impact as fuel for rural communities, it is imperative that an efficient, cost effective and easy to duplicate technology is developed specifically for rural communities.

The general objective of the study was to develop a biomass briquetting machine appropriate for rural communities of developing countries; in terms of its operating technicalities and socio-economic requirements. The specific objectives of the study were:

i. To design and construct a biomass briquetting machine;
ii. To undertake a performance evaluation of the briquetting machine using sawdust at varying binder levels; and
iii. To determine the physical and combustion properties of the sawdust briquette.

II. MATERIALS AND METHODS

For the purpose of the study, sawdust was used for the performance evaluation of the machine. The sawdust sample was collected from a saw mill in Nsukka, Enugu state, South-Eastern Nigeria. Cassava starch was procured from a local market and used as a binding agent mainly to overcome the major problem of material compaction – post-compaction recovery - which represents enormous waste in energy input [4].

A. Design and Construction

A biomass briquetting machine was designed and constructed (Figure 1). The briquetting machine was equipped with thirty-six moulds (A) each measuring 100 x 70 x 150mm welded together and positioned vertically over equal number of pistons (B). The pistons were made such that there was a clearance of about 2mm between the piston head and the mould walls to allow the escape of water during compaction. The opposite ends of the rods were welded on a flat metal plate (C) of 10mm thickness which rests on a 20 ton capacity hydraulic jack (D). The jack drives the pistons in and out of the moulds during operation.

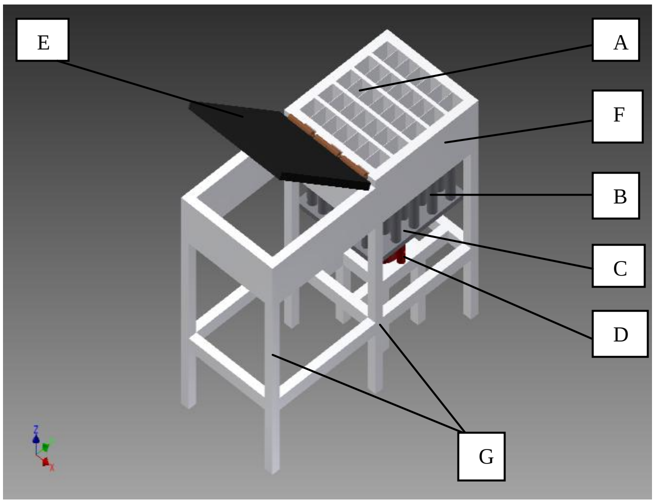

Figure 1: The biomass briquetting machine
A – Moulds, B – Pistons, C – Flat plate, D – Hydraulic jack, E – Mould cover, F – Mould box, G – Iron frame.

A flat metal plate (E), 10 mm thick, was hinged to the mould box (F) to cover the open ends of the moulds during compaction; and opened during ejection of the briquettes. To prevent the bulging of the mould cover during compaction, two cross bars were placed and firmly locked over the cover during compaction. The vertical motion of the pistons in and out of the moulds, and the ejection of compressed briquettes from the moulds were effected through the manual operation of the hydraulic jack. The hydraulic jack rests on angle bars welded to the frame (G) of the machine. By this arrangement, the force from the hydraulic jack is centrally applied to the metal plate bearing the pistons. The machine was fabricated using mild steel and angle bar at a cost of ₦35,000.00 (USD218). Different views of the machine are given in Figure 2.

