CUTTING PROPERTIES OF COMMON REED BIOMASS

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Abstract. The EU Common agricultural policy stimulates farmers to grow more energy crops, including short rotation coppice and other perennial crops. There are other resources of bioenergy as agricultural residue and peat. Peat can be used as an additive for manufacturing of solid biofuel, because it improves the density, durability of stalk material briquettes (pellets) and avoids corrosion of boilers. Naturally herbaceous biomass is a material of low density (20-60 kg m^{-3}) and not favorable for transportation on long distances. Baling can increase the bulk density to 100-200 kg m^{-3}. The main conditioning operation before biomass compacting is shredding. The shredder cutterbar has to be designed with friction energy losses decreased to minimum. According to this mainly stalk material cutting properties have to be investigated. Experimental investigation of common reed stalk conditioning properties as different cutting methods can characterize maximum of energy consumption in these operations for all groups of stalk materials in Latvia, because reeds have higher tensile strength (~200 N mm^{-2}) and accordingly other strength parameters.

Keywords: biomass, common reeds, cutting properties.

Introduction

Development of biomass as a renewable energy resource can help Europe reduce dependence on energy imports and increase sustainability. Biomass has relatively low costs, less dependence on short-term weather changes; it is a possible alternative source of income for farmers. Energy crops would be as the main basis for solid biofuel production in agricultural ecosystem in future. Today straw, common reed and peat utilization are the main possibilities for biomass energy production in Latvia. There is a possibility to utilise natural biomass of common reeds (Phragmites communis) overgrowing shorelines of more than 2000 lakes of Latvia. 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. If only wood chips or herbaceous biomass are burned, the sulphur content is low and chlorides are formed [1]. The chlorides are causing the risk of high temperature corrosion. If the sulphur content of the fuel is increased by blending peat with chips or herbaceous biomass, sulphates are formed instead of chlorides and high temperature corrosion is avoided. For these reasons herbaceous biomass compositions with peat for solid biofuel production are recommended. Naturally herbaceous biomass is a material of low density (20-60 kg m^{-3}) and not favorable for transportation on long distances. Baling can increase the bulk density to 100-200 kg m^{-3}. The main conditioning operation before preparation of herbaceous biomass compositions with peat is shredding. The shredder cutterbar has to be designed with friction energy losses decreased to minimum. 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 this purpose.

Materials and methods

Growing of herbaceous energy crops for solid biofuel production in rural area is more preferable, because delayed harvesting in winter time allows to obtain biomass with humidity less than 15 % and the content of nutrients (P, K) 50 % less than in autumn [2] season. Such material after shredding can be used for compacting without drying. Therefore 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. Earlier experimentally stated common reed stalk material ultimate tensile strength is 256±27 N mm^{-2}. This value testifies that common reeds are the strongest material among other stalk materials, mentioned before, because the experimentally stated value of wheat stalk (with moisture content ~10 %) ultimate tensile strength is only 118.7±8.63 N mm^{-2}. The experimentally obtained values of mechanical properties are therefore more reliable for 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 minimum. The final determination of the best cutting method must be carried out experimentally, evaluating the specific energy consumption for this operation. The specific cutting energy consumption for unit of area E_{scq} is:

$$E_{scq} = \frac{E_c}{A}, \tag{1}$$

where E_{scq} – specific cutting energy consumption for unit of area , J m^{-2};
E_c – cutting energy, J;
A – cutting area, m^2.

Energy consumption for reed stalk cutting has been investigated using the Zwick materials testing machine TC-FR2.5TN.D09, equipped with a cutting device. The original cutting device has been designed for the Zwick material testing machine for flattened stalk material cutting. The cutting device (Fig. 1a) consists of the die 1 with a gap and a turnable specimen fastening 4 and a rectangular prismatic punch with 5 mm thickness. The clearance between the punch and the gap is 0.02 mm from each side. Cutting using two types of knives – with edge angles 20˚ and 90˚ (Fig. 1b) was investigated. Flattened reed stalks were used for cutting experiments. Displacement, stress and energy data were collected on the computer. Stress and energy diagrams can be got by means of Microsoft Office Excel program from the collected data. The cutting device (Fig. 1.) lets to investigate the shear cutting method.

