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Turning Waste into Calcium Source: Design, Fabrication, and Performance Evaluation of a Motorized Oyster Shell Crushing Machine at Different Speeds

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Abstract

A motorized oyster shell crusher machine was designed and fabricated in the study to turn waste shells into lime for agricultural application. The study evaluated the performance of the machine at different speeds (348rpm, 290rpm, and 249rpm) in terms of crushing efficiency, crushing capacity and power consumption in crushing oyster shell for layer's feed; establish the optimum speed (rpm) of two rollers in crushing; and perform a simple cost analysis of the machine. Results showed that the rollers speed significantly affected the crushing efficiency, crushing capacity and power consumption. The highest efficiency was attained at 290rpm (90.32%) and lowest at 348rpm (84.76%). On the other hand, the highest capacity was attained at 348rpm with 54.99kg/hr and lowest at 249rpm with 40.78kg/hr. The power consumption of the machine increases as the rollers speed decreases, from 20.10 W-hr to 31.16 W-hr with a speed of 348 to 249rpm, respectively. The optimum speed of the machine is at 290rpm with a crushing efficiency of 90.32% and has a crushing capacity of 53.11kg/hr. After a simple cost analysis of the machine, the computed initial cost of the machine is Php 46, 267.50. The computed payback period is 0.3 years with 115.37% return on investment, annual net income of Php160, 707.11, and break-even point of 2,459.23kg of dried oyster shells per year.

KEYWORDS

Motorized oyster shell crusher
performance evaluation
design and fabrication of machine

Introduction

The Philippines is an archipelago with numerous sites suitable for oyster farming. The average size of a farm is 0.5ha to 5ha with an average production of approximately 50 metric tons per hectare. For these, oysters marketing has not been difficult. The current demand for oysters worldwide exceeds supply but shells being dumped in open fields has been a global issues. It contributes to more than 7 million tons of "nuisance waste" discarded every year by the seafood industry that mostly winds up thrown into landfills or dumped into the ocean (Food and Agricultural Organization [FAO], n.d.; Cimons, 2017).

Innovation in managing such vast amount of waste is a continuous challenge. Oyster shells, being about 96% calcium carbonate, should make a perfect material in making concrete aggregates, supplement calcium for laying hens, and improving farmers' field soil condition (Philippine Council for Agriculture, Forestry and Natural Resources Research and Development [PCARRD], 1988). Rather than being a waste, researcher James Morris have a better idea – one that could reap huge ecological benefits – proposing crushed shells for agriculture and engineering applications. Moreover, Cimons (2017) stated,

> "Reusing shell waste is a perfect example of a circular economy, particularly as shells are a valuable biomaterial. Not only does it improve the sustainability of the aquaculture industry moving forwards, but it can also provide secondary economic benefits to shellfish growers and processors as well".

Currently, there are no small scale oyster shell crushing technology that is being used in the Philippines. Agricultural and fishery operations in the Philippines are mostly done manually with the use of hand tools and equipment. At present, crushing the shell are done by loading the shells into an old sack or feed bag and being brought to the highway. These shells are crushed by cars by passing over it and some are crushed by striking it with a hammer. Also, existing crusher technology used in crushing shells is relatively heavy, uses high powered engines, and imported materials which indicates that it is expensive (WikiHow, 2019).

These conditions prompted the conduct of the study, to design and fabricate a small-scale crushing machine to reduce oyster shell volume and intend to supply the end-product as supplemental calcium for laying hens. It is an opportunity to minimize environmental problems and to help both farmers and disposers of oyster shells into secondary markets for additional income. The designed machine was partly based on WKD brand, XPZ model (2002) and was intended for crushing dried oyster shells. This study specifically designed, fabricated and evaluated the performance of the machine in terms of its crushing efficiency, crushing capacity and power consumption in crushing oyster shell as layer's feed. The study also determined the optimum speed (rpm) of the two rollers of the machine in crushing dried oyster shell and conducted a simple cost analysis on the use of the fabricated machine.

