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A Comprehensive Design and Performance Assessment of a Reel-Type Blade Organic Waste Chopper Machine

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ABSTRACT

The global issue of organic waste poses a serious threat to the environment and public health. With the increasing production of organic waste driven by population growth and urbanization, waste management systems worldwide are confronted with inevitable pressures. The decomposition process of organic waste generates methane gas, contributing not only to global climate change through the greenhouse gas effect but also posing risks of air and water pollution. The primary function of organic waste lies in its ability to become a valuable resource through recycling and composting processes. The potential use of organic waste as a source of renewable energy through biogas or biomass production also presents promising prospects. The objective of this research is to design a reel-type chopper machine for more optimal waste processing. The research method employed is engineering, involving non-routine design activities to create something new in both process and form. The results of the study show that the designed reel-type organic waste shredder has dimensions of 800 mm in length, 750 mm in width, and 1042 mm in height. The machine consists of four main components: the frame hopper, shredding cylinder, and discharge hole. The chopper machine has a power of 2.2 kW, a chopper capacity of 1 ton/hour, and a cutting length of 2–5 cm. The advantages of the shredded output from this reel-type chopper machine can accelerate the decomposition and fermentation processes of organic waste. The smaller and uniformly shredded particles provide a larger surface area for the activities of decomposing microorganisms. Additionally, reel-type machines are more efficient in processing materials with high moisture levels, such as wet branches or leaves. By ensuring optimal particle size, reel-type machines also enhance the efficiency of composting, as well as the production of compost briquettes and briquettes fueled by organic waste. Therefore, the role of reel-type organic waste shredder machines is crucial in maximizing the value of organic waste, accelerating the recycling cycle, and effectively reducing environmental impact.

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1. Introduction

The issue of waste has become a significant concern, especially in densely populated areas. Waste is an integral part of human life and various activities, as it is the byproduct of both industrial and household activities. With the increasing population and human activities, the amount of waste generated has also increased. Several factors influencing the amount of waste include the population of an area, waste management systems, geographical conditions, timing, population habits, technology, and socio-economic status [1]

Organic waste poses significant challenges to the environment, and scholars have extensively studied its effects and potential solutions. A study by Jain and Pal explores the effects of both organic and inorganic wastes on the environment, providing insights into the environmental impact of different waste types and suggesting solutions to mitigate related problems [2]. Additionally, research by Shukor evaluates composting technologies for organic waste, considering environmental, social, and economic sustainability criteria. This study emphasizes the importance of assessing specific technologies to ensure they align with broader sustainability goals [3].

According to previous research [4], to establish an integrated waste management system, the concept of appropriate technology application is essential, either in the form of integrated tools or machines, to achieve desired products such as compost or biomass briquettes. The tools and machines referred to include shredding machines that process organic waste into compost or biomass briquettes. Shredding is meant to increase the surface area of organic materials, thereby accelerating the decomposition process with the help of decomposing bacteria [5]. Based on research results [6], the significant influence of the effective microorganism four bioactivator was observed in expediting the decomposition process of organic materials into Compost.

Several studies related to the chopping process have been conducted, such as the mechanism of grass cutters' rotary types [7], the design of straw chopper machines for compost production [5], the design of tobacco choppers [8], the performance of chopper of sugarcane harvester [9], and design of a bionic blade for the vegetable chopper [10]. However, in several studies, no machine specifically handles processing organic waste, considering that the characteristics of the waste are clay and bulky, it is difficult to get chopped according to SNI standards for making compost briquettes and fuel briquettes which have a high calorific value Therefore, it is necessary to have a technology for shredding waste using a reel type organic waste chopping machine that is more precise to obtain optimal results. This study aims to design and evaluate the performance of an organic waste shredding machine, encompassing machine design, functional design, structural design, machine capacity, cutting power, and cutting length. To produce optimal chopping according to SNI standards [11].

2. Materials and Methods

This study employs an engineering method, namely, making a design irregularly so that there is a new contribution both in process and form (Figure 1).

