Research Article

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PRODUCTION AND CHARACTERIZATION OF FUEL BRIQUETTES AS ALTERNATIVE ENERGY SOURCE

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Abstract

The aim of this research was the production and characterization of fuel briquettes from waste paper, saw dust and hybrid binder. Searching for alternative energy suggests that in Ethiopia, electrical coverage is limited. On the other hand, tons of wastes are disposed as solid waste. In this work, availability and combustion properties of the raw materials have been studied. To conduct experiments, raw materials mix proportions were prepared using Taguchi's $L_9(3^4)$ design. Sample briquettes were produced by a manually operated machine. Furthermore the, briquettes were characterized for combustion and physical properties. The highest calorific value, 3898.57 Kcal/Kg, was recorded from ratio of 65:15:20:15 waste paper, sawdust, wet cow dung, and waste flour, respectively. For this sample, a dry density of 0.26 gm/cm^3, durability of 99.28%, weathering resistance of 6.37, Moisture content of 5.34%, ash content of 10.31, volatile matter of 73.54% and fixed carbon of 10.81 were recorded. In addition, the flame center temperature measured was 700-845 ^oC. The practical success of this briquette was validated by baking the common Ethiopians food 'Enjera'. A temperature of 200 ^oC – 220 ^oC was recorded at the center of the baking clay, which is more than the required 200 ^oC. The overall burning duration of briquettes was 40 minutes and almost smokeless. To have effective burning that is free of smoke, a suitable stove design that allows good oxygen circulation is recommended. Therefore, popularizing this technology will contribute to substituting for the non-renewable energy demand of Ethiopians and other lower income communities.

Keywords: Characterization, Briquettes, Manually operated, Saw dust, Waste paper

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1. Introduction

Briquetting is the process of converting biomass waste into uniformly shaped briquettes that are easy to use, transport, and store. The briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs, and makes it available for a variety of applications [1]. The use of briquettes can drastically reduce the demand for wood and therefore decrease deforestation. Besides, briquettes have advantages over firewood in terms of greater heat intensity, cleanliness, convenience in use, and a relatively smaller space requirement for storage [2]. 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 [3].

Concerning Ethiopia's energy consumption, it is predominantly based on biomass energy sources. An overwhelming proportion (92.4%) of the country's primary energy demand is met by waste and biomass, followed by oil (5.7%) and hydropower (1.6%) [4]. A large proportion of the population living in Ethiopia has no access to electricity. Among more than 110 million people living in Ethiopia, 46% only use electric energy for day-to-day activities like food preparation. In the rural areas of the country, where 80% of the population lives, there is no sustainable energy supply [5]. On the other hand, Ethiopia has ambitious plans to achieve climate resilient development until 2025 [6]. Besides, the most important issue in the energy sector is the supply of household fuels, which is associated with massive deforestation and the resultant land degradation. As a clean and renewable energy source, biomass energy can reduce our reliance on fossil fuels and relieve pollution. Compared with coal and diesel, biomass energy has such advantages as renewability, high calorific value, low pollution, zero carbon emissions, and high density [7]. Such a situation leads to exploring renewable energy sources and recycling waste for fuel briquettes.

To produce fuel briquettes, different kinds of machines were designed and fabricated by researchers. Some of the existing machines are either gender-unfriendly, or have poor production capacity and briquette quality and depend on direct human strength for densification. In developing countries, the need at the moment is the development of an appropriate briquetting machine suitable for the local communities [3]. The manual briquette-making machine designed and fabricated by Oladeji, J. T. [2], has different limitations such as productivity, briquette durability, and size variability problems. Obi et al. [8] developed a briquetting machine for use in rural communities, though its mold design is not suitable for smooth ejection and has a low capacity. In

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general, to maximize the benefit of using briquettes, briquette technologies are required to be suitable for users. They should be easy to operate, affordable maintenance, have good productivity per unit time, and environmentally friendly.

