DESIGN AND CONSTRUCTION OF CHOPPER MACHINE AE02-TYPE FOR OIL PALM FROND
/
RANCANG BANGUN DAN KONSTRUKSI MESIN PENCACAH TIPE-AE02 UNTUK PELEPAH SAWIT

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ABSTRACT

A low-cost and a small-scale chopper machine for oil palm frond (OPF) was locally designed, manufactured and simply evaluated. It's called chopper machine AE02-type. This type of machine is designed so that it can be of appropriate technology and affordable for smallholders of palm oil in Indonesia. The effect of chopper machine AE02-type operating conditions (three different blade rotation speeds: 800 rpm, 1200 rpm and, 1600 rpm; and three branches of fresh OPF with leaves was cut into ±2.0 m length at three different sections: initial, middle, and edge were investigated. The performance of the developed machinery was evaluated regarding (i) machine capacity, (ii) size of chopped OPF, (iii) percentage of chopped OPF, and (iv) chopper machine efficiency. The chopper machine AE02-type essentially consists of the hopper, mainframe, diesel engine, outlet and chopping blade. It was powered by an 8.5 hp diesel engine and the blade of a chopper is powered through a V-belt connection. Results revealed that the increase of the rotations speed was found to increase the machine capacity and chopping of OPF percentage at all OPF sections. On the other hand, it also results in smaller chopping dimensions. However, it caused a decrease in the mean values of chopping efficiency.

ABSTRAK

Sebuah mesin pencacah daun kelapa sawit berbiaya rendah dan skala kecil telah dirancang, dimanufaktur, dan diuji secara sederhana. Mesin jenis ini dirancang sedemikian rupa sehingga dapat memiliki teknologi tepat guna dan terjangkau bagi petani kecil kelapa sawit di Indonesia. Mesin ini disebut mesin pencacah tipe AE02. Pengaruh dari kondisi kerja mesin pencacah tipe AE02 (putaran pisau: 800 rpm, 1200 rpm, 1600 rpm; dan bagian pelepah sawit dengan dengan panjang ±2,0 m: bagian pangkal, bagian tengah, bagian ujung) telah diselidiki. Parameter kinerja mesin yang diamati diantaranya adalah (i) kapasitas mesin pencacah, (ii) ukuran cacahan pelepah, (iii) persentase pelepah tercacah, dan (iv) efisiensi mesin pencacah. Mesin pencacah tipe AE02 terdiri dari saluran pengumpanan, rangka, mesin penggerak, saluran pengeluaran, dan pisau potong. Mesin penggerak menggunakan diesel berdaya 8,5 hp dan sistem transmisi menggunakan sabuk V-belt. Hasil penelitian menunjukkan bahwa peningkatan kecepatan putar mesin pencacah akan meningkatkan kapasitas mesin dan persentase pelepah yang tercacah pada semua bagian pelepah sawit. Di sisi lain, peningkatan kecepatan putar menghasilkan dimensi cacahan yang lebih kecil. Namun, hal ini menyebabkan penurunan efisiensi mesin pencacah.

Nomenclature			
n_1	Speed of driving motor, rpm	W_{OC}	Weight of OPF chopper, g
n_2	Speed of the blade shaft, rpm	W_{NOC}	Weight of OPF losses, g
d_1	Diameter of driving pulley, m	π	Constant
d_2	Diameter of the driven pulley, m	T	Time, s
W_t	Total weight of OPF put into the machine, g	Cc	Capacity of the chopper machine, kg·h^{-1}
T	Torque, Nm	M_S	Mass of the shaft, kg
F_1	Tight side, N	τ	Torque generated, N·m
F_2	Slack side, N	M_P	Mass of the pulley, kg
c	Centre to centre distance of driving and the driven pulleys, m	M	Total mass of the material contain in blade, kg
M_B	Mass of chopping blade, kg	d	Diameter of shaft, mm
M_b	Maximum bending moment, Nm	M_{OPF}	Mass of OPF, kg
ω	Angular speed of blade, rpm	Mt	Moment of torsion, N·m
K_b	Combined shock and fatigue factor applied to bending moment	Kt	Combined shock and fatigue factor applied to the moment of torsion
n	Revolution per minute of blade, rpm	P	Power required by the machine, W
S_s	Allowable shear stress, Mpa	μ	Coefficient of friction
η_c	Chopper efficiency, %	r_d	Radius of the blade, m
η_{oc}	Percentage of chopped OPF, %	F	Total force, N

INTRODUCTION

The most abundant biomass from oil palm plantation is not oil palm empty fruit bunch (OPEFB) (*Raju and Sitorus, 2017)* or oil palm trunk (OPT) (*Zahari et al., 2012)*. The most generated oil palm biomass is oil palm frond (OPF), which amounted to 83 million tonnes (wet weight) annually (*MPOC, 2011*). OPF is obtained during pruning for harvesting fresh fruit bunch (FFB), therefore it is available daily. OPF is currently under-utilized as the plantation owners believe that all the OPF are necessary for nutrient recycling and soil conservation (*Hassan et al., 1994*, *Bulan et al., 2017*).

