ARTICLE

Performance of a locally developed automated screw-type charcoal briquetting machine

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ABSTRACT

This study aimed to develop and evaluate the performance of an automated screw-type charcoal briquetting machine using four (4) different auger speeds and to conduct a simple cost analysis of the machine. All of the gathered data was analyzed using a single factorial experiment arranged in Completely Randomized Design (CRD) and replicated three (3) times. Based on the result, the performance of the machine and the quality of the produced briquette were significantly affected by the auger speed. Furthermore, the machine obtained the highest output capacity, lowest energy consumption rate, and fastest kindling time when the auger speed was 188 - 194 rpm with a treatment means of 91.53 kg/h, 0.50 kWh, and 2.58 mins, respectively, while at 113 – 116 rpm, the machine attained the optimum briquetting efficiency and produced high-density briquettes, highest moisture resistance, highest shattering resistance and most prolonged time of burning with a treatment means of 94.70%, 0.94 g/cc, 95.43%, 99.79% and 2.38 h, respectively. The machine’s total cost was P33,993.75, with an annual net income of P44,773.45 with a payback period of 8.18 months. In addition, the machine's benefit-cost ratio and return on investment were 1.01 and 128.77 %, respectively.

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INTRODUCTION

In the coming decades, the global population is predicted to surge beyond 11.2 billion by the year 2100 (United Nations 2017). This unexpected growth will lead to a substantial increase in energy demand. However, relying heavily on fossil fuels as the primary energy source will intensify environmental pollution, putting future generations in danger.

In addition, burning of agricultural residue in the field is a common practice in many parts of the world, mainly developing countries, to eliminate waste after harvesting. Still, this act causes pollution to the environment. Instead of burning, processing agricultural residues into renewable energy is one alternative to avoid direct burning, and one example is briquettes. Development and application of locally made briquette machines as part of agricultural mechanization would help in the production of briquette due to its affordability. In support of this, an evaluation of such a machine to determine its optimum performance in terms of capability and efficacy shall be conducted.

Lastly, the adaptation of briquetting machines is in line with the Sustainable Development Goals (SDGs) of the United Nations, specifically goal number 7, which is Affordable and Clean Energy, which ensures access to affordable, reliable, sustainable,

KEYWORDS

Briquettes, Automated, Charcoal, Screw Type, Auger

and modern energy for all. (United Nations, 2015). Briquetting machine has great potential to attain this goal, offering the conversion of agricultural waste into a more efficient and sustainable source. This study will help address deforestation and environmental degradation problems while aligning with the broader global agenda of achieving sustainable and accessible energy for all.

The study aimed to fabricate an automated screw-type charcoal briquetting machine, conduct a performance evaluation of the machine in terms of output capacity, briquetting efficiency, and energy consumption rate, assess the quality of the produced briquettes in terms of shattering resistance, moisture resistance, and burning time, and conduct a simple cost analysis of the machine.

MATERIALS AND METHODS

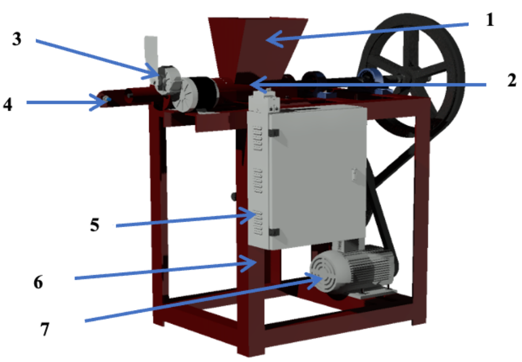
Description of the Machine

The briquetting machine was conceptualized based on existing designs from other emerging and developing countries. Previous studies, such as those by Kapadani, 2020, emphasized that using simple mechanisms with widely available machine elements can significantly reduce costs. Similarly, Hood, 2020 stressed the need to develop appropriate briquetting machines specifically designed for local communities in developing nations. He further noted that for biomass to make a meaningful impact as a rural fuel source, it is essential to create efficient, cost-effective, and easy-to-duplicate technologies tailored to these communities. These insights guided the conceptualization and adaptation of the machine's design.