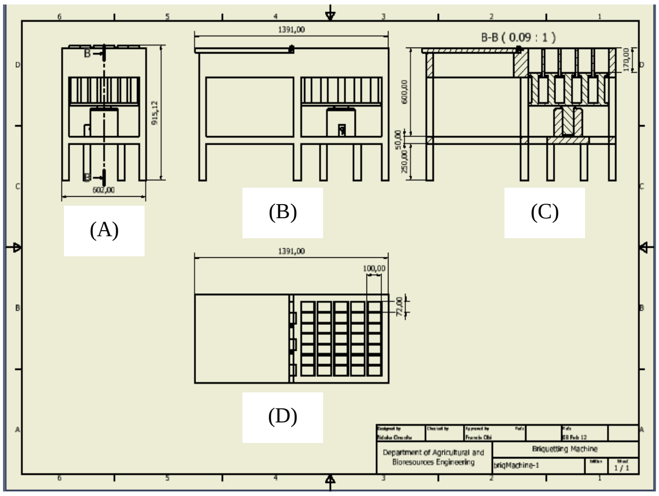

Figure 2: Design of the briquetting machine

A – Side view, B – Front view, C – Section across the front view, D – Plan.

B. Biomass-binder Mixture

Sawdust sample was mixed with an already prepared cassava starch in proportions of 100:15, 100:25, 100:35 and 100:45 by weight respectively in line with the works of [5], [6]. The starch and the biomass sample were well mixed without forming a muddy mixture because the formation of muddy mixture due to excess addition of water reduces both the durability and density of the briquette [7]. The biomass-binder mixture was hand fed into the moulds and compacted to form the briquettes after which they were sun dried to constant weight. A dwell time of 20 minutes was observed during the production of the briquette.

III. PERFORMANCE EVALUATION

For the performance evaluation, six briquette samples were randomly selected from the sawdust briquette for evaluation. During the process of densification, the following statistic: time for loading biomass into moulds, t_1, sec, time for compressing the biomass, t_2, sec, and time for ejecting the biomass briquettes, t_3, sec, were observed and recorded following after [8]. The production capacity of the machine in kg/hr was also recorded. On ejection of the briquettes from the moulds, the mass and the dimensions of the briquettes were taken to determine the density in g/cm^3 using a digital weighing balance and a digital caliper. The compressed density, relaxed density, relaxation ratio and dimensional stability of the sawdust briquette were determined in accordance with the methods described by [9]. Figure 3 shows the sawdust briquette from the briquetting machine.

Figure 3: Sawdust briquette

A. Physical Properties Determination

The bulk density of the loose biomass sample was determined by weighing an empty cylindrical container of known volume and mass, and then carefully filled with the biomass sample. After filling every third portion of the container with the sample, it was tapped on a wooden table for approximately 10 times to allow the material to settle down. After completely filling the container, excess material at the top was removed by moving a steel roller in a zig-zag pattern over the container. The mass of the containing sample was determined.

The compressed density (density immediately after compression) of the briquette was determined immediately after ejection from the moulds as the ratio of measured weight to the calculated volume. The relaxed density (density determined when dried) and relaxation ratio (ratio of compressed density to relaxed density) of the briquette were determined in the dry condition of the briquette after about 27 days of sun drying to a constant weight at an ambient temperature of 34 ± 4^{o}C and relative humidity of 68 ± 5% respectively. The relaxed density was calculated as the ratio of the briquette weight (g) to the new volume (cm^3). This gave an indication of the relative stability of the briquette after compression. The compaction ratio was obtained from the ratio of the maximum density and the initial density of the sawdust sample [10].

Briquette stability was measured in terms of its dimensional changes when exposed to the atmosphere [5]. To determine the dimensional stability of the briquette, the height was measured at 0, 30, 60, 1440 and 10,080 min intervals [5]. Durability represents the measure of shear and impact forces a briquette could withstand during handling, storage and transportation processes [11]. The durability of the briquette was determined in accordance with the chartered index described by [12] after sun drying to a constant weight. The briquette was dropped repeatedly from a height of 1.5m onto a metal base. The fraction of the briquette that remained unshattered was used as an index of briquette durability [13], [14]. The durability rating of the briquette was expressed as a percentage of the initial mass of the material remaining on the metal plate and this gave an indication of the ability of the briquette to withstand mechanical handling.

