PARAMETERS OF STALK BIOMASS CUTTER

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Abstract. The topic of this paper deals with biomass briquettes from long hemp, reed and reed canary grass stalks. The orientation of straw or reed stalks had to promote binding by the pressing operation. The specific briquetting energy of coarse chopped arranged reed and hemp stalk particles ranges from 51.61 $kJ \cdot kg^{-1}$ to 67.23 $kJ \cdot kg^{-1}$. Arranged structure of biomass particles in briquetting die is recommended for significant increasing of durability of stalk material briquettes. The splitting force of the hemp stalk briquettes ranges from 110 $N \cdot mm^{-1}$ to 122.37 $N \cdot mm^{-1}$, the splitting force of the arranged reed particles lies between 65 $N \cdot mm^{-1}$ and 80 $N \cdot mm^{-1}$. The specific splitting force is 2 to 5 times higher than for non arranged stalk briquettes. New briquetting equipment is necessary to be designed for biomass particle arranging before pressing. The objective of the study is to develop a method for determination of the specific cutting energy for stalk materials. The article presents the specific cutting energy calculation method and the results of experiments for determining the specific energy for different stalk biomass. The measurement results show that the specific cutting energy of hemp stems reaches 274 $J \cdot m \cdot kg^{-1}$, 50.3 $J \cdot m \cdot kg^{-1}$ for lake reeds, and for reed canary grass – only 7.8 $J \cdot m \cdot kg^{-1}$. These values will be used in calculation of the energy consumed in the cutter.

Keywords: biomass, cutters, cutting energy.

Introduction

The basic standards for solid biofuels are developed by the Technical Committee - CEN/TC 335 Solid Biofuels. The Standard EN 14961: Solid Biofuels – Fuel Specification and Classes determine the briquette density ρ = 0.8-1.2 $g \cdot cm^{-3}$. The density of ρ > 1.0 g·cm-3 is recommendable for high quality wood briquettes. This value had been used for evaluation of herbaceous material densification results. In the previous investigations it was stated that the density of the arranged reed and hemp stalk particles exceeds the recommended in the standards 1000 $kg \cdot m^{-3}$ and reaches the value 1185 $kg \cdot m^{-3}$ for the arranged hemp stalk particles with the length 150 mm and briquetting pressure 212 MPa. The splitting force of the hemp stalk briquettes ranges from 110 $N \cdot mm^{-1}$ to 122 $N \cdot mm^{-1}$, the splitting force of the arranged reed particles lies between 65 $N \cdot mm^{-1}$ and 80 $N \cdot mm^{-1}$ [1]. New briquetting equipment is necessary to be designed for biomass particle arranging before pressing. Reeds in several countries are commonly used for roof building. The necessary material for it is collected in bundles. This harvesting technology could be used also for reed material planed for briquetting. Stalks in bundles already are oriented in the direction necessary for it. Actuality of this paper is connected with the bundle cutter which provides stalk orientation after cutting. Crushing energy is an important parameter for characterizing biomass cutting machines. Crushing energy reduction reduces the cost of briquettes and increases the competitiveness of the market for that fuel. The objective of the study is to develop a method for determination of the specific cutting energy for stalk materials.

Materials and methods

The study was carried out in the Institute of Mechanics, Faculty of Engineering. There are several methods used in biomass cutting. It has been proved that the lowest energy consumption of stalk shredding provides "shear cutting" [2]. In the result of the research a cutting method with two rotating knife rollers was developed, Fig. 1. The experimental model of the cutter was designed and experimentally tested, Fig. 2. The cutter consists of two rotors with blades that rotate with the synchronization gears 3. The blades 2 are mounted on the rotor and are powered by an electric motor 4. Biomass (common reed stalks) is fed to the knives on the tray 5. Angular velocity of the rotor was measured using the tachogenerator 6. In previous studies geometric and kinematic parameters of the stalk biomass cutter were evaluated [3].