A design drawing was prepared as a basis for fabricating the machine. The machine comprises a screw-type conveyor (auger) assembly driven by a 5 hp single-phase electric motor, a frame assembly, a feed hopper, a mold, and an automated cutting mechanism. The design of the screw conveyor assembly was based on the study of Inegbedion, et al 2022 which he used a single mild steel shaft that conveys the raw material and feed through the die. This mechanism creates needed pressure as the raw material passes through the die to produce the briquettes.

The automated cutting mechanism, originally designed in this study, consist of an eight-pin relay, a normally open-type proximity sensor, a power supply, and 24 volts, 350 watts geared motor.

The proximity sensor is positioned at a distance where the desired length of the briquettes is set. When the briquette is detected by the proximity sensor, it sends a signal to the DC motor, which activates the cutting blade to cut the briquette to the preset length.



Part No.	Part Description
1	Hopper
2	Briquetting Chamber
3	Automated Cutter (DC Motor)
4	Proximity Sensor
5	Control Box
6	Frame
7	5 hp Electric Motor

Figure 1: Basic Component Parts of the Machine

Preparation of Samples

Coconut shells were gathered at the Public Market of Diffun Quirino and used as biomass in this study. They were carbonized using locally fabricated carbonizing equipment.

Three (3) kilograms of carbonized coconut shells were used during the test. Cassava starch was used as a binding agent due to its availability on the market.

As recommended by the Philippine Coconut Authority (PCA), one hundred grams (100 g) of cassava starch was thoroughly mixed with every kilogram of coconut shell.

The amount of water added depends on the moisture content of the biomass material. Pre-testing was carried out to determine the amount of water to be used; it was found that mixing three hundred fifty milliliters (350 ml) of water in every kilogram of the sample appears to be the best.

Test Parameters

Output Capacity (kg/h)

This was calculated by dividing the weight of output briquettes by the total operating time. A stopwatch was used to measure the total operating time.

$$Co = Wout/To$$

Where:

Co = Output Capacity, kg/h
Wout = Weight output briquettes, kg
To = Operating time, h

Briquetting Efficiency (kg/h)

This was calculated by dividing the weight of output briquettes by the weight of input biomass expressed in percentage.

$$Effs = (Wout / Win) \times 100$$

Where:

Effs = Briquetting Efficiency, %
Wout = Weight Output briquettes, kg
Win = Input biomass, kg

Energy Consumption Rate (kWh)

A kilowatt-hour meter was used to measure the energy consumption rate. This was quantified by subtracting the final reading from the initial reading.

Shattering Resistance (%)

The durability of briquettes was determined following the procedure of Ghorphade, 2006 and Sengar, et al. 2012. Briquette samples with known weight were selected randomly from each of the treatments and then dropped on a concrete floor from a height of one (1) meter three (3) times. The retained briquette was then weighed.

Shattering resistance was computed using the following formula:

% weight loss = $[(w_1 - w_2)/w_1]$ 100
% shattering resistance = 100 - % weight loss

Where:
w_1 = weight of briquettes before shattering
w_2 = weight of briquettes after shattering

Moisture Resistance (%)

The moisture resistance was determined by the procedure described by Davies and Davies, 2013. A weighing scale was used to determine the initial weight of each sample and then immersed in water for two (2) minutes. The briquette's weight was measured again and relative weight change was recorded.

Moisture resistance was calculated using the following formula:

% moisture absorbed = $[(w_2 - w_1)/w_1]$
% moisture resistance = 100 - % moisture absorbed

Where:
w_1 = weight of briquettes before immersion in water
w_2 = weight of briquettes after immersion in water

Density (g/cc)

The density of the produced briquettes was determined by measuring the volume and weight of the briquettes. It is calculated by determining the ratio of the mass and volume of the briquette.

