

SIZE REDUCTION OF COMMON REEDS FOR BIOFUEL PRODUCTION

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Abstract. The main conditioning operation before preparation of herbaceous biomass compositions for solid biofuel production is shredding and grinding. Naturally herbaceous biomass is a material of low density $\approx 60 \text{ kg}\cdot\text{m}^{-3}$ and not favorable for transportation on long distances. Grinding and compacting with normal pressure up to 0.17 MPa, the bulk density of common reed biomass increases up to $390 \text{ kg}\cdot\text{m}^{-3}$. In this study, size reduction of common reeds (*Phragmites Australis*) was carried out using a hammer mill Peruzzo Export 200 and material testing machine Zwick TC-FR2.5TN.D09. The hammer mill was equipped with eight different screens with mesh size within 1 and 20 mm. According to the standard DD CEN/TS 15103..2005 the bulk density of comminuted common reed material for each screen grinds was determined. For compacting pressure influence on the material bulk density Zwick TC-FR2.5TN.D09 was equipped with compression cell. Bulk density changes were determined for the pressure up to 0.17 MPa. Relationship between comminute material bulk density, hummer mill screen size and compacting pressure was determined as non-linear functions which were used for mathematical model development. The purpose of the work was to determine the common reed bulk density dependence on the hummer mill screen size and primary compacting pressure.

Key words: herbaceous energy crops, common reed comminuting.

Introduction

Latvia has a target [1] 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 are situated on the shorelines of the Latvian lakes. There are more than 2256 lakes with the area at least 1 ha in Latvia. Most of these lakes are eutrophic and common reed stands often have invaded areas of eutrophic shallow lakes.

The main conditioning operations before preparation of herbaceous biomass compositions for solid biofuel production are shredding and grinding. Naturally herbaceous biomass is a material of low density $\approx 60 \text{ kg}\cdot\text{m}^{-3}$ and not favorable for transportation on long distances.

The bulk density has a significant effect on the material handling and storage aspects in a biorefinery, and it depends on the material composition, particle size, shape and distribution, moisture content, specific density and applied pressure [2]. Bulk density of biomass increases during transportation, handling, and storage which can be caused by compaction due to vibration, tapping, or normal load [3]. Shredding, milling and primary compacting with normal load can increase the bulk density to $390 \text{ kg}\cdot\text{m}^{-3}$.

In this study, size reduction of common reeds (*Phragmites Australis*) was carried out using a hammer mill Peruzzo Export 200 and material testing machine Zwick TC-FR2.5TN.D09. The hammer mill was equipped with eight different screens with the mesh size 1, 1.5, 3, 6, 10, 12, 15 and 20 mm. Shredded common reeds (bulk density $60 \text{ kg}\cdot\text{m}^{-3}$) milling increases the bulk density from 30 (if screen with mesh size 20 mm is used) to $200 \text{ kg}\cdot\text{m}^{-3}$ (if screen with mesh size 1 mm is used). For pressure influence to comminute common reed density the material testing machine was equipped with compression cell. The compression piston pressure was limited to 0.17 MPa. The average bulk density value increases for $120 \text{ kg}\cdot\text{m}^{-3}$ if normal pressure for primary compacting 0.17 MPa is used.

Relationship between comminute material bulk density, hummer mill screen size and compacting pressure was determined as non-linear functions which were used for mathematical model development. The mathematical model is usable for comminute and compacted common reed material bulk density theoretical calculation depending on the hammer mill screen mesh size and compacting pressure. The mathematical model is usable for the hammer mill screen mesh size within 1 and 20 mm, and compacting pressure till 0.17 MPa. From the obtained results it can be concluded that fixed bulk density can be obtained with different hammer mill screen mesh sizes and compacting pressure variations.