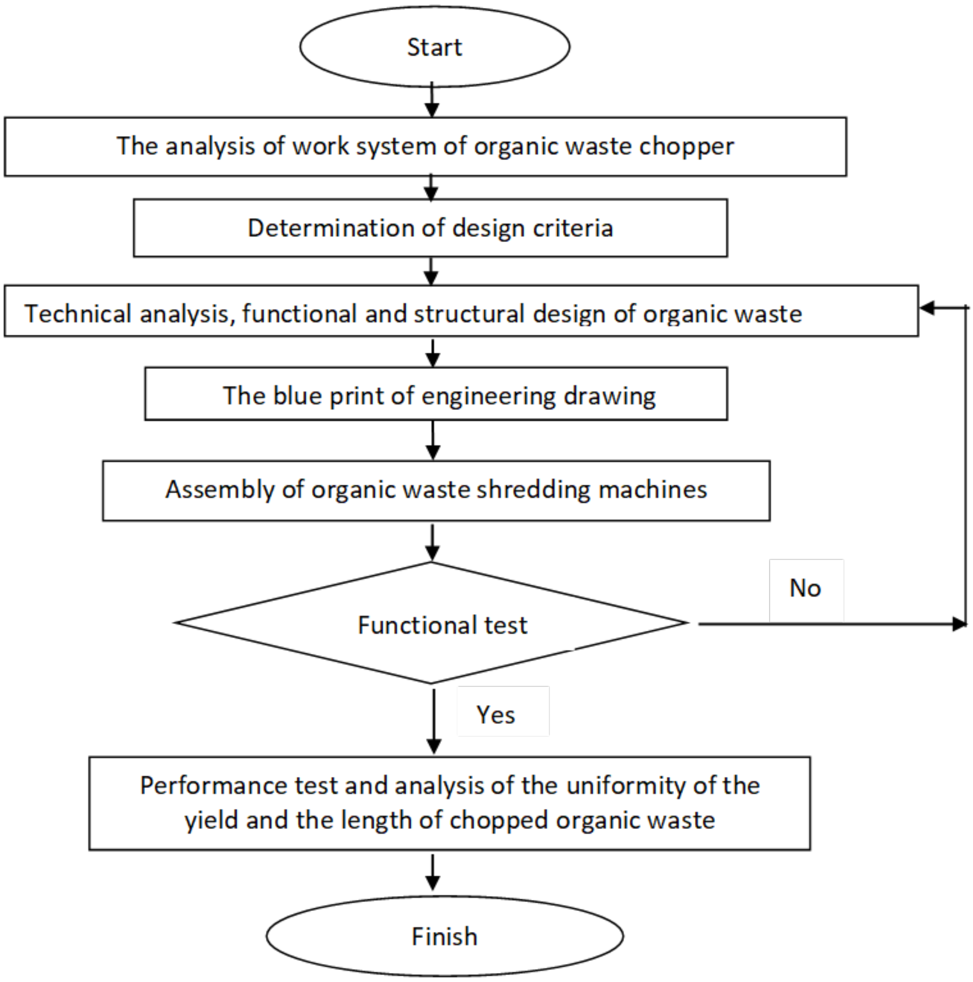


Fig. 1. Flowchart of the research stages of organic waste chopper

The materials utilized in this research include organic waste, and workpieces in the form of angle iron, shaft, plate, and rebar. The equipment used in this research comprises workshop tools, digital scales, hanging scales, belts, and pulleys, a 5 HP electric motor, bearings, a stopwatch, a tachometer, a sound level meter, a vibration meter, and a clamp meter.

In detail, the research stages in Figure 1 can be described as follows:

i. The Work System Analysis of the Organic Waste Chopper: Determining a chopping mechanism suitable to be applied to the chopper [9], in the hope that the length of the chopping process result will meet standard National Indonesia SNI standard, namely 5-10 cm.
ii. Functional Design: The functional design emphasizes the machine functionalities as a whole and the produced output. Meanwhile, this functional design consists of the mechanism analysis of the chopping blades, the chopping blade holder cylinder, the machine construction analysis, the transmission system analysis, the chopping power analysis, and the organic waste chopper ergonomic and anthropometric analysis.
iii. Structural Design and Technical Analysis: Structural design is an essential stage in determining the final chopper design, in which the hoper position, the chopping blades, the blade holder cylinder, the engine frame, the driving motor holder, and the discharge holes are assembled into a unified form and placed by the original functions and design.

Meanwhile, technical analysis is more about the calculation of shaft, pegs, bearings, chopping blade dimension, cutting angles, chopping blade cylinder, frame, weld.

iv. The Blue Print Figure of Machine Design: The whole process of structural design of the straw chopper will be presented in 2D and 3D using Autocad.

v. The Manufacturing of Chopper Machine: After the figure design was made perfectly, the next step is making and assembling the organic waste chopper.

vi. Machine Functional Test: A machine functional test will be performed to determine the function of the organic waste chopper when it operates. Has the chopper functioned according to the initial planning? If not, a more detailed design study will be conducted.

vii. Performance Test and Analysis of The Uniform of The Yield and the Length of Chopped Organic Waste: Machine performance tests include actual capacity, actual power requirements, machine efficiency, chopping energy, chopping yield, and cutting length analysis.

2.1 Technical Analysis

Technical analysis aims to determine the strength of the material from each component of the machine which is carried out using theoretical calculations and direct observations that occur in the field. The technical aspects considered in the engineering analysis of the Organic Waste chopping machine are the analysis which includes [12,13]:

2.1.1 Theoretical power requirement

The Power capacity of the propulsion engine used must be equal to or more than the propulsion power requirement. The calculation of driving force requirement [13] can be calculated by Eq. (1):

$$\mathrm{P_t} = \frac{2\pi\times\mathrm{M_t}\times\mathrm{n_c}}{60} \tag{1}$$

Whereas P_t is theoretical power (W); nc is the rotational speed of the chopping cylinder (rpm) and M_t is torque moment (Nm).

2.1.2 Transmission unit analysis

Analysis of the transmission unit aims to determine and determine the number of belts and pulleys needed in the transmission of the machine which is then matched with the transmission shaft diameter requirements. In determining the length of the belt used, it can be calculated using the equation The transmission ratio in the belt and pulley transmission system [13] can be calculated by Eq. (2)

$$N_s = \frac{P_t}{P} \tag{2}$$

where $N_{s\,t}$ is the Number of belts required; P_t is Theoretical force (W) and P is Force per belt (W).

