CUTTING PROPERTIES OF ARRANGED STALK BIOMASS

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Abstract
In Latvia, approximately 14.6% of unfarmed agricultural land can be used for herbaceous energy crop growing. Herbaceous energy crops would be the main basis for solid biofuel production in agricultural ecosystem in future. There is possibility to utilize for bioenergy production natural biomass of common reeds (*Phragmites Australis*) overgrowing shorelines of Latvian more than 2000 lakes. Common reed stalk material ultimate tensile strength average value was stated 330 ± 29 N mm^{-2}. This value testifies that common reeds are the strongest material between other energy crop stalk materials. The main conditioning operation before preparation of herbaceous biomass compositions for solid biofuel production is shredding. Therefore common reed stalks were used for cutting experiments. The main hypothesis for cutter design is that cutting method has to be used with minimum of energy consumption by reducing frictional forces to a minimum.
In experiments was used common reed bundles harvested with Seiga harvester in Pape lake. The experimental bundle cutting mechanism was equipped with a round-shaped counter knife, but the single stalk cutting mechanism was equipped with six different shaped cutting knives. The energy consumption was obtained by integrating force - displacement diagrams. Cutting energy per mass unit dependence on the length of fraction size was calculated. Specific shear cutting energy for a single common reed stalk was determined within $(0.011 \div 0.015)\cdot10^{-6}$ J m^{-2}. Common reed bundle specific cutting energy was determined within $(0.02 \div 0.09)\cdot10^{-6}$ J m^{-2}. The weighted average value was $0.06\cdot10^{-6}$ J m^{-2}. Specific cutting energy for reed bundle cutting significantly exceeded the single stalk specific cutting energy, therefore cutting in thin layers is recommended.
Key words: herbaceous energy crops, common reed bundle cutting.

Introduction

Latvia has target (Directive 2009/28/EC, 2009) in 2020 for renewable energy resources to be 40% in gross final consumption of energy. Common reeds (*Phragmites Australis*), as a natural energy crop material, in Latvia can be found in wetlands and on the shores of rivers, lakes and the Baltic Sea. Mainly they grow on shorelines of Latvian lakes. Therefore herbaceous energy crop growing on these lands can provide sustainable farming practice. There is possibility to utilize for bioenergy production natural biomass of common reeds, overgrowing shorelines of Latvian more than 2000 lakes. The main conditioning operation before preparation of herbaceous biomass compositions for solid biofuel production is shredding. Naturally herbaceous biomass is a material of low density (≈ 60 kg m^{-3}) and not favorable for transportation on long distances. Shredding can increase bulk density to 100 ÷ 200 kg m^{-3}.

The purpose of research was to determine cutting properties of common reeds, arranged in bundles. Shredding is the main conditioning operation before preparation of herbaceous biomass compositions for solid biofuel production. According it cutting properties of common reed bundles has to be investigated in order to find the minimum energy consumption for shredding. The main hypothesis for cutter design is that cutting method has to be used with minimum of energy consumption by reducing frictional forces to a minimum. Different mechanisms of cutting knives have to be investigated for energy consumption evaluation. The objective of this study is to determine common reed stalk and bundles cutting properties and energy efficiency of different cutting methods. Different cutting methods have to be investigated for energy consumption evaluation and shredder cutter mechanism design.

Materials and Methods

In cutting experiments were used common reed stalks with moisture of 10% and stalk material density of 615 kg m^{-3}. In single stalk cutting experiments were used stalks with diameter 7 mm, thickness of wall – 0.5 mm. In common reed bundle cutting experiments were used bundles with height within 1.2 – 1.5 m, upper diameter – 0.08 m, lower diameter – 0.18 m. Bundles were harvested with Seiga harvester in the Pape lake.

In single stalk cutting experiments, energy consumption for stalk cutting was investigated using the Zwick materials testing machine TC-FR2.5TN. D09 with 0.4% force resolution, 0,1 μm displacement resolution and the maximal force for testing - 2,5 kN. For shear cutting parameter determination, an original cutting device was designed. The cutting device was equipped with six different cutting knives (Fig. 1) where bevel angle for all cutting knives was 45°, but the blade angle was within 0° - 25°. The blade angle more than 25° was not used because it is

