STALK MATERIAL CUTTING ENERGY

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Abstract

Sustainable energy systems and food security can be obtained in rural areas by usage of renewable energy resources and development of agro–ecotechnologies. Substitution of fossil feedstock for energy and raw materials by biomass is important measure also for greenhouse gas (GHG) emission mitigation. The article presents investigation of reed biomass size reduction processes: flattening and cutting. Necessity to reduce the size of common reeds (*Phragmites australis*) to particles smaller than 3 mm for solid biofuel production is determined by compaction properties of biomass. It was stated that unflattened reed stem cutting energy consumption is 2 times more than flattened stem cutting energy. There are no sufficient differences in the energy consumption values for single flattened reed stalk cutting with different shaped knives. The average difference is approximately 2.4 kJ m^{-2} with knife edge angles 90° and 20°.

Key words: reed biomass, cutting.

Introduction

As the fossil fuel resources are decreasing, in future we will have to rely on renewable energy sources. The World Energy Council Committee estimates that by the year 2020 the share of renewable energy will grow to 21–30% of the total energy consumption. In a shorter term, the EU assumes that the share of renewable energy in the fuel and energy balance will rise from 6% in 1998 to 12% in 2010 [1]. In rural agro – ecotechnologies, main resources for solid biofuel are residues of cereal crops, peat and emergent vegetation as common reed etc. Solid biofuels are residues from agriculture and – still to a very limited extent – energy crops grown especially for energy purposes.

Properties of stalk materials as reeds and straw have to be investigated [2] for the design of processing and handling equipment, economical transport and storage.

In Latvia, straw resources that can be used for energy production have increased (more than 171 000 t of straw annually), because cattle breading has decreased in previous years [3]. Only one part of straw residue (20–30%) is planned to use for heat production, but another part will be used as organic fertilizer. Besides that more than 230 million tons of peat are available for biofuel production. Peat can be used as additive for manufacturing of briquettes, because it improves density of stalk material briquettes. Latvia is a country of lakes (more than 2000), which are overgrowing with common reed (*Phragmites australis*) on shorelines. There is a possibility to utilize this natural biomass. Biomass energy production can be realized only in accordance with an ecosystem approach and good understanding of agricultural ecosystem function. Straw, peat and reed materials can denominate as agricultural ecosystem biomass resources only if there are mechanization tools and technologies for collection and utilization processes.

Materials and methods

Mechanical properties of biomass are not favourable for transport, storage and usage of energy. Naturally herbaceous biomass is a material of low density (0.02–0.06 g cm^{-3}) and is not favourable for transportation over long distances, therefore new mobile equipment and technologies for mechanization of biomass flattening, comminution and densification have to be worked out. A demand for density of solid biofuel briquettes and pellets is >1.0 g cm^{-3} in the standards of European countries [4]. This value has been used for evaluation of herbaceous material densification results. Size reduction is a very important conditioning process for dry biomass densification.

From densification experiments it is stated that higher density has been obtained with a stalk material particle size smaller than 3 mm [3]. During cutting operation with counter shear, stalk flattening occurs at first. For this reason flattening of reed specimens with 10% moisture content has been investigated previously.

Reed stalk cutting experiments have been carried out by means of Zwick material testing machine TC-FR2.5TN.D09 (Fig. 1). Zwick material testing machine has force measurement accuracy – 0.1 N, displacement meas-

Fig. 1. Zwick material testing machine.

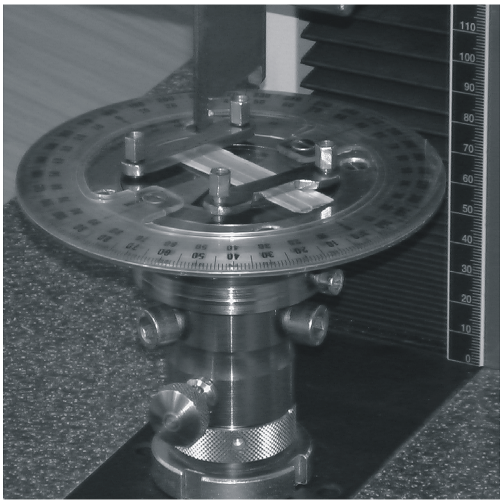

Fig. 2. Cutting device.