2.1.3 Chopper capacity (theoretical)

Theoretical chopping capacity [12] can be found using equation with the components that must be known first are the density of the Organic Waste bottle, consequently the area of the chopping area, the expected length of the cut, the number of blades, and the rotational speed of the cylinder enumerator can be write as Eq. (3)

$$m_f = \frac{\rho_f A_g L_c \lambda_k n_c}{6x10^8} \tag{3}$$

where:
m_f = Chopper Capacity (kg/hour)
ρ_f = density of forage in the throat (kg/m^3)
A_g = throat area (cm^2)
L_c = theoretical length of cut (mm)
λ_k = number of knives on the cutter head
n_c = rotational speed of cutter head (rpm)

2.2 Performance Test

The performance test of the Organic Waste chopping machine aims to determine the reliability or ability of the machine to be operated under optimal conditions. Parameter measurements carried out include [12]:

2.2.1 Actual Power Requirement

The actual power measurement using a Prony break tool in the Prony brake there are two sensors used, namely the load cell to read the load and the rotary encoder to read the rotational acceleration [12]. The reading results are read by Arduino uno which is programmed with the Eq. (4):

$$P_t = \frac{2\pi . M_t . n_c}{60} \tag{4}$$

where P_t is Power (W); n_c is cleaning cylinder rotational speed (rpm) and M_t is Torque moment (Nm).

2.2.2 Chopper capacity (actual)

The actual capacity [16] of the chopping process can be determined by measuring the mass of the material that has been processed by the machine divided by the chopping time be written as Eq. (5):

$$K_{ap} = \frac{B_{bh}}{t} x3600 \tag{5}$$

where K_{ap} is the Capacity actual of the organic waste chopper (kg/hour); B_{bh} is the Mass of Organic Waste flakes from the Organic Waste chopping machine (kg) and t is the time (s).

2.2.3 Machine efficiency

The Machine efficiency [16] of chopped organic waste can be calculated using the Eq. (6):

$$\eta = \frac{K_{actal}}{K_{teoritis}} x100\% \tag{6}$$

where η is Machine efficiency (%); K_{actual} is Capacity actual machine (kg/hour); $K_{theoretical}$ is Capacity theoretical machine (kg/hour).

2.2.4 Specific energy

The Specific Energy of chopped organic waste [16] can be calculated using the Eq. (7):

$$E_{sp} = \frac{P_{actual} \quad x \quad 3600}{K_{actual}} \tag{7}$$

where E_{sp} is Machine efficiency (%); P_{actual} is Power actual machine (kW); K_{actual} is Capacity actual machine (kg/hour).

2.2.5 Percentage number of organic waste chopped yield

The percentage number of Organic Waste chopped yield [11] can be calculated using Eq. (8) :

$$R = \frac{m_{out}}{m_{in}} x100\% \tag{8}$$

where:
R = percentage number of organic waste chopped yield (%)
m_{out} = The mass of flakes of organic waste coming out of the outlet (kg)
m_{in} = Incoming organic mass (kg)

2.2.6 Percentage of the chopped length

The percentage of the length of chopped organic waste can be calculated according to SNI 7580:2010 [11] using Eq. (9)

$$P_{pk} = \frac{B_{b1}}{B_{b1}+B_{b2}} x100\% \tag{9}$$

where:
P_{pk} = Percentage of long-cut organic waste output (%)
B_{b1} = Mass of chopper organic waste with a length of less than 50 mm (grams)
B_{b2} = Mass of chopper organic waste whose length is more than 50 mm (grams)

3. Results
3.1 Criteria Design

The criteria design must follow some of the following requirements:

i. The planned capacity of the chopping machine is 1.2 tons per hour.
ii. The cutting mechanism is a reel type, chosen for its ability to handle the clay and bulky nature of organic waste.
iii. The reel is equipped with eight blades, aiming to cut organic waste into pieces ranging from 1 to 5 cm in length.

3.2 The Analysis of Work System of Organic Waste Chopper

Generally, the chopper process (Figure 2) begins with manually pushing organic waste into the hopper. The chopping cylinder rotates clockwise, entering the hopper and processing the organic waste through the chopping blades. The resulting small pieces are then discharged through the outlet hole. This chopping section is designed to cut organic waste into pieces ranging from 1 to 5 cm in length.

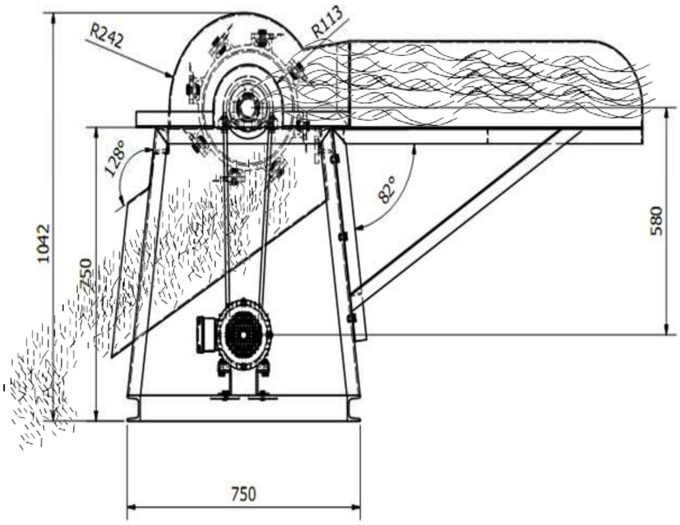


Fig. 2. Analysis of work system of organic waste chopper

3.3 Functional Design

The primary function of organic waste shredding is to process organic waste by the waste condition and desired length of pieces [18]. To fulfill this primary function, supporting functions are essential, namely feeding organic waste to be shredded and cutting the fed organic waste to the desired length of pieces.