Water resistance of the briquette was tested by immersing the briquette in a container filled with cold tap water and measuring the time required for the onset of dispersion in water. The higher the water resistance time, the more stable the briquette is in terms of weathering resistance [15].

B. Combustion Properties Determination

Proximate analysis was carried out to determine the percentage volatile matter, fixed carbon and ash content of the sawdust briquette. The proximate analysis was determined based on ASTM Standard [16]. For the percentage volatile matter, 1g of the sawdust briquette was placed in a crucible of known weight and oven dried (ELE Limited – Serial no: S80F185 – Hemel Hempstead Hertfordshire, England) to a constant weight after which it was heated in a furnace (Isotemp Muffle Furnace Model 186A – Fisher Scientific) at a temperature of 600°C for 10 minutes. The percentage volatile matter was then expressed as the percentage of loss in weight to the oven dried weight of the original sample. The percentage of ash content followed the same procedure as the volatile matter except that the sample was heated in the furnace for 3 hours. The ash content obtained after cooling in a dessicator was then expressed as a percentage of the original sample. The percentage of fixed carbon was calculated using the equation below:

$$\%\,Fixed\ Carbon = 100 - (\%\,Volatile\ matter + \%\,Ash\ content) \qquad (1)$$

The heating value for the sawdust briquette produced was calculated using the Gouthal formula:

$$H_V = 2.326\,(147.6C + 144V) \qquad (2)$$

Where, H_V is the heating value ($MJ \cdot kg^{-1}$), C is the percentage fixed carbon, and V is the percentage volatile matter [17].

C. Statistical Analysis

The experiment was set up as a Completely Randomized Design (CRD) with 6 replications. Statistical analyses were conducted using GenStat Discovery edition 4 (VSN International). Analysis of Variance (ANOVA) for CRD was carried out at 5% significant level ($P < 0.05$) and where significant differences were identified, the difference between the mean values of the properties tested for were determined using the Fisher's Least Significant Difference (FLSD) at 5% level of significance.

IV. RESULTS AND DISCUSSIONS

The mean biomass loading time, t_1, mean biomass compaction time, t_2, and the mean briquette ejection time, t_3 as well as their percentages of the total production time were recorded as shown in Table 1.

Table 1: Production time components of the briquetting machine

Mean production time components	Time (Sec)	% of Total production time
Biomass loading time, t_1	45	32.14
Biomass compaction time, t_2,	58	41.43
Briquette ejection time, t_3	37	26.43
Total	140	100

In comparison to 74.8% of the total production time attributed to briquette ejection as reported by [8], 48.37% of the time was saved on briquette ejection using the developed briquetting machine. The mean total production time of 140 seconds (2.33 minutes) was lesser than the mean total production time of 868.1 seconds (14.47 minutes) reported by [8]. The production capacity of the machine was about 43 kg/hr.

A. Physical and Combustion Properties of Sawdust Briquette

The physical properties of the sawdust briquette are shown in Table 2. The influence of binder level was significant on the physical properties of the briquette ($P < 0.05$). The compressed density ranged from 0.6125 to 0.7269 g/cm^3 on the addition of 15 to 45% cassava starch.

The maximum compressed density of 0.7269 g/cm^3 was reached at the 25% binder level and it was significantly different from the value obtained at 15, 35 and 45% binder levels. This was reflected in the compaction ratio at this binder level which was recorded as 2.9:1 showing that the particles were well compacted compared to the briquettes with 15, 35 and 45% binder having compaction ratios of 2.4:1, 2.8:1 and 2.7:1 respectively. A direct relationship was observed between the compressed density and the relaxation ratio: the higher the compressed density, the higher the relaxation ratio. This shows that the sawdust briquettes became more unstable with increasing compressed density.