This research aims to recycle waste paper by blending it with specified ingredients which are sawdust, cow dung and waste flour test. To produce briquettes from biomasses, the share of binders is from 20 – 40 % [13-15].

In briquette-making studies, studying the combustion characteristics of the raw materials and conducting heating intensity laboratory tests are critical. Major tests on the produced briquettes include the calorific test, proximate analysis, ultimate analysis, durability, relaxed density, and water absorption. The heating intensity of a briquette is measured by its calorific value. The calorific value of briquettes is affected by different variables. Major factors affecting calorific value include fixed carbon, volatile matter, and ash content [19]. Volatile matter is defined as those products, exclusive of moisture, given off by a material as gas or vapour. Its percentage is determined as the ratio of the difference between the oven dry weight and the weight of the charred sample to the oven dry weight [21-22]. The high volatile content of biomass means it can lose over 90% of its mass in combustion, compared with coals, which lose between 5 and 65% of their mass in this process [1]. In addition, percentage ash content is calculted by taking the ratio of ash from charred weight to dry weight [19].

Calorific value results are compared with the standard values of other materials. For instance, the calorific value of paper briquettes is 4,801 kcal, rice husk briquette is 3,200 Kcal, coconut coir is 4,146 kcal and sawdust charcoal 4,820 kcal/kg [9]. Briquette durability is another physical criterion that should be tested to determine the extent of briquette resistance to shatter. It is the fraction of the briquette that remained un-shattered after dropping used as an index of briquette durability or durability rating in percent [10-12], [16-17]. A.Olorunnisol [11] found the durability rating of the different briquette compositions ranged from 93.3% to 98.5%; these are relatively high values, higher than the 46.5 and 88.4% reported by Wamukonya and Jenkins [12] for sawdust and wheat straw briquettes. Another important physical property is the dry density calculated as the ratio of dry weight to volume [11]. Moreover, the weathering resistance of briquettes is related to their water resistance. The higher the water resistance time, the more stable the briquette is [18]. As stated by Sengar, S.H. [20], moisture content of briquettes is determined by the oven dry method.

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2. Methodology / Materials and Methods

2.1 Methods for data collection

Primary data sources such as experiments, electronic instrument data reading, field visits, and questionnaires have been applied. Moreover, secondary sources like journals, conference proceedings, websites, reference books, manuals, and recorded videos were referred to.

2.2 Methods of data analysis

To analyze the collected data, tables, graphs, physical formulas, computer applications (Excel, AutoCAD, Solid Works, and Picolog), the design of the experiment, and machine design principles and procedures were used.

2.3 Raw materials availability, collection, and preparation

The main ingredients to make the solid fuel briquettes were waste paper and sawdust. Whereas, wet cow dung and waste flour dust were binding ingredients. Waste paper is easily available from higher educational institutions and offices in Mekelle. And the wet cow dung can be collected from city livestock owners. Moreover, to know the monthly extract of sawdust, an interview was made with sixty-nine (69) Mekelle City furniture enterprises. A similar assessment of the availability of adequate waste flour dust was conducted in three Quiha flour factories using an interview questionnaire.

Saw dust: The result of the interview showed that 665.6 bags (324 m3) of saw dust can be collected in Mekelle city. This indicates that with proper and regular collecting mechanisms, there will be a good supply for small-scale branding enterprises in the city.

Waste flour dust: data from the three factories indicated that an average of 110 kg of dust can be collected from one factory. Since this ingredient is used in a small amount as a binder, its availability is sufficient for the purpose. Enough of the briquette ingredients were collected from the indicated sources. The waste paper was prepared by first tearing, wetting, and soaking in water for hours or days to blend with the other ingredients. Using a digital balance, the amount of the raw materials was measured to prepare the mix for making sample briquettes.