3.4 Structure Design

The structural design results of the organic waste chopper machine, utilizing reel-type blades, are categorized into four parts: hopper unit design, chopping material unit design, transmission system design, and machine frame unit design. Following the completion of the design for these four machine units, they are assembled to form the complete unit of the organic waste chopper machine.[17]

3.4.1 Hopper

The hopper is a component of the chopping machine designed to facilitate the manual feeding of organic waste into the chopping cylinder, done horizontally. The operator stands on the right side of the machine to avoid potential splashing from the chopped material. The specifications of the hopper include a length of 1000 mm, a width of 400 mm, and a height of 550 mm (refer to Figure 3).

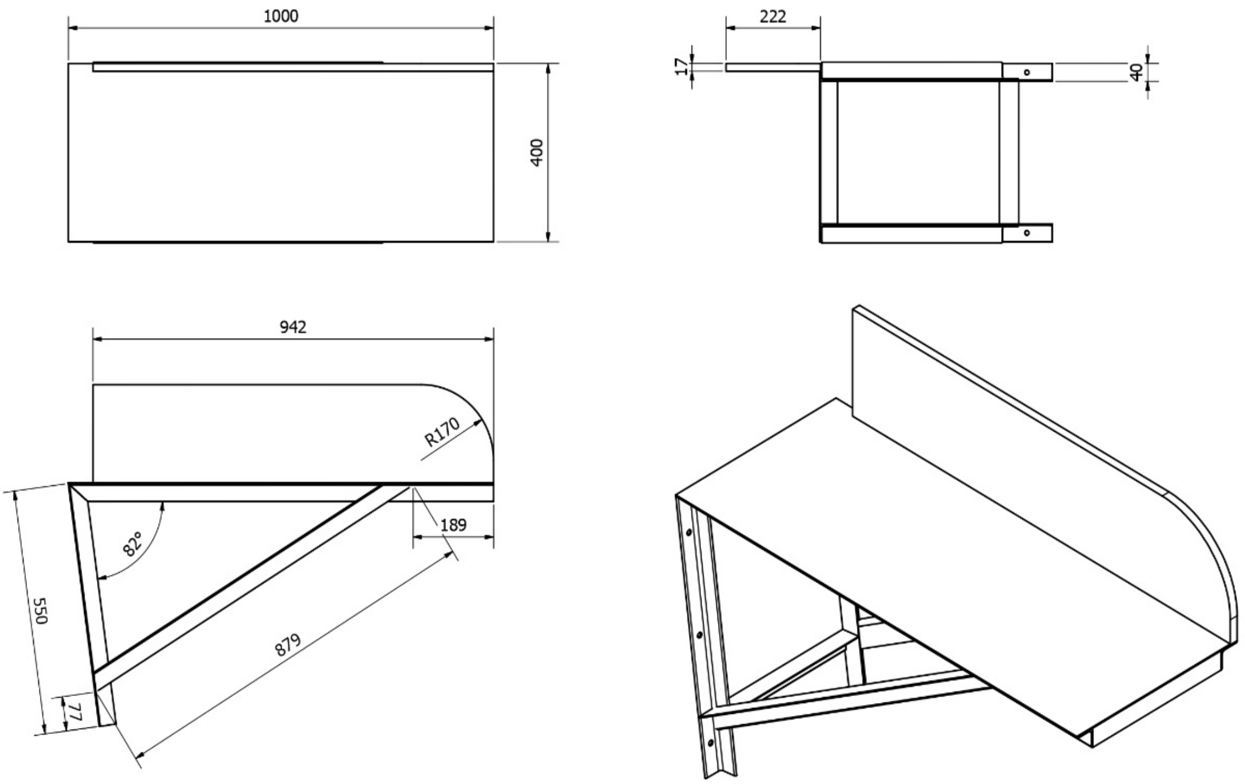


Fig. 3. Hopper

3.4.2 Chopper unit design

The blades used are reel-type blades positioned on the blade holder, which is cylindrical and functions as the cutter for organic waste [15]. This type is chosen due to the tough and bulky nature of organic waste, with the expectation of achieving even cutting results. In constructing the chopping cylinder, there are eight movable blades and one stationary blade. The blades are made of hardened steel (heat-treated). The movable blades are positioned on a cylinder with a diameter of 320 mm and a weight of 50 kg.

To facilitate the transmission system in the chopping unit, the diameter of the cylinder shaft needs careful planning to ensure the proper functioning of the chopping operation. According to calculations, the minimum diameter required for the chopping cylinder shaft is 40 mm. For safety reasons, a shaft diameter of 45 mm is used, taking into consideration market availability. The design of the shaft diameter and chopping cylinder is illustrated in Figure 4

