RESEARCH OF WILLOW STEM CHAFF DRYING DURING THE COLD SEASON

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Abstract. One to two years of growth willow stems, chopped by the forage combine *Maral 125*, were used for experimental investigation of the storage of willow stem chaffs intended for biofuel, as well as drying them in the stores with active ventilation in natural ambient air. During the investigation (40 days), the air to the dryers was supplied by active ventilation equipment with different intensity. It was determined that in the first dryer, the chaff kept in the bottom (first) section and ventilated with 900 $m^3 \cdot t^{-1} \cdot h^{-1}$ air flow dried the fastest. The constant drying rate period in the middle section lasted for 6 days and reached about 0.006 $\% \cdot h^{-1}$ of the moisture removed from the chaff. In the second storage, the chaff mass was blown by the air flow reduced twice, i.e., 450 $m^3 \cdot t^{-1} \cdot h^{-1}$. Therefore, after 40 days of continuous ventilation, the desired moisture content was achieved only in the bottom part of the layer. The constant drying rate period in the middle section lasted for 18 days and was about 0.0035 $\% \cdot h^{-1}$. At the end of the constant drying rate period, while approaching to the equilibrium moisture of the chaff, the received measurement data were unstable. Ventilation modes of willow chaffs must be adjusted according to the ambient weather conditions.

Keywords: energy plants, willow, chaff, storage, drying, moisture content, temperature variation.

Introduction

Lately, fast-growing trees and shrubs are gaining popularity as a material for energy fuel. 400 ha of osier plantations used for biofuel are grown in Lithuania [1]. In order to assimilate these renewable energy sources, the preparation technique and technology of biofuel storage must be investigated and improved.

The cut willows are of about 50 % of moisture. The chaff of 15-20 % of moisture content is best suitable for fuel. Therefore, it is a necessary condition for gasification or pyrolysis processes. The experience of Great Britain, Germany and Sweden shows that properly stored willow stems during 1.5-2 months naturally dry to 15-25 % of moisture content [2]. Poured in a pile, wet wood chips begin to heat up quickly and compact. Within a few days, the temperature can reach 60 ºC. As a result, a part of energy value is lost, whereas the occurred mold spores are dangerous to the environment and health. This is the main disadvantage of the chopped biofuel storage technology [3].

The high boiler efficiency is determined not only by the boiler construction but the fuel quality as well. Effective burning of wet wood is possible only in condensation boiler-houses. To carry out burning in other types of boiler-houses is irrational. Therefore, it is relevant to dry the felled wood to the equilibrium moisture [4].

Thermodynamically, wood drying with ambient air circulation is justifiable, while protecting the wood from direct rainfall. Keeping the wood in such a way, the natural drying process takes place with the smallest labor and energy expenditures [5].

Willows are perennial and are cut unseasoned, just as grassy plants. Cut and chopped willows of 40-50 % moisture content are frequently burned moist, however, greater burning efficiency is reached by burning them dried up to 15-20 % moisture content. The grain drying technique could be applied for willow drying, though the chopped stem layer is not as thick as of grain and it crumbles worse. Data of experimental research in Germany shows, that while using the stove with ventilated floors and blowing natural ambient air, it is possible to dry willow shingles from 50 % to 15 % in three weeks. On the stove, which uses heated up to 40 °C air, it is possible to dry willow shingles in 1-2 days. In order to reduce mould and dried material losses, low intensity ventilation for willow chaff and shingle could be applied [6; 7].

Harvesting osier willow in late autumn is technologically bound with stem chopping; therefore, it is necessary to dry the chaff mass. The method of willow chaff mass drying, when ambient air in November and December is blown into layer, is not enough investigated. The storage and drying of immature willows, which could be used for biofuel, are not enough investigated as well.

Objective – to investigate the drying process of the chopped immature willow stems to 20 %, as well as, to determine the comparative energy expenditures.

Materials and methods

In order to investigate the dynamics of chaff drying, willow stems of 45 % of moisture cut in November 2009 were used. The moisture content of the wood was determined applying the methodology of the European Union [8] according to the standard (CEN / TC 14774-1).