2.4 Experiment design

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Taguch's L9 (34) orthogonal array mix design (Table 1) was selected to produce sample briquettes, which have four ingredients at three levels. Since the main objective of this research was to produce fuel briquettes from waste paper by blending it with sawdust, in all mixes, the percentage of waste paper is higher. Levels of (45, 55, 65), (15, 20, 25), (10, 15, 20), and (10, 15, 20) were used for waste paper, sawdust, cow dung, and waste wheat flour dust, respectively.

Table-1 Nine group of samples experiment L_9 (3^4)

Experiments	**Ingredients**			
	Waste paper	Sawdust	Cow dung	Waste flour dust
1	45	15	10	10
2	45	20	15	15
3	45	25	20	20
4	55	15	15	20
5	55	20	20	10
6	55	25	10	15
7	65	15	20	15
8	65	20	10	20
9	65	25	15	10

2.5 Briquette making machine

A manually operated lever arm press machine that works by compressing the briquette material in a cylindrical mold (Figure 1) was used to produce sample briquettes.

Figure 1: Lever-arm-operated briquetting machine

2.6 Determination of physical properties

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2.6.1 Dry density (DD) (Relaxed density)

The dry density of briquettes was calculated as the ratio of their dry weight to their volume. The volume of the cylindrical-shaped briquettes was determined using the formula;

V= ΠD^2 x H /4, Where: V= Volume D= diameter, H=height, Π = 3.14

DD = Dry Weight / Volume -- Equation 1

2.6.2 Briquette durability

The durability of briquettes was determined based on the shattered index. The briquette samples were dropped repeatedly from a specific height of 1.5m onto a solid base three times. The fraction of the briquette retained was used as an index of briquette breakability in%.

Durability = (Final weight of briquette/ initial weight) x 100 ------------------------Equation 2

2.6.3 Weathering resistance

It is expressed as percentages of dimensional changes (height and diameter).

Weathering resistance = %DD + %DH---Equation 3

Where: %DD = percentage of change in diameter, %DH = percentage of change in height

2.7 Determination of combustion properties

Most combustion properties, calorific and proximate analyses, and tests were conducted in the Messebo cement factory located in Mekelle city, Tigray region.

2.7.1 Calorific value Test

Instruments used were a jaw crusher, grinding mill, digital balance, bomb calorimeter (IKA-Calorimeter C4000, adiabatic, figure 2), and hand tools. With the proper sample set up in the bomb calorie meter, the calorific values of the nine samples were read out in two trials.

Calorific value = 0.35((147.6 x FC) + (144 x VM) + (%Ash)) Kcal/kg ---------------Equation 4

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Figure 2: Bomb calorie meter used in mesebo cement factory

2.7.2 Determination of proximate analysis values

i. **Moisture content**

The measured pulverized briquette initial weight (w1) was kept in the oven at 103 ºC for 3 hours to obtain the oven dry weight (w2). Moisture content (M) of the sample was calculated using;

%M = (w_1 – w_2)/ w_1 x 100---Equation 5

Where; w_1 = initial weight of sample (g), w_2 = dry weight of sample (g),

ii. **Percentage of volatile matter in the samples**

The volatile matter of the sample was determined by measuring 2g of the oven dry weight (w2) to be preheated in the furnace for 4 minutes at 400 oC to obtain the charred weight (w3). The percentage volatile matter (%VM) was calculated as:

%VM = [Dry weight (w_2) – weight of charred sample (w_3)/ Dry weight (w_2)] x 100 ……Equation 6

iii. **Percentage of ash content**

This was determined by placing the charred weight (w3) in the furnace for 3 hours at 600 ºC to obtain the ash weight (w4).

% Ash content = [ash weight (w_4)/ dry weight (w_2)] x 100 ------------------------------Equation 7

iv. Fixed carbon (FC)

% FC = 100 – %Ash content – %Volatile mater – %Water content ---------------------Equation 8

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2.8 Temperature measurements and practical baking

2.8.1 Flame center temperature

The instrument used was a digital thermocouple. Using the instrument, the temperature was recorded at the center of the flame (Figure 3), while the briquette was burning.