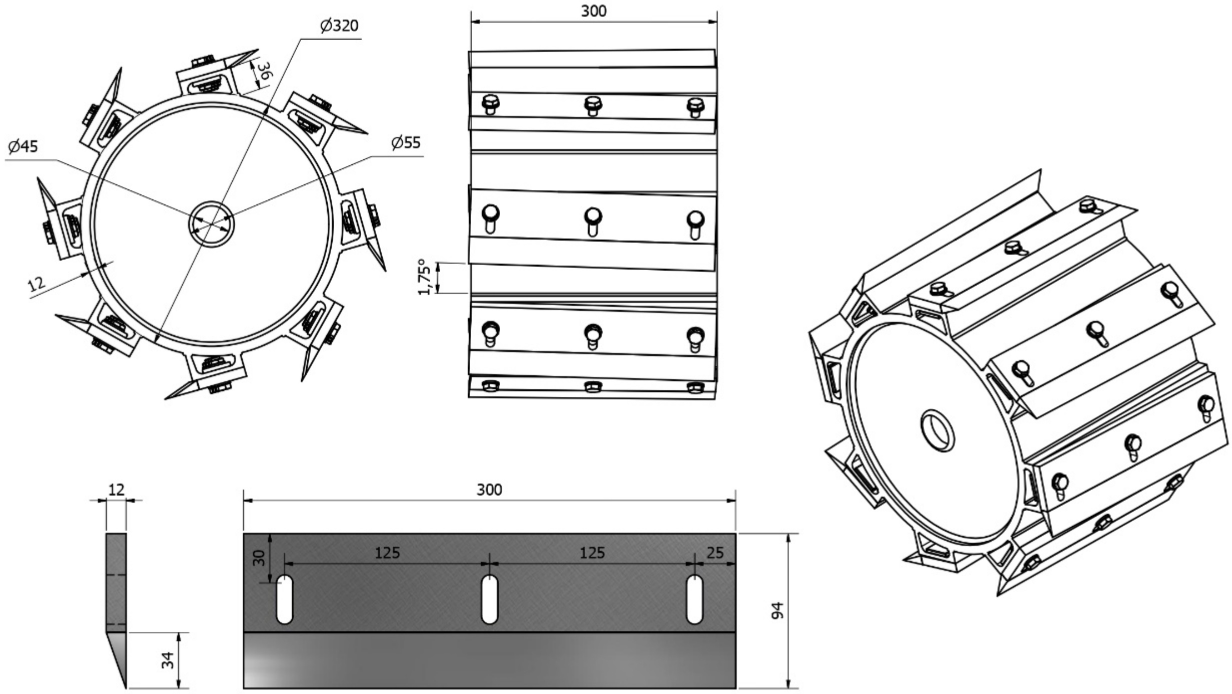


Fig. 4. Chopper unit design

3.4.3 Frame Design

The machine frame functions to support the entire organic waste chopper machine [16]. The dimensional measurements of the frame have taken into account ergonomic and anthropometric aspects for operator comfort [20]. The dimensions of the organic waste chopper machine frame are a length of 800 mm, a width of 750 mm, and a height of 750 mm, as depicted in Figure 5.

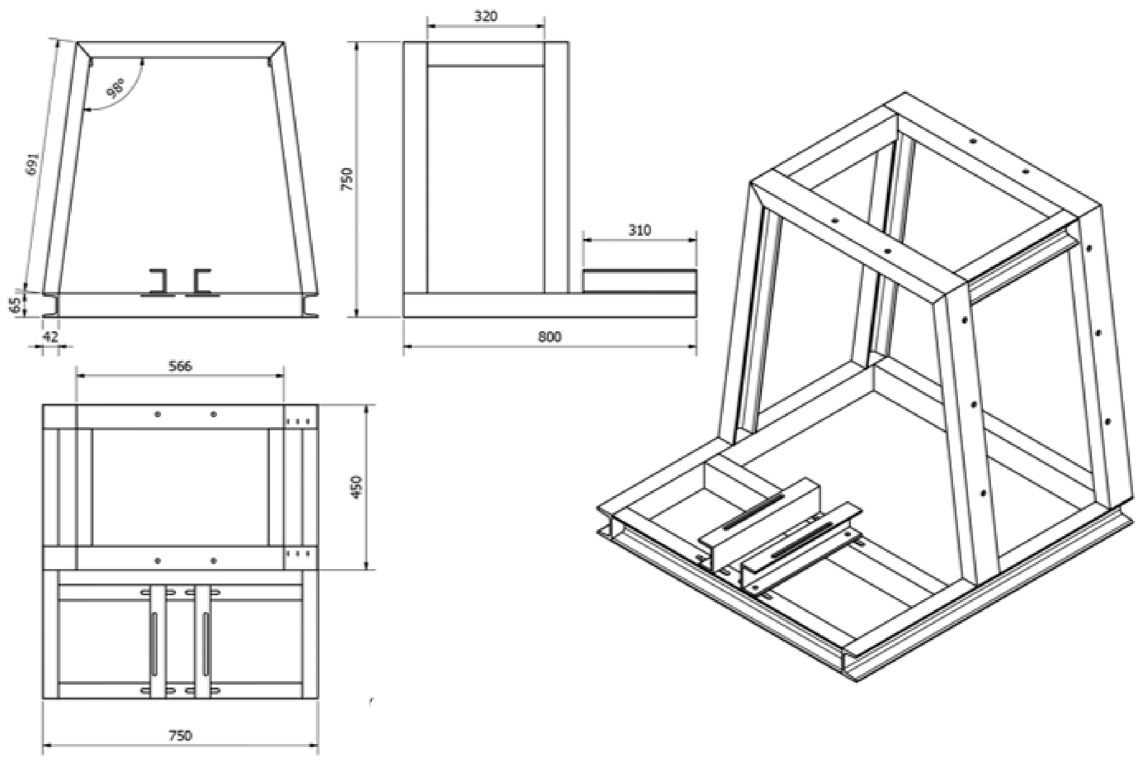
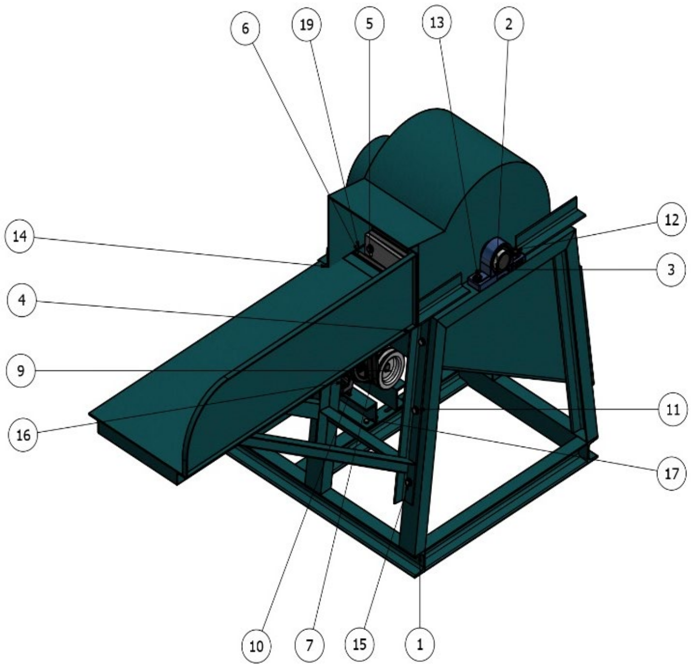


