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Assessment of the physical and combustion properties of briquettes produced from banana tree waste

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Abstract

Biomass is by far the most important primary energy source in Nepal. Heavy dependence on traditional source and waste management resulting from agricultural waste is one of the major problem in our country. Briquetting from agricultural waste can be an option for resource management. This study was undertaken to investigate the physical and combustion properties of briquettes produced from dried banana tree waste (leaves + pseudostem). Altogether four types of briquettes were produced, two from uncharred biomass using screw extruder and hydraulic jack briquetting machine and other two briquettes were produced from charred biomass/charcoal using screw extruder and beehive briquetting machine. For uncharred briquette, the density of screw extruder briquette (1.06 g/cm^3) was higher than hydraulic briquette (0.33 g/cm^3). For charred briquette, the density was higher (0.72 g/cm^3) for screw extruder than beehive briquette (0.44 g/cm^3). The Moisture content of briquettes varied from 7.23% to 11.04%, Volatile matter varied from 11% to 68.74%, Ash content varied from 4.94% to 49.43% and fixed carbon content varied from 15.27% to 32.34%. The calorific values of the briquettes ranged from 2462.0827 kcal/kg - 3899.193 kcal/kg, while the thermal efficiency ranges between 24.02% – 30.71%, other results shows that the average burning rate between 3.55 g/min and 6.41 g/min. Screw extruder briquette from uncharred Banana tree waste and beehive from charred/carbonized banana tree waste biomass was found to be comparatively better from the present study.

1. Introduction

The word briquette is derived from French word brique, meaning brick. The process of converting low bulk density biomass into high density and energy concentrated fuel briquettes is termed as briquetting. Briquette can be made from charcoal together with binder. In this briquetting technology, loose biomass or charcoal powder is densified or turned into a solid form of particular shape and size by the use of pressure, heat and/or binding material [1]. The blackish residue consisting of impure carbon which is obtained by removing water and other volatile constituents from animal and vegetable substances is known as charcoal. It is usually produced by slow pyrolysis i.e. heating of wood, bone char or other agricultural substances in the absence of oxygen environment at 450°C - 510°C by using either in a kiln or a continuously fed furnace [2].

According to statistics, three billion people – or more than 40 per cent of the world's population – do not have access to clean cooking fuels and technologies. The situation of energy use in terms of cooking is not promising in Nepal. According to the most recent statistics of the Central Bureau of Statistics, percentage of total households which relies on firewood for cooking is 64 percent. Cow dung and animal waste for cooking are still used by people. There were 74.7 per cent of households using solid fuels for cooking in 2015. Household air pollution from burning biomass for cooking and heating is responsible for some four million deaths a year, with women and children at the greatest risk. The solid fuels comprise mainly firewood, animal waste and agriculture

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residues [3].

In Nepal, banana is being grown since time immemorial for home consumption. Banana being a prioritized high-value agricultural product and a major fruit in Nepal in terms of the potential growing area, production and domestic consumption, is currently grown in 68 districts with total productive area of 14311 hectares and production of 234319 tones and productivity 13.2 tonnes per hectare [4]. The waste that a single banana plant produces can make up to 80% of the total plant mass [5].

The study on the use of agricultural and agro-industrial wastes as biomass is being increased and it could be an alternative solution to the problems related to them [6]. But due to some factors of biomass like high moisture content, irregular shape and sizes , low bulk density, the biomass are very difficult to handle, transport, store and utilize in its original form. Densification process can produce briquettes of uniform shape and sizes that can be more easily handled [7].

In this work, the physical and combustion properties of both uncharred/brown as well as charred/black briquettes made from banana tree waste (Leaves + pseudostem) using different briquetting technology i.e. High, medium and low compaction technology were determined. Clay and paper were used as binder. Clay is used as binder as it has high chemical stability, low expansion coefficient, high hardness and strong layers [8].