Materials and Methods

In the experiments common reed stalks with moisture 10 % and stalk material density $615 \text{ kg}\cdot\text{m}^{-3}$ were used. In the common reed bundle cutting experiments bundles with the height within 1.2 – 1.5 m, upper diameter – 0.08 m, lower diameter – 0.18 m were used. The bundles were harvested in Pape lake with Seiga harvester.

For common reed bundles primary shredding the wood chipper Tuenniseen GM-10 was used. The machine was equipped with a 10 kW electric motor and feeding system with hydraulically adjustable rotational speed. The average particle length for the shredded material is $20 \pm 10 \text{ mm}$. For shredded material comminuting the hammer mill Peruzzo Export 200 was used. The machine was equipped with a 15 kW electric motor and eight different screens with the round hole size within 1 and 20 mm. The bulk density for comminuted common reed material was measured according to DD CEN/TS 15103.2005.

The material testing machine Zwick TC-FR2.5TN.D09 with force resolution 0.4 % and displacement resolution $0,1 \mu\text{m}$ and the maximal force for testing 2.5 kN is used for comminute common reed stalk material compacting. The material testing machine was equipped with compression cell (Fig. 1) which consists of a cylinder and piston which was connected to the continuous force and displacement measuring equipment. In the compacting experiments the comminute reed material was placed into the cylinder and pressed with the piston up to 0.17 MPa. For all experiments the displacement speed of the piston did not exceed $0.05 \text{ m}\cdot\text{min}^{-1}$. The displacement and stress data were collected and processed by using Zwick software program TestXpert V9.01. The material density was calculated by using the primary bulk density, material volume and piston displacement values for all kinds of comminuted materials.

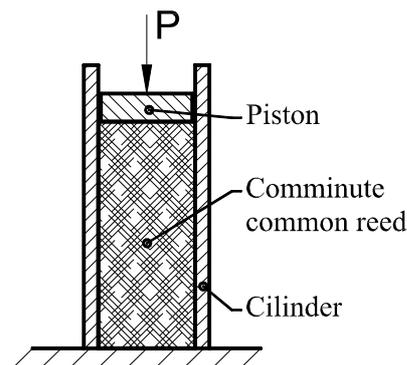


Fig. 1. Compression cell

The material density was calculated:

$$\rho = \rho_0 + \Delta\rho \quad (1)$$

where ρ – material bulk density, $\text{kg}\cdot\text{m}^{-3}$;

ρ_0 – comminuted material density, $\text{kg}\cdot\text{m}^{-3}$;

$\Delta\rho$ – bulk density increase depending on compacting pressure, $\text{kg}\cdot\text{m}^{-3}$.

The material density dependence on the hammer mill screen mesh size was calculated:

$$\rho_0 = f(D) \quad (2)$$

where D – hammer mill screen mesh size, mm;

The material density increase depending on the compacting pressure was calculated:

$$\Delta\rho = \rho' - \rho_0 = f(p) \quad (3)$$

where ρ' – calculated material density in the compacting process, $\text{kg}\cdot\text{m}^{-3}$;

p – compacting pressure, MPa.

The results of the comminuting and compacting experiments were processed by Microsoft Excel, TestXpert and MathCAD programs.

Results and Discussion

Shredded common reed (bulk density $60 \text{ kg}\cdot\text{m}^{-3}$) comminuting increases the bulk density from $30 \text{ kg}\cdot\text{m}^{-3}$ (if screen with mesh size 20 mm is used) to $200 \text{ kg}\cdot\text{m}^{-3}$ (if screen with mesh size 1 mm is used). Using Microsoft Excel program the comminuted common reed material density dependence on the hammer mill screen size was determined (Fig. 2). The trend line shows the hammer mill screen size influence to the material density.