To determine the cutting energy of the biomass stalks, the experimental tests were carried out. Energy consumption for stalk cutting has been investigated using experimental equipment, Fig. 2. To calculate the cutting energy the electric drive voltage and current consumption were measured. The measurement data were recorded with a 12-bit virtual data logger *Picoscope 4424*. Measurement error for this data logger does not exceed ± 1 %. Further the obtained data were imported in *Excel* datasheets and the energy consumption for every cut was calculated. The total cutting power for one cut was represented by the area underneath the entire power-time curve, Fig. 3. No-loading energy was recorded and subtracted from the total energy and free rotation periods were excluded from the diagrams.

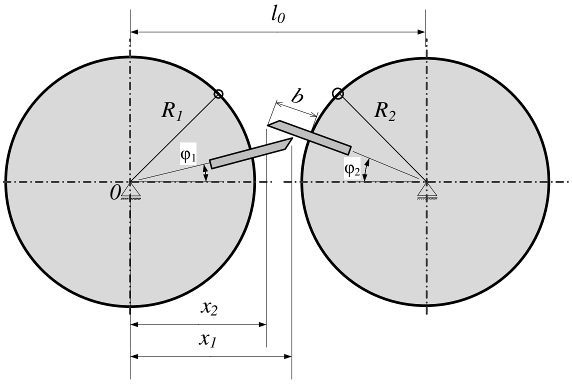


Fig. 1. **Working principle of the cutter [3]**

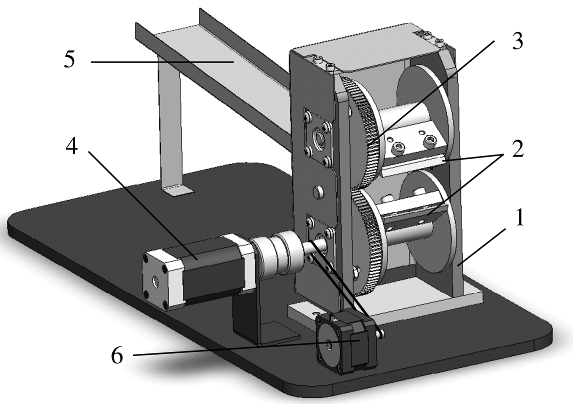


Fig. 2. **Experimental cutter design:** 1 – body; 2 – blades; 3 – gears; 4 – electric drive; 5 – tray; 6 – tachogenerator

The calculation of the energy for one cut E_{1i} is done according to equation (1):

$$E_{1i} = \left[\left(\frac{P_2 + P_1}{2} \right) \Delta t + \left(\frac{P_3 + P_2}{2} \right) \Delta t + \ldots + \left(\frac{P_n + P_{n-1}}{2} \right) \Delta t \right], \quad (1)$$

where E_{1i} – is energy for one cut, J;
P_1 – first data point, W;
P_2 – second data point, W;
P_n – nth data point, W;
Δt – time interval between data points, ms.