The durability rating of the sawdust briquette ranged from 37.75 – 91.43%. The durability rating was observed to vary directly with the compressed density. A durability rating of 91.43% was recorded for sawdust briquette with 25% binder having the highest compressed density while 37.75% was recorded for the briquette with 15% binder having the least compressed density. This shows that the durability of sawdust briquettes is dependent on the compressed density. The resistance of the briquette to weathering effect measured in terms of the length of time it takes just for the onset of dispersion in water was observed to vary directly with the compressed density and the durability rating of the briquette.

Table 2: Physical properties of sawdust briquette

% binder	Compressed density (g/cm^3)	Relaxed density (g/cm^3)	Relaxation ratio	Compaction ratio	Durability rating (%)	Water resistance test (hrs)
15	0.6125 ± 0.0011^a	0.2663 ± 0.0010^a	2.3002 ± 0.0110^a	2.4199 ± 0.0044^a	37.75 ± 0.91^a	4.33 ± 0.04^a
25	0.7269 ± 0.0037^b	0.2518 ± 0.0012^b	2.8873 ± 0.0163^b	2.8721 ± 0.0094^b	91.43 ± 0.26^b	7.86 ± 0.01^b
35	0.7028 ± 0.0010^c	0.2878 ± 0.0005^c	2.4422 ± 0.0071^c	2.7768 ± 0.0039^c	87.52 ± 0.47^c	6.02 ± 0.02^c
45	0.6822 ± 0.0007^d	0.2756 ± 0.0006^d	2.4749 ± 0.0075^d	2.6952 ± 0.0028^d	76.71 ± 0.86^d	5.27 ± 0.01^d

Mean values with the same alphabet in each column are not significantly different ($P < 0.05$) using FLSD.

The dimensional stability of the briquette which was measured in terms of its dimensional changes when exposed to atmosphere is shown in Figure 4. From the figure, briquette produced with 35% of the binder appeared to be most stable between 30 – 1440 minutes, hence it can be inferred that it produced the most stabilizing effect when exposed to the atmosphere compared to briquettes at other binder levels.

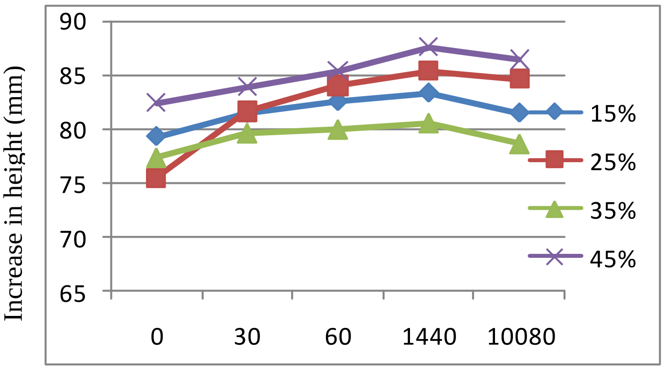

Figure 4: Expansion in the height of sawdust briquette with time

The combustion properties of the sawdust briquette produced are shown in Table 3. The different binder levels had a significant effect on the combustion properties of the briquette ($P < 0.05$). The volatile matter recorded ranged from 67.08% to 91.63%. These values fell outside the range of smokeless fuel which is known to contain no more than 20% volatile matters [18]. The highest volatile matter content was recorded at the 35% binder level. The ash content ranged from 0.56% to 19.21%. Ash content in briquettes normally causes increase in combustion remnant in the form of ash which lowers the heating value of briquettes; the lowest value was recorded at the 35% binder level. The calculated fixed carbon was highest at the 25% binder level with a value of 13.71%.