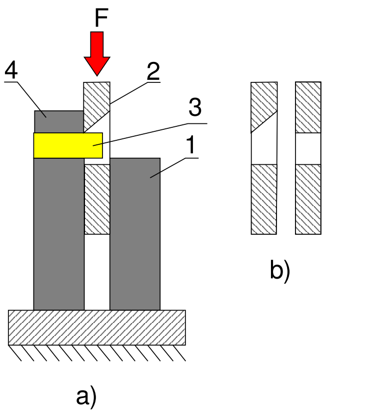

Fig. 1. **Flattened reed cutting device**

The straw cutter design theory, developed in the previous century by academician V. Gorjackin [3] recommended the sliding cutting method in order to reduce normal component of cutting force to the knife edge. For investigation of the sliding cutting of flattened common reeds, the equipment (Fig. 2.) to Zwick materials testing machine TC-FR2.5TN.D09 has been designed.

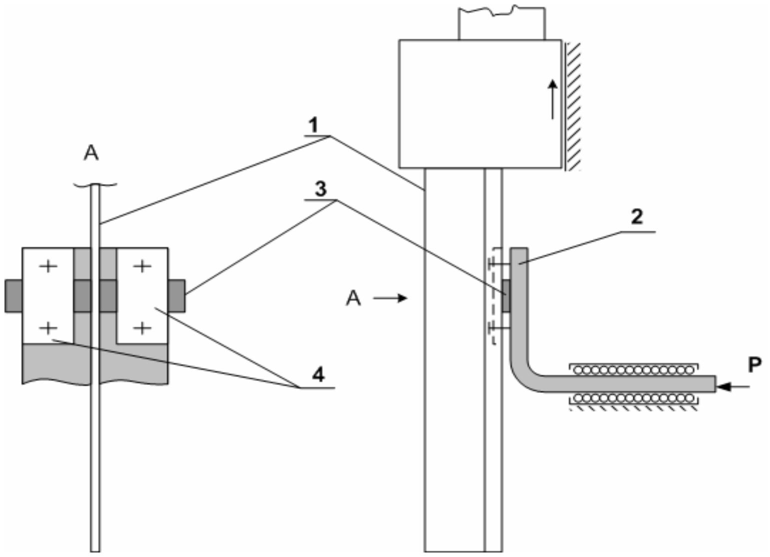

Fig. 2. **Equipment for sliding cutting**

The knife 1 is strengthened vertically in Zwick 2.5 clamping system. The specimen 3 is rigidly secured to the vertical support by the plates 4 on both sides. Normal force *P* to the knife cutting edge is applied to the specimen 3, but the force of knife vertical displacement is registered as a function of displacement. During the experiments the value of force *P* is adjusted and the value of vertical displacement force is registered. Software of Zwick 2.5 allows to obtain graphs of force and cutting energy consumption for vertical displacement of the knife. The vertical displacement of the knife 0.1 m has been adjusted. After measurement of the depth of cut-in into specimen the energy consumption in force *P* direction can be calculated and added to the energy consumption for vertical displacement of the knife.

Results and discussion

Shear cutting experiments were realized with flattened common reed stalks in stack according to the situation of bale shredding. The cutting energy consumption for two types of knives used to cut flattened reed stem stacks can be seen in Fig. 3. For cutting two and three layer stack of flattened reed stalks the knife with edge angle 90º shows twice more energy consumption than the knife with the edge angle 20º. The specific energy consumption of reed cutting for both knives is within 8-58 kJ m^{-2}. For single flattened reed stalk there are not sufficient differences in the energy consumption values for the mentioned knives. Therefore, for reed stalk stack cutting more favorable will be usage of single reed stalk layers and chopping with a cutter which edge angle is 90˚. If the cutter edge angle is smaller, then the cutter edge stays edgeless faster. Sharpening of shredder knives can be a serious problem during maintenance. If easy maintenance is preferred, then a simple shape of the cutter knife edge with angle 90˚ has to be used. The similar problem is for the choice of the shape of cutter counter knives and it has to be solved accordingly.