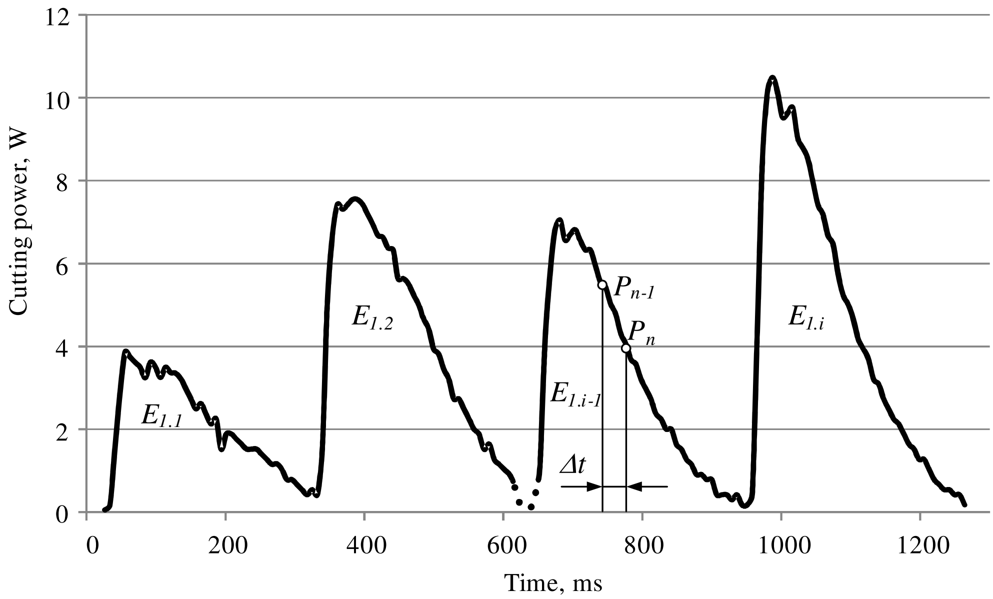


Fig. 3. **Cutting power depending on the cutting time**

Stalk biomass samples were prepared using a different number of stalks for one sample. For the experiments air dried reed stalks were used. The samples were weighed using electronic scales with measurement error ± 0.01 g. The sample with certain length l was cut into the same size particles with a length Δl = 280mm (Fig. 4).

In order to cut down the *n* particles from the sample, it is necessary to make $n + 1$ cut. Given that the sampling parameters are heterogeneous, the average cutting energy for one cut E_{1av} of the sample was calculated according to equation (2):

$$E_{1av} = \frac{\sum_{1}^{n+1} E_{1i}}{n+1}, \tag{2}$$

were n – number of particles (Fig. 4).

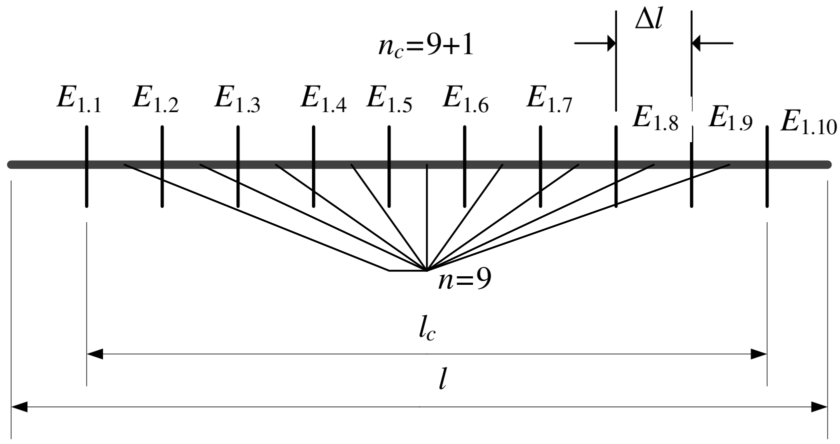


Fig. 4. **Example scheme of stalk length parameters of the cutting process**

In order to calculate the energy consumed in the shredder, it is necessary to find some universal parameter characterizing the cutting energy per unit mass and per unit particle length. The discussion below analyzes the specific energy detection method.

Results and discussion

Suppose that for the cutting energy evaluation parameter the specific energy is used. In this case, the total cutting energy E depends on the mass of the material m and the resulting particle length Δl. Assuming that the weight gain increases the cutting power, but larger particle length reduces the total energy, it can be described by the equation (3):

$$E = \frac{E_s \cdot m}{\Delta l}. \tag{3}$$

Given that $E = E_{1av} \cdot (n+1)$, from equation (3) the specific energy can be expressed as follows:

$$E_s = \frac{E \cdot \Delta l}{m} = \frac{E_{1av} \cdot (n+1) \cdot \Delta l}{m}. \tag{4}$$

Assuming that the particles are of equal length, the number of particles n can be expressed as follows:

$$n = \frac{l}{\Delta l}. \tag{5}$$

Substituting equation 4, we obtain:

$$E_s = \frac{E_{1av} \cdot \left(\frac{l}{\Delta l} + 1\right) \cdot \Delta l}{m} = \frac{E_{1av} \cdot (l + \Delta l)}{m}. \tag{6}$$

where E_s is the specific cutting energy, J·m·kg^{-1}.