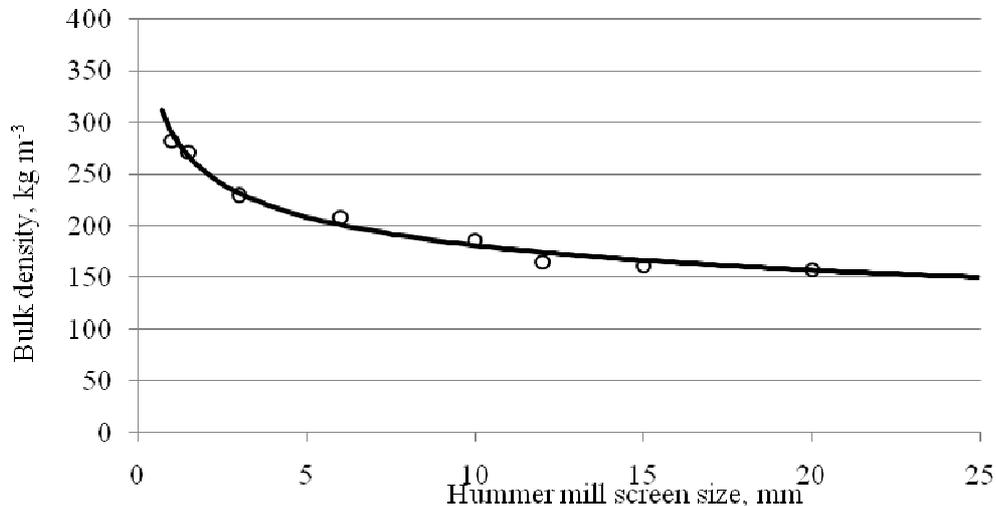


Fig. 2. Bulk density dependence on hammer mill screen size

Screen size influence trend line formula was:

$$\rho_0 = f(D) = 289 \cdot D^{-0.205} \quad (4)$$

Compacting with pressure to 0.17 MPa increases the material bulk density within 90 to $130 \text{ kg}\cdot\text{m}^{-3}$ (Fig. 3) for every screen grinds. The significant bulk density increasing is in the range when the compacting pressure is within 0 and 0.05 Mpa, when the average bulk density difference is $78 \text{ kg}\cdot\text{m}^{-3}$.