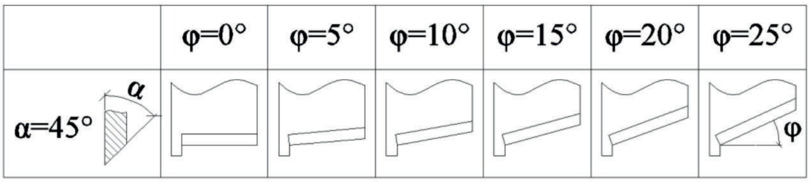

Figure 1. **Cutting knives with different blade angle**

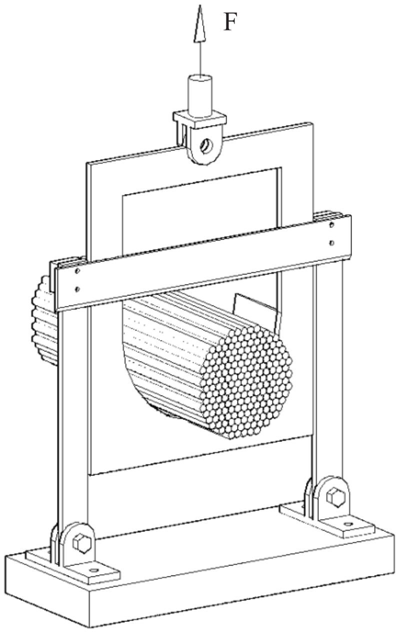

Figure 2. **Bundle cutting mechanism**

a nip angle for polished steel and common reed stalk materials.

Displacement and stress data for single stalk cutting experiments were collected and processed by using Zwick software program TestXpert V9.01. The energy consumption was obtained by integrating force – displacement diagram. Specific cutting energy consumption was investigated for all types of cutting knives.

In reed bundle cutting mechanism (Fig. 2) one cutting knife with blade angle of 0° and bevel angle of 45° was used. Common reed bundle was cut first from the upper end, the length of cut stalk particles was 0.1 m. The weight of cut stalk material was calculated as difference of bundle weight before and after cutting. The displacement and cutting force sensor data was used for cutting energy determination. The displacement and cutting force sensor data from Pico data logger were processed by Microsoft Excel program. MathCAD program was used for cutting energy per mass unit calculation.

In all experiments the common reed stalks or reed bundles were orientated perpendicularly to the cutting knife. The displacement speed of cutting knives was 0.15 m min^{-1}. Single stalks cut area was calculated from data obtained from direct measurement with sliding calliper (accuracy ± 0.01 mm).

Specific cutting energy was calculated:

$$E_{SC} = \frac{E_C}{A} \tag{1}$$

where

- E_{SC} – specific cutting energy, J m^{-2};
- E_C – cutting energy, J;
- A – stalks cut area, m^{-2}.

Cutting energy per mass unit was calculated (Srivastava, et.al., 1993):

$$E_{CM} = \frac{E_{SC}}{L \cdot \rho} \tag{2}$$

where

- E_{CM} – specific cutting energy per mass unit, J kg^{-1};
- L – length of stalk cut, m;
- ρ – stalk material density, kg m^{-3}.

Specific cutting energy was calculated:

$$E_{SC} = E_{CM} \cdot L \cdot \rho = \frac{E_C}{m} \cdot L \cdot \rho \tag{3}$$

where

m – cut stalk mass, kg.

Cutting area was calculated:

$$A = \frac{m}{L \cdot \rho} \tag{4}$$

The average specific cutting energy for common reed bundle cutting was calculated:

$$E_{SC}^{A} = \frac{\Sigma E_C}{\Sigma m} \cdot L \cdot \rho \tag{5}$$

where:

E_{SC}^{A} – average specific cutting energy for common reed bundle, J m^{-2};

ΣE_C – total cutting energy consumption for all experiments, J;