2.8.2 Temperature on 'injera' baking clay surface

A TC-08 data logger coupled with a K-type thermocouple (Figure 3) was used to record the temperature level of the 'Enjera' backing clay surface.

Figure 3: Temperature measurement at the clay surface

2.8.3 Practical baking

This was to validate the research results of the briquette sample with the highest calorific value. Hence, using the clay surface baking stove obtained in the renewable energy demonstration center of the thermal and energy chair, practical baking of 'Enjera' was conducted.

2.9 Production of sample briquettes

A blend of waste paper, sawdust, cow dung, and waste flour dust was prepared based on the designed experiment. This mix is then used to produce nine groups of briquettes using the fabricated lever-arm-operated briquette-making machine.

3. Results and Discussion

Nine groups of sample briquettes (Figure 4) with different compositions of ingredients were produced and allowed to sun-dry for 14 days.

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Figure 4: Briquettes from nine experiments on open-sun drying

3.1 Physical property tests

3.1.1 Dry density (DD) (Relaxed density)

Briquettes of the nine samples result in a relaxed density range between 0.25 and 0.31 gm/cm3 (figure 5 (a)). Actually, this dry density value is lower than biomass briquettes of different raw material compositions and the specific briquetting machine used in [21], [23–25]. But compared to briquettes from 'Ficus nitida' tree residuals [26], the dry density is higher. In general, this lower density record is expected to be due to the higher percentage of waste paper compared to the reviewed biomass briquettes.

3.1.2 Briquette durability

Samples were dropped from 2 meters high three times. Even though none of these shatter, this is an indication of their good durability—100% durability. Hence, based on this experiment and compared to related research conducted so far on biomass briquettes, these briquettes are found to be exceptionally durable. This durability is the result of the higher waste paper proportion contributing to the binding effect and the binder mixtures used. Therefore, transporting and storing these briquettes is easy. However, again, samples were dropped ten times from the same height; still, the durability was found to be 93–100%, as shown in Figure 5(b).

3.1.3 Weathering resistance

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The samples were soaked in water for thirteen hours. The sum of (%DD) and (%DDh) for the nine samples was found to be 15.00, 12.41, 18.21, 14.38, 12.76, 9.22, 6.37, 8.31, and 6.71, respectively (figure 5 (c)). The result shows that sample 7 has better water resistance or a lower water absorption property, which confirms its suitability for storage issues.