2. Material and methods

2.1. Preparation of raw material

The banana tree waste (i.e. leaves + pseudostem) was collected from Tribhuvan University professor quarter, nayabato. The pseudostem and leaves were obtained only from plants that had been cut for obtaining fruit. The raw material collected were chopped into small pieces, spread and dried using direct sunlight until it was completely dried so as to reduce the moisture content. Some of the sun dried biomass was ground into powder form using hammer mill and then disc mill to make brown briquettes and the rest was used to make charcoal using charring drum. After the carbonization process, the charring drum was allowed to cool to atmosphere for 1 day. Then the bio char / Charcoal was removed from the drum and ground into very fine particles and was also measured to calculate the percent yield. The charcoal was also grinded using disk mill. In this study, both uncharred/brown and charred/black briquettes were produced. Altogether, four types of briquettes were produced. Two types of brown briquettes were produced i.e. under high pressure using screw extruder without using any any binder with 300°C die temperature and under medium compaction technology using Hydraulic press briquetting machine machine having 10 ton capacity bottle type hydraulic jack (using 30% paper binder). Produced brown briquettes are shown in Figure 1 & 2.

Figure 1: Screw extruder briquette S1

Figure 2: Hydraulic briquette

Similarly, two black briquettes were produced from charcoal under high pressure using screw extruder briquetting machine and under low compaction technology i.e beehive briquette. Both were produced using 30% clay as binder. Produced brown briquettes are shown in Figure 3 & 4.

2.2. Experimental analysis

2.2.1. Physical properties

Determination of density

Density of briquettes were calculated using Eq. 1.

$$\text{Density} = \frac{\text{Mass of briquitte (gm)}}{\text{Volume of briquette (cm)}^3} \quad (1)$$

Figure 3: Screw extruder briquette S2

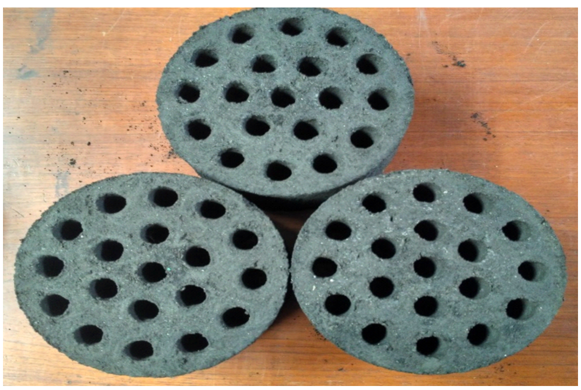

Figure 4: Beehive briquette

Percentage moisture content (% MC)
Percentage of moisture content calculation was carried out following the procedures of the Japanese Industrial Standard (JIS, 8812) as in Eq. 2.

$$\% \text{ MC} = \frac{\text{LoWoST}}{\text{WoST}} \times 100\% \tag{2}$$

Where,

LoWoST : Loss on weight of sample taken in gm

WoST : Weight of sample taken in gm

2.2.2. Combustion properties

Calculation for volatile matter content, ash content and fixed carbon content were carried out following the procedures of the Japanese Industrial Standard (JIS, 8812).

Percentage volatile matter (% VM)

$$\% \text{ VM} = \frac{\text{LoWoST} \times \text{MCotS}}{\text{WoST}} \times 100\% \tag{3}$$

Where,

LoWoST : Loss on weight of sample taken in gm

MCotS : Moisture content of the sample in gm

WoST : Weight of sample taken in gm

Percentage ash content (% AC)

$$\% \text{ AC} = \frac{\text{QoA}}{\text{WoST}} \times 100\% \tag{4}$$

Where,

QoA : Quantity of ash in gm

WoST : Weight of sample taken in gm

Percentage fixed carbon (% FC)

$$\% \text{ FC} = 100\% - (\%MC + \%VC + \%AC) \tag{5}$$

Calorific value (CV)
Calorific value of different biomass and fuel samples were determined according to British Standard Institution BS 1016 using the Toshniwal digital bomb colorimeter interfaced with a computer.