Materials and Methods

Design of the Machine

This machine was fabricated using locally available materials and is composed of major components like the crushing chamber, prime mover (2HP), roller assembly, sifter, hopper and the frame (Figure 1). The roller assembly is composed of four shafts. The two 3" ø x 12" in length shafts at the upper part is equipped with geared-shape teeth that are alternately placed, 0.4 inch spacing and 0.4 inch depth. It holds 14

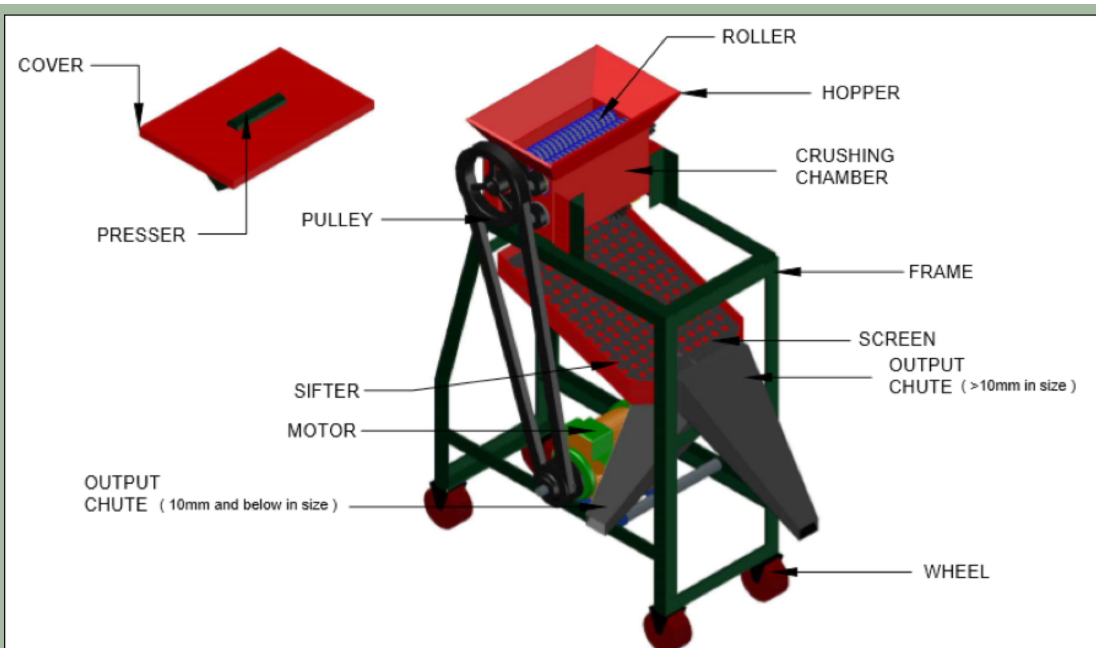

Figure 1. Oyster shell crusher machine design and components in the machine

geared-shape teeth and 15 spacers, with the two rollers rotating at same speed to crushed the dried oyster shells. It is protected by 6mm thick steel plate crushing chamber and a hopper. The rollers are equipped with bearings and gears and are connected to the sifter. The sifter is composed of a perforated 0.762cm diameter screen and a galvanized iron sheet gauge #20. The frame is made of 3.81cm angular bars, which holds all of oyster shell crusher machine parts (Nepalar, 2012).

Design Considerations. During the design conceptualization, certain criteria were considered. First, the machine should be able to crush the oyster shells to be used for laying hens with specific size range of 10mm and below (Rao et al., 1992). It has to be portable, safe to operate and has ease of maintenance and operation for secondary markets, growers and processors. The clearance between the rolls depend upon the dried oyster shell to be crushed; thus, the double roller should be adjustable, and has to be made from locally available materials.

Construction. The entire construction utilized locally available materials. The machine's main frame was first constructed (Figure 2). It is made up of 1.5" x 0.25" angular bar welded together. The roller and transmission assembly (Figure 3) was made of two rollers with geared-shaped teeth carbon steel (spacing-.4", depth-.4", 3" ø and 12" in length) at the upper part of the assembly for primary crushing, and two small solid carbon steel shaft rollers (12" in length and 2" ø) at the lower part of the assembly for further crushing. The four rollers are connected to each shafts equipped with 6006 bearings and gears. The clearance between the rollers depends on the size of material to be crushed. The opposite rotation of the rollers causes the crushing of the oyster shell.