Time of Burning (h)

Briquettes' time of burning was determined by monitoring the time when the briquettes were completely burned. A stopwatch was used on this test.

Statistical Analysis

The performance of the machine was evaluated using different auger speeds by varying the diameter of the pulley attached to it. All data gathered was analyzed using a single-factor factorial experiment arranged in Completely Randomized Design (CRD) replicated three times. Analysis of Variance (ANOVA) was used to determine if there are significant differences among treatment means. Least Significant Differences (LSD) were used to determine differences between treatment means.

T_1 = 189-194 rpm T_3 = 120-125 rpm
T_2 = 148-161 rpm T_4 = 113-116 rpm

RESULT AND DISCUSSION

Output Capacity

The output capacities of the machine at different auger speeds were listed in Table 1, with a grand mean of 73.18 kg/h. It revealed that varying the speed of the auger significantly influenced the input capacity of the machine. This is because the auger triggers the flow of the material from the hopper to the inlet; it means the faster the auger speed, the faster the material flows, as depicted in Figure 2.

Further analysis was done using the Least Significant Difference (Table 1) to determine the difference among treatment means and it was found out the mean output capacity were different from each other. This was also true because output capacity is a function of time of operation, where making the auger rotate to a faster speed will lead to a shorter operating time while lower auger speed leads to a longer operating time.

Table 1: Output Capacity (kg/h) of the Machine at Different Auger Speed

Treatment	Replication			Treatment Mean
	I	II	III	
T_1	77.58	79.90	81.19	79.56^d
T_2	82.23	83.00	83.58	82.94^c
T_3	88.07	88.40	88.40	88.29^b
T_4	94.85	94.66	94.59	94.70^a
Grand Mean				86.37

Note: Means with the same superscripts were not significantly different from each other.

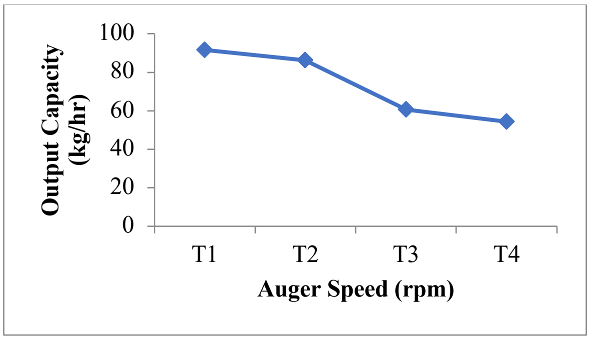


Figure 2: Relationship between Auger Speed and Output Capacity

Briquetting Efficiency

Table 2 presented the briquetting efficiencies of the machine at different auger speeds with a grand mean of 86.37%. The table also shows that the highest briquetting efficiency was attained using 113-116 rpm (T_4) with a treatment mean of 94.70%. The analysis of variance revealed that the speed of the auger is significantly influencing the briquetting efficiency. This means that the faster the auger speed yields a lower briquetting efficiency, as shown in Figure 3. Operating the machine at a higher auger speed will lead to uneven compaction of briquettes, resulting in a lower quality briquette that shatters quickly when dropped from the outlet resulting in a lower briquetting efficiency.

Table 2 also showed that the mean briquetting efficiency for all of the treatments was statistically different with each other having a grand mean of 86.37 %.

Table 2: Briquetting Efficiency (%) of the Machine at Different Auger Speeds

Treatment	Replication			Treatment Mean
	I	II	III	
T_1	89.85	93.00	91.75	91.53^a
T_2	85.75	86.64	86.48	86.29^b
T_3	59.95	61.80	60.00	60.58^c
T_4	54.52	54.01	54.37	54.30^d
Grand Mean				73.18

Note: Means with the same superscripts were not significantly different from each other.