Water boiling test
Water boiling test was conducted as per the standard described by Aprovecho (Water boiling test version 4.2.4) using Agni stove. This test was carried out to compare the cooking efficiencies of fuel samples. During this test, fuel characteristics like thermal efficiency, ignition time and burning rate was calculated.

The conversion of energy in the fuel to heat energy is termed as thermal efficiency [9].

The thermal efficiency η was calculated using Eq. 6

$$\eta = \frac{M_w \times C_p \times (T_b - T_o) + M_c \times L}{M_f \times CV} \times 100\% \tag{6}$$

Where,

M_w : Mass of water to be boiled (kg)

C_p : Specific heat of water (kJ/kgK)

T_b : Local boiling point of water (K)

T_o : Initial Temperature of Water (K)

M_c : Mass of water evaporated (kg)

L : Latent heat of evaporation (kJ/kg)

M_f : Mass of fuel consumed (kg)

CV : Calorific value of fuel (kcal/kg)

Ignition time: The time taken by a known of fuel to ignite is termed as ignition time [9].

The rate at which specific mass of fuel is burned is termed as burning rate [9].

3. Result and discussions

3.1. Physical properties

3.1.1. Density

The Briquette produced using screw extruder technology of uncharred biomass have higher density of 1.06 gm/cm^3, whereas other briquettes have densities between 0.33 gm/cm^3 to 0.72 gm/cm^3. The density of screw extruder briquette S1 (1.06 gm/cm^3) was found to be higher than that of hydraulic briquette (0.33 gm/cm^3). In case of briquette from charred biomass/ black briquette, Screw extruder briquette S2 had higher density (0.72 gm/cm^3) as compared with beehive briquette (0.44 gm/cm^3). High density in screw extruder briquette from both uncharred and charred briquette is due to high compaction of mixture as it was made using tapered die screw extruder briquetting machine.

Higher density leads to higher energy-volume ratio which is desirable in terms of transportation, storage and handling [10].

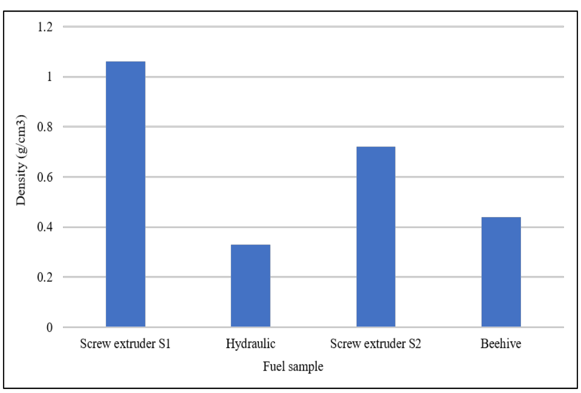

Figure 5: Density

3.1.2. Moisture content

The moisture content of banana tree waste biomass sample was found to be 11.07% which lies within the acceptable working range of 8 – 12% [11]. The moisture content obtained in the present study is lower than lantana camera (12.12%) [12] but higher than the value i.e. 8.41% for pine needles [13] and 6.8% for mikania micrantha [14].The moisture content of banana tree waste char (6.4%) was less than that of banana tree waste biomass. Reduction in moisture content of char is due to carbonization process.

In case of briquette from uncharred biomass/ brown briquette, the moisture content of screw extruder briquette

S1 (8.89%) is lower than that of briquette produced using hydraulic jack i.e. Hydraulic briquette (11.04%). This is because during screw extruder briquetting, biomass are processed under high temperature.

In case of briquette from charred biomass/ black briquette, the moisture content of beehive briquette (7.23%) is lower than that of screw extruder briquette S2 (10.33%).

Low moisture content of briquettes helps in their storage. It prevents the briquettes from rotting and decomposition [15].

