Proceedings of IOE Graduate Conference, 2016
pp. 57–63

Effects of Binder and Charcoal Particle Size on the Physical and Thermal Properties of Beehive Briquettes

Pushkar Bhattarai [1], Ramchandra Sapkota [2], Rudra Mani Ghimire [3]

[2,3] *Department of Mechanical Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal*
Corresponding Emails: [1] pushkarioe@gmail.com, [2] rc.sapkota1@gmail.com, [3] rghimire@ioe.edu.np

Abstract

Beehive briquetting technology is already well known technology for compaction of loose biomass char into more dense form. Rural population of Nepal is still using biomass as source of energy in in-efficient way. This thesis is intended to study the effect of binders' selection and charcoal particle sizes on physical and thermal properties of beehive type of briquette. The physical and thermal properties of beehive briquettes were studied varying the four grades of charcoal particle sizes and three types of binder. The particle sizes were 0.425mm, 0.6mm, 1.18mm and 1.7mm. Three types of binder were clay, wheat flour and cow dung. Compressive strength, moisture content, ash content, calorific value and total burning period were test for each sample.

Strength was maximum for briquettes made from wheat flour as binder. Compressive strength was decreased with increase in charcoal particle size. Maximum value of compressive strength was 289.06 Kpa for wheat flour and minimum value was 92.34 Kpa for clay as binder. Moisture content was found maximum for clay and minimum for wheat flour as binder. Ash content was minimum value for wheat flour and maximum for clay as binder. Ash content was increased with increase in charcoal particle size. Since, charcoal was same for all types of briquettes, there was small difference in calorific values according to variation of charcoal particle size. Range of calorific values for all samples was 3600 Kcal/kg to 6000 Kcal/kg. Calorific value was maximum for wheat flour as binder whose values were in the range of 5616.42 Kcal/kg to 5922.52 Kcal/kg. Total burning period was ranged from 80 to 110 minutes and burning rate increased with decrease in charcoal particle size.

Keywords

Briquette – Binder – Particle Size – Strength – Moisture – Ash – Calorific Value – Burning Period

Introduction

Nepal relies mainly on traditional sources of fuel for cooking, heating and livestock feeding [1]. Heavy dependence on traditional sources of energy such as fuel wood, animal dung and agro-forest residues causes deforestation, soil erosion, floods, climate change and global warming. Among many alternatives, briquetting of waste or residual biomass to produce Bio briquettes is one reliable option. The major sources of renewable energy are hydropower, solar energy, various forms of biomass energy, biogas and wind energy etc. [2].

In Nepal rural people have been using manually made traditional animal dung briquettes for cooking since time immemorial. Animal dung particularly, cow and buffalo dung as binder, is mixed with fillers such as straw, jute sticks and other biomass materials to produce guitha - traditional low pressure bio-briquettes. Such low pressure fuel briquettes are quite common in Asian and African countries. These low pressure briquettes, made from locally available materials are cheap and popular, but produce a lot of smoke and indoor air pollution. Traditional dung briquettes and loose biomass during combustion are inefficient and polluting; hence improving fuel efficiency and quality through briquetting is the key technological intervention [1].

There are many types of briquetting technology on the basis of structure, size, compaction rate and type of material used. There are some important parameters that will effect on the performance, durability of any type of briquette. The major parameters are thermal properties of a briquette [3]. Among them, moisture content, ash content, calorific value, combustion rate are important properties that affect the performance of briquette in terms of changing the bio energy into useful heat energy. Another important physical parameter that affects in briquetting is size of particles that is used to make compact biomass, the briquette. For easy and safe transportation of briquette, the binding of it should be rigid as much as possible. The size of particle in feedstock material for it affects in great extent. Also, that varies according to the type of biomass used. The major biomass used for compaction of it is wood charcoal, saw dust, rice husk etc.[4].

The biomass is being used in inefficient way. There are many practices in biomass briquette technology. Also, biomass can be converted into three main products such as energy, biofuels and fine chemicals using a number of different processes. So, the important parameters such as biomass processing, technology, impact of energy production and efficient use of biomass should be considerd [5].