The heating value is the most important combustion property for determining the suitability of a material as fuel. It gives the indication of the quantity of fuel required to generate a specific amount of energy. The heating value ranged from 27.17 $MJ.Kg^{-1}$ to 33.37 $MJ.Kg^{-1}$. The highest value was recorded at the 35% binder level and the lowest at the 25% binder level; and they were all significantly different from one another (Table 3). The low heating value at the 25% binder level could be due to the high ash content recorded at that binder level. The highest heating value of 33.37 $MJ.Kg^{-1}$ was found to be higher than 18.89 $MJ{\cdot}kg^{-1}$ obtained in banana peel briquette [19] and 14.1 $MJ{\cdot}kg^{-1}$ obtained in maize cob briquette [20], 24–27 $MJ{\cdot}kg^{-1}$ for lignite with bio-binder [18], 12.60 $MJ.kg^{-1}$ for groundnut shell briquette [21] and 33.08 $MJ{\cdot}kg^{-1}$ obtained by [5] for sawdust briquette. This makes the sawdust briquette a good potential fuel for domestic cooking. In the production of the sawdust briquette, 3700cm^3 of water per kilogram of sawdust was in producing a good biomass-binder mix for briquetting.

B. Optimum Sawdust-Binder Blend

The optimum blend of biomass-binder ratio was assessed on the basis of the briquette compressed density and heating value since they are two of the major indices for assessing the combustion, handling characteristics and ignition behaviour of briquettes as reported by [5]. A blend of sawdust and cassava starch in the ratio of 100:25 gave the optimum compressed density of 0.7269 g/cm^3 with a heating value of 27.17 $MJ.Kg^{-1}$ while a blending ratio of 100:35 gave the highest heating value of 33.37 $MJ.Kg^{-1}$ with a compressed density of 0.7028 g/cm^3. The heating values were higher than those reported by some researchers for some biomass briquettes [18], [20], [21], [19]. In terms of quality specification of briquettes, excellent briquette can be produced from sawdust using the developed biomass briquetting machine.

Table 3: Combustion properties of sawdust briquettes

% binder	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Heating value ($MJ{\cdot}kg^{-1}$)
15	77.95 ± 0.09^a	11.66 ± 0.06^a	10.39 ± 0.08^a	29.68 ± 0.02^a
25	67.08 ± 0.18^b	19.21 ± 0.24^b	13.71 ± 0.21^b	27.17 ± 0.08^b
35	91.63 ± 0.06^c	0.56 ± 0.19^c	7.81 ± 0.16^c	33.37 ± 0.06^c
45	78.35 ± 0.20^d	14.05 ± 0.29^d	7.61 ± 0.17^d	28.85 ± 0.10^d

Mean values with different alphabet in each column are significantly different ($P < 0.05$) using FLSD.

V.CONCLUSIONS

The study on the development of a biomass briquetting machine is of great importance to poor and developing countries as it addresses the issues surrounding the efficient utilization of abundant quantities of agricultural wastes and residues which provide an enormous untapped fuel resource. The following conclusions were arrived at from the study:

1. A biomass briquetting machine suitable for the production of biomass briquettes on a small scale with a production capacity of 43kg/hr was developed and successfully used in the production of biomass briquette using sawdust.
2. The physical and combustion properties of the sawdust briquette were found to be significantly affected by the binder level.
3. Briquette with satisfactory qualities was produced using the developed briquetting machine. However for optimum sawdust briquette quality on the basis of compressed density, a blending ratio of 100:25 should be used while on the basis of the heating value, a blending ratio of 100:35 should be used.
4. The heating value calculated at the optimum biomass-binder ratios were sufficient to produce heat required for household cooking in rural communities and small scale industrial cottage applications.