The sieve and the output chute (Figure 4), on the other hand, were made of GI sheet gauge #20. Sieves were composed of a catchment tray and perforated screen with 0.03" ø. Two output chute, output chute for <10mm and below and output chute for >10mm, were bended and shaped to ease the passage of crushed dried oyster shells during operation. Two HP or 1.5kW electric motor was used to power the machine. Preliminary testing was done to determine the crushing speed to be used during the evaluation. Belts and pulleys (measuring 10", 12" and 14" in diameter) were used to achieve the crushing speed and were used as the three treatments during the final testing.

Principle of Operation. The machine is operated by starting the prime mover, and then the power is transmitted to the roller and sifter by

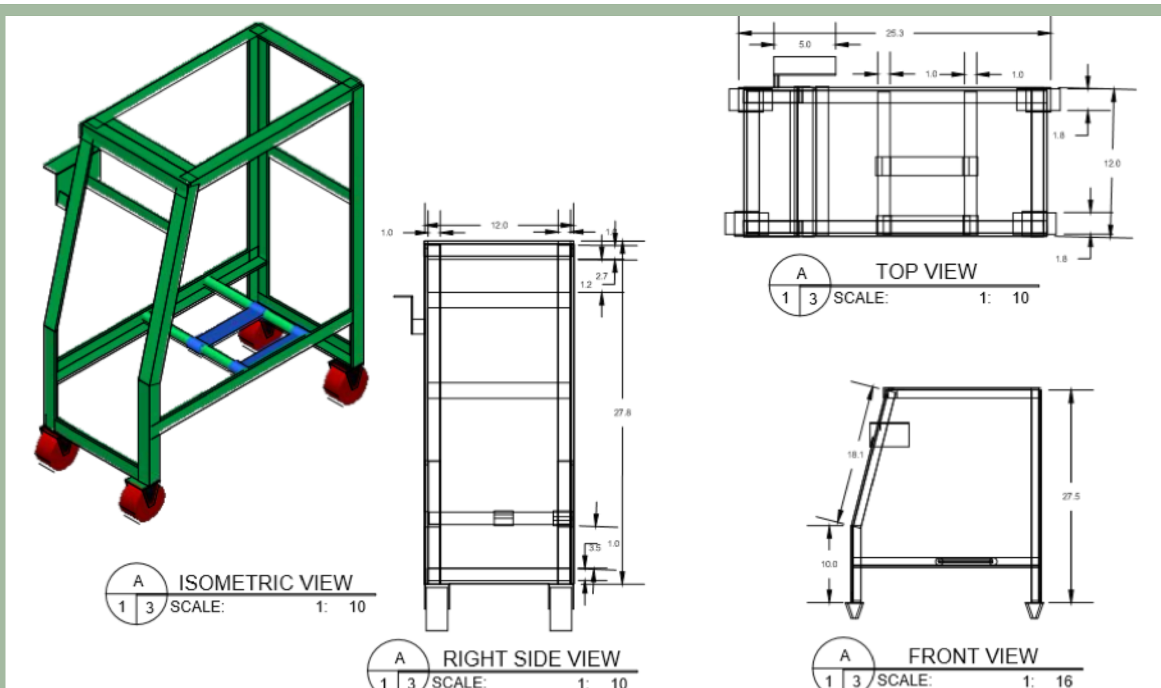

Figure 2. Frame assembly of the machine

means of pulley, v-belt, shafts and gears (Figure 5). Dried oyster shells (at least one week of drying) are then feed to the crushing chamber through the hopper. As the active roller rotates, the fixed roller also rotates in an opposite direction. It crushed the oyster shell by means of geared-shaped teeth of the rollers and becomes finer as it moves to the small rollers. Then the crushed oyster shells falls down to the screen. The screen will separate the larger crushed shells and the smaller ones. It will be dropped in the output chute through the aid of gravity. The output chute is also inclined to help the output materials fall to the waiting collection bin. The outputs are then manually separated and weighed.