Fig. 5. Frame design

The raw material for constructing the frame includes an angle iron, chosen to provide comprehensive support to the machine [14], and a channel iron is installed under the frame to absorb vibrations and bear the load, especially from the chopping unit. These components are then assembled and connected using bolts, bearings, pulleys, and belts. It's noteworthy that the assembly of the organic waste chopper machine can be easily disassembled and reassembled, aiming to facilitate maintenance in case of damage. Specifically, the chopping blades can be periodically removed and sharpened as needed.

Overall, the design of the organic waste chopper machine, when drawn from an isometric perspective is displayed in Figure 6.



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Frame
2	2	Bearing
3	1	Shaft
4	1	Hopper Inlet
5	1	Drum Blade
6	1	Blade
7	2	V-Belt
8	1	Grooved Pulley1
9	1	Grooved Pulley2
10	1	Dynamo
11	28	Ring - 10 - 140 HV
12	4	Baut - M10 x 45
13	14	Mur - M10
14	1	Engine Cover
15	6	Baut - M10 x 20
16	4	Baut - M10 x 35
17	4	Baut - M8 x 16
18	4	Baut - M8
19	1	Hopper Outlet

Fig. 6. Design of the organic waste chopper machine

3.5 Technical Analysis

Analysis techniques refer to systematic procedures or methods used to examine, understand, and interpret information or data [17]. Technical analysis conducted on an organic chopping machine includes calculations for theoretical power requirements, transmission unit analysis, shaft analysis, frame strength analysis, and the theoretical capacity of the organic waste chopper (Table 1).

Table 1
Recapitulation Results of Technical Analysis

Parameter	Unit	Actual	Analysis Technique	Standard terms	Information
Theoretical Power Requirement					
Power Requirement	HP	8	3	Engine power ≥ power required (SNI 7580:2010)	Good
Transmission Unit Analysis					
The number of belts	Pieces	2	1,5 ≈ 2	The number of belts ≥ the number of belts required (Sularso & Suga, 2004)	Good
Shaft					
Shaft diameter	Mm	43	23	Actual diameter ≥ diameter recommended (Sularso & Suga, 2004)	Good
Frame Strength Analysis					
The frame of the chopper machine	Mm	0,044	1,82	The deflection that occurs must not exceed the permitted deflection (Pytel & Singer, 1987)	Good
Electric motor frame	Mm	0,016	1,21	The deflection that occurs must not exceed the permitted deflection (Pytel & Singer, 1987)	Good

The theoretical power required to drive the organic waste-chopping machine is 2.2 kW, while the power of the diesel driving motor used is 4.4 kW. Therefore, based on this data, it can be observed that the power of the driving motor used exceeds the overall engine power requirement, confirming compliance with SNI 7580:2010 [11]. The recommended number of belts required is 1.5, approximately 2 belts, to deliver power. The actual number of belts used is 2, meeting the standard requirements [19] for the transmission unit. Thus, the transmission reel-type organic waste chopper uses V-type B61. The recommended diameter is 23 mm, whereas the actual diameter is 43 mm. Consequently, technically, the shaft diameter meets the standard requirements. Other parameters, such as torsional deflection, were also calculated. Overall, the deflection occurring in the chopper machine frame (0.044 < 1.82) mm and the electric motor frame (0.016 < 1.21) mm is below the allowable deflection. Therefore, the frame used is deemed safe for operation, and the framework analysis employed has met the requirements. Based on theoretical calculation variables, the theoretical capacity value for the chopping process is determined to be 1.4 tons per hour.

4. Discussion

4.1 Actual Power Requirement and Actual Capacity

A reel-type chopper machine has several advantages compared to other types of choppers, especially in terms of capacity and material crushing efficiency. The machine boasts a high capacity, capable of shredding organic materials up to 1 ton per hour with a low power consumption of only 2.2 kW. In contrast, similar machines such as disk chippers, strippers, or hammer mills require a minimum power of 4.4 kW to achieve a capacity of 1 ton per hour, making the reel-type chopper more energy-efficient by 50%. The reel-type chopper also operates at a high rotation speed of up to

2200 RPM, ensuring a more efficient chopper process. Materials fed into the machine can be quickly processed by the reel, resulting in a more uniform chopped output.