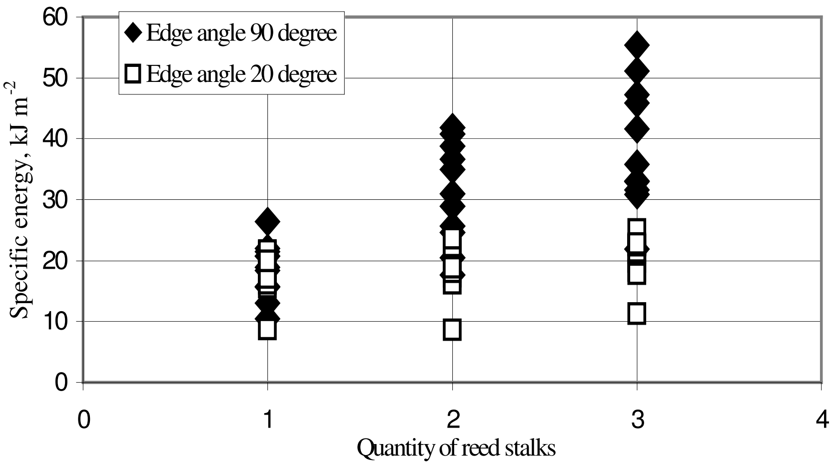

Fig. 3. **Reed stalk specific cutting energy consumption**

The records obtained in common reeds sliding cutting experiments (Fig. 3.) show the force for vertical displacement of the knife. Numbering of curves is done in accordance with the values of normal force P (Fig. 2.) pressing specimen against the cutting edge of the knife as follows: 1-5 N; 2-10 N; 3-15 N; 4-20 N; 5-25 N and 6-30 N. The knife vertical displacement force is the sum of the friction force from moving the blade in cut-in of specimen and force for cutting common reed material. It can be seen (Fig. 4.) that the average vertical displacement force value for curves 3, 4 and 5 is the same as the value of normally pressing force *P*. Considering that the main part of the vertical displacement force is friction force *F*, it can be calculated:

$$F = f' \cdot P, \tag{2}$$

where f' – generalized coefficient of friction;
P – normally pressing force.

The generalized coefficient of friction f':

$$f' = \frac{F}{P}. \tag{3}$$

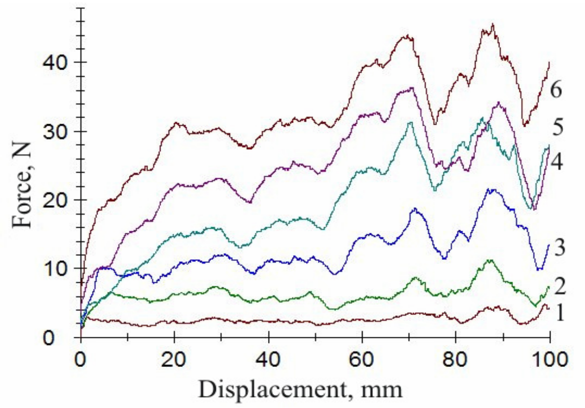

Fig. 4. **Knife vertical displacement force**

From sliding cutting experiments the generalized coefficient of friction *f'* has been investigated for three knives with edge angles 10˚; 20˚ and 30˚. Theoretically approximate value of the coefficient of friction *f'* can be found considering longitudinal friction and disregarding transverse friction of the knife. Then according to Fig. 5 reactions can be found:

$$R_1 = \frac{P}{tg\beta} \text{ and } R_2 = \frac{P}{\sin\beta} \quad (4)$$

The longitudinal friction force F considering (4) can be found:

$$F = f(R_1 + R_2) = f(\frac{1+\cos\beta}{\sin\beta})P. \quad (5)$$

Then

$$f' = f\frac{1+\cos\beta}{\sin\beta} \quad (6)$$

Fig. 6 demonstrates generalized coefficient of friction *f'* for three knives with edge angles 10˚; 20˚ and 30˚, obtained experimentally and theoretically, using *f* = 0.25.