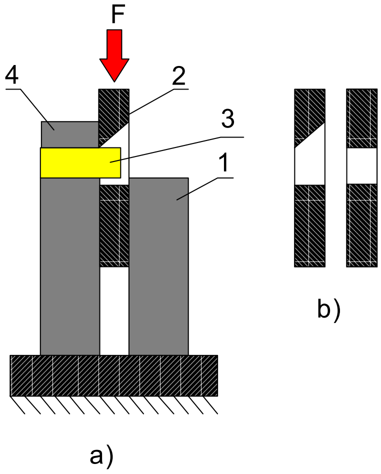

Fig. 3. Flattened reed cutting device.

urement accuracy – 0.01 mm, max force measurement – 2.5 kN. Computer controls the Zwick material testing machine. The force and displacement measurement data were collected on the computer.

Energy consumption for reed stalk cutting has been investigated using the Zwick material testing machine equipped with a cutting device (Fig. 2). Original cutting device has been designed for the Zwick material testing machine for flattened stalk material cutting.

The cutting device (Fig. 3a) consists of the die 1 with a gap and a turnable specimen fastening 4 and a rectangular prismatic punch with 5 mm thickness. 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. 3b) was investigated. Flattened reed stalks were used for cutting experiments. Displacement, stress and energy data were collected on the computer. Stress and energy diagram can be obtained by means of Microsoft Office Excel program from the collected data.

Cutting shear stress for reed stalk material can be calculated using equation [2]:

$$\sigma = \frac{F}{A}, \tag{1}$$

where

σ – ultimate cutting stress, N m^{-2};
F – maximal cutting force, N;
A – cutting area, m^2.

Specific cutting energy per area unit E_{scq} for stalk biomass can be calculated using equation [5]:

$$E_{scq} = \frac{E_c}{A}, \tag{2}$$

where

E_{scq} – specific cutting energy per area unit, J·m^{-2};
E_c – cutting energy, J;
A – cutting area, m^2.

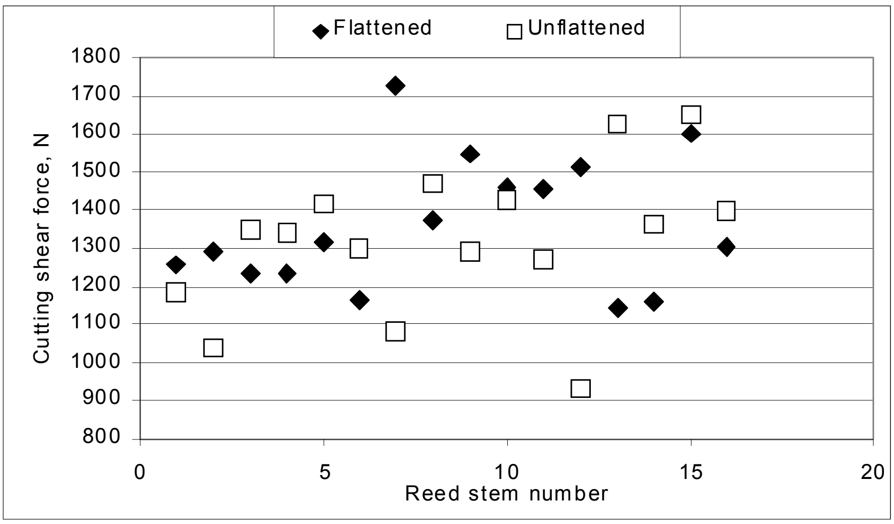

Fig. 4. Reed stem cutting shear force.