REFERENCES

[1] Felfli, F. F., Mesa P, J. M., Rocha, J. D., Filippetto, D., Luengo, C. A. and Pippo, W. A. (2011). Biomass Briquetting and its Perspectives in Brazil. *Biomass and Energy* (35): 236 – 242.
[2] Grover, P. D. and Mishra, S. K. (1996). Biomass Briquetting: Technology and Practices. FAO Regional Wood and Energy Development Programme in Asia, Bangkok, Thailand.
[3] Hood, A. H. (2010). Biomass Briquetting in Sudan: A feasibility Study. The United States Agency for International Development (USAID) and the Women's Refugee Commission.
[4] Faborode, M. O. (1998). Rural Domestic and Agro-Industrial Energy from Biofuels. Proceedings of the CIGR Inter-Sections Symposium. National Center for Agricultural Mechanization, Ilorin, Nigeria, pp. 129 – 140.
[5] Sotannde, O. A., Oluyege, A. O. and Abah, G. B. (2010). Physical and Combustion Properties of Briquettes from Sawdust of *Azadirachta indica*. *Journal of Forestry Research*, 21(1): 63 – 67.
[6] Martin, J. F., Pineda, R. M. A., Manaay, J. A., Handa, S. R. A. and Ocreto, A. B. (2008). Design and Development of Charcoal Briquetting Machine. *USM R & D* 16(2): 85 - 90.
[7] Mohamed, F. M., Ahmed, Y. M. Z. and Shalabi, M. E. H. (2004). Effect of Organic Binders on the Quality of Manganese Ore Sinter Fines Briquettes. *TESCE*, Vol. 30, No.2, pp. 871 – 889.
[8] Adekoya, L. O. (1998). Briquetting of Agricultural Wastes: A Preliminary Study. Proceedings of the CIGR Inter-Sections Symposium. National Center for Agricultural Mechanization, Ilorin, Nigeria, pp. 218 – 225.
[9] Olorunnisola, A. (2007). Production of Fuel Briquettes from Waste Paper and Coconut Husk Admixtures. Agricultural Engineering International: The *CIGR E journal*. Manuscript EE 06 006. Vol. IX. February.
[10] Oladeji1, J. T. and Enweremadu, C. C. (2012). The Effects of Some Processing Parameters on Physical and Densification Characteristics of Corncob Briquettes. *International Journal of Energy Engineering*, 2(1): 22-27.
[11] Adapa, P., Tabil, L. and Schoenau, G. (2009). Compaction Characteristics of Barley, Canola, Oat and Wheat Straw, *Biosystems Engineering* (1 - 10).
[12] Suparin, C., Suwit, S. and Prattana, K. (2008). Development of Fuel Briquettes from Biomass-Lignite Blends. *Chiang. Mai. J. Sci*., 35(1): 43 – 50.
[13] Sah, P., Singh, B. and Agrawal, U. (1980). Compaction Behavior of Straw. *Journal of Agricultural Engineering-India*, 18(1), pp. 89 - 96.
[14] Khankari, K. K., Shrivastava, M. and Morey, R. V. (1989). Densification Characteristics of Rice Husk. *ASAE Paper* No. 89-6093. St. Joseph, MI: ASABE.
[15] Richards, S. R. (1990). Physical Testing of Fuel Briquettes, *Fuel Processing Technology*, 25: 89 - 100.
[16] ASTM Standard E711-87 (2004). Standard Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter. *Annual Book of ASTM Standards*, 11.04. ASTM International.
[17] Bailey, R.T. and Blankenhorn, P. R. (1982). Calorific and Porosity Development in Carbonized Wood. *Wood Science*, 15(1): 19 − 28.
[18] Ivanov, I. P., Sudakova, I. G., and Kuznetsovv, B. (2003). Manufacture of Briquetted and Granulated Fuels from Lignite with Bio-Binders and Heated Die. Chem. *Sustai. Devel.*, 11, 847 - 852.
[19] Wilaipon, P. (2008). Density Equation of Bio-coal Briquettes and Quantity of Maize Cob in Phitsanulok, Thailand. *Am. J. App. Sci*., 5(12): 1808−1811.
[20] Wilaipon, P. (2007). Physical Characteristics of Maize Cob Briquette under Moderate Die Pressure. *Am. J. Appl. Sci*., 4, 995-998.
[21] Musa, N. A. (2007). Comparative Fuel Characterization of Rice Husk and Groundnut Shell Briquettes. NJRED. 6(4): 245-262.

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