Hence, pruned fronds are just left in the plantation. OPF are left natural rotting between the rows of palm trees, mainly for soil conservation, erosion control and ultimately the long-term benefit of nutrient recycling. However, according to researchers (*Bulan et al., 2017*, *Bulan et al., 2015*) natural rotting takes a long time for an OPF. The large quantity of fronds produced by a plantation each year makes them a very promising source of raw material for compost (*Hassan et al., 1994*). However, Study from researcher (*Zahari et al., 2012*) shows that OPF does not contain high metal contents as widely thought, but it contains high carbohydrates in the form of simple sugars. Therefore, part of the OPF can be utilized for other purpose without affecting the nutrient recycling process.

One of the OPF left on the plantation can be processed into compost. The composting process requires a size reduction process called chopping. A chopper machine for OPF with AE01-type (Figure 1) has been designed and tested in terms of performance (*Bulan et al., 2017*; *Bulan et al., 2015*; *Bulan et al., 2016*). This machine has dimensions of length, height and width respectively 1964 mm, 1902 mm and 1567 mm. This machine also has a weight and capacity of 500 kg and 1966 kg·h^{-1}, respectively.

However, the design of the AE01-type OPF counter still has the disadvantage of being too large and not practical/portable to be transported to the plantation or field. Also, the AE01-type chopper machine cannot be categorized as appropriate, affordable and inexpensive technology to be obtained by smallholders of palm oil in Indonesia. Therefore, it is important to develop a type AE01 chopper machine for OPF that can overcome these disadvantages. The results of the development of the chopper machine are called AE02-type (second generation of AE01-type). The advantages of this designed machine are a low-cost and a small-scale chopper machine.

Therefore, the purpose of this study is to design, manufacture and evaluate the performance of an AE02-type OPF machine.

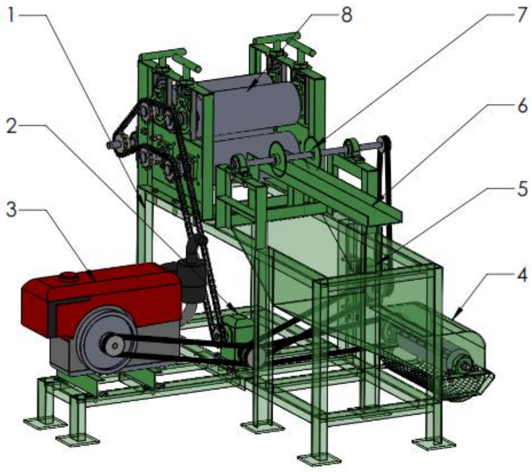

Fig. 1 - Integrated chopper machine AE01-type

1-Frame/stands; 2-Gear box system (1:30); 3-Diesel engine; 4-Chopper unit; 5-Gear box system (1:10); 6-feed channel; 7-Cutter for leaves OPF; 8-Compression unit for OPF

MATERIALS AND METHODS

Machine descriptions and design consideration

As shown in Figure 2-3, The chopper machine for OPF consists of the following major parts: hopper, mainframe, 8.5 hp diesel engine, outlet and chopping blade. The chopping knife consists of 30 blades and 4 fan plates. The total of chopping blade is 30 pieces with 3 pieces per circle and 10 rows. The distance between the blades is 183 mm. The total length of the shaft is 790 mm. The thickness of the blade is 0.5 mm. In operation, OPF will be fed from the hopper to enter the chopping knife. The chopper will chop and distribute the OPF for 550 mm. Furthermore, the OPF that arrives at the end of the chopping knife will be pushed by the fan plate out through the outlet. Materials used for fabrication of this machine are locally available at have affordable costs.