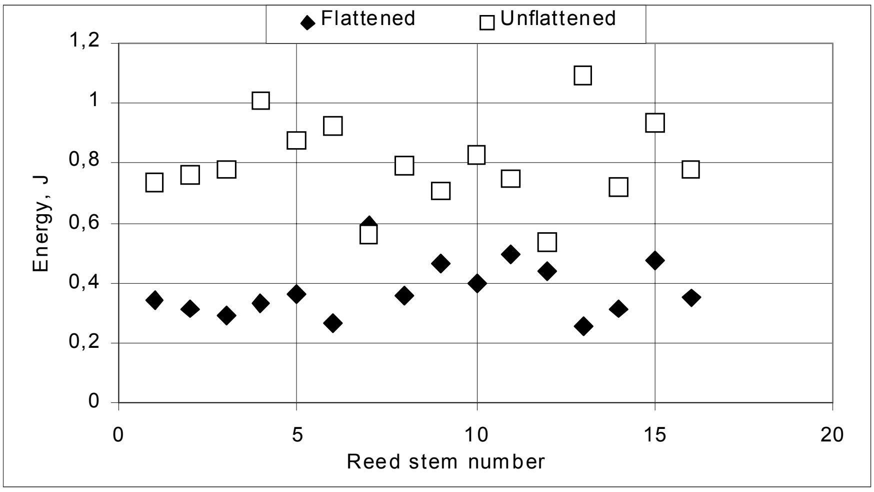

Fig. 5. Reed stem cutting energy.

Results

Reed stalk biomass cutting experimental investigations are necessary for new chopping equipment design. Stalks are the main part of any herbaceous material, their cutting properties determine the shredder and grinder design. Reed stalks consist of nodes and tubular internodes. The cross-section shows air channels for internal ventilation on periphery, because reeds are aquatic plants. Stalk cross section and structural studies show that it is a complicated structure. During cutting operation with counter shear, stalk flattening occurs first. Flattened and unflattened reed specimen cutting shear force (Fig. 4) average values were the same, using a knife with the edge angle of 90°. For the experiments, the same reed stem material was used (one part of stem was flattened and used for cutting, but the other part for cutting was used unflattened).

Exchange of flattened und unflattened common reed cutting energy consumption during this process is shown in Fig. 5. From force – displacement diagrams, energy consumption for cutting was calculated. Average energy consumption 0.8 J has been stated for unflattened single reed stalk cutting. But average energy consumption for flattened reed cutting is 0.38 J. The difference between flattened and unflattened reed stem cutting energy consumption is 0.42 J. From previous flattening experiments it is stated that flattening energy consumption for reed stem with length 6 cm is 0.2 J. Therefore it is more economically to use flattened reed stems for cutting. It is simpler also for tech-