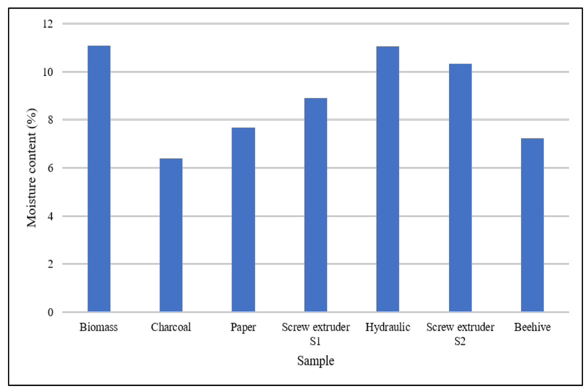

Figure 6: Moisture content

3.2. Combustion properties

3.2.1. Volatile matter content

The volatile matter content of different fuel samples varied from 11% to 68.74%. Volatile matter content of char (15.9%) was much lower as compared to biomass (67.5%). Paper has the highest volatile matter content (68.7%) than other biomass and fuel sample. Volatile matter consists of elements such as carbon, hydrogen and oxygen which are present in the biomass .Most of the biomass fuels have high volatile matter content [14].

Low volatile matter in char is because of the carbonization process. High volatile matter in hydraulic briquette (68.74%) as compared to screw extruder briquette S1 (65.56%) may be due to addition of paper as binder in hydraulic briquetting as paper had higher volatile matter as compared with biomass.

Higher volatile matter eases ignition and enhances combustion due to increased chemical reactivity [15]. Material with high volatility can be ignited easily, would burn with long smoky flames but will produce more smoke [16].

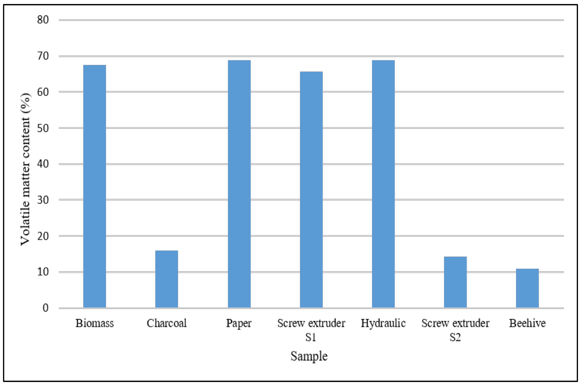

Figure 7: Volatile matter content

3.2.2. Ash content

Ash content of fuel samples varied from 4.94% to 49.43The ash content of Charcoal, Paper and biomass were 30.94%, 5.9% and 4.92% respectively. Ash content of banana waste (leaves and pseudostem) char was higher as compared to that of banana tree waste biomass. This implies that during carbonization, most of the ash in biomass remained in char. The tolerance level of ash content for fuel is below 4% [17]. The ash content of biomass obtained from present study is lower than Mikania. micrantha biomass (7.04%) [14] but higher than pine needles biomass (2.79%) [13].

In case of brown briquette, ash content of screw extruder briquette S1 (6.94%) was higher than that of hydraulic briquette (4.94%). In case of black briquette, ash content of beehive briquette (49.43%) was higher than that of screw extruder briquette S2 (48.3%). Higher ash content indicates more mineral matter present in fuel [13].

High ash is undesirable as it reduces handling and burning capacity and also affects the combustion efficiency [16].

