HERBACEOS ENERGY CROP SHREDDING SIZE DETERMINATION

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Abstract. Latvia has a target in 2020 for renewable energy resources to be 40 % in gross final consumption of energy. In 2005 EU biomass accounted for 66 % of renewable primary energy production. Herbaceous energy crops would be as the main basis for solid biofuel production in agricultural ecosystem in future. In Latvia approximately of 14.6 % of unfarmed agricultural land can be used for herbaceous energy crop growing. Energy crop stalk material cutting properties were investigated in order to find minimum of energy consumption for shredding. It was stated that flattened reed test package thickness changes from 0.4 to 3.8 mm rise the specific cutting energy from 0.025 to 0.078 $J \cdot mm^{-2}$. Specific cutting energy per mass unit is growing considerably from 2000 $J \cdot kg^{-1}$ to 4000 $J \cdot kg^{-1}$ then the shredding size is changed from 20 to 10 mm. If cutting energy per mass unit is advisable less than 2000 $J \cdot kg^{-1}$ and homogeneity of composition with peat is preferable, then the shredding size 20 mm is recommended.

Keywords: herbaceous energy crops, shredding size.

Introduction

The target for share of energy from renewable sources [1] in gross final consumption of energy in 2020 in Latvia is 40 %. In 2005 EU biomass accounted for 66 % [2] of renewable primary energy production. Biomass has relatively low costs, less dependence on short-term weather changes and it is a possible alternative source of income for farmers. Herbaceous energy crops would be as the main basis for solid biofuel production in agricultural ecosystem in future. There is no problem in Latvia that if bioenergy crops are encouraged, then less land will be available for growing food. In 2005 investigation it was stated that 14.6 % of agricultural land [3] of Latvia was unfarmed. Therefore, herbaceous energy crop growing on these lands can provide sustainable farming practice. Beside that there is a possibility to utilize for bioenergy production natural biomass of common reeds (Phragmites Australis) overgrowing shorelines of more than 2000 Latvian lakes. Peat can be used as the best additive for manufacturing of solid biofuel, because it improves density, durability of stalk material briquettes (pellets) and avoids corrosion of boilers. For this reason herbaceous energy crop biomass compositions with peat for solid biofuel production are recommended. The main conditioning operation before preparation of herbaceous biomass compositions with peat is shredding. There are different cutting methods of agricultural materials. According to this stalk material cutting properties have to be investigated in order to find minimum of energy consumption for shredding.

Materials and methods

Herbaceous biomass as cereal crop straw (mainly wheat straw), common reeds, rape straw and reed canary grass are the most prospective stalk materials for solid biofuel production in Latvia. For production of solid biofuel mainly herbaceous plant stalks are used. The experimentally stated common reed stalk material ultimate tensile strength is 330 ± 29 $N \cdot mm^{-2}$. This value testifies that common reeds are the strongest material between other stalk materials mentioned before, because the experimentally stated value of wheat stalk (with moisture content ~10 %) ultimate tensile strength is only 118.7 ± 8.6 $N \cdot mm^{-2}$. The experimentally obtained values of common reed cutting properties therefore would be more reliable for herbaceous energy crop shredder design in solid fuel production technologies. The main hypothesis for cutter design is that the cutting method has to be used with minimum of energy consumption, reducing frictional forces also to a minimum. Flattened common reeds (Phragmites Australis), with moisture content ~10 %, were used for cutting experiments, because the previous research verifies that reed flattening before cutting allows to save the total shredding energy. The ultimate shear strength and energy consumption for reed stalk cutting has been investigated using the Zwick materials testing machine TC-FR2.5TN.D09 with force resolution 0.4 % and displacement resolution 0,1 µm, the maximal force for testing is 2.5 kN. For cutting parameter determination an original cutting device has been designed. The cutting device was equipped with two types of cutting knives, for the first knife the edge angle is 90°, for the second – 20°. Both knives simulated four different cutting mechanisms (Figure 1), which are used in industrial shredders. For any cutting mechanism 13 samples were used. In the cutting mechanisms N1 and N3 the test piece has been fixed in booth sides by pressure plates, but in the cutting mechanisms N2 and N4 only in one side.