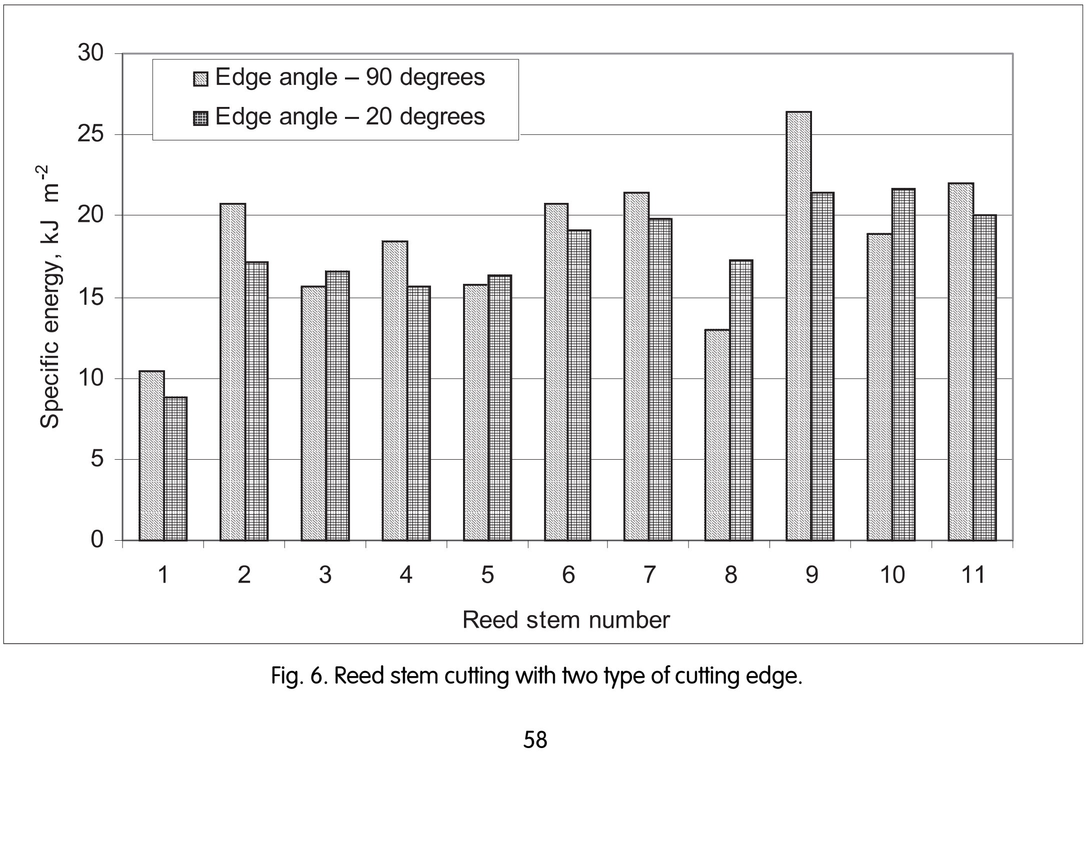

Fig. 6. Reed stem cutting with two type of cutting edge.

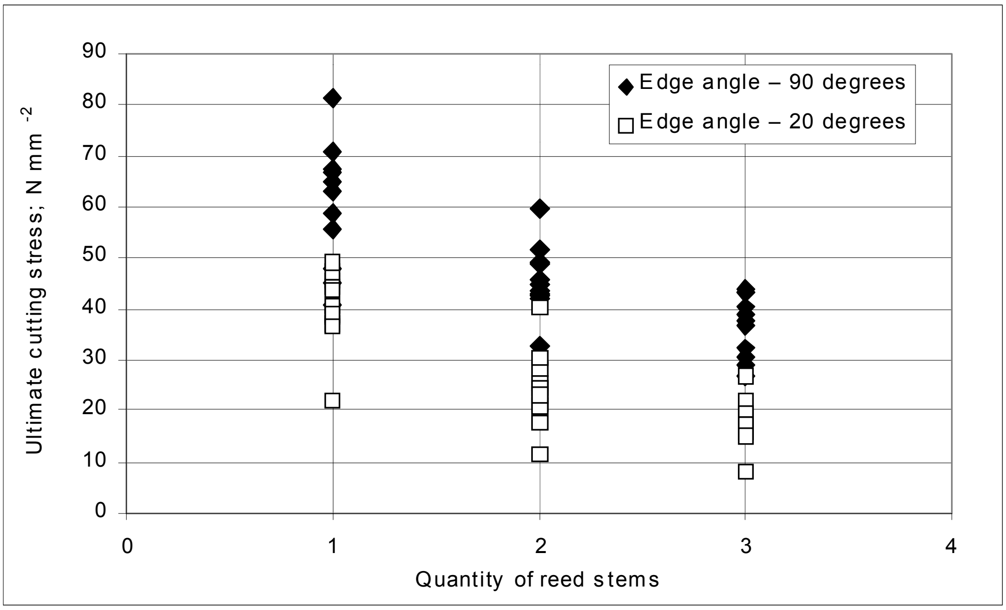

Fig. 7. Reed stem stack ultimate cutting stress.

nology, because reed stem transporting can be realised with drive rolls. Rolls can implement two functions – drive and flattening.