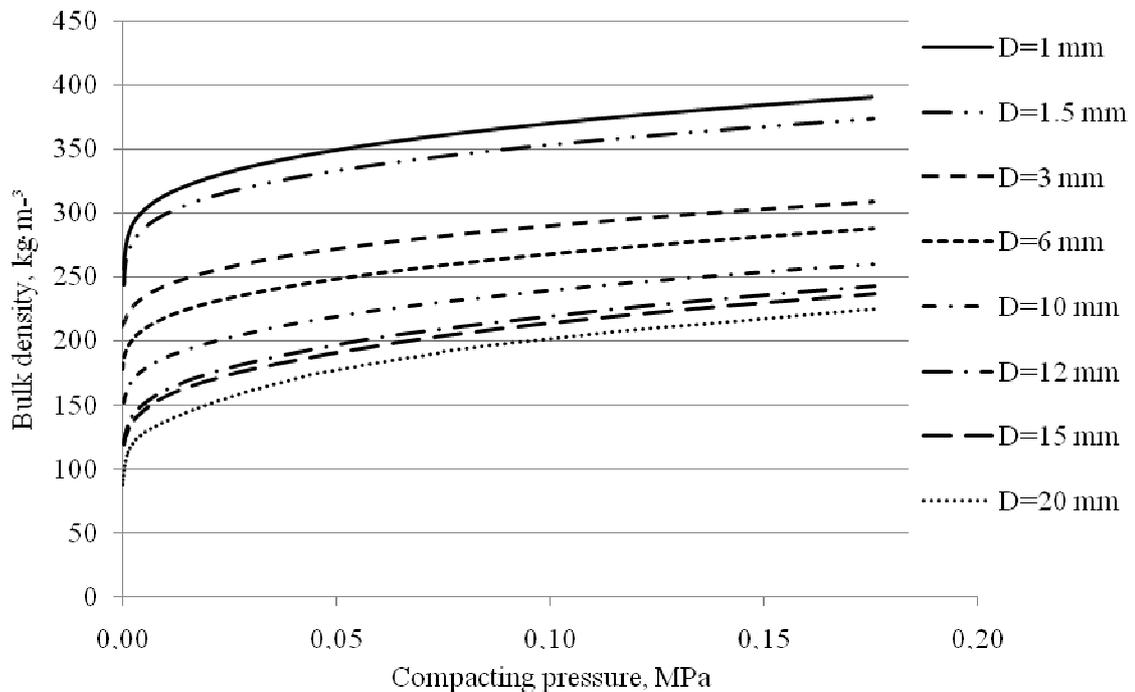


Fig. 3. Compacting pressure influence on bulk density

The average bulk density difference depending on the compacting pressure (Fig. 4) for all screen mesh sizes can be calculated:

$$\Delta\rho = f(p) = \frac{10^3 \cdot \sqrt[3]{p}}{4,7} \tag{5}$$

The results of the calculation and compacting experiments are shown for comparing. It can be stated that the calculated average bulk density difference includes in deviation limits $\pm 20 \text{ kg}\cdot\text{m}^{-3}$ experimentally determined density difference for all screen mesh size grinds.

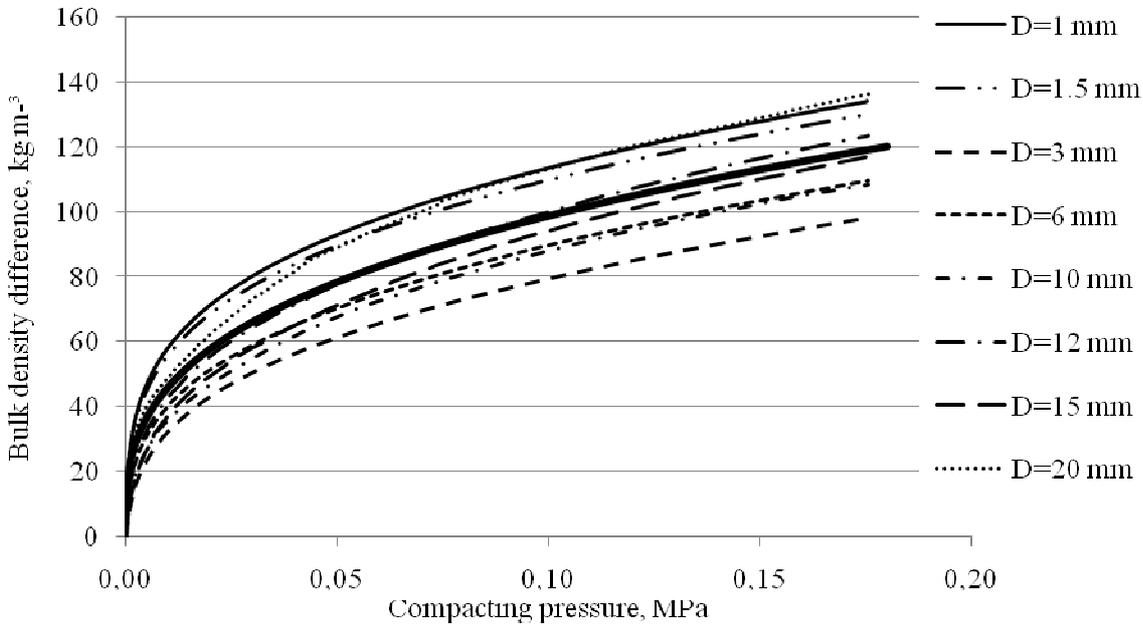


Fig. 4. Bulk density dependence on compacting pressure

The comminuted material bulk density can be calculated as a sum of the primary bulk density and the bulk density difference. The comminuted material bulk density mathematical model was:

$$\rho = \rho_0 + \Delta\rho = f(D) + f(p) = 289 \cdot D^{-0.205} + \frac{10^3 \cdot \sqrt[3]{p}}{4,7} \tag{6}$$