The locally available binders differ from place to place. The cost of these binders is also different. But, the performance of type of binder selected affects in the properties of the briquette. The mainly used binder is Clay. But, we can use binders like waste wheat flour, cow dung and other locally available chemicals. The suitable type of binder helps in maintaining good strength of briquette during transportation. The charcoal particle size can be graded and see their performance for respective binders. Hence, this paper focuses on how charcoal particle and type of binder affects briquetting.

1. Materials and Methods

1.1 Raw Material Procurement

Banmara charcoal was used for briquette preparation.

Figure 1: Four grades of charcoal after sieving

Three binders viz: waste wheat flour, cow dung and clay were used. Binders were collected locally and charcoal was brought form Himilayan Natural Pvt. Ltd, Bhaktapur. The charcoal was dried in sun and crushed manually by wood hammer. The crushed samples were sieved into four sizes (0.425mm, 0.6mm, 1.18mm and 1.7mm).

1.2 Briquette Preparation

Binders were mixed with water and solution was made with it. That solution was mixed thoroughly with charcoal. The semiautomatic beehive briquette machine was used for binding charcoal into briquette for each sample as shown in figure 2. The mixture of charcoal and binder was put into cylinder of briquetting machine and pressure was applied form die. All together there were 24 briquettes (three binders and four grades of charcoal for each binder). The briquettes were sun dried and they were ready for testing of physical and thermal properties. The compaction was easy for charcoal with particle size of smallest size. As the charcoal particle size was increased, the mixing of binders and compaction became more difficult. With upper handle, position of die was matched with cylinder and foot press was used to compress mixture of charcoal and binder to form required shape of briquette.

Figure 2: Briquetting machine with beehive briquettes

1.3 Moisture Content Test

The procedure followed by Tokan et al., 2014 was used. The weighed briquettes were put into hot air oven. The temperature was set for 100^0C to 110^0C and samples were left for 24 hours. The moisture content of each sample can be expresses as a percentage of its dry mass and can be computed using following equation:

$$Moisture(\%) = \frac{w_2 - w_3}{w_2 - w_1} \text{ x } 100\% \tag{1}$$

Where, w_1 = mass of empty container, w_2 = mass of container and wet sample and w_3 = mass of container and drying sample (after heating)

1.4 Ash Content Test

The procedure as in the ASTMD-3174 was followed. The weighted samples were heated up to 750^0C in furnace for half an hour. The samples were first cooled in air, and then in desiccator. Each sample's ash was measured. The ash content was calculated using following equation:

$$Ash(\%) = \frac{w_4 - w_1}{w_2 - w_1} \text{ x } 100\% \tag{2}$$

Where, w_1 = mass of empty container, w_2 = mass of container and wet sample and w_4 = weight of the sample after heating in muffle furnace

1.5 Calorific Value Test

Calorific values of each sample were tested using bomb calorimeter except the briquettes with largest charcoal particle size because it was avoided due to low strength i.e. low durability. Three samples were taken from each briquettes and average was taken. Calorific Value was determined by following IP-12 corresponding to 1359-1959 standard method, using calibrated Toshniwal Digital Bomb Calorimeter. The calorific value was tested in a company (Center for Energy and Environment, CEEN, Bhotebahal, Kathmandu). The software was used which includes the two inputs; weighted mass of the sample and initial temperature of the water inside the calorimeter. The software automatically showed the calorific value for each samples.

1.6 Compressive Strength Test

Compressive strength of briquettes was tested using manual compressive strength testing machine in soil laboratory,civil department, Pulchok Campus, Lalitpur, Nepal. Two samples were taken for each type of briquettes and average was taken.

1.7 Burning Peroid Calculation

For each type of briquettes, total burning period was measured. Two samples of each type were burned in a beehive briquette stove and average time period was taken. The standard stove was bought from Center for Energy and Environment (CEEN), Bhotebahal, Kathmandu.