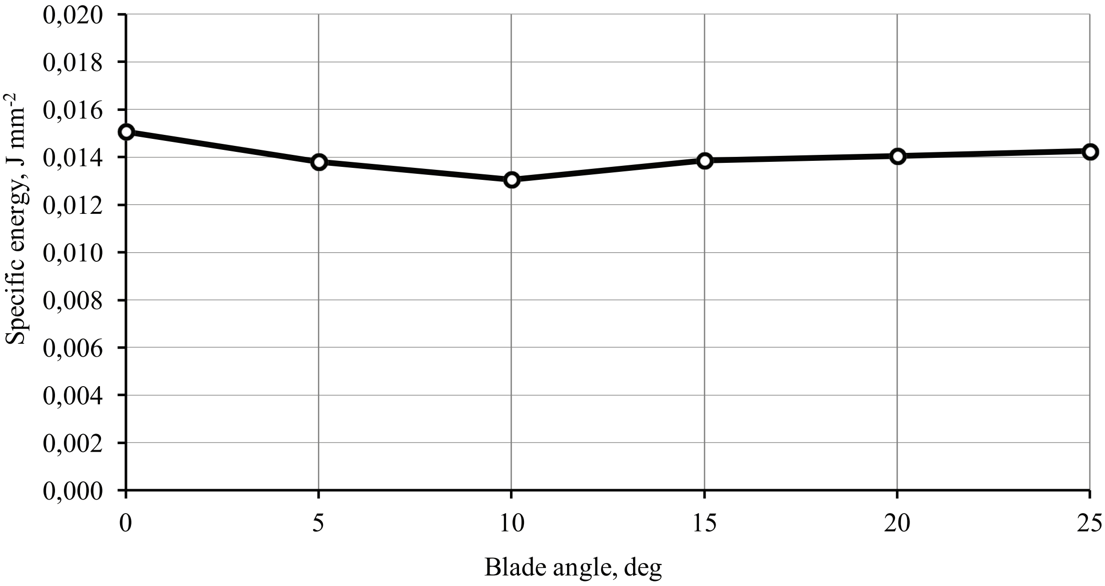

Figure 3. **Reed stalks material specific cutting energy dependence on knife bevel angle**