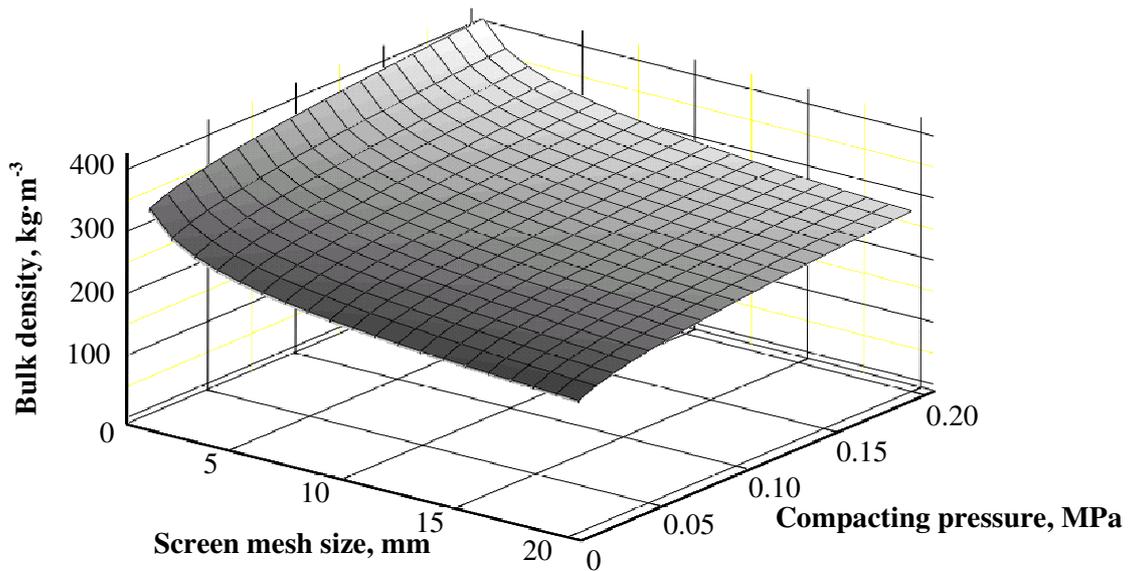


Fig. 5. Bulk density dependence on hammer mill screen mesh size and compacting pressure

The comminuted material bulk density mathematical model can be used for the hammer mill screen mesh sizes within 1 and 20 mm, and the compacting pressure up to 0.17 MPa.

MathCAD program was used for the bulk density mathematical model visualization (Fig. 5). From the obtained results it can be concluded that fixed bulk density can be obtained with different hammer mill screen mesh sizes and compacting pressure variations.

The material comminuting and compacting consumes different amounts of energy, therefore, further studies for estimating the most energy efficient variation of the screen mesh sizes and compacting pressures are needed.

Conclusions

1. Shredded common reed (bulk density 60 kg·m⁻³) comminuting with the hammer mill increases the bulk density from 30 kg·m⁻³ (if screen with mesh size 20 mm is used) to 200 kg·m⁻³ (if screen with mesh size 1 mm is used).
2. Compacting with pressure to 0.17 MPa increases the material bulk density within 90 to 130 kg·m⁻³ for every screen grinds. The significant bulk density increasing is in the range when the compacting pressure is less than 0.05 Mpa, when the average bulk density difference is 78 kg·m⁻³.
3. It can be stated that according to formula (5) calculated average bulk density difference includes in the deviation limits ± 20 kg·m⁻³ experimentally determined density difference for all screen mesh size grinds.
4. The comminuted material bulk density mathematical model (6) can be used for the hammer mill screen mesh sizes within 1 and 20 mm, and the compacting pressure up to 0.17 MPa.
5. From the obtained results it can be concluded that fixed bulk density can be obtained with different hammer mill screen mesh sizes and compacting pressure variations.

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