The mass of the material is given by the density ρ and volume V (7):

$$m = \rho \cdot V \quad . \tag{7}$$

Then:

$$E_s = \frac{E_{1av} \cdot (l + \Delta l)}{\rho \cdot V} \quad . \tag{8}$$

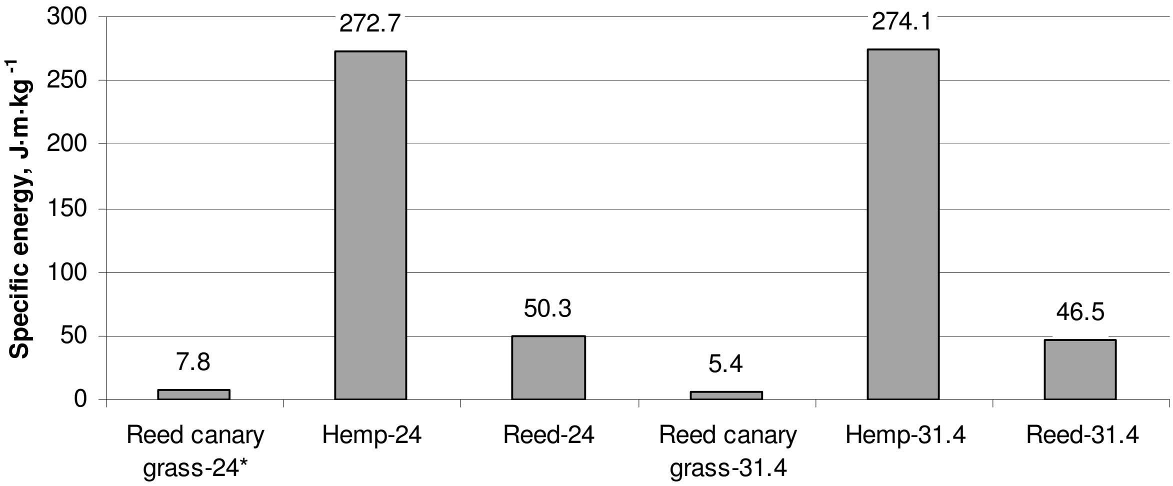
Equation (8) is recommended for practical calculation of the consumed energy, when the density and volume of the stalk material are known:

$$E = \frac{E_s \cdot \rho \cdot V}{\Delta l} \quad . \tag{9}$$

To be able to cut the calculations are necessary to know the specific energy values for different uses of biomass. The specific cutting energy of lake reed, hemp straw and reed canary grass was determined experimentally. The specific cutting energy was stated for overlay of the knives equal 5.2 mm with different rotation velocity. The samples were formed with three and five stalks for reeds, one stalk for hemp and 10 stalks for reed canary grass.

The experiments were carried out at two rotational speeds of the cutter – $\omega = 24$ s^{-1} and $\omega = 31.4$ s^{-1}.

Since biomass is inhomogeneous material, more than 10 repetitions were made with each setting. The measurement data distribution depends on the type of biomass and reaches ± 20 %.



* – Angular velocity of rotor, s^{-1}

Fig. 5. **Specific cutting energy for different stalk materials**

The experimentally obtained specific cutting energy of various stalk biomasses is displayed in Fig. 5. The specific cutting energy of hemp stalks is 274.1 J·m·kg^{-1} at the rotation speed 31.4 s^{-1}. Reducing the rotor rotation speed to 24 s^{-1}, the hemp specific cutting energy decreases for about 0.5 %. Such a reduction is not significant and it can be assumed that the rotational speed does not affect the specific cutting energy. The reed specific cutting energy is 50.3 J·m·kg^{-1} which is 5 times less than the hemp specific cutting energy. The lowest specific cutting energy was stated for reed canary grass. This is 7 times less than the reed specific cutting energy.

The experimentally obtained stalk biomass specific cutting energy will be used in the calculation of shredder parameters.

Conclusions

1. Specific cutting energy can be used as a parameter for evaluation of the shredder power consumption. It is recommended for calculation of various stalk biomasses cutting energy consumption.

2. The hemp stem specific cutting energy reaches 274.1 $J \cdot m \cdot kg^{-1}$, and it is 5 times greater than the reed cutting specific energy.
3. The reed canary grass stalk specific cutting energy does not exceed 7.8 $J \cdot m \cdot kg^{-1}$. It is 35 times less than the hemp straw specific cutting energy and 6.4 times lower than the cane specific cutting energy.

Acknowledgments

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