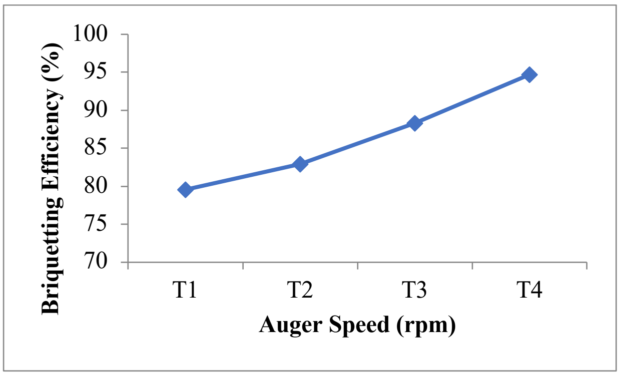


Figure 3: Relationship between Auger Speed and Briquetting Efficiency

Energy Consumption Rate

The energy consumption rates of the machine at different auger speeds were tabulated in Table 3 with a grand mean of 0.6 kWh. The analysis of variance revealed that the speed of the auger significantly influenced the energy consumption rate (p-value < 0.01).

The comparison of treatment means using the Least Significant Difference (Table 3) revealed that there are no significant differences between 189-194 rpm (T_1) and 148-161 rpm (T_2) with the same values of 0.5 kWh and 120-125 rpm (T_3) and 113-116 rpm (T_4) with values of 0.67 kWh and 0.73 kWh, respectively. It implies that reducing the auger speed will lead to a higher energy consumption rate as depicted in Figure 4.

Table 3: Energy Consumption Rate (kWh) of the Machine at Different Auger Speeds

Treatment	Replication			Treatment Mean
	I	II	III	
T_1	0.50	0.50	0.50	0.50
T_2	0.50	0.50	0.50	0.50
T_3	0.70	0.60	0.70	0.70
T_4	0.80	0.70	0.70	0.80
Grand Mean				0.60

Note: Means with the same superscripts were not significantly different from each other.

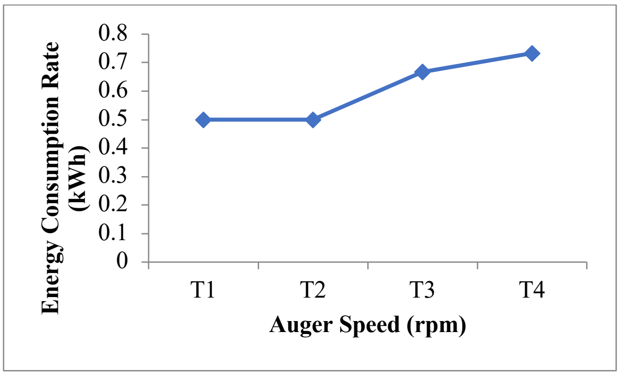


Figure 4: Relationship between Auger Speed and Energy Consumption Rate

Density

Briquettes' density is an important parameter in briquetting. Briquettes with high density are highly preferable in terms of transportation and storage. Table 4 shows the density of produced briquettes at different auger speeds with a grand mean of 0.77 g/cc. Briquettes with the highest density were produced using 113-116 rpm (T_4) with a treatment mean of 0.94 g/cc. It was also observed that the auger speed significantly influenced the density of produced briquettes (p-value < 0.01). This means that by decreasing the auger speed, higher-density briquettes will be produced as presented in Figure 5.

The treatment means were analyzed using the Least Significant Difference to determine the difference among treatment means and it was found that 189-194 rpm (T_1) and 148-161 rpm (T_2) with treatment means of 0.60 g/cc and 0.71 g/cc, respectively were statistically equal it is also true with 120-125 rpm (T_3) and 113-116 rpm (T_4) with treatment mean of 0.85 g/cc and 0.94 g/cc, respectively.

Table 4: Density (g/cc) of the Produced Briquettes at Different Auger Speed

Treatment	Replication			Treatment Mean
	I	II	III	
T_1	0.55	0.65	0.60	0.60^b
T_2	0.64	0.75	0.73	0.71^b
T_3	0.87	0.89	0.79	0.85^a
T_4	0.95	0.93	0.94	0.94^a
Grand Mean				0.77

Note: Means with the same superscripts were not significantly different from each other.