2. Results and Discussion

2.1 Results of Moisture Content Test

Figure 3 and Table 1 shows moisture content of each type of briquettes.

Table 1: Moisture content of all briquettes

S.N.	Binder	Particle Size (mm)	Moisture content (%)
1.	Clay	0.425	14.53
		0.6	14.66
		1.18	13.95
		1.7	13.71
2.	Wheat Flour	0.425	7.67
		0.6	6.95
		1.18	7.07
		1.7	6.60
3.	Cow Dung	0.425	10.47
		0.6	8.33
		1.18	9.39
		1.7	9.54

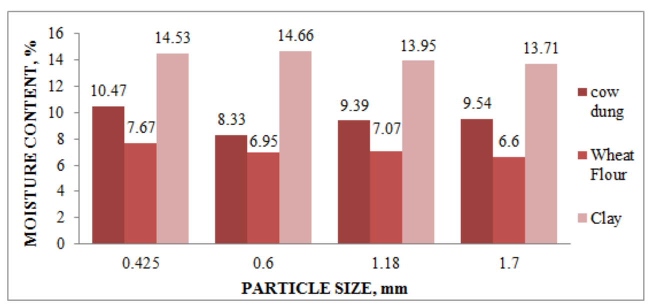

Figure 3: Plot of particle size versus moisture content of briquettes

Moisture content was found maximum for the briquettes using clay as binder. The range of moisture content for these types of briquettes was ranging from 13.71 to

14.53%. The second position was gained by briquettes made form cow dung as binder. The range of moisture content for these types of briquettes was ranging from 8.33 to 10.47%. The lowest moisture content was found in briquettes made form waste wheat flour which ranges from 6.60 to 7.67%. For all the samples, the moisture content was in satisfactory range. But, briquettes with wheat flour as binders had lowest moisture content. Moisture content lowers the calorific value of the fuel. Hence, lower value of moisture content is acceptable for maximum conversion of fuel into heating value. The variation in the moisture content is due to the type of binders used. Different binders contain different levels of moisture content.Generally for the best performance, the range of moisture content should be between 10-15% percent of moisture as discovered during the moisture test. Moisture content of a briquette can be as low as 4 percent. Similar results were discovered by Tokan et al., 2014 [6] and D. Huko et al.,2014 [7]. The range of moisture content for Tokan et al., 2014 was 10 to 17.65%.

2.2 Results of Ash Content Test

Figure 4 and Table 2 shows variation of ash content with variation of charcoal particle sizes for all types of briquettes. Ash content was of highest value for briquettes for binder as clay. Following clay, briquettes with cow dung was of in second position and lowest ash content was found in briquettes with waste wheat flour as binder.

Table 2: Ash content of all briquettes

S.N.	Binder	Particle Size (mm)	Ash content(%)
1.	Clay	0.425	39.87
		0.6	25.67
		1.18	32.23
		1.7	18.40
2.	Wheat Flour	0.425	13.00
		0.6	9.28
		1.18	5.73
		1.7	9.89
3.	Cow Dung	0.425	17.90
		0.6	10.33
		1.18	10.47
		1.7	14.00

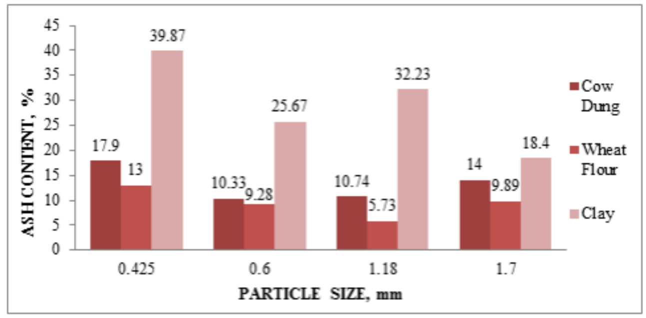

Figure 4: Plot of particle size versus ash content of briquettes

Ash content of briquettes with clay as binder was ranged from 18.40 to 39.87%. Similarly for briquettes with cow dung, ash content was ranged from 10.33 to 17.90%. The lowest values were obtained for briquettes with wheat flour as binder which was ranged from 5.73 to 13.00%.