4.2 Machine Efficiency and Specific Energy

Counting efficiency compares actual capacity and theoretical capacity. Based on the calculation results, the efficiency of the organic waste chopper machine for this organic waste sample is 71.4%. With an actual capacity of 1000 kg/hour and a theoretical capacity of 1400 kg/hour, this value already meets the standard. According to [12], the efficiency of the chopper is expected to be at least 70%. Meanwhile, the calculation results show that the efficiency of the organic waste chopper has reached 71.4%. Hence, based on the data, the efficiency of this organic waste shredder exceeds the standard of 71.4% > 70%; therefore, the machine meets the standards and is suitable for use. The amount of specific energy is affected and directly proportional to the power of the chopper. This implies that the greater the power required for chopping, the higher the specific energy of the machine for chopping organic waste per kilogram. In addition to being influenced by the actual power of the chopping process, the specific energy is also affected by the actual capacity. However, with this actual capacity, it is inversely proportional, so that the greater the actual capacity, the smaller the specific energy required. Moreover, the lower the actual capacity, the greater the specific energy required. The specific energy of the reel-type organic waste chopper is 7.92 kJ/kg. This value has an impact on energy efficiency, especially in the context of fuel storage or use.

4.3 Percentage Number of Organic Waste Chopped Yield and Percentage of the Chopped Length

Based on the results of the measurements, the average yield of this organic waste chopper machine was 85.86% (Figure 7) with a standard deviation (SD) value of ±4.86 and a coefficient of variation (CV) value of 5.53%. According to SNI 7580:2010, the yield value must be ≥80% to meet the testing requirements. A high yield value is crucial for users of organic waste chopping machines as it minimizes losses incurred during the organic material chopping process, including fuel costs and product failure costs. Regarding the loss of organic material that has been chopped, some of it gets stuck in the hopper, and some become entangled in the chopping knives.

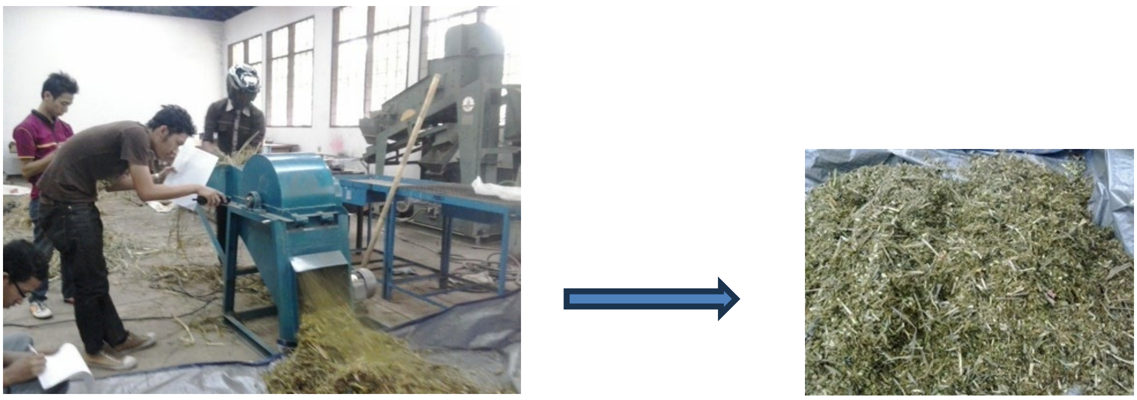


Fig. 7. Organic waste chopped yield

The percentage of chopper length represents the amount of material exiting the outlet channel of the organic waste chopping machine, with a size meeting expectation—that is, the resulting chopped organic waste having a length smaller than or equal to 50 mm. Based on the calculation results, it was determined that the average percentage of chopped length ≤ 50 mm was 91.2% with a standard deviation (SD) value of ±0.29 and a coefficient of variation (CV) value of 0.29%. These results meet the standard criteria, as per SNI 7580:2010, where the chopping results ≤ 50 mm should be at least 80%. In theory, the expected cut length is ≤ 50 mm. However, in reality, there are also cut lengths ≥ 50 mm. Several factors influencing the cutting length beyond the theoretically calculated length include the following :

i. When cutting, the litter is in a slanted position, so the size of the litter will be longer than n a straight position as shown in Figure 8.

Fig. 8. Cutting position

ii. In Figure 9 it can be seen that the cut is approaching the theoretical count, namely around 0.5 cm but has not yet broken. This is because the size of the litter is so thin that it is carried or attracted by the first knife, and may only be cut by the next knife.

Fig. 9. Cutting Organic Waste

iii. The distance between the cutting knife and the bed knife is 0.5 mm. If the thickness of the litter, especially leaves, is thinner than this value, the litter will not be cut but will be carried and entangled in the chopping cylinder as shown in Figure 10.

Fig. 10. Uncut Organic Waste

5. Conclusion

Based on the technical analysis of the reel-type organic waste chopper machine, the theoretical power requirement value is 2.2 kW, the number of belts is 2 with V type B61, a minimum shaft diameter of 23 mm, deflection in the chopping machine frame is 0.044 mm, electric motor frame deflection is 0.016 mm, and the theoretical capacity of the chopping machine is 1.4 tons per hour. The results of the technical analysis of the organic waste chopping machine indicate that it is suitable for use. Performance testing of the reel-type organic waste chopper revealed an actual capacity of 1 ton per hour, chopping efficiency of 71.4%, and a specific energy of 7.92 kJ/kg.

