STALK BIOMASS DRYING RATE EVALUATION AT VARIOUS LAYERS AND DRYING PARAMETERS

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Abstract. Stalk biomass is recognized as a potential renewable energy source. Biomass drying is one of the conditioning operations that is applied to material to achieve the necessary moisture content for briquetting or pelletizing. To develop efficient drying technology and avoid overdrying there is a need to determine the drying rates of materials in different temperatures of the drying agent. Reed canary grass (*Phalaris arundinacea* L.), reed (*Phragmites australis* L.) and hemp (*Cannabis sativa* L.) are potential energetic crops suitable for fuel production in Latvia. They can be combined with peat to increase fuel durability and density. In the research the drying rates of the above mentioned materials are determined at different layer thicknesses (50; 100; 150 mm), temperatures (65-95 ºC) and constant air flow (0.6 $m \cdot s^{-1}$). The results show differences in the drying technology needed for production of fuel with composite biomass structure. Reed canary grass has the highest drying rates, but has peat has the lowest. Because of the high moisture content in material, the drying rates are increasing till temperature of biomass reaches a certain level, after which the drying rates start to decrease. Drying of materials should be done separately to avoid dissimilar moisture content in the structure of fuel and loss of energy. The results provide data for design and technology of drying equipment. Material with the moisture content above 30 % should be pre-dried in natural drying (open field) to avoid excessively high energy input.

Keywords: drying, stalk biomass, bioenergy, renewables.

Introduction

Energy security and climate change mitigation are core elements in the current European energy policy. The European Union is mandated to meet by 2020 a target of 20 % renewable resources in the energy supply [1]. Bioenergy projects will provide greater diversification and income opportunities for agriculture, agroindustries and forestry [2]. Biomass production with energy aims can generate employment and if intensive agriculture is replaced by less intensively managed energy crops, there are likely to be environmental benefits, such as reduced leaching of fertilizers and use of pesticides [3].

In order to increase energy efficiency, improve energy produced quality, and reduce emissions in its thermochemical energy conversion, drying of biomass to the required moisture content is important in the development of energy production systems [4].

The drying rate is defined as the variation of the moisture content with respect to the time. In the drying process it is necessary to distinguish theoretically three periods [5]:

1. Increase of the temperature of the product to desiccate;
2. Superficial evaporation of the adherent water. The process exists while the process of evaporation takes place up to the point of “critical content water”. In this period the drying rate is constant;
3. Final phase. The process in this period slows down due to the water absence adherent in the surface.

In drying biomass materials organic compounds are released as a result of volatilization, steam distillation and thermal destruction, and cause emissions into the air or wastewaters. Acids and higher terpenes, emitted at over 100 ºC, might condense on equipment surfaces and thus cause technical problems. As a general rule low material temperatures (under 100 ºC) should be maintained when possible [6].

In previous researches it has been investigated that 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. Peat can be used as heat additive, because it improves the density, durability of stalk material briquettes and pellets and avoids corrosion of boilers [7].

The aim of this research is to determine the drying rates of materials at different layer thicknesses and in different temperatures of the drying agent to develop efficient drying technology and avoid overdrying.

Materials and methods

Drying rates are investigated for reed canary grass (*Phalaris arundinacea L.*), reeds (*Phragmites australis L.*), hemps (*Cannabis sativa L.*) and peat. The samples are prepared with Hummer mill cutter providing that the fraction size is less than 8mm. Due to small particles air is chosen as a drying agent to avoid dust explosion that can occur if flue gas is used.

Materials were dried at three different layer thicknesses – 50; 100; 150 mm. Different drying layer thicknesses are used in convective conveyor belt driers. Layer thickness can be important to avoid incomplete drying or over-drying. To avoid emission of organic compounds the drying temperature should not exceed 100 ºC, therefore three different drying temperatures were used – 65; 78; 95 ºC. To decrease heat losses the drying chamber is made of foam plastic. Theoretical heat losses through chamber walls did not exceed 60W at temperature 95 ºC. Area of the drying zone is 0.073 m^2 and the air flow through it was 0.6m·s^{-1}. Ambient temperature was kept constant 20±1.5 ºC, but air humidity at the inlet of the drying chamber was 4.8±1.3 %.

The drying equipment (Fig. 1) consists of the drying chamber, fan, and heater. The chamber was fixed on force sensors for uninterrupted mass change measurements. Air temperature was recorded in the inlet of the drying chamber – t_1 (inflow temperature), in the material layer – t_2, and at the outlet of the chamber – t_3. Humidity of the drying agent is recorded at the inlet and outlet of the chamber (ω_1; ω_2).