The willows stems were chopped (the average length of chaff $l = 20 \pm 3$ mm) by the drum forage harvester *Maral 125.* The dynamics of willow stem chaff temperature during the storage period was investigated while drying chaff by active ventilation in unheated barn [1]. For this experiment a laboratory stand – stove was used and natural ambient air was blown (Fig. 1).

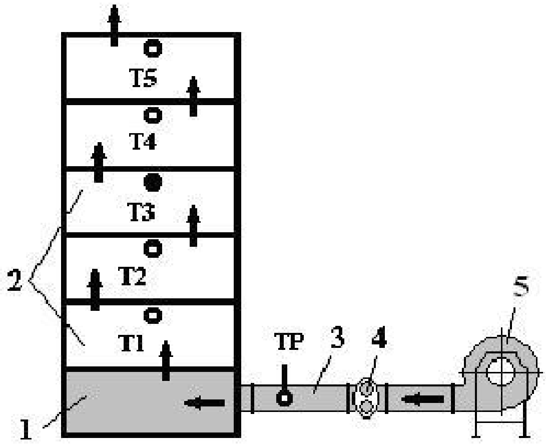

Fig. 1. **Stand for investigation in storage and drying of willow stem chaff:** 1 – air expansion chamber; 2 – container section filled with chaff; 3 – air supply channel; 4 – meter for supplied air amount measurement; 5 – ventilator with valve; T1-T5 – sensors for chaff mass measurement; TP – sensor for temperature of blown air measurement

The centrifugal ventilator VC4-70 Nr. 2.5 was used for air blowing into the chaff layer. The amount of blown air was adjusted by a valve, mounted on the 5 admission vent, and was measured by the meter 4, mounted on the air supply channel 3. Air from expansion chamber 1 was gradually supplied into the sections 2, which were mounted above it. The temperature of the supplied air and dried chaff was measured by temperature sensors and their index ALMEMO 2590-9 V5, which absolute error – 0.1 ºC.

Two storages, with five sections each, filled with chopped stem chaff, were used for the experiments. The diameter of the section is 0.5 m, height of it – 0.25 m. 10 kg of chaff was bulked into each section.

In the first storage loaded chaff was ventilated by blowing the air flow with the intensity of $Q = 900 \pm 2$ $m^3 \cdot t^{-1} \cdot h^{-1}$, in the second storage the chaff was ventilated by double reduced air flow with the intensity of $Q/2 = 450 \pm 2$ $m^3 \cdot t^{-1} \cdot h^{-1}$.

The willow chaff was incessantly ventilated for 40 days. During the experiment the ambient air temperature, relative air humidity and the temperature of the layer in each section in indicated spots were measured on each day at 12 o'clock. The sections were separately weighted at 0.1 g accuracy by the scale METLER TOLEDO SB 1601.

The amount of evaporated air from the material m_v in kg was calculated according to the following formula (1):

$$m_v = m_d \frac{\varphi_1 - \varphi_2}{100 - \varphi_2}, \quad (1)$$

where m_d – mass of moist material, kg;

φ_1 and φ_2 – moisture content of moist and dried material, %.

The chaff drying speed φ^w was calculated by dividing the amount of evaporated moisture from the amount of ventilation hours and put in $\% \cdot h^{-1}$. The final desiccation of willow chaff was evaluated in the laboratory.

When ventilation was concluded, trials from each section were taken and their moisture content was determined applying the standard method [1]. The ambient air temperature in the room, where the dryers were equipped, in November – December varied from -2.2 ºC at night up to +10.6 ºC during the day time, and the relative air humidity at measurement time ranged from 71 % up to 98 %.

Results and discussion

The process of agricultural product drying has a number of periods. The process of willow chaff drying can be divided into the initial – material heating period, constant drying rate period and the final – when the material moisture is asymptotically approaching to the equilibrium moisture. When the equilibrium moisture is reached, the drying is completed [9; 10].