For each type of briquettes, if we see the variation with particle size, the ash content increased as particle size decreased. Particle size of 0.425 had maximum ash content percentage and highest particle size (1.7 mm) had lowest ash content percentage. It is due to the fact that small particle sizes are less coarse, compact easily leading to the incomplete combustion due to small number of pore spaces available. Similar results were described by Tokan et al., 2014 [6]. The range of ash content form Tokan et al., 2014 experiment was 7.69 to 45.45%. Also ash content for specific beehive briquette was 32.1% (Shrestha, 2009) [8]. Larger particles which were the most difficult to compact were more loosely bonded that allows the adequate amount of oxygen to flow so that the combustion was complete resulting in lower value of ash content. Lower values of ash content are desired. Variation of ash content among the types of binder is due to the property and nature of individual binders.

2.3 Results of Calorific Value Test

Figure 5 and Table 3 shows variation in calorific valus of briquettes with change in charcoal particle sizes. Among binders, briquettes using wheat flour as binder had highest calorific value and second highest value was found briquettes using cow dung as binder. The highest value of calorific value of briquettes is due to the reason that there was lowest ash content and moisture content. Also, the wheat adds calorific value to the charcoal. The briquettes with clay as binders were of lowest calorific value among 3 different binders. It is because of higher moisture content and higher ash content values of the sample. Form the figure 4 we also observed that the calorific value increases in small amount with increase in charcoal particle size. Similar results were obtained by Tokan et al., 2014 [6]. During that research also, calorific value was increased with increase in charcoal particle size. The reason behind it was the ash content was highest for briquettes with smaller particle size and the closely packed small charcoal particles limit the flow of oxygen and hence results in decrease in overall calorific value of briquette.

Table 3: Calorific value of all briquettes

S.N.	Binder	Particle Size (mm)	Calorific Value (Kcal/kg)
1.	Clay	0.425	3668.86
		0.6	4405.93
		1.18	3806.44
2.	Wheat Flour	0.425	5616.42
		0.6	5917.62
		1.18	5922.42
3.	Cow Dung	0.425	4972.81
		0.6	5601.73
		1.18	5696.40

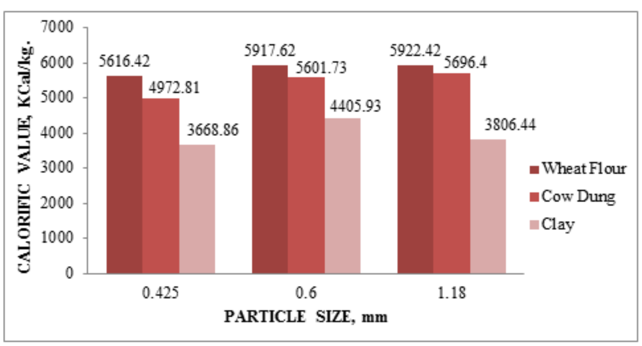

Figure 5: Plot of particle size versus calorific value of briquettes

For all samples, increase in charcoal particle size resulted in increase in calorific values of briquettes in small amount. But calorific value for the briquettes made form clay was lower than average value. It may be due to the formation of clinker while burning inside the bomb. For clay as binder of particle size 1.18, calorific value decreased as compared to other two lower sizes. It was due to the formation of higher percentage of clinker inside the bomb compared with other samples and was responsible for calorific value reduction. The range of calorific value for all samples ranged from 3800 Kcal/kg to 6000 Kcal/kg.

2.4 Results of Compressive Strength Test

Figure 6 and Table 4 shows variation in compressive strength of briquettes with alteration in charcoal particle sizes.