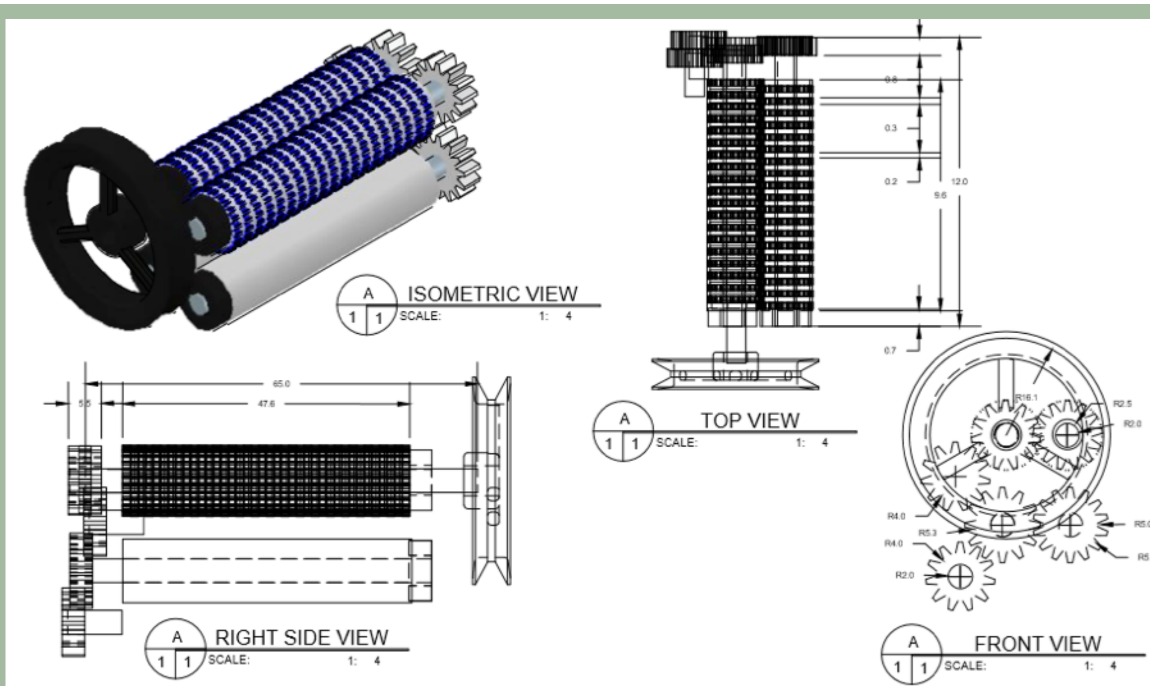

Figure 3. Roller and transmission assembly

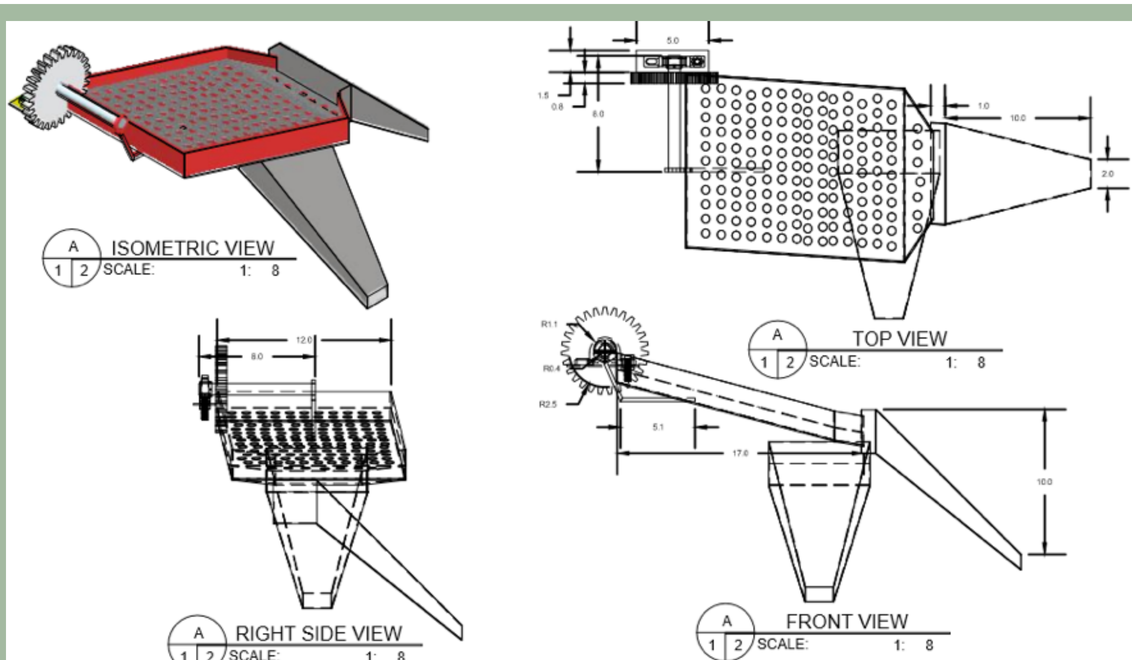

Figure 4. Sieve and output chute assembly

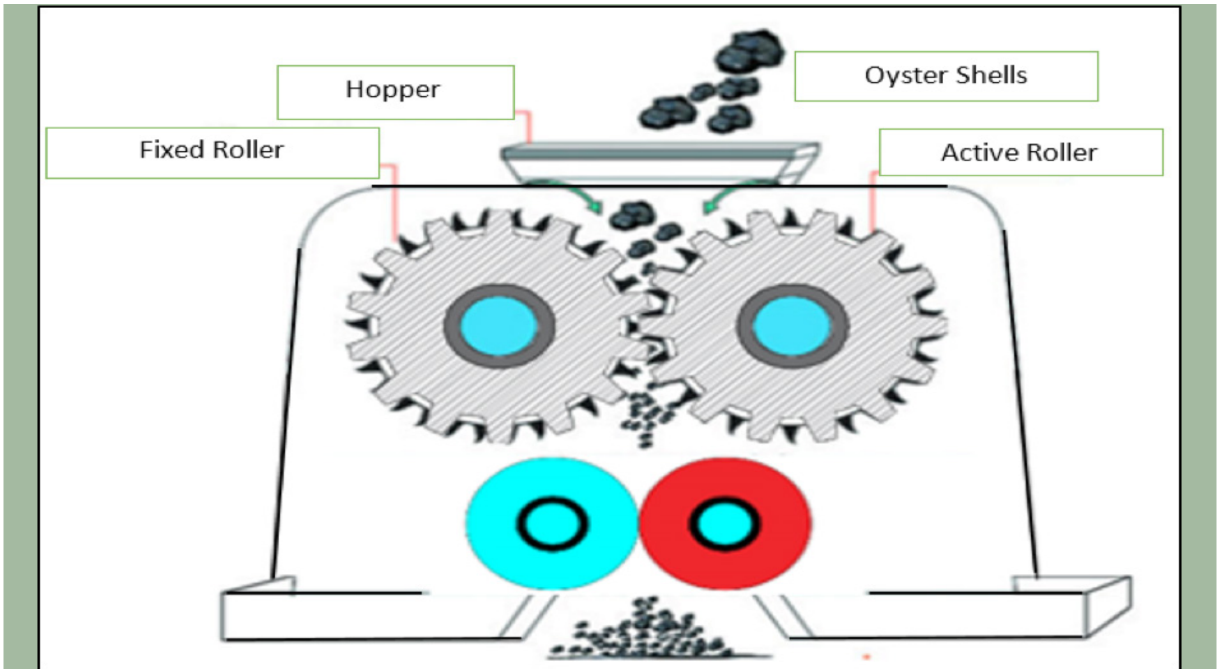

Figure 5. Process of crushing

Performance Evaluation of the Machine

The performance of motorized oyster shell crusher machine was determined in terms of speed (rpm) of the two rollers. A preliminary test was first performed to determine feasible speed (rpm) of the two rollers for crushing. Three replications for each treatment level were executed using the same weight and material used during the preliminary test. The test material were dried oyster shell. The test materials that were used during the preliminary test and final testing were 1.5 kg of dry oyster shell. This feed rate was also determined during the preliminary test.

The speed of the rotating rollers was obtained through mathematical calculations and through tachometer during final testing. Clamp meter and mathematical calculations were also used during final testing. Treatment rpm's were 348, 290 and 249. The same feed rate was maintained during final testing. After each replication, the area and the rollers of the crusher were cleaned and then prepared for the next test. The procedures were repeated for the succeeding replications. All output products from each replication were placed separately in clean and dry plastic bags and labeled properly.

The duration of each replication commenced when the oyster shell crusher were fed into the machine and ends after feeding of the last test material, and when no processed materials can be seen to fall off the outlet chute. The duration of the test varies in accordance with the treatment speeds.