The willow stem chaff drying was tested from November to December, when the ambient air temperature ranged from -5 to +8 ºC and the moisture – 88-96 %. The temperature of the air flow blown by the ventilator was higher than the ambient air temperature 3-5 ºC. While the chaffs are being dried with the active ventilation, the curves characterizing the process show that the process proceeded sufficiently intensively (Fig. 2 and 3.).

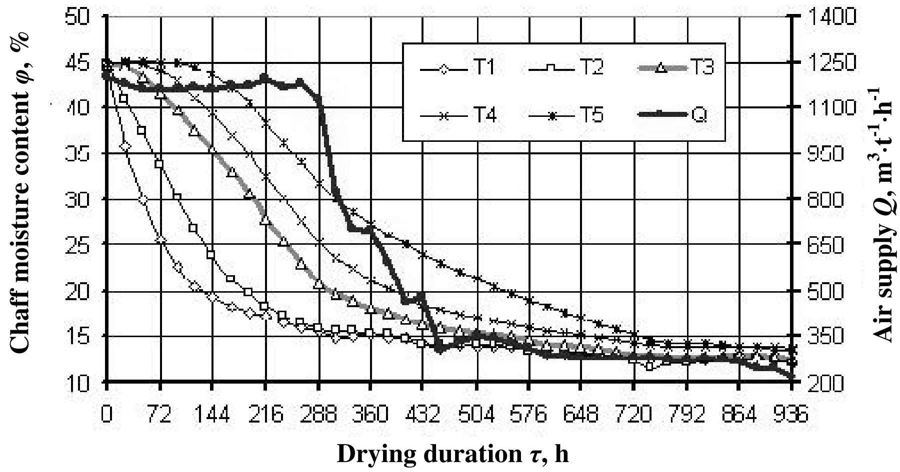

Fig. 2. **Curves of willow stem chaff drying in the first drier according to the layers:**
T1 ... T5 – moisture of the chaff mass layers according to temperature measuring points;
Q – air flow efficiency

In the first dryer, the air was blown with 1190 ± 10 $m^3 \cdot t^{-1} \cdot h^{-1}$ intensity, the heating of the chaff was seen only in the upper layers in the points T4 and T5. During this period, in the lower T1 and T2 layers, the moisture content reached 15 %, whereas in the middle of the T3 – almost 20 %.

In the upper layers (T4 and T5) the chaff dried up, respectively, to 25 % and 33 % of 288 hours of ventilation. When the lower layers dried up, the intensity of the air flow was reduced to 300 ± 10 $m^3 \cdot t^{-1} \cdot h^{-1}$. The drying of such intensity was continued from 456 hours and the equilibrium moisture of willow chaffs (15 %) in all layers was reached after 720 hours.

In the second dryer the average of the blown air flow intensity over the entire ventilation period was 560±5 $m^3 \cdot t^{-1} \cdot h^{-1}$ and the chaff drying in the heating period took place in all layers, except the point T1. The drying to 20 % in the lower layer of the moisture lasted for 272 hours, whereas in the upper (T5) – 950 hours of ventilation. In the middle layer (T3) the drying lasted for 624 hours of ventilation.

The moisture content of the material being dried and the drying rate have the greatest impact on chaff drying.

The willow stem chaff drying rate curves are obtained modifying the willow chaff drying curves.

The drying rate curve can take many forms. It depends on the structure of the material, size, moisture relation energy and drying mode. For example, in the grain drying process, in the heating stage, the drying rate rises from zero to the maximum value. In the period of constant rate this value remains constant, and later, while reaching the critical point, starts to decrease [9].