Table 4: Compressive strength of all briquettes

S.N.	Binder	Particle Size(mm)	Compressive Strength(KPa)
1.	Clay	0.425	172.63
		0.6	153.50
		1.18	150.69
		1.7	92.34
2.	Wheat Flour	0.425	282.64
		0.6	251.05
		1.18	246.91
		1.7	289.06
3.	Cow Dung	0.425	232.85
		0.6	182.40
		1.18	120.44
		1.7	116.56

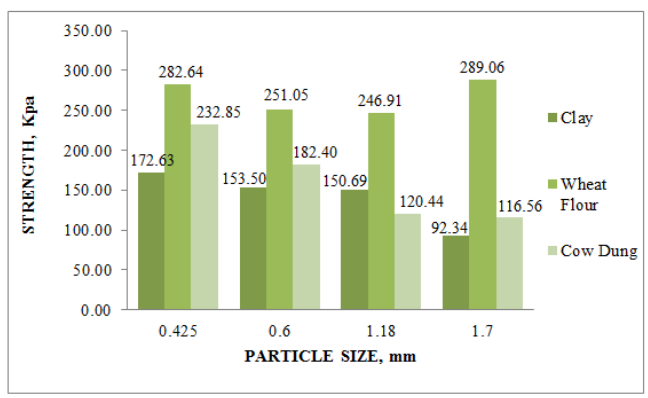

Figure 6: Plot of particle size versus compressive strength of briquettes

Compressive strength was highest for briquettes made form wheat flour as binder. Briquettes made form cow dung as binder were in second position and briquettes made form clay were in third position. But, the strength was almost similar for clay and cow dung as binder. The maximum strength for wheat flour is due to its good binding property. Similarly, there was significant effect on strength of briquettes with variation of both particle size and type of binder used. But, for wheat flour as binder, briquettes have almost equal strengths. They have higher strength among all binders. If we see the strengths among the particle sizes; compressive strength was decreased when the particle size was increased. Similar results were explained by D.P. Patil, 2009 [9] and Stephen J Mitchual et al., 2013 [10] where strength was decreased when charcoal particle size was increaesed. Very large size of particle has porous structure and it is very difficult to compress. Even the binding material cannot be mixed thoroughly. Hence, briquettes with higher particle size will be of low load bearing capacity. If any briquette has low compressive strength value, there will be the chance of breaking of briquette and loss of fuel. This ultimately bears higher cost. Hence, we shouldn't select too coarse particle size for preparation of briquette form charcoal.

2.5 Results of burning period

Figure 7 and Table 5 below shows the total burning period for each briquette. There was variation in burning period of each period while varying particle size as well as binder.

Table 5: Result of burning period of briquettes after burning

S.N.	Binder	Particle Size (mm)	Burning Period (Minutes)
1.	Clay	0.425	110
		0.6	103
		1.18	95
		1.7	84
2.	Wheat Flour	0.425	105
		0.6	94
		1.18	87
		1.7	80
3.	Cow Dung	0.425	108
		0.6	101
		1.18	93
		1.7	82

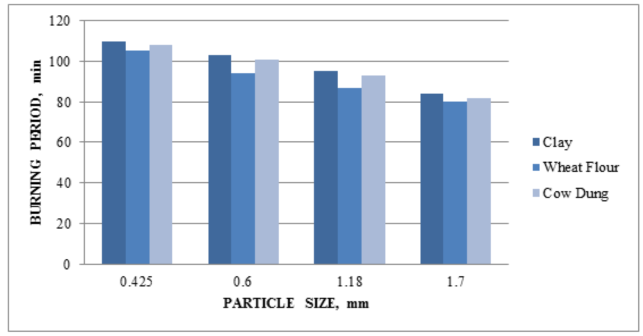

Figure 7: Plot of total burning periods of each briquette

The total burning period was ranged from 80 to 110 minutes. Burning period decreased when increase in charcoal particle size. Similar results were explained by H. Saptoadi, 2007 [11]. The reason behind the decrease in burning period is: smaller the charcoal particle size, higher will be the density and lesser will be the porosity. Higher particle sizes were burned in faster rate and penetration of flame was faster in case of briquettes made form larger particle size. Burning period depends on density of the briquettes. Higher the density of briquette, more compact will be the particles. Here also, the briquettes made from smaller particle sizes were of denser than other higher sizes. Hence, time period was in highest value for lower size of charcoal.