Overall, the design and performance test results of the reel-type organic material shredding machine demonstrate positive outcomes. This is evidenced by the notably high yield of 85.86%. A key contributing factor to this high yield is the reel-type working system, ensuring a meticulous and uniform material-shaving process. The cutting length of material less than 5 cm reaches 91.2%, highlighting the effectiveness of the slicing process. Therefore, the utilization of an organic waste chopping machine employing a reel system proves to be both effective and efficient, meeting SNI standards for the chopping process.

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References
[1] Ayilara, Modupe Stella, Oluwaseyi Samuel Olanrewaju, Olubukola Oluranti Babalola, and Olu Odeyemi. "Waste management through composting: Challenges and potentials." *Sustainability* 12, no. 11 (2020): 4456. https://doi.org/10.3390/su12114456

[2] Shukor, Junidah Abdul, Mohd Faizal Omar, Maznah Mat Kasim, Mohd Hafiz Jamaludin, and Mohd Azrul Naim. "Assessment of composting technologies for organic waste management J." *Assessment* 9, no. 8 (2018). https://doi.org/10.14716/ijtech.v9i8.2754

[3] Kharola, Shristi, Mangey Ram, Nupur Goyal, Sachin Kumar Mangla, O. P. Nautiyal, Anita Rawat, Yigit Kazancoglu, and Durgesh Pant. "Barriers to organic waste management in a circular economy." *Journal of Cleaner Production* 362 (2022): 132282. https://doi.org/10.1016/j.jclepro.2022.132282

[4] Prasetyo et al. 2012. Implementation of Appropriate Technology for Community Empowerment: Opportunities, Strategies and Challenges.Jakarta (2012).

[5] Sugandi, W., A. Yusuf, A. Thoriq, and A. Kramadibrata. "Designing of straw chopper machine for compost production." *International Journal on advanced science engineering information technology* 8, no. 5 (2018): 2122-2127. http://dx.doi.org/10.18517/ijaseit.8.5.5810

[6] Andriany, Fahruddin, and A. As'adi. "Effect of bioactivators types on the rate of teak Tectona grandis leaf 'seresah'decomposition, in the campus Unhas Tamalanrea." *Bioma: Jurnal Biologi Makassar* 3, no. 2 (2018): 31-42. https://doi.org/10.20956/bioma.v3i2.5820

[7] Pirchio, Michel, Marco Fontanelli, Fabio Labanca, Christian Frasconi, Luisa Martelloni, Michele Raffaelli, Andrea Peruzzi et al. "Comparison between different rotary mowing systems: Testing a new method to calculate turfgrass mowing quality." *Agriculture* 8, no. 10 (2018): 152. https://doi.org/10.3390/agriculture8100152

[8] Febrina, Dewi Cahya. "Prototype of Automatic Tobacco Chopper Using PLC Omron CPM1-A Type." *INAJEEE (Indonesian Journal of Electrical and Electronics Engineering)* 6, no. 1 (2023): 13-18.

[9] Xu, Hai, Tao Wu, Qingting Liu, and Jinxin Li. "Research on the cut-throwing performance of chopper of sugarcane harvester." *Computational Research Progress in Applied Science & Engineering (CRPASE)* 5, no. 03 (2019): 85-91.

[10] Tong, Jin, Shun Xu, Donghui Chen, and Mo Li. "Design of a bionic blade for vegetable chopper." *Journal of Bionic Engineering* 14, no. 1 (2017): 163-171. https://doi.org/10.1016/S1672-6529(16)60387-6

[11] SNI 7580:2010. Organic Fertilizer Material Counting Machine Standard. National Standardization Agency of Indonesia. 2010

[12] Srivastava, Ajit K., Carroll E. Goering, Roger P. Rohrbach, and Dennis R. Buckmaster. "Engineering principles of agricultural machines." (1993): S774. https://doi.org/10.13031/epam.2013
[13] Mott, Robert L. *Machine elements in mechanical design*. Pearson Educación, 2004.
[14] Ramnath, B. Vijaya, C. Elanchezhian, J. Jeykrishnan, R. Ragavendar, P. K. Rakesh, J. Sujay Dhamodar, and A. Danasekar. "Implementation of reverse engineering for crankshaft manufacturing industry." *Materials Today: Proceedings* 5, no. 1 (2018): 994-999. https://doi.org/10.1016/j.matpr.2017.11.175
[15] Nur, Ichlas, Nofriadi Nofriadi, and Rusmardi Rusmardi. "Pengembangan Mesin Pencacah Sampah/Limbah Plastik dengan Sistem Crusher dan Silinder Pemotong Tipe Reel." *Prosiding Semnastek* 1, no. 1 (2014).
[16] Pytel, A., and F. L. Singer. "Simple stress." *Strength of materials* (1987).
[17] Hafezalkotob, Ashkan, Aida Hami-Dindar, Naghmeh Rabie, and Arian Hafezalkotob. "A decision support system for agricultural machines and equipment selection: A case study on olive harvester machines." *Computers and Electronics in Agriculture* 148 (2018): 207-216. https://doi.org/10.1016/j.compag.2018.03.012
[18] Yantony, Didit, Harman L. Tosaleng, and Kartiny Taslim. "Rancang Bangun Mesin Pencacah Plastik Tipe Sumbu Menyudut untuk Usaha Mikro." *JTERA (Jurnal Teknol. Rekayasa)* 4, no. 1 (2019): 47. https://doi.org/10.31544/jtera.v4.i1.2019.47-52
[19] Mott, Robert L. *Machine elements in mechanical design*. Pearson Educación, 2004.
[20] McCormick, Ernest James. "Human factors in engineering and design." (1976).