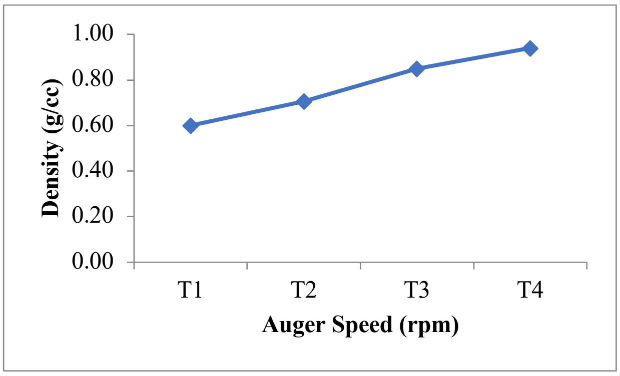


Figure 5: Relationship between Auger Speed and Density

Kindling Time

Kindling time is an important factor in briquette production. Table 5 presented the kindling time of produced briquettes at different auger speeds with a grand mean of 2.99 mins. It also showed that 189-194 rpm (T_1) produced the briquettes with the lowest kindling time with a mean value of 2.58 mins. Analysis of variance revealed that different auger speeds significantly influenced the kindling time of the produced briquettes (p-value < 0.01). This was true because a briquette with a higher density that was produced by a slower auger speed became well compacted resulting in a minimal pore space than the lower density briquettes leading to a longer combustion time.

The treatment means were further analyzed using the Least Significant Difference to determine their differences it was found that 189-194 rpm (T_1) and 148-161 rpm (T_2) with mean values of 2.58 mins and 2.80 mins respectively were statistically equal this was also true with 120-125 rpm (T_3) and 113-116 rpm (T_4) with mean values of 3.17 mins and 3.40 mins, respectively.

Table 5: Kindling Time (mins) of the Produced Briquettes at Different Auger Speeds

Treatment	Replication			Treatment Mean
	I	II	III	
T_1	2.73	2.53	2.47	2.58^b
T_2	2.80	2.85	2.75	2.80^b
T_3	3.10	3.25	3.15	3.17^a
T_4	3.20	3.53	3.47	3.40^a
Grand Mean				2.99

Note: Means with the same superscripts were not significantly different from each other.

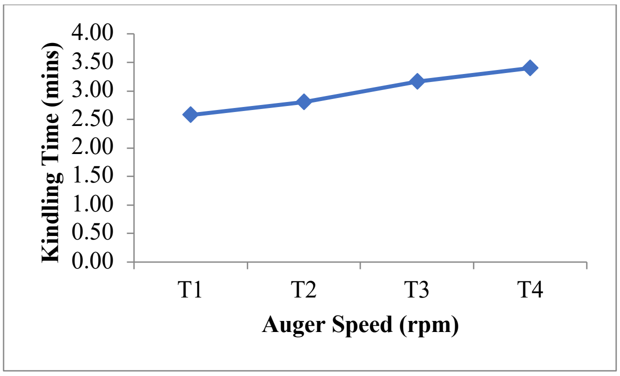


Figure 6: Relationship between Auger Speed and Kindling Time

Burning Time

Burning time is a direct indicator of how effectively the briquettes sustains combustion and provides heat over a given period. The effect of auger speed on the burning time of produced briquettes is presented in Table 6. Based on the table, 189-194 rpm (T_1) has the lowest burning time with a mean value of 1.87 hours while 113-116 rpm (T_4) has the longest burning time with a mean value of 2.38 hours. It indicates that the slower the auger speed, the produced briquettes will have a longer time to burn. This was true because briquettes produced with 113-116 rpm (T_4) were the most compact among the other resulting in a longer burning time.