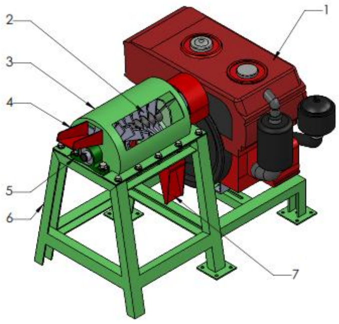

Fig. 2 - Isometric view of the machine

1-Diesel engine; 2- Chopper blade; 3-Top cover for chopper blade; 4-Hopper 5-Bearing; 6-Frame/stands; 7-Outer

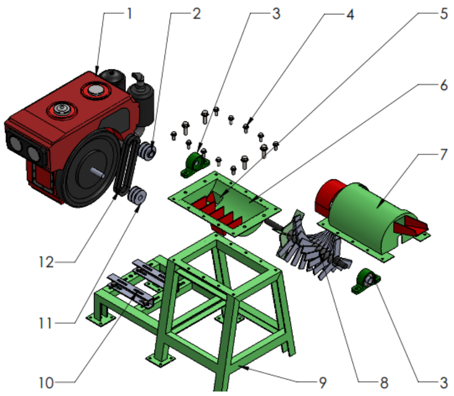

Fig. 3 - Exploded view of the machine

1-Diesel engine; 2-Pulley of the blade shaft; 3-Bearing; 4-Nut-bolt; 5-Outer; 6-Bottom cover for chopper blade; 7-Top cover for chopper blade; 8-Chopper blade; 9-Frame/stands; 10-Frame for diesel engine; 11-Pulley of driving motor; 12-V-belt

Factors considered in the design of this machine were construction cost, the materials availability, machine components strength, construction materials simplicity, ease of operation, maintenance, easy inspection, serviceability, maintenance of the machine and energy requirement. Also, the necessary properties of agricultural materials considered were: the physical and mechanical properties of the oil palm frond (OPF).

Design of chopper machine elements

Power Requirement

The machine power requirement is a function of force upon materials inside the blending chamber such as the weight of the blending blade, the shaft and machine pulley. It is given by below equations (1-5) as reported by researcher (*Khurmi and Gupta, 2005; Sitorus and Sartika, 2017; Sitorus et al., 2017*).

$$P = \frac{2\times\pi\times n\times\tau}{60} \tag{1}$$

$$\tau = F\times r_d \tag{2}$$

$$F = M\times r_d\times\omega^2 \tag{3}$$

$$\omega = \frac{2\times\pi\times n}{60} \tag{4}$$

$$M = M_{OPF} + M_B + M_S + M_P \tag{5}$$

Belt design

The shaft speed was determined using equation (6) and length of belt was calculated by equation (7) (*Khurmi and Gupta, 2005*). A standard V-belt C522 size having top width of 9.5 mm, bottom width of 4 mm and 8 mm thicknesses was used. The V-belt was chosen to minimize slippage during motion transfer.

$$\frac{n_1}{n_2} = \frac{d_2}{d_1} \tag{6}$$

$$L = 2c + \frac{\pi(d_2+d_1)}{2} + \frac{(d_2-d_1)^2}{4c} \tag{7}$$

Belt forces

The forces on the belt were calculated according to researchers (*Schmid et al., 2014; Kilanko, 2017*) by equation (8-9).

$$T = \frac{(F_1-F_2)\times d_1}{2} \tag{8}$$

$$\frac{F_1}{F_2} = e^{\mu\left(180-2\left(\sin^{-1}\left(\frac{d_1-d_2}{2c}\right)\right)\right)\left(\frac{\pi}{180}\right)} \tag{9}$$

Shaft diameter

Based on the design, the machine used a vertical shaft with a large part of its stress caused by bending and torsion load. It has little or no load to cause buckling. Hence, the diameter of the shaft was calculated using equation (10) (*Khurmi and Gupta, 2005; Kolawole and Ndrika, 2012; Olughu and Simonayan, 2017*).

$$d^3 = \frac{16}{\pi\times S_s}\sqrt{(K_b\times M_b)^2+(K_t\times M_t)^2} \tag{10}$$

Design of chopper machine elements

In order to study, composition and distribution in the petiole of the OPF, several branches of fresh OPF with leaves were cut into ± 2.0 m length at three different sections; initial, middle and edge as shown in Fig. 4. Three levels of blade rotation speeds (800 rpm, 1200 rpm, and 1600 rpm calculated using the method by researcher (*Ogunsina and Bamgboye, 2014*) were used for three branches of fresh OPF. The parameters determined during the machine evaluation were machine capacity, size of chopped OPF, percentage of chopped OPF and chopper machine efficiency.