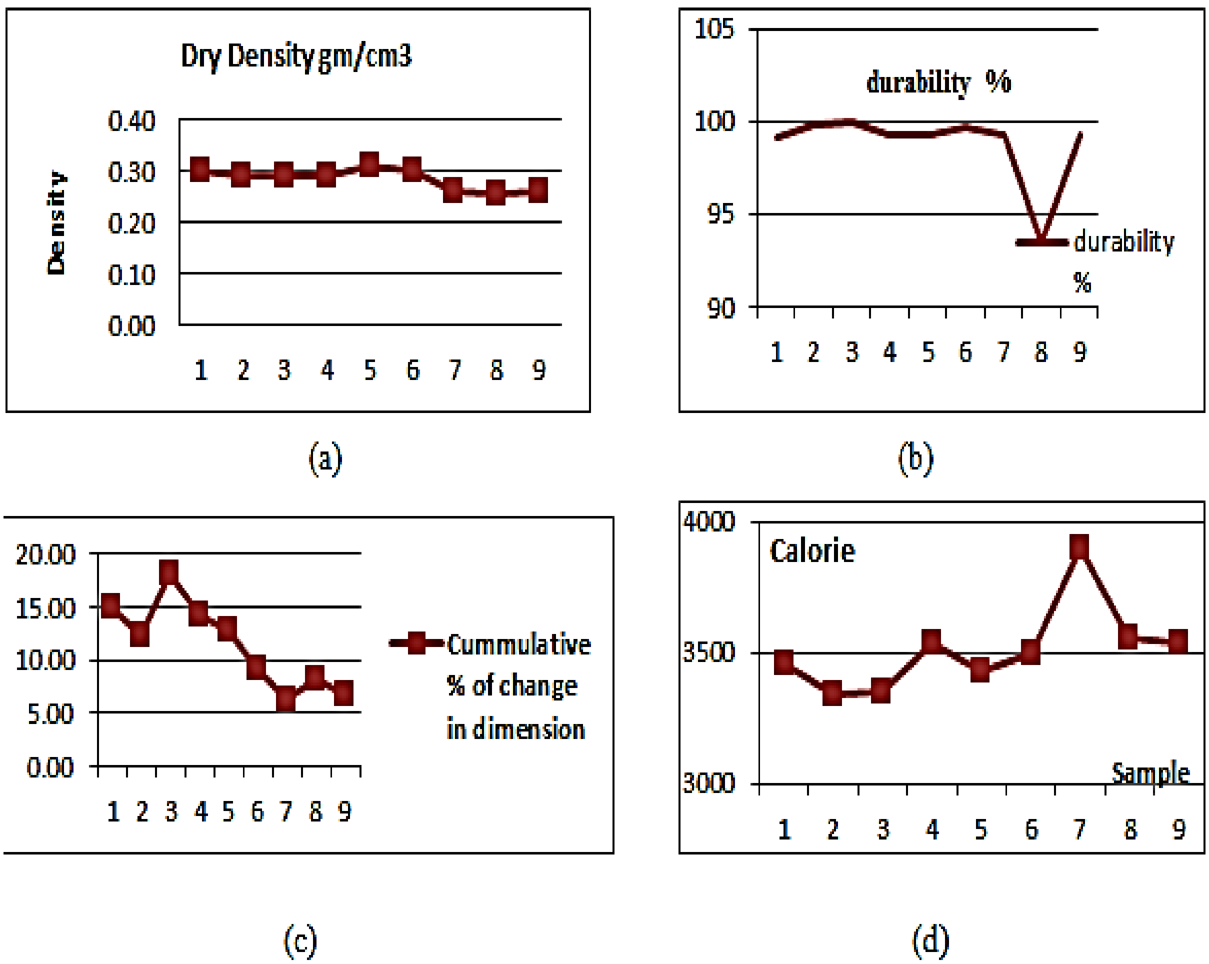

Figure 5: Dry density (a), durability (b), weathering resistance (c), and calorific value (d) of nine samples

3.2 Calorific value test

The calorific value of nine samples was measured (table -2) and (figure 5(d)) using the bomb calorimeter.

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Table-2: Calorific test results

Sample No.	**Calorific values in Kcal/Kg**		
	Trial-1	Trial-2	Average
1	3466.02	3450.43	3458.23
2	3267.77	3411.95	3339.86
3	3348.87	3348.87	3348.87
4	3511.08	3565.15	3538.12
5	3429.98	3434.48	3432.23
6	3475.03	3515.58	3495.31
7	3907.58	3889.56	3898.57
8	3574.16	3538.11	3556.14
9	3506.57	3574.16	3540.37

The highest calorific value (3898.57 kcal/kg) record was from sample 7 with a 65:15:20:15 mix ratio for waste paper, sawdust, cow dung, and waste flour dust. Compared to other biomass raw materials stated in [21] and [23], the calorific value is lower. This can be due to its higher volatile matter content (73.54%) and lesser fixed carbon (10.81%), comparatively. On the other hand, this 3898.57 kcal/kg calorie is found to be higher than the calorie from briquettes of sawdust, rice husk, and paper (0.03-0.19 MJ/kg, 0.02-0.27 MJ/kg) [7]. Moreover, it also recorded a higher value relative to the calorific values of 'Ficus nitida' (3250.7 kcal/kg/17.38 MJ) [26]. An almost comparable result was observed in comparison with the calorie value of rice husk (16.51 MJ/kg, 3944.1 kcal/kg) [25]. In comparison, the calorific value of the briquettes produced by this research work shows comparable value with other biomass briquettes to generate adequate heat intensity for household cooking and baking. Therefore, popularizing briquettes of waste paper, sawdust, cow dung, and waste flour dust at a 65:15:20:15 composition ratio can be a potential source of biomass renewable energy.