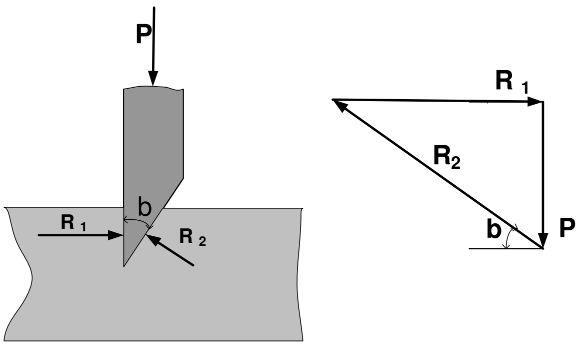

Fig. 5. **Reactions for sliding of knife wedge**

The coefficient of friction experimentally was determined [2] sliding against polished steel barley straw surfaces *f* = 0.16 ... 0.3, when straw humidity changed from 10 % to 46 %. The coefficient of friction for steel knife flat surface sliding into common reed cut-in gap has to be of similar values. Therefore the value *f* = 0.25 for theoretical calculation of generalized coefficient of friction *f'* is used reasonably and conformity of theoretically and experimentally obtained curves prove it. Fig. 6. shows that generalized coefficient of friction for knife sliding longitudinally in cut-in gap is higher for lesser edge angles of knives.

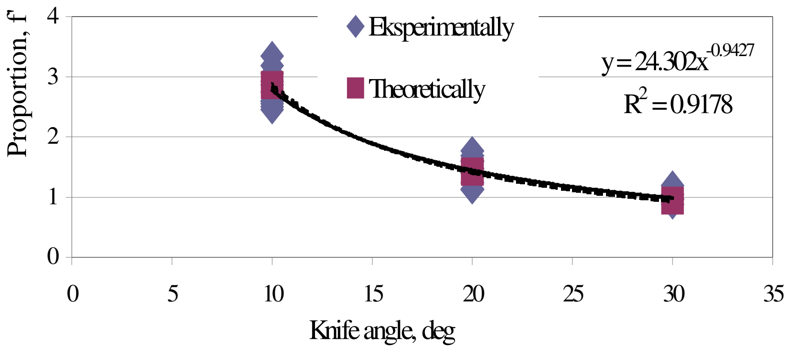

Fig. 6. **Generalized coefficient of friction** ***f'***

Summarizing the work consumed for knife with edge angle 10º pressing into reed material and work for knife sliding longitudinally in cut-in gap, relating this sum to the cut cross section was found E_{scq} – specific energy consumption per unit of area. The results of calculations, based on Zwick 2.5 measurement data are presented by Fig. 7.

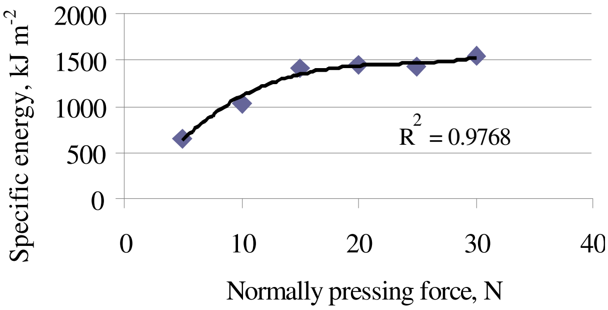

Fig. 7. **Specific energy consumption**

Changing the knife normally pressing force into reeds specimen from 5-30 N, the specific energy consumption for sliding cutting changes 653-1500 kJ m^{-2}. Compared with it shear cutting specific energy consumption (8-58 kJ m^{-2}) is many times less than for sliding cutting. Force value reduction in shear cutting can be obtained if angled (guillotine type) knives are used. The results indicate that the shear cutting method may be recommended for common reed shredder design, because the friction force of sliding cutting in cut – in gap causes the energy consumption approximately 30 times greater.

Conclusions

1. Specific energy consumption of reed shear cutting is within 8-58 kJ m^{-2}.
2. If easy maintenance is preferred, then a simple shape of the cutter knife edge with angle 90° has to be used for shredder design.
3. Generalized coefficient of friction for the knife sliding longitudinally in cut-in gap is higher for lesser edge angles of knives.
4. The specific energy consumption for common reed flattened stalk sliding cutting changes within 653 - 1500 kJ m^{-2}.
5. The friction force of sliding cutting in cut – in gap causes energy consumption approximately 30 times greater than for the shear cutting method.

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