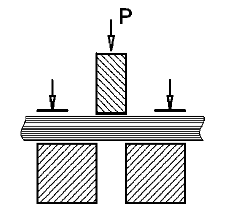
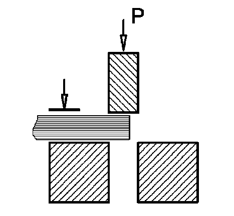
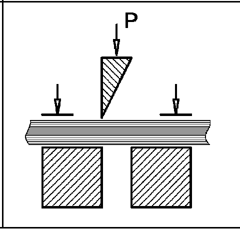
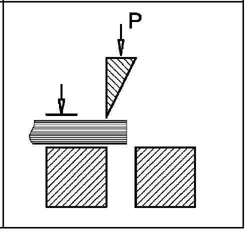
	Knife edge angle 90°		Knife edge angle 20°	
	N1	N2	N3	N4
Cutting mechanism				

Fig. 1. **Cutting mechanisms**

The ultimate shear strength was calculated:

$$\sigma_C = \frac{F_C}{A}, \tag{1}$$

where σ_C – ultimate shear strength, N·mm^{-2};

F_C – maximal cutting force, N;

A – cutting area, mm^{-2}.

The specific cutting energy was determined:

$$E_{SCQ} = \frac{E_C}{A}, \tag{2}$$

where E_{SCQ} – specific cutting energy, J·mm^{-2};

E_C – cutting energy, J;

A – cutting area, mm^{-2}.

The displacement and stress data were collected and processed by using Zwick software program TestXpert V9.01. The energy consumption was obtained by integrating force – displacement diagram. The specific cutting energy consumption was investigated for flattened reed packages with different thickness. These test packages are shown in Figure 2. The material testing machine maximal force and cutting equipment limited test package dimensions: thickness 0.4-3.8 mm and width 4.0-30.0 mm. Material homogeneity was obtained by using flattened reed layers with equal thickness.

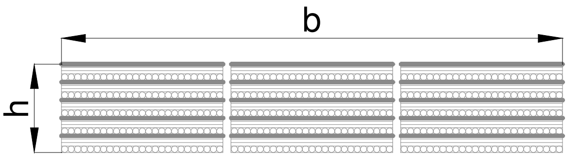


Fig. 2. **Test package of flattened reeds**

The results of the cutting experiments were processed by Microsoft Excel program. The cutting (chopping) energy E_C for stalk biomass unit (kg) is calculated [4] using equation:

$$E_C = \frac{E_{SCQ}}{L_C \cdot \rho} \tag{3}$$

where E_C – cutting energy per unit mass, J·kg^{-1};

L_c – length of stalk cut, mm;

ρ – reed stalk material density, kg·mm^{-3}.

The recommendation for herbaceous energy crop shredding size was determined on basis of the cutting energy E_C and mixing with peat convenience evaluation.

Results and discussion

Results of the ultimate shear strength and specific cutting energy determination for the mentioned before four cutting mechanisms are presented in Figure 3.

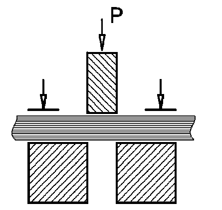
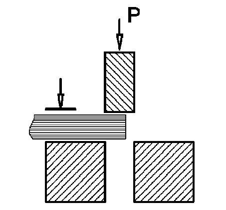
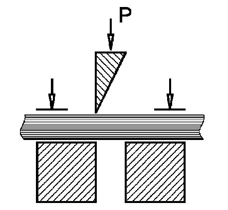
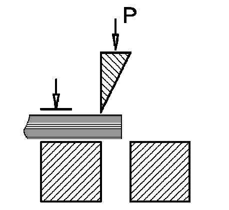
	Knife edge angle 90°		Knife edge angle 20°	
	N1	N2	N3	N4
Cutting mechanism				
Ultimate shear strength, N mm^{-2}	109.3 ± 5.5	112.8 ± 5.0	57.6 ± 2.9	45.9 ± 2.1
Specific energy, J mm^{-2}	0.031 ± 0.002	0.029 ±0.002	0.020 ± 0.001	0.018 ± 0.001

Fig. 3. **Ultimate shear strength and specific energy**

Significant differences were found between the results (Figure 3) for investigated the cutting mechanisms. There is influence of the knife edge angle and test piece fixing method, which is the cause of different friction forces. The cutting force and specific energy depend also on thickness of the test package.