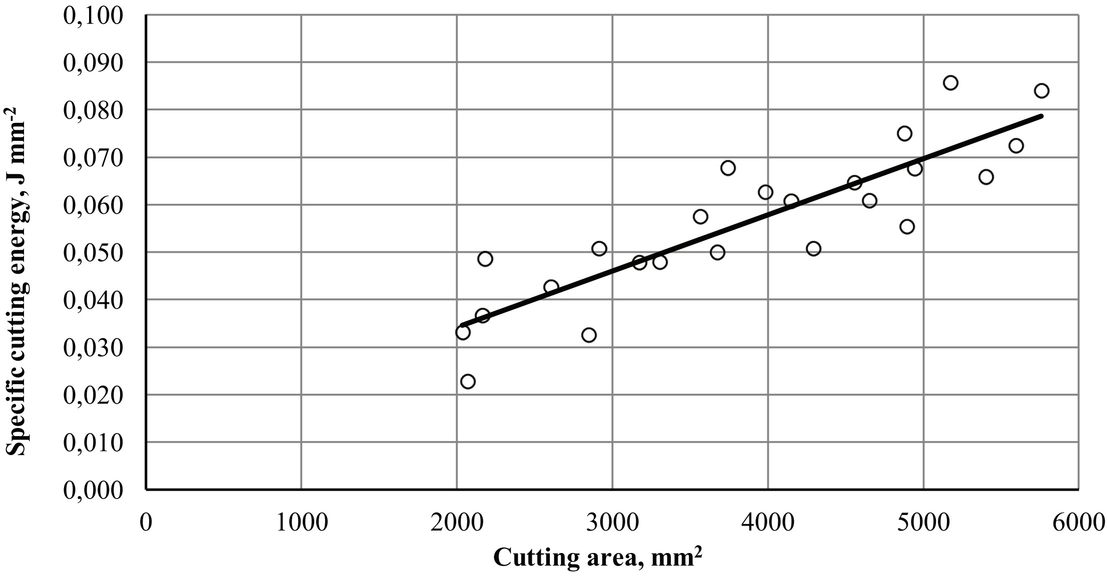

Figure 4. **Specific cutting energy dependence on cutting area**

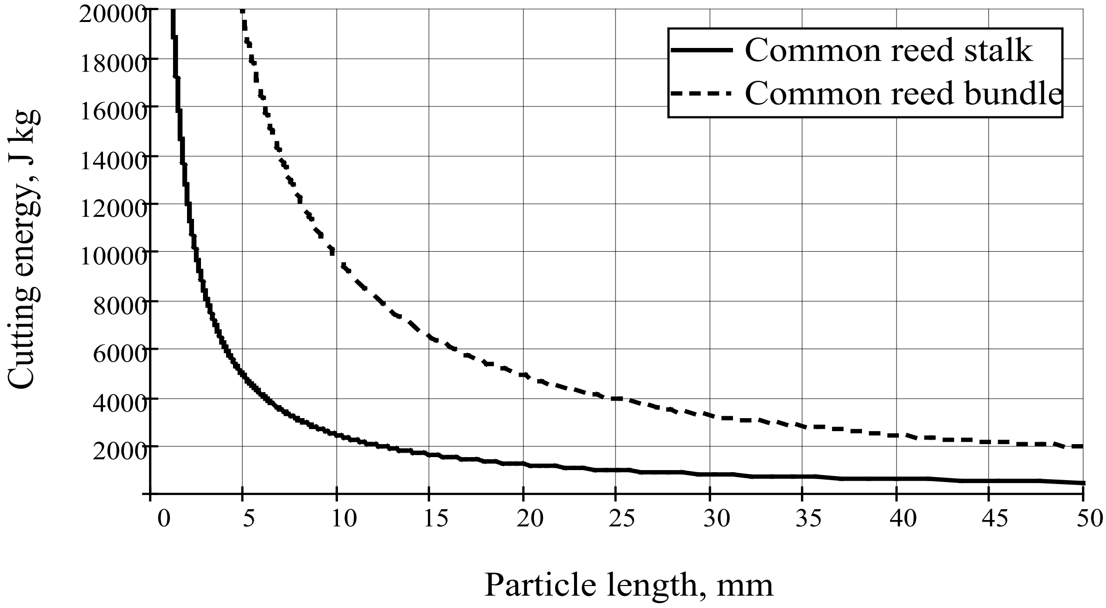

Figure 5. **Cutting energy per mass unit dependence on particle length**

Σm – total cut stalk mass in all experiments, kg.

Results and Discussion

Common reed single stalk material specific cutting energy values are shown in Figure 3. Average specific cutting energy for single common reeds was within $(0.013 \div 0.015) \cdot 10^{-6}$ J m^{-2} when cutting knives with different bevel angles were used. There was no significant difference between the specific cutting energy values for different blade angles, therefore maximal value $0.015 \cdot 10^{-6}$ J m^{-2} can be used for calculations.

Common reed bundle specific cutting energy values are shown in Figure 4. Common reed bundle specific cutting energy was within $(0.02 \div 0.09) \cdot 10^{-6}$ J m^{-2}, and the weighted average value was $0.06 \cdot 10^{-6}$ J m^{-2}, if the cutting knife with the bevel angle of 45° and blade angle of 0° was used.

Specific cutting energy for reed bundle cutting significantly exceeded single stalk cutting specific energy, therefore cutting in thin layers is recommended. The point of intersection of trend line extension with ordinate axis (Fig. 4) was near the value of single common reed stalk specific cutting energy ($0.015 \cdot 10^{-6}$ J m^{-2}). These results prove that common reed bundles specific cutting energy linearly depends on the cross section of the bundle.

Specific cutting energy per mass unit (Fig. 5) was determined on the basis of stalk material density of 615 kg m^{-3}, specific cutting energy value for single stalk - $0.015 \cdot 10^{-6}$ J m^{-2}, and average for bundle - $0.06 \cdot 10^{-6}$ J m^{-2}.

Specific cutting energy per mass unit for reed bundles significantly exceeded the single stalk specific cutting energy per mass unit; therefore it is more preferable to harvest common reed bundles with smaller dimensions if common reeds are used for solid fuel production.

Conclusions

Specific cutting energy for single common reed stalk cutting is within $(0.011 \div 0{,}015) \cdot 10^{-6}$ J·m^{-2}, if cutting blades with bevel angle 45° and blade angles within 0° - 25° are used.

There is no significant difference between specific cutting energy values for different blade angles, therefore maximal value $0.015 \cdot 10^{-6}$ J m^{-2} can be used for calculations.

Common reed bundle specific cutting energy is within $(0.02 \div 0.09) \cdot 10^{-6}$ J m^{-2}, the weighted average value is $0.06 \cdot 10^{-6}$ J m^{-2}, if the cutting knife with bevel angle 45° and blade angle 0° is used.

The experiment results prove that common reed bundles specific cutting energy linearly depends on the cross section of the bundle.

Specific cutting energy per mass unit for reed bundles significantly exceeds the single stalk specific cutting energy per mass unit; therefore it is more preferable to harvest common reed bundles with smaller dimensions if common reeds are used for solid fuel production.

References

1. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable

sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance) (2009). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0028:EN:NOT, (Accessed on 13.01.2012).

2. Srivastava AK, Goering CE, Rohrbach RP. (1993) Engineering principles of agricultural machines. ASAE Textbook Number 6. Pamela De Vore-Hansen, Editor, Books&Journals. p. 601.

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