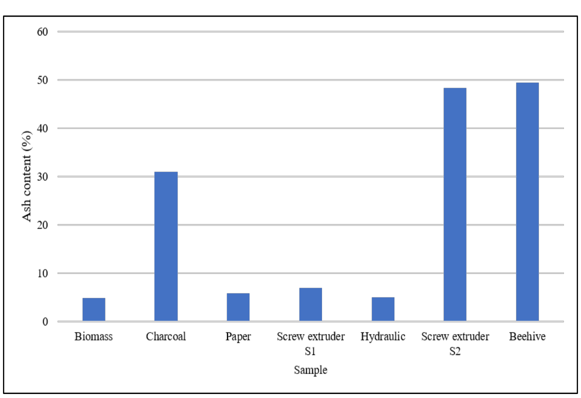

Figure 8: Ash concent

3.2.3. Fixed carbon content

The fixed carbon content of fuel samples varied from 15.27% to 32.34%. The highest fixed carbon content 46.77% was found to be in charcoal while paper had 17.65% and biomass had 16.51%. The fixed carbon content of biomass obtained from this present study is higher than Mikania micrantha biomass (11.26%) [14] but lower than pine needles (17.66%) [13].

Similarly, fixed carbon content of beehive briquette was found to be 32.34%, screw extruder briquette of charred biomass (S2) was found to be 27.09%, screw extruder briquette of uncharred biomass was found to be 18.62% and briquette produced using hydraulic jack was found to be 15.27%.

High fixed carbon is desirable as it increases the calorific value [16].

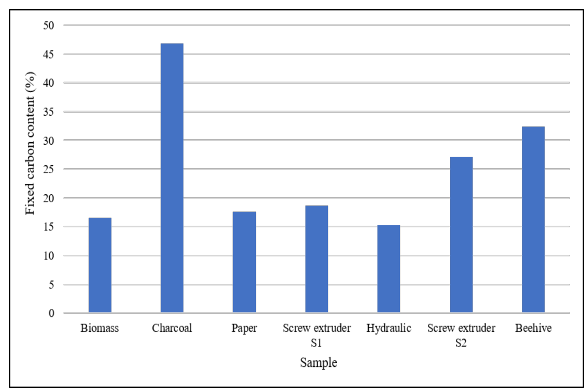

Figure 9: Fixed carbon content

3.2.4. Calorific value (CV)

CV of banana tree waste char (4677.14 kcal/kg) was higher than that of banana tree waste biomass (3605.76 kcal/kg).In this present experiments, the calorific value of banana tree waste biomass is higher than mikania micrantha biomass (3616 kcal/kg) [14]. High CV in char is due to low moisture content and high fixed carbon content. In case of brown briquette, the CV of screw extruder briquette S1 (3899.19 kcal/kg) was higher than that of hydraulic briquette (3729.26 kcal/kg). In case of black briquette, the CV of beehive briquette (3042.65 kcal/kg) was higher than that of screw extruder briquette S2 (2462.08 kcal/kg).

High CV in screw extruder briquette S1 from brown briquette and beehive briquette from black briquettes is due to low moisture content and high fixed carbon content. The quality of fuel depends upon the CV. Higher the CV, better the quality of fuel [16].

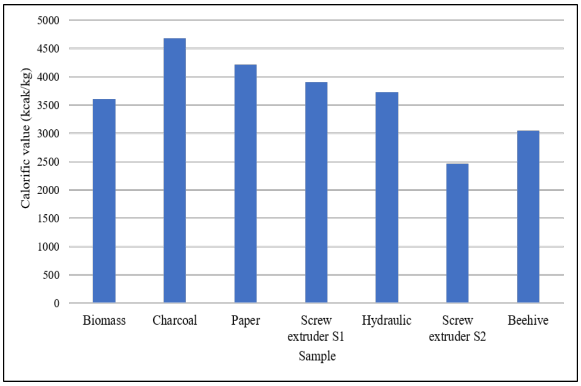

Figure 10: Calorific value

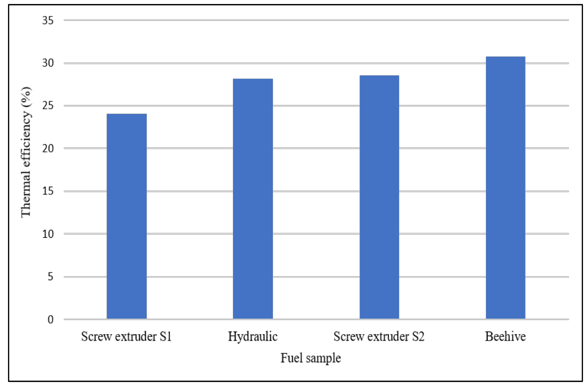

Figure 11: Thermal efficiency

3.2.5. Water boiling test

Water boiling test was conducted in this study to determine the ignition time, thermal efficiency of the stove and burning rate.