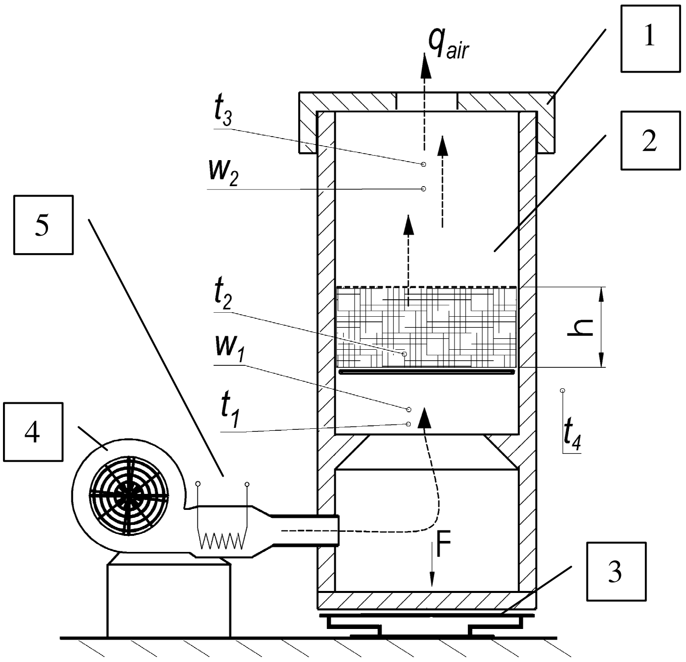

Fig. 1. **Experimental drying equipment:** 1 – drying camera; 2 – drying material; 3 – force sensor; 4 – fan; 5 – heater

The drying rates [8] are determined as loss of the moisture content in a time period in equation (1):

$$R = \frac{MC_1 - MC_2}{t_2 - t_1} \qquad (1)$$

where R – drying rate, %·min^{-1};
MC_1 – initial moisture content in period, %;
MC_2 – final moisture content in period, %;
t_1 – start time of drying, min;
t_2 – end time of drying, min.

The moisture content is defined according to equation (2):

$$MC\%_n = \frac{m_{M\,n}}{m_{T\,n}} = \frac{m_{M(n+1)} - m_{T\,n} + m_{T(n+1)}}{m_{T\,n}} \tag{2}$$

where $MC_{\%\,n}$ – moisture content in material, %;
$m_{M\,n}$ – initial moisture mass in period, g;
$m_{M\,(n+1)}$ – final moisture mass in period, g;
$m_{T\,n}$ – initial total material mass in period, g;
$m_{T\,(n+1)}$ – final total material mass in period, g.

The measurements were recorded using computer program PICO Recorder, afterwards the data were processed in MS Excel and resulting graphs were developed.

The final moisture content was determined by using the oven drying method described in the standard LVS EN 15414 3. The samples were weighted before the experiment and after. Then they were fully dried at 105 ºC temperature and again their final weight was recorded. Constant mass has been achieved when less than 0.1 % of the test sample wet mass is lost during an additional exposure to the drying process. Subsequent drying periods to verify constant mass were at least 1 h duration.

Results and discussion

Conducting experiments there were fixed coolant temperature and moisture content in different places of the equipment (Fig. 2). By the analysis of the curve, which is shown in Fig. 2, we conclude that the drying process can be divided into three main stages.

In the first stage, from the beginning of drying up to about 2100 seconds of exhaust air humidity approaching 100 %, while the air temperature and the temperature of the material do not change. This shows intense unbound water evaporation.

The second drying stage of the 2100s to about 3600 seconds, the material is characterized by a rapid increase in temperature and outgoing air moisture loss. At this stage, there is an intensive drying of the material as evidenced by the rapid decline of the material moisture.

The third stage begins after 4000 seconds runoff water from the deeper layers of the material and the material moisture content will reduce slowly. The outgoing air temperature increases significantly as the amount of heat required to vaporize water decreases.