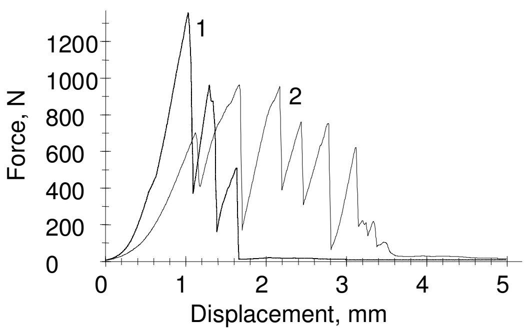


Fig. 4. **Cutting force**

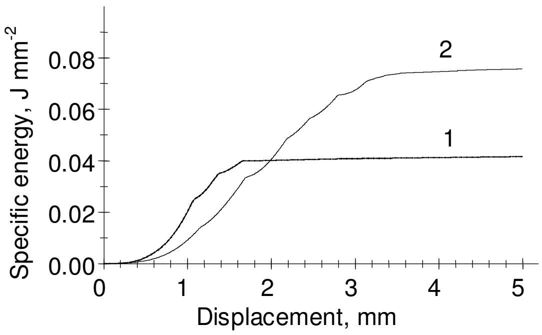


Fig. 5. **Specific energy**

Cutting of two test packages with approximately equal cross-section can be seen in Figure 4 and Figure 5 with the knife edge angle 90°. The curved line 1 demonstrates cutting of the test package with thickness 1.52 mm and width 13.7 mm, but the curved line 2 demonstrates cutting of the test package with thickness 3.37 mm and width 6.00 mm. It can be concluded, that for shredder design cutting of thin layer crop material is recommended, because the specific cutting energy then is less needed. The experiments with test packages of different size show that the specific cutting energy significantly depends on thickness of the crop material layer. Flattened reed test package thickness change (Figure 6) from 0.4 to 3.8 mm rises the specific cutting energy from 0.025 to 0.078 J mm^{-2}.

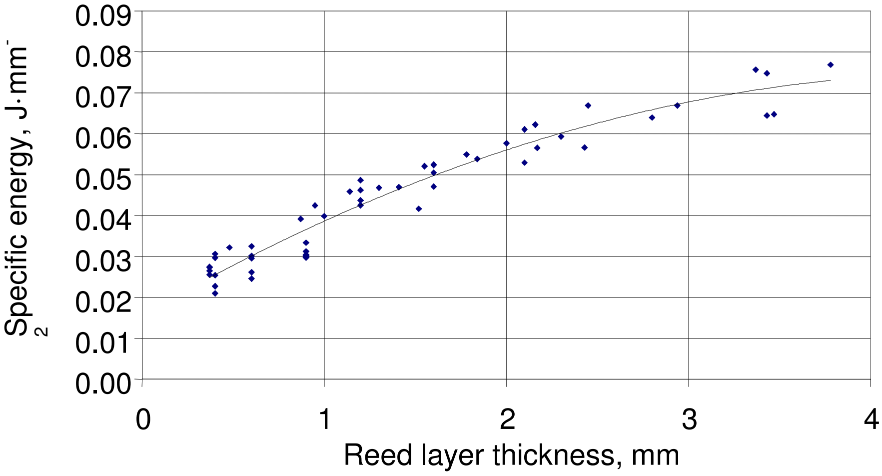


Fig. 6. **Specific cutting energy in dependence on crop layer thickness**

Using formula (3) and the experimental investigation results (Figure 3) the cutting energy E_C per unit mass was calculated for different flattened reed shredding sizes. The density $\rho = 615$ kg·m^{-3} was used in calculations. Figure 7 presents the specific cutting energy per mass unit in dependence of the flattened reed shredding size.