Data Gathered

The data gathered in the study include operating time (hr), weight of input materials (kg), weight of crushed materials (<10mm, >10mm crushed material in kg), power consumption, crushing capacity and crushing efficiency. Operating time refers to the amount of time required to crush the dry oyster shell. This will start from putting the dried oyster shell into the hopper and will end to the output chute. The total weight of the crushed dry oyster shell with a size of 10 mm and below were collected from the <10mm output chute while >10mm crushed materials were collected from the >10 mm output chute. The <10mm crushed materials were separated from >10mm output chute after manual sieving. The power consumed (W) during each operation were recorded using clamp meter. Crushing capacity (C_O) is the ratio between the <10mm crushed materials and the operation time of the device. C_O, crushing efficiency (C.E) and power consumption (E.C; W-hr) were computed using the formulas adopted from (Philippine Agricultural Engineering Standards (PAES 245; 2010):

$$C_O = W_c / t$$

where: W_c = Weight of crushed materials ranging 10mm and below (kg)
t = Operating time (hr)

$$C.E = \frac{W_c}{W_I}(100)$$

where: W_c = Weight of crushed materials ranging 10mm and below (kg)
W_I = Weight of input materials (kg)

$$E.C = (EI)\,t$$

where: E= Voltage (volts)
I = Current (ampere)
t= Operating Time

Statistical Analysis

The statistical analysis used in crushing was one factorial in Completely Randomized Design (CRD), wherein variables were analysed as affected by the peripheral speed of the two rollers. Each treatment had three (3) replications. One replication consisted of loading 1.5kg of dried oyster shell for crushing in the machine. The significant difference among the treatment means were tested using the Least Significance Difference Test (LSD) at 5% level of significance.

Economic Analysis

Some basic assumptions were considered to perform the simple cost analysis of the machine. The depreciation was determined using the straight line method with other assumptions such as: machine life of 5 years; interest on investment of 10%; tax and insurance of 3%; and repair and maintenance of 10%. The annual use of the machine was assumed to be 200 days and custom rate of Php 6/kg. These assumptions were based on the harvesting of time and the quantity of harvested oyster shells.

Results and Discussion

Machine Description

The oyster shell crushing machine is composed of major components including the hopper, output chute, the crushing chamber, roll assembly, retractable roll assembly, sifter, cover, presser, and prime mover (Figure 6). The hopper was constructed from steel plate (0.61cm) with a wooden cover. It was designed to accommodate the materials being fed and serves as guard preventing materials from coming out of the crushing chamber and being scattered. The output chute collects the output products (crushed and uncrushed) and conveys these materials to the collection bins by gravitational force achieved by inclination. It is made of G.I sheet (gauge #20) connected to the screen and sifter. The crushing chamber holds, protects and contains the double roller assembly. It was made of steel plate, 0.61cm thick. The roll

Figure 6. The designed and fabricated oyster shell crusher machine

assembly consists of two rollers with geared-shaped teeth carbon steel (spacing - 1.02cm, depth - 1.02cm, 7.62cm diameter and 30.48cm in length) at the upper part of the assembly for primary crushing, and two small solid carbon steel shaft rollers (30.48cm in length and 5.08 cm in diameter) at the lower part of the assembly for further crushing. The four rollers were connected to each shafts. The clearance between the rollers depends on the size of material to be crushed. The opposite rotation of the rollers causes the crushing of the oyster shell. Additionally, there is a retractable roll assembly which consists of flat bars (1.02 cm), machine bolts, 6006 bearings and gears corresponding to the four rollers. One gear is connected to the fixed roller to adjust the clearance in between the two rollers. The sifter consists of screen and under it is the catchment tray. The catchment tray under the screen catches the small crushed oyster shells. Large crushed oyster shells will fall down due to the inclination of the screen which diverts it toward the outlet. The screen and the catchment tray are made with perforated sheet (0.762cm diameter) and galvanized iron sheet (gauge #20), respectively. The sifter is connected to rollers through shafts and gear. The sifter is connected on a 1.2 cm ø RSB and attached to the frame. The cover of the hopper was made of wood with dimensions of 25.4cm x 38.1cm x 2.54cm. This prevents the shells from coming out and where the presser is attached. The presser was constructed for faster crushing and also serves as the handle of the cover. Lastly, the machine is powered by prime mover (electric motor), a 2HP electric motor where the first roller is connected through a 30.48 cm diameter pulley and v-belt, which also makes the remaining rollers rotate via gears at the other end.