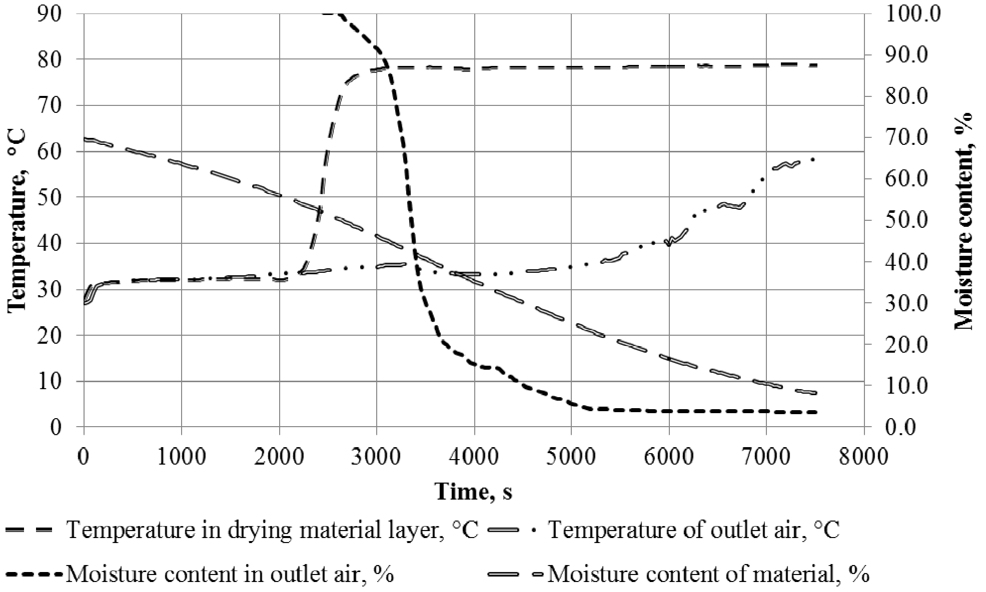

Fig. 2. **Temperature and moisture content of air and drying material depending on time at 100mm layer and 78 ºC temperature for reed canary grass**

Drying of reed canary grass at different layer thicknesses is shown in Figure 3. Because of the high moisture content in material at the beginning of the drying process moisture evaporates slower due to low material temperature (Fig. 2).

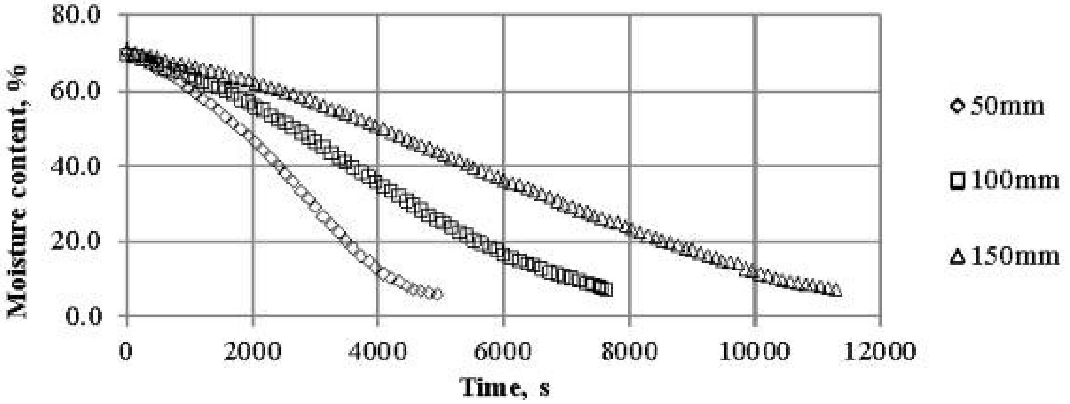

Fig. 3. **Moisture content of reed canary grass depending on drying time at temperature 78 °C for various layer thicknesses**

From Figure 3 we conclude that the drying time increases in proportion to the thickness of the material layer.

Figure 4 demonstrates the drying rates of reed canary grass at various layer thicknesses. The drying process and drying rates can be divided into two sections – A and B. A is a section where the drying rates are slowly increasing and stabilizing, but section B – decrease of the drying rates due to water absence adherent in the surface. The drying rate values proportionally decrease with layer thicknesses.