3. Conclusion

Following conculsions are made form this research:

- Briquettes made form wheat flour as binders had lowest moisture content with range of 6.60 to 7.67% and maximum for briquettes made form clay as binder with range of 13.11 to 14.66%. Particle size had no significant effect on the moisture content of the all types of briquettes.
- Ash content of briquettes with waste wheat flour as binder was found lowest with the range of 5.73 to 13% and highest values were of briquettes with clay as binder with the range of 18.40 to 39.87%. There was significant effect on ash content of samples with variation of particle size. The ash content was decreased with increase in charcoal particle size.
- Calorific value was found maximum for briquettes with binder as waste wheat flour whose

calorific value was 5922.42 Kcal/kg for all briquettes, range of calorific value was 3668.86 Kcal/kg to 5922.42 Kcal/kg. For all samples, increase in charcoal particle size resulted in increase in calorific values of briquettes in small amount.
- The briquettes obtained from waste wheat flour as binder were of highest strength. Highest value of strength was 289.06 Kpa for wheat flour as binder and lowest value was 92.34 KPa for clay. Strength of other briquettes was in satisfactory range. But the strength of briquettes was decreased with increase in charcoal particle size.
- Total burning period of briquettes ranged from 110 to 80 minutes. Burning period decreased with increase in charcoal particle size.

Recommendations

Following recommendations are suggested for further research and study in the field of briquetting technology during this research:

- The variation in amount of binders and its effect on the performance of briquette can be studied. But careful attention is required to the amount that should not exceed the optimum ratio of fuel to binder.
- The research can be done with the use of other environment friendly binders. One of the possible binders may be molasses.
- During the testing of samples, it is recommended that the samples shouldn't test in longer interval. That changes the physical and thermal properties of briquettes.
- Effect of binders and particle size can be studied with variation of type of charcoal. The charcoal may be of agricultural waste, municipal waste.
- Researcher should study the quality of binder and correct method for thorough mixing of binders with charcoal.

References

[1] Ramesh Man Singh. *Bio briquetting In Nepal - Scope and Potentials*. 2013.

[2] MoSTE. *Nepal Interim Benchmark for solid biomass Cook stoves (NIBC)*. Government of Nepal, Alternative Energy Promotion Center, 2014.

[3] P.D. Grover and S.K. Mishra. *Biomass Briquetting: Technologies and Practices*. Food and Aagriculture Organization of The United Nations, Bangkok, 1996.

[4] Ishmael Nartey Amanor. *Design, Construction and Testing of a Briquetting Machine*. 2014.

[5] Chinnappan Baskar, Shikha Baskar, and Ranjit S Dhillon. *Biomass conversion: The interface of biotechnology, chemistry and materials science*. Springer Science & Business Media, 2012.

[6] A. Tokan, A.S. Sambo, J.S. Jatau, and Kyauta. *Effects of Particle Size on the Thermal Properties of Sawdust, Corncobs and Prosopis Africana Charcoal Briquettes*. 2014.

[7] D. Huko, D.N. Kamau, and W.O. Ogola. *Effects of Varying Particle Size on Mechanical and Combustion Characteristics of Mango Seed Shell Cashew Nut Shell Composite Briquettes*. 2014.

[8] Krishna Raj Shrestha. *Beehive Briquette - A Reliable Alternative Fuel*. 2009.

[9] DP Patil. *Briquetting of Coal Fines and Sawdust – Effect of Particle-Size Distribution*. 2009.

[10] S. J Mitchual, K. Frimpong-Mensah, and N. A Darkwa. *Briquetting of Coal Fines and Sawdust – Effect of Particle-Size Distribution*. 2013.

[11] Saptoadi. *The Best Biobriquette Dimension and its Particle Size*. 2007.