Performance Evaluation of the Machine

Crushing Capacity. The capacity of the oyster crusher machine is presented in Table 1, taking into considerations the crushing time and weight of crushed materials. The highest crushing capacity is 56.24 kg/hr which is much higher than the manual crushing capacity of 5kg/hr. It can be readily gleaned from the table that as the crushing speed increases, the crushing capacity also increases. The lowest speed of 249rpm recorded the lowest capacity of 40.49 kg/hr which is significantly lower than the two treatments. This agrees with the study of Bullan et al. (2018) that as the speed increases, the crushing capacity also increases in size reduction machine. On the other hand, there is a significant difference in the crushing capacity of the machine.

Crushing Efficiency. The crushing efficiency of the oyster crusher machine is also presented in Table 1, taking into considerations the weight of input materials and weight of crushed materials, expressed in percent. The crushing efficiency ranged at 84.35% - 92.56% with significantly lower efficiency at 348rpm. This result showed that 348rpm may have the highest crushing capacity but its efficiency was significantly lowered. Treatment 2 at 290rpm had statistically the same crushing capacity with 348rpm but the former's efficiency did not suffer significantly. In fact, its efficiency is even higher than the lowest 249rpm, though not statically significant.

Power Consumption. Power consumption of the machine ranged from 19.01–33.37 W-hr. Significant differences between the three treatments were noted in the power consumption of the machine. Slower rpm consumed more power than higher rpm. Highest power consumption of

Table 1

Performance evaluation of the oyster crushing machine

Treatment (rpm)	Crushing Capacity (kg/hr)	Crushing Efficiency (%)	Power Consumption, W-hr
348	55.00[a]	84.76[b]	20.10[c]
290	53.11[a]	90.32[a]	23.70[b]
249	40.78[b]	90.24[a]	31.16[a]

Means with the same letter are not significantly different at 5% by LSD

20.10 W-hr was recorded at the lowest 249rpm while lowest power consumption was noted in the highest 348rpm.

From these parameters, it is readily apparent that 290rpm is the optimum speed for the oyster shell crushing machine. It had comparable crushing capacity with the highest rpm but its crushing efficiency did not suffer, in fact it's the best among the treatments, and its power consumption was reasonably low.

Cost and Return Analysis of the Oyster Shell Crusher Machine

The cost of fabricating the machine is Php 46, 267.50. Some basic assumptions were considered to perform the simple cost analysis of the machine. The depreciation was determined using the straight line method with other assumptions such as: machine life of 5 years; interest on investment at 10%; tax and insurance at 3%; and repair and maintenance at 10%. The annual use of the machine was assumed to be 200 days and custom rate of Php 6/kg. These assumptions were based on the harvesting of time and the quantity of harvested oyster shells. The farmer paid an average wage of Php 270.00/day. The machine was calculated to operate with a fixed annual cost of Php12,260.89 and a variable cost of Php105.86/hr. The annual use was assumed to be 1200 hours for crushing dried oyster shells.

From these basic assumptions, the machine has a calculated annual profit of Php300,000.00 and net income of Php 160,707.11 (Table 2). The calculated payback period is 0.3 years, breakeven point of 2,459.23kg and ROI of 115.37% (Figure 7).