Analysis of variance revealed burning time of produced briquettes was significantly affected by the auger speed (p-value < 0.01). Since it was significant, treatment means were subjected to the Least Significant Difference to determine their differences it was found that 189-194 rpm (T_1) and 148-161 rpm (T_2) were statistically the same with mean values of 1.87 h and 1.96 h, respectively it was also true with 120-125 rpm (T_3) and 113-116 rpm (T_4) with mean values of 2.32 h and 2.38 h, respectively as also shown in Table 6.

Table 6: Burning Time (h) of the Produced Briquettes at Different Auger Speeds

Treatment	Replication			Treatment Mean
	I	II	III	
T_1	1.85	1.78	1.97	1.87^b
T_2	1.90	2.10	1.87	1.96^b
T_3	2.38	2.27	2.32	2.32^a
T_4	2.53	2.20	2.42	2.38^a
Grand Mean				2.13

Note: Means with the same superscripts were not significantly different from each other.

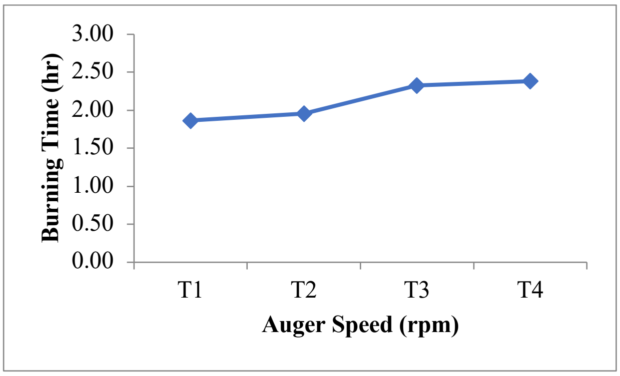


Figure 7: Relationship between Auger Speed and Burning Time

Moisture Resistance

Table 7 presented the effect of auger speed on the moisture resistance of produced briquettes with a grand mean of 90.43%. Analysis of variance revealed that there is a significant difference between treatment means (p-value < 0.01). Also, briquettes produced with lower auger speed had higher moisture resistance than the other as depicted by Figure 8 this was due to the researcher's findings that these briquettes had higher density and contained relatively low pore spaces where moisture/water may accumulate.

Further analysis using the Least Significant Difference found that 189-194 rpm (T_1) and 148-161 rpm (T_2) with mean values of 80.97% and 89.40% were statistically different with other treatments it was also true with 120-125 rpm (T_3) and 113-116 rpm (T_4) with mean values of 93.09% and 95.43% respectively are statistically equal.

Table 7: Moisture Resistance (%) of the Produced Briquettes at Different Auger Speeds

Treatment	Replication			Treatment Mean
	I	II	III	
T_1	85.96	85.00	82.98	84.65^b
T_2	90.91	85.94	88.89	88.58^b
T_3	92.07	93.45	93.74	93.09^a
T_4	94.57	95.67	96.04	95.43^a
Grand Mean				90.43

Note: Means with the same superscripts were not significantly different from each other.

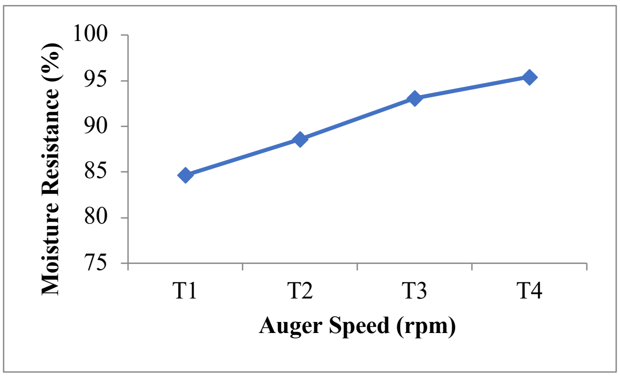


Figure 8: Relationship between Auger Speed and Moisture Resistance

Shattering Resistance

Shattering resistance is an important parameter in briquetting. Briquettes with high shattering resistance are highly preferable in terms of transportation and storage. Table 8 presented the mean values for the treatments and it was found that 113-116 rpm (T_4) had the highest shattering resistance with a mean value of 99.79% while 189-194 rpm (T_1) had the lowest resistance on shattering with a mean value of 80.97%. It indicates that briquettes produced with higher auger speed break more easily than the briquettes produced with lower auger rpm as presented in Figure 9.