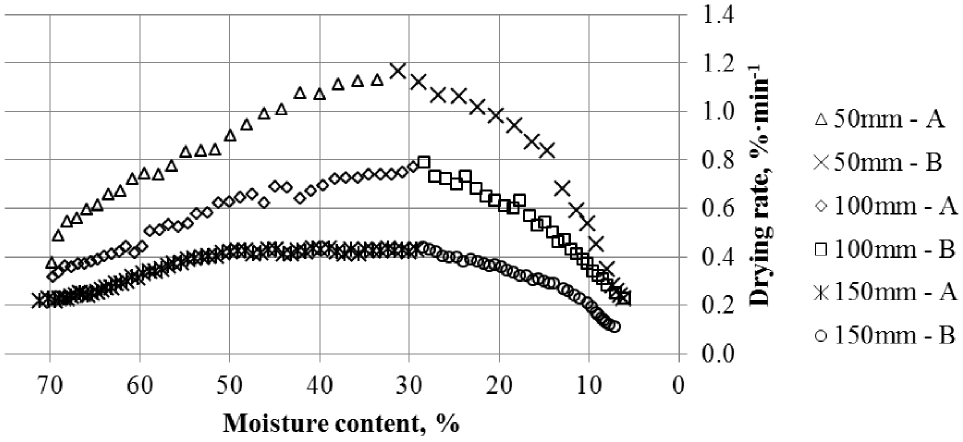

Fig. 4. **Drying rates of reed canary grass depending on moisture content at various layer thicknesses at 78 °C**

To assess the impact of the material layer thickness on the drying rate the specific drying rate r should be calculated using the equation (3):

$$r = \frac{R_{\max}}{\delta}, \tag{3}$$

where R_{max} – maximum drying rate to a certain thickness of the layer, $\%\cdot\text{min}^{-1}$;
δ – thickness of the layer, m.

Figure 5 shows that the specific drying rate for all materials is higher with smaller thickness of the drying layer. The intensity of the specific drying rate change decreases with increasing the material layer thickness. The results show that reed canary grass has a higher specific drying rate at 50 and 100mm than for other materials. The specific drying rate of the layer thicknesses of 100 and 150 mm is similar for all three materials.

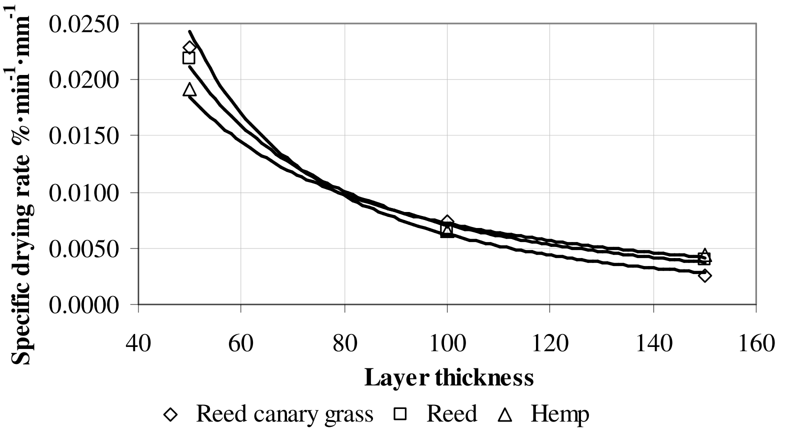

Fig. 5. **Specific drying rate depending on the layer thickness for different materials**

Assuming that the mass distribution in the layer is homogeneous, the specific drying rate *r* can be used to describe the specific drying rate per unit mass. Assuming that the flow area is the same, the dried mass can be calculated by the formula:

$$m = \frac{\Delta MC \cdot \rho \cdot A}{r \cdot \Delta t}, \tag{4}$$

where ΔMC – moisture change, %;
ρ – density of the material, kg·mm^{-3};
A – area, mm^2;
Δt – drying time, min.

Equation (4) analysis shows that the process with a smaller specific drying rate allows to increase the quantities of the dried mass.