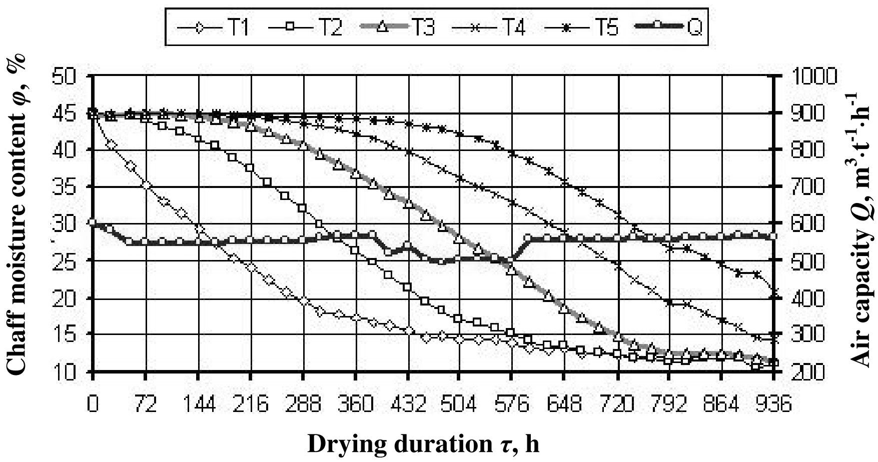

Fig. 3. **Curves of willow stem chaff drying in the second drier according to the layers:**
T1 ... T5 – moisture of the chaff mass layers according to temperature measuring points;
Q – air flow efficiency

The drying rate curves are given to the middle layer point (T3), which best characterize the whole layer of the material being dried (Fig. 4 and 5), since the lower layers of the chaff being ventilated dry more quickly, whereas the upper - slower and are dependent on the weather conditions.

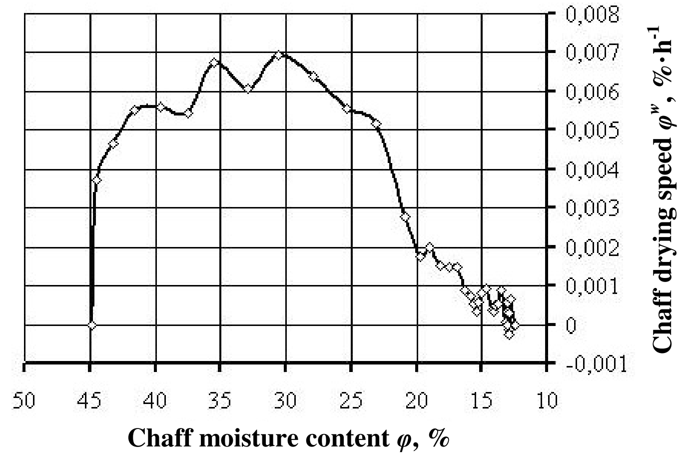

Fig. 4. **Dependence of the willow chaff middle layer drying rate on the mass moisture in the first drier**

In the first drier, the period of the decreasing drying rate in the middle of the layer began when the moisture content of the mass being dried reached about 43 % of moisture, and this period lasted until the moisture in the chaff layer reduced to 22 % of the moisture content.

In the second dryer, the period of the decreasing drying rate, in the middle of the layer began and ended respectively, when the moisture of the mass shifted from 42 to 18 %. While willow chaff was drying, at the beginning, the drying rate in both dryers was increasing until the moisture content of the chaff dropped to 42-43 %. Later, the drying rate stabilized and in this period ranged between 0.0055 and 0.007 $\%\cdot h^{-1}$ in the first dryer and 0.0035 to 0.004 $\%\cdot h^{-1}$ in the second.

At the end of the constant drying rate period, while approaching to the equilibrium moisture content, the received measurement data were unstable. It is believed that this could have been influenced by the constant ventilation when in the willow chaff layer which cooled off at night, the warmer day air was being blown and the moisture concentrated on the surface of the chaff.