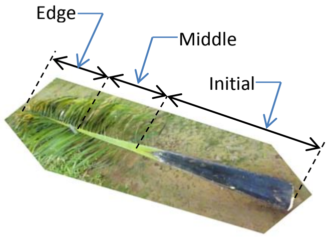

Fig. 4 - Schematic diagram of fresh oil palm frond (OPF) with leaves

The machine was evaluated based on two indices that include percentage of chopped OPF (η_{oc}) and chopping efficiency (η_e) was done by researcher (*Kolawole and Ndrika, 2012; Ojolo et al., 2010; Adekanye and Adelakun, 2018; Drees et al., 2018*). These were calculated respectively by using equations (11-12).

$$\eta_c = \frac{W_{oc} + W_{noc}}{W_t} \times 100\% \tag{11}$$

$$\eta_{oc} = \frac{W_{oc}}{W_t} \times 100\% \tag{12}$$

This is also referred to as the rate of chopping. The capacity of the machine was evaluated as the quantity of the OPF the machine could process within a recorded time (*Fadele and Aremu, 2016; Aremu and Fadele, 2011*). In this case, OPF was introduced into the machine while the time for the chopping operation to complete was recorded. This was calculated using equation (13).

$$C_c = \frac{3.6 \times 10^6 \times W_t}{T} \tag{13}$$

RESULTS

Size of chopped OPF

The average values of the size of chopped OPF at different rotation speeds (800 rpm, 1200 rpm, and 1600 rpm) and sections of OPF (initial, middle and edge) are plotted in Figure 5. It can be observed that, at given rotation speeds and sections of OPF, the size of chopped OPF decreased with the increase of the rotation speeds. The largest and smallest chopped sizes are respectively the edge sections and middle sections. The smallest size of chopped OPF from this research is 1.66 cm.

Machine capacity

The machine capacity versus rotations speed is demonstrated in Figure 6. It could be noticed that increasing the rotations speed resulted in increasing the machine capacity at other parameters used in this study. These results may attribute to increasing rotations speed from the blade. The results of this study also show that chopped on the initial sections OPF gives a larger capacity of the machine than the others. This is due to the initial sections OPF having harder structural characteristics than the others (*Yusri et al., 1995; Shafawati and Siddiquee, 2013; Bulan et al., 2017; Anyaoha et al., 2018*). It makes the chopping process easier to do with the blade. The highest machine capacity from this study is 116.98 kg·h^{-1}.

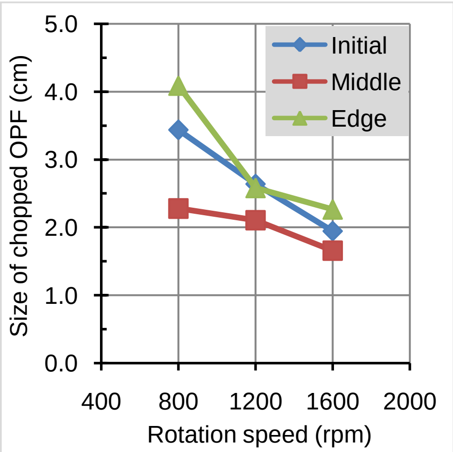

Fig. 5 - Effect of blade rotation speeds and sections of OPF on the size of chopped material

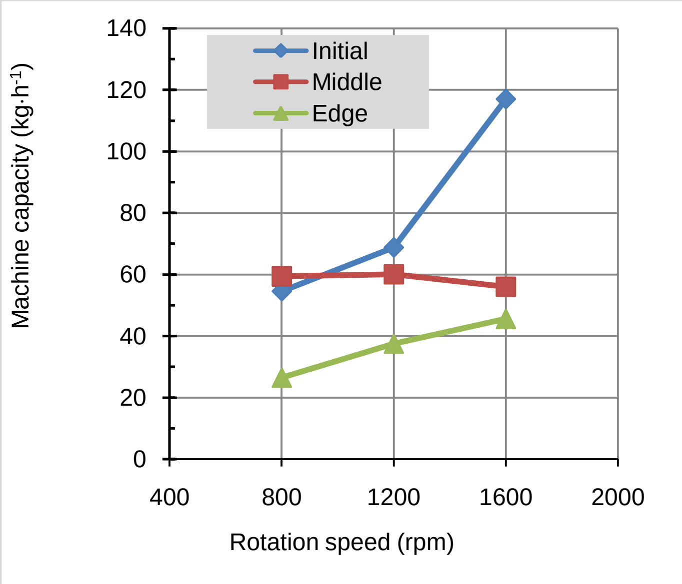

Fig. 6 - Effect of blade rotation speeds and sections of OPF on the machine capacity