Fig. 6 demonstrates reed stalk cutting using two types of knives with edge angles 20° and 90°. Cutting properties of these two types cutting knives were compared. The differences were not sufficient in the specific energy values for single flattened reed stalk cutting (average difference is approximately 2.4 kJ m^{-2} for the two types of knives).

Figure 7 shows ultimate cutting stress of flattened reed stem stack. Ultimate cutting stress is lowest for stack with maximum amount of layers. Flattened reed ultimate cutting stress for two types of knifes cutting edge is different. Ultimate cutting stress for the knife with cutting edge angle 20° is twice lower than the cutting stress for the knife with cutting edge angle 90°.

Cutting energy consumption for two types of knives and flattened reed stem stacks can be seen in Fig. 8.

For cutting two – and three – layer stack of flattened reed stalks, the knife with edge angle 90° shows twice more energy consumption than the knife with edge angle 20°. For a single flattened reed stalk there are no sufficient differences in the energy consumption values for the mentioned knives. Therefore, for reed stalk stack cutting, more

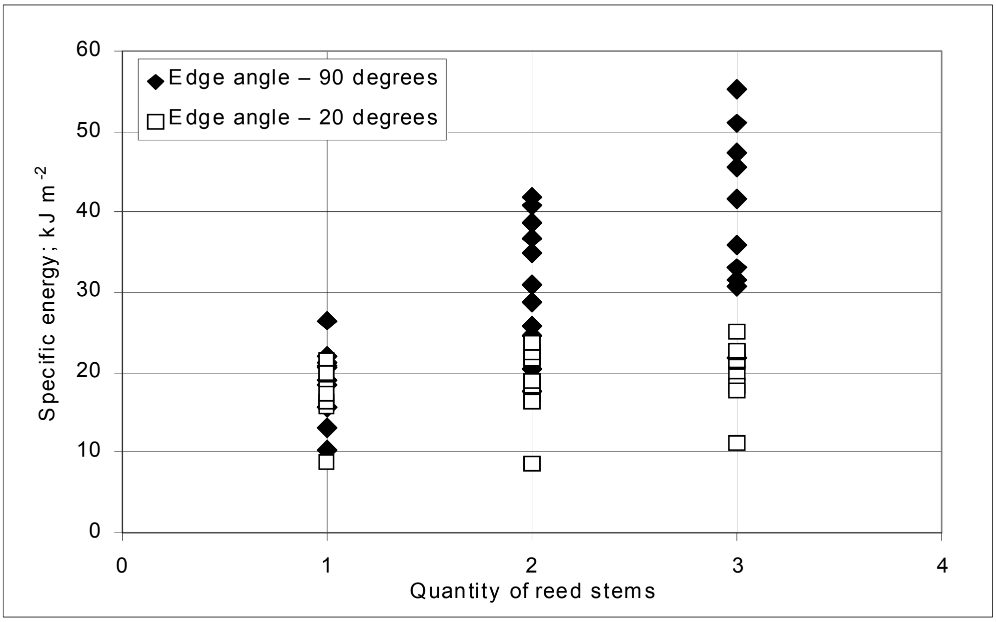

Fig. 8. Reed stem specific energy consumption.

favorable will be usage of single reed stalk layers and chopping with a cutter with the edge angle 90°. If the cutter edge angle is smaller, the cutter edge sties edgeless faster.

Conclusions

1. The main reed biomass size reduction processes are flattening and cutting.

2. The difference between flattened and unflattened reed stem cutting energy consumption is 0.42 J.

3. Ultimate cutting stress for the knife with cutting edge angle 20° is twice lower than cutting stress for the knife with cutting edge angle 90°.

4. There are no sufficient differences (2.4 kJ m^{-2}) in the energy consumption values for single flattened reed stalk cutting with knife edge angles 20° and 90°.

5. Thin herbaceous biomass layer cutting is recommended for shredder design.

6. Flattening and cutting force and energy consumption values obtained experimentally are necessary parameters for calculations and design of the cutting tools.

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