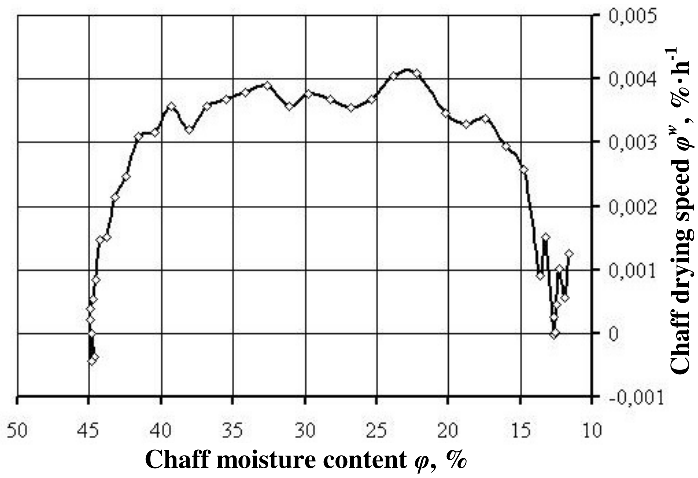

Fig. 5. **Dependence of the willow chaff middle layer drying rate on the mass moisture in the second drier**

The temperature curve characterizes the change of the material temperature while its moisture content is changing. The dependence of the temperature change on the chaff moisture content in the middle of the chaff layer (T3) of the willow being dried is given in Fig. 6 and 7.

In the first dryer, the temperature at the beginning of drying rises to the point corresponding to greater than 35 % of the chaff moisture content, and then remains stable until the moisture content reduces to 23 %.

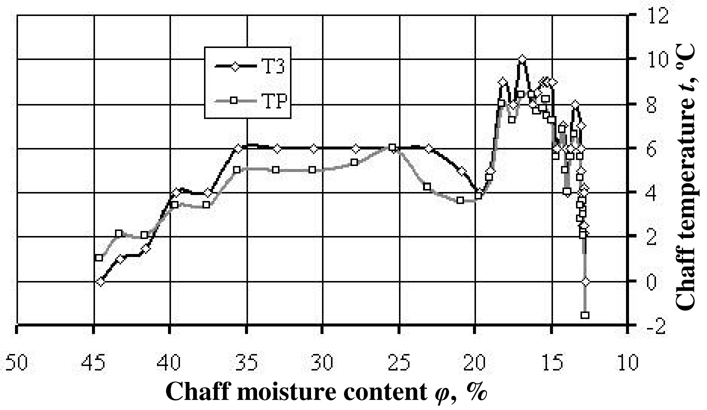

Fig. 6. **Dependence of the willow chaff temperature on the mass moisture in the first drier:**
T3 – temperature of chaff mass; TP – temperature blow in chaff mass

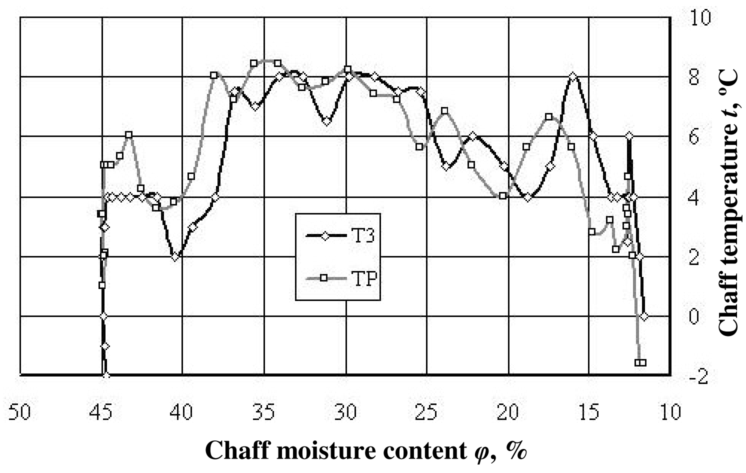

Fig. 7. **Dependence of the willow chaff temperature on the mass moisture in the second drier:**
T3 – temperature of chaff mass; TP – temperature blow in chaff mass

In the second dryer, the mass temperature at the beginning of ventilation was rising until the chaff moisture content reduced to 37 %. Moreover, later it stabilized and remained constant by 25 % of the mass moisture content level. This stage can be seen as a period of the constant moisture evaporation rate, during which the temperature of the mass was about 7-8 ºC. Moreover, the chaff drying at this stage is confirmed by the fact that the mass temperature was lower than the temperature of the air being blown. When the mass moisture content decreased from 20 to 13 %, the chaff temperature variation coincided with the temperature fluctuations of the air being blown.