Ignition time

Ignition time of briquettes were recorded using stopwatch. Screw extruder briquette S1 took more time (10.33 min) to ignite as compared to hydraulic briquette (2.67min) in case of brown briquette. The low ignition time in hydraulic briquette is due to the presence of paper as binder during briquetting process. As paper, contains more volatile matter than banana waste biomass, it is easier to ignite. The increase in ignition time of screw extruder briquette S1 is due to increase in density which might have resulted in low porosity and hence reduced infiltration of oxygen. In the case of black briquette, screw extruder briquette S2 took more time (20min) to ignite as compared to beehive briquette (7min). Beehive briquette took less time to ignite as compared to screw extruder briquette S2 as it has low density, which might have resulted in high porosity increasing the infiltration of oxygen.

Thermal efficiency

The thermal efficiency of the stove using different fuel sample were obtained. The result showed that the thermal efficiency of hydraulic briquette was higher (28.12%) as compared to screw extruder briquette S1 (24.02%) in case of brown briquette.

In case of black briquette, the thermal efficiency of beehive briquette was higher (30.71%) as compared to screw extruder briquette S2 (28.57%).

Burning rate

Burning rate of screw extruder briquette S1 (3.55 g/min) was low as compared to hydraulic briquette (6.41 g/min) in case of brown briquette.

In case of black briquette, the burning rate of beehive and screw extruder briquette S2 was found to be similar. Briquettes having high burning rate indicate that more briquettes will be required in combustion as they burn off readily [9].

4. Conclusions

The conclusions drawn from this study are as follows:

i Briquette with high density (1.06 gm/cm^3) was prepared from screw extruder briquetting machine for uncharred biomass and from screw extruder briquetting (0.72 g/cm^3) for charred biomass

ii Moisture content from uncharred and charred briquette was found higher in hydraulic and screw extruder briquette S2 but was within the general range of 10 − 15%.

iii From uncharred briquette, high volatile matter was found in Hydraulic and from charred briquette high volatile matter was found in screw extruder briquette S2.

iv Screw extruder S1 from uncharred briquette and beehive briquette from charred briquette had higher ash content.

v High Fixed carbon from uncharred briquette was found in Screw extruder S1 and in beehive briquette from charred briquette. High Fixed carbon is desirable as it increases the CV. Higher the CV, better the quality of fuel.

vi The higher Calorific value recorded for uncharred and charred briquettes were 3899.19 kcal/kg and 3042.65 kcal/kg respectively.

vii High thermal efficiency was recorded for hydraulic (28.12%) and beehive briquette (30.71%) for uncharred and charred briquette respectively.

5. Recommendation

i Due to high amount of waste from BTW, there is a need for further research on the utilization of these waste.

ii Briquettes were produced using screw extruder, hydraulic jack and beehive briquetting machine, so production of briquettes using different briquetting technology and different binder with varying proportions can be done.

iii Energy efficiency of fuel samples was studied only in Agni stove. Further testing of fuel samples with different kinds of stove is necessary as Agni stove is designed especially for beehive briquette.

iv Researches on the emissions can be done.

v In order to ensure faster ignition and complete combustion of briquettes, hole should be created in briquettes.

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References

[1] Shrestha K R. Study on Feasibility and Market Identification of Densified Biomass Briquettes[R]. Kathmandu, Nepal: Alternative Energy Promotion Center (AEPC), 2014.