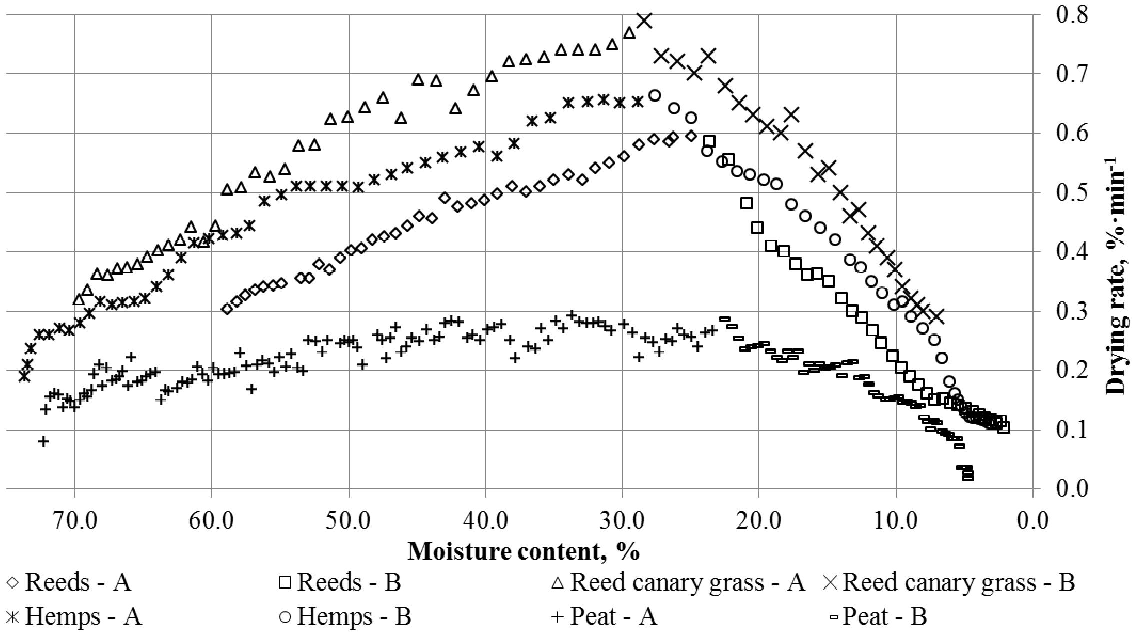

Fig. 6. **Drying rates of different materials at 100 mm layer thickness and at 78 ºC temperature**

Comparing different biomass drying rate changes depending on the layer thickness, we can see that the highest rate was obtained by drying reed canary grass (Fig. 6). Reed canary grass showed the highest drying rate 0.79 %·min^{-1} (temperature 78 ºC, layer thickness 100 mm). Peat has the lowest drying rate values and the highest drying rate reaches 0.29 %·min^{-1}. The rates for hemps and reeds are approximately in the same level, accordingly 0.66 and 0.60 %·min^{-1}.

Fig. 7 shows the drying rates of reed canary grass depending on temperature. The drying rates increase with rise of temperature.

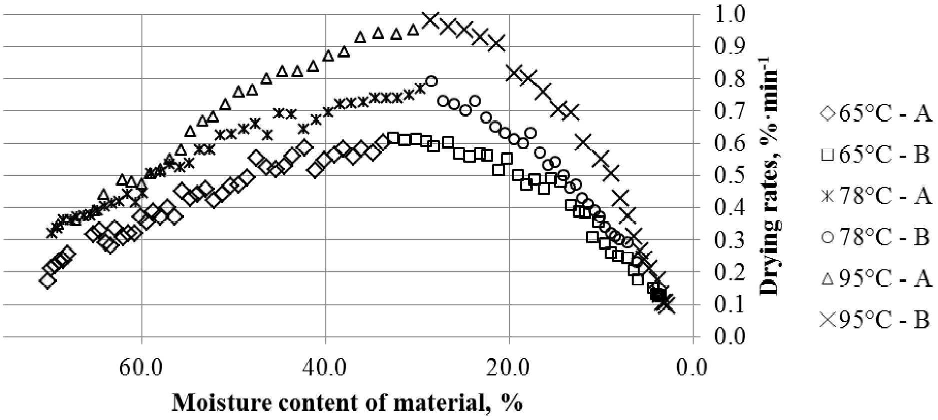

Fig. 7. **Drying rates of reed canary grass at different temperatures**

At 95 ºC the highest value of the drying rate reaches 0.98 $\%\cdot min^{-1}$, but at 65 ºC the highest value is 0.6 $\%\cdot min^{-1}$. With the lowest drying temperature 65 ºC the value of the initial drying rate is noticeably lower as at 78 and 95 ºC temperature.

Conclusions

1. For materials with high moisture content the drying rates are increasing with rise of material temperature and decreasing due to water absence adherent in the surface. The highest value of the drying rates at 78 ºC temperature is shown by reed canary grass with the initial moisture content 69.7 % and at 100mm layer thickness it reaches 0.79 $\%\cdot min^{-1}$.
2. Drying rates significantly are dependent on the drying temperature, layer thickness and material being dried. The material layer thickness effect on the drying rate can be estimated determining the specific drying rate. The specific drying rate change for the layer thickness above 100mm decreases significantly.
3. To avoid incomplete or overdrying of biomass it is necessary to dry each material separately because their drying rates are different.

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