Conclusions

1. Drying willow chaff of 1-2 years of growth under November-December climatic conditions and continuously blowing the ambient air with active ventilation equipment 900 ± 2 $m^3 \cdot t^{-1} \cdot h^{-1}$ of intensity, the chaff, from 45 % to the equilibrium moisture content, dries out in 720 hours.
2. When the air was blown 900 ± 2 $m^3 \cdot t^{-1} \cdot h^{-1}$, the constant drying rate was about 0.006 $\% \cdot h^{-1}$, whereas ventilating with twice smaller 450 ± 2 $m^3 \cdot t^{-1} \cdot h^{-1}$ intensity, the constant drying rate was about 0.0035 $\% \cdot h^{-1}$.
3. When chaff is ventilated intensively, the period of the constant drying rate in the middle of the layer lasted for 9 days, whereas blowing the air with a twice lesser intensity – 18 days.
4. Ventilation modes of willow chaff must be adjusted according to the ambient weather conditions.

References

1. Jasinskas A. and Scholtz V. 2008. Plant biomass harvesting and preparation of fuel technology and its assessment. Studio, Raudondvaris. 74 p. (In Lithuanian)
2. Hall P. 2000. Effects of storage on fuel parameters of piled and comminuted logging residues. LIRO Report, vol. 25 No. 5.
3. Danfords B., Leding S. and Rosenquist H. 1998. Short-rotation willow coppice growers manual. Swedish Institute of Agricultural Engineering. 53 p.
4. Vares, V., Kask, U., Muiste, P., Pihu, T and Soosaar, S. 2007. Manual for Biofuel Users. Vilnius, Zara. 168 p. (In Lithuanian)
5. Scholz V., Kruger K. and Honh A. 2001. Environmentally compatible and energy-efficient production of energy plants. Agrartechnische forschung, vol. 7, pp. 63-71. (In German)
6. Scholz V., Berg W. and Kaulfuss P. 1998. Energy balance of solid biofuels. Journal of agricultural engineering research, vol. 71, pp. 263-272.
7. Scholz V., Hellebrand, J. and Hohn, A. 2004. Energetic and ecological aspects of the product box timber Transportation. Potential, Machinery, Technologies, Ecology and Economy. Seminar, 29 January. 138 p. (In Germany)
8. Alakangs E. 2005. Propeties of Wood Fuels in Findland, Technical Research Centre of Findland, VTT Processes. Project report PRO2/P2030/05, Jyvaskyla.
9. Boblikov E.M., Buhantzov V.A., Maratov B. K., Prokopetz A.S. 2003. Grain storage technology. Moscow. 438 p. (In Russian)
10. Ginsburg, A. S. 1973. Fundamentals of the theory and technique of drying food products. Moscow. 528 p. (In Russian)
11. Hall P. 2005. Storage Gudelines for Wood Residues for Bioenergy. EECA Report by Scion, UK. 25 p.
12. Hill C. A. S. 2006. Wood Modification: Chemical Thermal and Other Processes, Series: Wiley Series in Renewable Resources, Chichester, Sussex, UK. 260 p.
13. Swajgon J. 1997. Drying biomass (waste from wood) prior to combustion]. Inzyneria Rolnictva, vol. 13, pp. 175-181 (In Polish)
14. CEN/TC 14774-1:2005. 2005. Solid biofuels – Methods for the determination of moisture content – Oven dry method – Part 1: Total moisture – Reference method.
15. Dzejanaviciene, E. F, Pedisius, N, and Skema, R. 2011. Sustainable bioenergy. Lithuanian Energy Institute, Kaunas. 136 p. (In Lithuanian)
16. Doom I. 1994. Green energy: energy from biomass. Energy Innowation, pp. 14-16.
17. Jasinskas, A. and Liubarskis, V. 2005. Production of energy crops and use of fuel technology. Studio, Raudondvaris. 90 p. (In Lithuanian)