[2] Seshadri S P, S. Biomass Charcoal Briquetting Technology For Alternative Energy Based Income Generation In Rural Areas[R]. 2010.

[3] Adhikari D. Fuel for thought: Cooking energy options[M/OL]// The Himalayan Times, International Media Network Nepal (Pvt) Ltd. Kathmandu, Nepal, 2018. https://thehimalayantimes.com/opinion/fuel-for-thought-cooking-energy-options.

[4] S. Ghimire B K. Economic analysis of commercial banana cultivation[R]. Food Security through Agriculture & Allied Sciences, 2019.

[5] Padam B S, Tin H S, Chye F Y, et al. Banana by-products: an under-utilized renewable food biomass with great potential[J/OL]. Journal of Food Science and Technology, 2014, 51 (12): 3527-3545. DOI: https://doi.org/10.1007/s13197-012-0861-2.

[6] Fernandes E R K, Marangoni C, Souza O, et al. Thermochemical characterization of banana leaves as a potential energy source[J/OL]. Energy Conversion and Management, 2013, 75: 603-608. DOI: https://doi.org/10.1016/j.enconman.2013.08.008.

[7] Karunanithy C, Wang Y, Muthukumarappan K, et al. Physiochemical Characterization of Briquettes Made from Different Feedstocks[J/OL]. Biotechnology Research International, 2012, 2012: 1-12. DOI: https://doi.org/10.1155/2012/165202.

[8] Mopoung S, Sriprang N, Namahoot J. Sintered filter materials with controlled porosity for water purification prepared from mixtures with optimal ratio of zeolite, bentonite, kaolinite, and charcoal[J/OL]. Applied Clay Science, 2014, 88-89: 123-128. DOI: https://doi.org/10.1016/j.clay.2013.11.035.

[9] Onukak I E, Mohammed-Dabo I A, Ameh A O, et al. Production and characterization of biomass briquettes from tannery solid waste[J/OL]. Recycling, 2017, 2(4). DOI: https://doi.org/10.3390/recycling2040017.

[10] Kaur A, Roy M, Kundu K. Densification of Biomass By Briquetting: a Review[J/OL]. International Journal of Recent Scientific Research, 2017, 8(10): 20561-20568. DOI: http://doi.org/10.24327/ijrsr.2017.0810.0916.

[11] Eriksson S, Prior M. The briquetting of agricultural wastes for fuel.: 11[R]// Environment and energy paper. Rome, Italy: FAO, 1990: 131.

[12] Pandey S, Regmi C. Analysis and Test of Biomass Briquette and Stoves[J/OL]. Nepal Journal of Science and Technology, 2013, 14(1): 115-120. DOI: https://doi.org/10.3126/njst.v14i1.8931.

[13] Baral A R, Shrestha K R. Properties of briquettes and pellets of pine needles from Hattiban Community Forest, Kathmandu, Nepal[J/OL]. Nepal Journal of Environmental Science, 2018, 6: 1-8. DOI: https://doi.org/10.3126/njes.v6i0.30115.

[14] Singh R M, Poudel M S. Briquette Fuel - An Option for Management of Mikania micrantha[J/OL]. Nepal Journal of Science and Technology, 2013, 14(1): 109-114. DOI: https://doi.org/10.3126/njst.v14i1.8930.

[15] Kakooza A W. Appraisal of Food Residue (Waste) Based Fuel Briquettes in Domestic Cooking Applications: a Case Study of Uganda[D]. 2017.

[16] Oyelaran O A, Olorunfemi B J, Sanusi O M, et al. Investigating the Performance and Combustion Characteristics of Composite Bio-coal Briquette[J]. Journal of Materials and Engineering Structures, 2018, 5: 173-184.

[17] Grover P D, Mishra S K. Biomass Briquetting: Technology and Practices: 46[R]// Regional Wood Energy Development Programme in Asia. Bangkok: FAO Regional Wood Energy Development Programme in Asia, 1996: 1-48.