The treatment means were then further analyzed using the Least Significant Difference as shown in Table 8. It was found that 189-194 rpm (T_1) and 148-161 rpm (T_2) were statistically the same with mean values of 80.97% and 88.58%, respectively; this was also true with 120-125 rpm (T_3) and 113-116 rpm (T_4) with mean values of 99.45% and 99.97%, respectively.

Table 8: Shattering Resistance (%) of the Produced Briquettes at Different Auger

Treatment	Replication			Treatment Mean
	I	II	III	
T_1	79.11	80.01	83.79	80.97^{c}
T_2	92.30	83.78	92.12	89.40^{b}
T_3	99.31	100.00	99.03	99.45^{a}
T_4	100.00	99.36	100.00	99.79^{a}
Grand Mean				92.40

Note: Means with the same superscripts were not significantly different from each other.

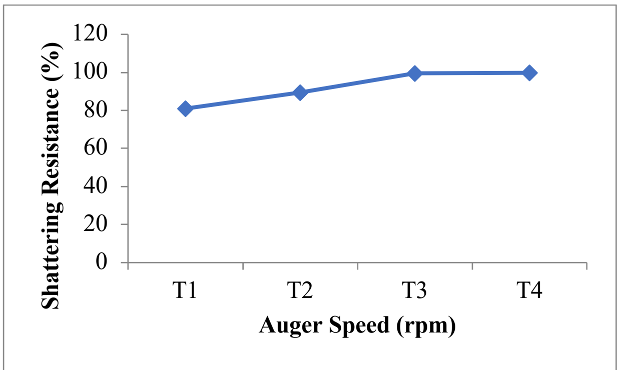


Figure 9: Relationship between Auger Speed and Shattering Resistance

Cost and Return Analysis

A cost estimate was made to guide users on possible benefit projections in using the briquetting machine. The machine was assumed to be utilized for 1,968 hours per year; that is 8 hours a day, 22 days per month. The machine was required to be operated by one operator.

The total cost of the machine was P 33,993.75 with an annual net income of P 44, 773.45 with a payback period of 8.18 months this means that the investment cost will be recovered after 8.18 months of operation.

The benefit-cost ratio and return on investment of the machine were 1.01 and 128.77 %, respectively which means that for every one peso of investment on the machine, 1.29 pesos will be generated.

CONCLUSION

Based on the result of the study, the following conclusions were drawn:

The performance of the machine (output capacity, briquetting efficiency, and energy consumption rate) and the quality of produced briquettes (density, kindling time, burning time, moisture resistance, and shattering resistance) are significantly affected by the auger speed.

The machine obtained the highest output capacity, lowest energy consumption rate, and fastest kindling time when the auger speed was 188 - 194 rpm (T_1) with a treatment means of 91.53 % 0.50 kWh, and 2.58 mins, respectively.

The machine attained the optimum briquetting efficiency and produced high-density briquettes, the highest moisture resistance, highest shattering resistance, and longest time of burning when the auger speed was running at 113 – 116 rpm (T_4) with a treatment means of 94.70 %, 0.94 g/cc, 95.43 %, 99.79 %, and 2.38 h, respectively.

Produced briquettes with high density are those briquettes with a long kindling time but have high moisture resistance, high shattering resistance, and a long time of burning.

The machine was economically viable and feasible.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

The main author conceptualized and designed the study, developed the methodology, collected and analyzed the data, and wrote and revised the manuscript. The second author provided supervision, guided the research methodology, and reviewed the manuscript. All Authors approved the final version of the manuscript

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