OPF chopping percentage

Data of the OPF chopping percentage as influenced by the different operation variables considered in this study is shown in Figure 7. At given rotation speeds and sections of OPF, the OPF chopping percentage was observed to decrease with increasing the rotation speed. For example, an increase in the rotation speed from 800 rpm to 1600 rpm caused the OPF chopping percentage increase from 66.98% to 87.59% in the initial sections.

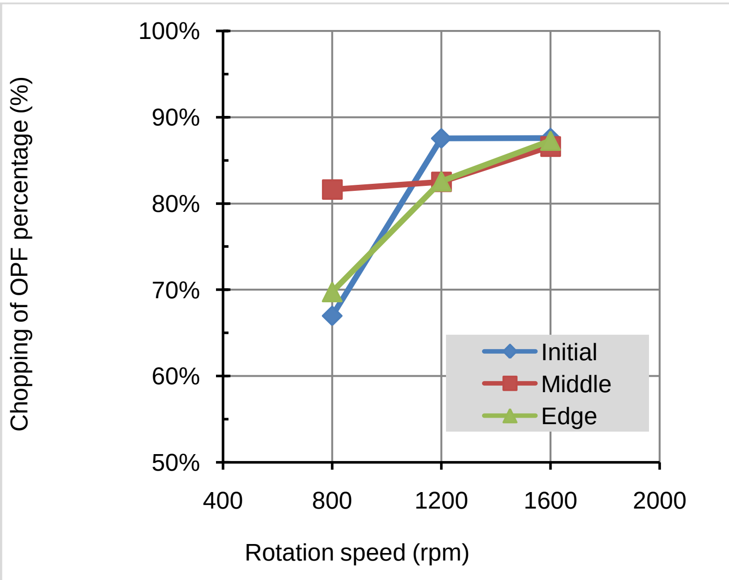

Fig. 7 - Effect of blade rotation speeds and sections of OPF on the chopping percentage

Chopping Efficiency

The average values of the chopping efficiency at rotation speeds levels and sections of OPF are plotted in Figure 8. It shows that increasing rotation speeds from 800 rpm to 1200 rpm can be increasing chopping efficiency in all treatments. However, increasing rotation speeds from 1200 rpm to 1600 rpm can be decreasing chopping efficiency in all treatments.

These results may be due to increasing rotation speeds causing a short time to carry out OPF chopping by the knife so that the OPF becomes non-chopped.

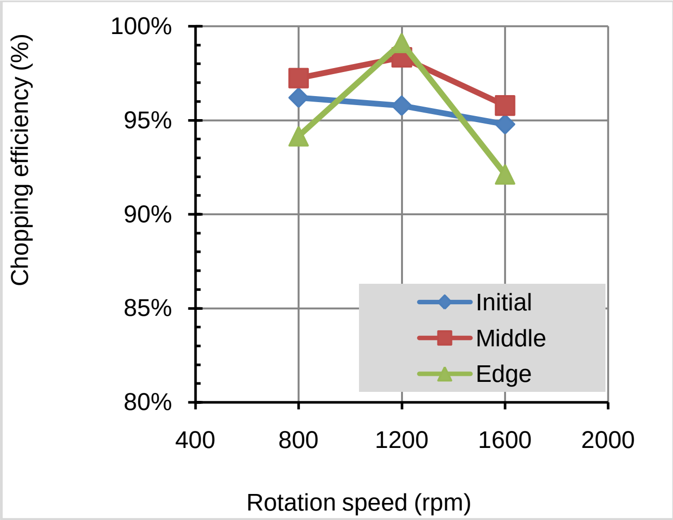

Fig. 8 - Effect of blade rotation speeds and sections of OPF on the chopping efficiency

CONCLUSIONS

A low-cost and a small-scale chopper machine for oil palm frond (OPF) locally was designed and manufactured. The performance of the developed machine was evaluated at three rotation speeds and three sections of OPF. The increasing of the rotations speed was found to increase the mean value of the machine capacity and chopping of OPF percentage at all OPF sections. It also results in smaller chopping dimensions. However, it caused a decrease in the mean values of chopping efficiency.

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