3.3 Proximate analysis

This test includes testing of ash content (AC), volatile matter (VM), moisture content (MC), and fixed carbon (FC) (Table 3).

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Table-3: Proximate analysis and energy content of the nine samples

Sample No.	M %	AC %	VM %	FC	Energy
1	5.14	11.44	74.17	9.25	3458.23
2	5.84	10.83	76.99	6.34	3339.86
3	1.89	6.58	78.06	13.47	3348.87
4	4.47	9.17	79.02	10.1	3538.12
5	4.93	9.85	74.2	11.02	3432.23
6	4.6	10.34	74.04	11.02	3495.31
7	5.34	10.31	73.54	10.81	3898.57
8	3.25	9.65	74.98	12.12	3556.14
9	4.18	10.03	74.62	11.17	3540.37

As the result in Table 3 shows, the cumulative effect of higher moisture content, higher volatile matter, and a relatively reduced amount of fixed care contributes to the reduced calorific value.

3.4 Temperature measurements

3.4.1 Flame center temperature

Flame center temperature measurement was done while the briquettes burned, as shown in figure 6. The reading results of the digital thermocouple are as shown in Table 4.

Figure-6: Flame center temperature measurement

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Table 4: Maximum temperature reading of flame centers

Sample number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Temperature, C^o	781	841	746	700	710	700	**845**	700	804

The maximum reading (845 oC) was found for sample 7, which fits with its higher calorific value. This helps to select the best ratio of compositions.

3.4.2 Temperature measured on 'injera' baking clay surface

A temperature reading at the center of the 'Enjera' baking clay surface gives 220 ^{o}C and 190 ^{o}C at the edges. The result satisfies the temperature level required for cooking 'Enjera', which is 200 °C.

3.5 Practical baking

To check the validity of the research results, 'Enjera' was baked practically. The first six briquettes were allowed to burn, and later an additional four briquettes were added at intervals to bake 10 'Enjera' as shown in figure 7. This experiment shows a one-to-one ratio of briquettes to 'Enjera'. The outcome was very good, beyond expectations, in terms of the heating intensity of the briquettes. Moreover, the overall burning duration of briquettes up to complete combustion was 40 minutes. This time is optimal compared to the common waiting time in practice to bake 'Enjera'.

Figure 7: Practical cooking of 'Enjera'

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4. Conclusion and Recommendation

It was assured that efficient cooking energy of 3,898.57 kcal/kg is possible to achieve from briquettes of waste paper, sawdust, wet cow dung, and waste flour dust with a mix ratio of 65:15:20:15. The focus of this research was to show an alternative biomass energy in substituting wood demands for baking the common Ethiopian food, 'Enjera'. A successful validation experiment of baking ’Enjera’ had been conducted. Moreover, the ratio to cook ‘Engera’ was one briquette to one ‘Enjera’. Overall burning and complete combustion time spent was 40 minutes. In addition, based on the physical properties tested so far, the briquettes are suitable for storage, transportation, and water resistance and exhibit full durability.

From these results, the researchers have concluded that the work can contribute significantly to providing an alternative source of biomass energy to rural and urban residents of developing countries. Furthermore, it will tackle the problem of massive deforestation and environmental degradation from using forest logs for cooking.

As a recommendation, even though the cooking process was almost smokeless, for efficient and effective combustion of the briquettes, a suitable design of cooking stove internally with a metal frame stand is recommended.

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6. Conflicts of Interest

The authors declare that there is no conflict of interest.

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