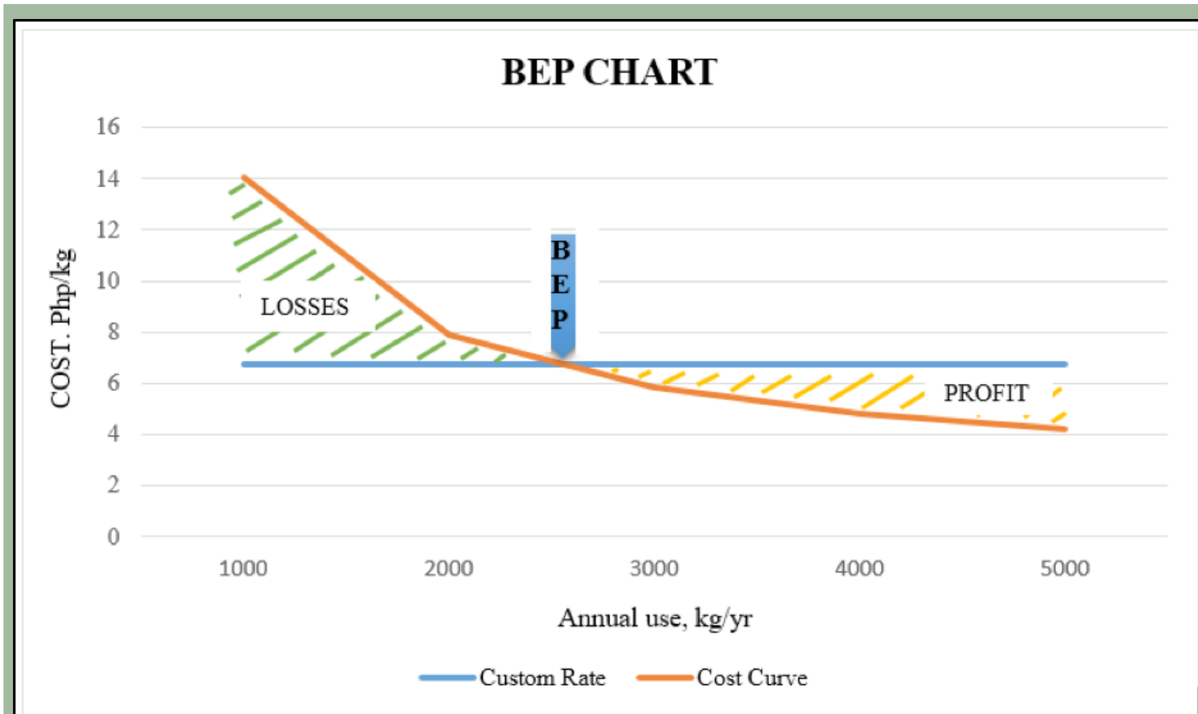

Figure 7. Break even point chart

Table 2

Assumptions and computed values for the cost analysis

Basic Assumptions	
Initial Cost	Php 46,267.50
Salvage value, 10%	10% of the initial cost
Estimated life, n	5 years
Interest	10%
Tax and Insurance	3%
Repair and Maintenance	10%
Labor requirement	2
Wage rate, Php/day	270
Total power (1.5 kW)	Php 8/kw-hr
Capacity	50 kg/hr
Annual use	1,200 hours
Operation per day	6 hours
Custom rate	Php 6/kg
Particular	**Assumed/ Computed values**
Initial Cost (Php)	46,267.50
Machine Useful Life (yr)	5
Salvage Value (Php)	4,626.75
Fixed Cost	
Depreciation Cost	8,328.15
Interest on Investment	2,544.7125
Tax and Insurance	1,388.025
Total	12,260.89
Variable Cost	
Labor Cost (Php/hr)	90
Repair and maintenance (Php/hr)	3.86
Power Cost (Php/hr)	12
Total	105.86
Total Annual Cost (Php/yr):	139,292.89
Profit During Operation	
Revenue (Php)	300,000
Net Income (Php)	160,707.11
BEP (kg)	2,459.23
Payback Period, years	0.3 (4 months)
Return on Investment, %	115.37%

Conclusions

The crushing capacity of the machine increases as the speed in crushing also increases. The crusher has the highest crushing capacity of 54.99 kg/hr at 348rpm and lowest crushing capacity of 40.78 kg/hr at 249rpm. The highest crushing efficiency is 90.32% at 290rpm, while 348rpm had the lowest crushing efficiency of 84.76%. This is due to the losses during the crushing operation using the different speeds as observed by the researchers. Also, the power consumption of the machine increases as the speed of crushing decreases. The lowest and highest power consumption of the machine are at 348 rpm with 20.10 W-hr and 249rpm with 31.16 W-hr, respectively. These results showed that the optimum speed of the device is at 290rpm with a crushing efficiency of 90.32% and has a crushing capacity of 53.11 kg/hr. In using this speed, it could attain the highest performance of the machine that would help the oyster shell farmers in gaining higher profit. The fabricated machine had a total cost of Php 46,267.50 covering materials and fabrication cost. Using standard assumptions, the computed payback period, return on investment and annual net income are 0.3 years, 115.37% and P160, 707.12 respectively.

Recommendations

Based on the observations and conclusions, it is recommended that the machine should be operate at the speed of 290rpm. Spike-shaped teeth should be added to the two solid shafts at the lower part of the roller assembly for efficient crushing and higher capacity. The sifter area should also be added to reduce losses of crushed materials, and more studies should be conducted to further improve the performance of the machine.

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