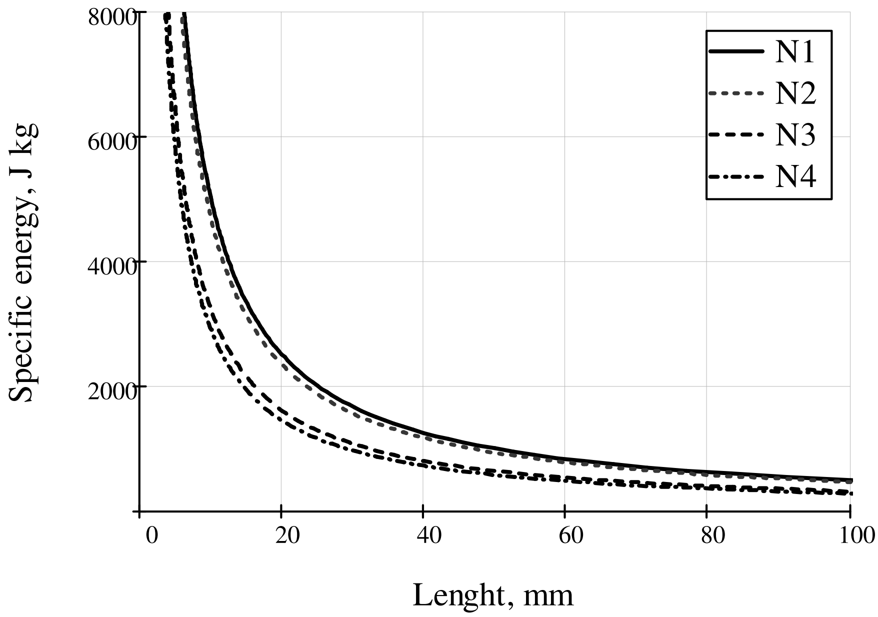


Fig. 7. **Specific cutting energy per mass unit**

The specific cutting energy per mass unit is growing considerably from 2000 J·kg^{-1} to 4000 J·kg^{-1} when the shredding size is changed from 20 to 10 mm.

For solid biofuel production after herbaceous energy crop material shredding it is necessary to mix it with peat additive. If briquettes are in a cylindrical form with diameter 60 mm (laboratory experiments), then for closed die loading the shredding size less than 50 mm is recommended. The experiments of mixing shredded crop material with peat shoved, that there are difficulties to obtain homogeneity of composition, if the size of shredded material exceeds 20 mm. Therefore, if the cutting energy per mass unit is advisable less than 2000 J·kg^{-1} and homogeneity of composition with peat is preferable then the shredding size 20 mm is recommended.

Conclusions

1. In Latvia approximately 14.6 % of unfarmed agricultural land can be used for herbaceous energy crop growing.
2. The experimentally stated common reed stalk material ultimate tensile strength is 330 ± 29 $N \cdot mm^{-2}$. As they are the strongest herbaceous energy crops, the values of common reed cutting properties would be reliable for crop shredder design.
3. For the investigated cutting mechanisms the flattened common reed ultimate shear strength values are from 45.9 ± 2.1 to 109.3 ± 5.5 $N \cdot mm^{-2}$, but the specific cutting energy from 0.018 ± 0.001 to 0.031 ± 0.002 $J \cdot mm^{-2}$.
4. Flattened reed test package thickness change from 0.4 to 3.8 mm rises the specific cutting energy from 0.025 to 0.078 $J \cdot mm^{-2}$.
5. The specific cutting energy per mass unit is growing considerably from 2000 $J \cdot kg^{-1}$ to 4000 $J \cdot kg^{-1}$ when the shredding size is changed from 20 to 10 mm.
6. If the cutting energy per mass unit is advisable less than 2000 $J \cdot kg^{-1}$ and homogeneity of composition with peat is preferable then the shredding size 20 mm is recommended.

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