Some aspects of biomass utilization concerning energy shortage

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Abstract: Some aspects of biomass utilization concerning energy shortage. Processes occurring during storage of wood chips for energetic purposes are presented. As a result of carried out investigations there were presented dependences between changes in temperature of stored material and relative humidity of ambient air. The modified Henderson’s equation can be used in simulation processes of broken-up wood storing and drying, since it well reflects results of investigations on this material. Besides, it enables to carry out computer simulation of storing the broken-up wood designed for energy purposes.

Key words: energy saving, forest wastes, biomass, storing, material moisture content, relative air humidity, material losses.

INTRODUCTION

Prices of traditional fuels are very high; there are many evidences that they will be increasing continuously. This is connected with their limited resources and – very often – with the lack of profitability in their production [Miszczak and Waszkiewicz 1988]. Poland’s membership in European union imposes certain strategic obligations of energy planning. The share of renewable energy in the Polish fuel-energy balance should amount to 7% in 2011 and 14% in 2020 (at present it is estimated at about 5%). The biomass takes a priority among the energy fuels. It is obtained of forest wastes, forest industry and home-garden green cultivation. The fast-growing energetic willow supplements biomass balance on energy market. The biggest cultivation areas of willow are situated in Sweden and take about 21 000 ha, while in Poland it amounts to about 2600 ha at present. The comparison between calorific values of various fuels is presented in Table 1.

The energetic willow is characterized by wood mass annual gains that are four times bigger then a typical natural forest. Annually one can obtain 30 to 40 t of wood mass per one hectare. Besides, this plant has low soil requirements, low costs of fertilizing and high resistance to climatic conditions, diseases and pests.

<table>
<thead>
<tr>
<th>Kind of fuel</th>
<th>Calorific value (GJ/t)</th>
<th>Purchase cost (PLN/t)</th>
<th>Energy cost per 1 GJ (PLN/GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel oil</td>
<td>43</td>
<td>2800</td>
<td>65.1</td>
</tr>
<tr>
<td>Mineral coal</td>
<td>26</td>
<td>320</td>
<td>12.3</td>
</tr>
<tr>
<td>Fine coal</td>
<td>21</td>
<td>210</td>
<td>10.0</td>
</tr>
<tr>
<td>Natural gas (GJ/1000 m³)</td>
<td>38</td>
<td>1000</td>
<td>26.3</td>
</tr>
<tr>
<td>Energetic willow – dry mass</td>
<td>20</td>
<td>25</td>
<td>1.25</td>
</tr>
</tbody>
</table>
The wood wastes and energetic willow material are stored in broken-up form of high moisture content – about 50% of dry mass.

**MATERIAL AND METHODS**

Storing of broken-up wood material is connected with possibility of raised temperature, material decomposition, development of harmful bacterial strains; it may result in dry mass losses. To avoid these losses during storing, it is important to learn about basic characteristics of process parameters e.g. the course of dependence between wood moisture content and relative air humidity at variable ambient temperature. Another important process element is finding and determination of equilibrium state between water content in the material and relative air humidity at constant ambient temperature. These data are important from the viewpoint of storing and drying process control and determination of calorific values of biological hygroscopic materials: wood, plant stems of field crops, cereal grain. More detailed evaluation of the process calls for laboratory investigations to obtain proper dependences for real conditions. Coleman (1995) investigated the equilibrium state of biological hygroscopic materials and relative air humidity and found that changes in air temperature of 10°C did not affect significantly on the equilibrium state. However, investigations [Hall 1957; Brooker 1974] considering the wider temperature range showed a distinct effect of temperature on material equilibrium and relative humidity of ambient air. [Rao and Pfost 1984] investigated isotherms of moisture content equilibrium state in twenty various seed varieties cultivated in agriculture and found that achievement of equilibrium state of a constant relative air humidity with variable sample moisture content is more difficult and longer, than in the case of constant sample moisture content and variable relative air humidity. The broken-up wood is similar to seeds of field crops with respect to hygroscopicity. Therefore, investigating the equilibrium state of important process parameters of its storing one can use some analogies.

The investigations of Henderson (1992) enabled to develop the dependence between equilibrium state of cereal grain and relative humidity of ambient air of the following form:

\[
\Phi = 1 - \exp \left(-K(T + C) \cdot (100W)^N\right)
\]

where:

- \(T\) – temperature of cereal, (°C),
- \(W\) – grain moisture content (decimal value),
- \(\Phi\) – relative air humidity (decimal value),
- \(K, C\) – constants,
- \(N\) – index exponent dependent on kind of cereals.

Working out of such dependence for wood equilibrium state would enable to develop a model for equilibrium state allowing for computer simulation for various conditions of stored wood designed for energy purposes. Solving of this task is possible by experiment. The most simple searching method is an experiment consisting in supplying a small amount of air to the equilibrium state with a relatively large sample of broken-up wood. An experimental set for carrying out such experiments is presented in Figure 1.

The spruce wood chips sample was placed in the glass container (1) of vol-
volume 0.5 dm³ and immersed in insulated water container (2) that enabled to maintain a constant temperature. The spiral (3) is immersed in the same water; the air is forced through the spiral by diaphragm pump of output 0.88 dm³/min. The spiral serves as heat exchanger. The air from spiral is pumped to the bottom of water container (where the sample is placed), it goes through broken-up wood mass, and enters the dew point temperature sensor creating a closed circulation of small air volume. The following parameters are recorded during investigations: sample temperature, water bath temperature, air temperature under insulation cover, dew point temperature and relative circulated air humidity.

The time for reaching the equilibrium state of hygroscopic material in the case of constant moisture content of the sample ranges from 5 to 10 hours. However, at constant relative humidity of ambient air and variable moisture content of sample, the equilibrium state of these two media is reached after several months. A very important element is exact preparation of samples of defined and different material moisture content. The relative air humidity in the closed cycle of experimental measuring equipment can be determined using dew point temperature and sample temperature.

RESULTS OF INVESTIGATIONS

The pressure of saturated vapour at appropriate sample temperature and dew point temperature can be calculated from the following equation, with consideration of Love (1988) investigations:

\[ P = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + a_4 T^4 + a_5 T^5 + a_6 T^6 \]

where:
- \( P \) – pressure of saturated vapour (Kpa),
- \( T \) – temperature (°C),
\[ a_0 = 6.1077 \text{ kPa} \]
\[ a_1 = 4.4365 \times 10^{-1} \text{ kPa (°C)}^{-1} \]
\[ a_2 = 1.4289 \times 10^{-2} \text{ kPa (°C)}^{-2} \]
\[ a_3 = 2.6550 \times 10^{-4} \text{ kPa (°C)}^{-3} \]
\[ a_4 = 3.0312 \times 10^{-6} \text{ kPa (°C)}^{-4} \]
\[ a_5 = 2.0340 \times 10^{-8} \text{ kPa (°C)}^{-5} \]
\[ a_6 = 6.1368 \times 10^{-11} \text{ kPa (°C)}^{-6} \]

The course of changes in broken-up spruce wood sample of moisture content 14.5% is presented in Figure 2. Despite the changes in sample temperature during experiment, its relative moisture content was constant.

\[ \Phi = 100 \{1 - \exp\left[(-B + T)M^C\right]\} \]

where:
- \( \Phi \) – relative air humidity (%),
- \( M \) – dry mass content (%),
- \( B, C \) – constant parameters of Henderson’s equation.
- \( T \) – temperature (°C).

It is evident from the presented equation that at relative air humidity of 90% the moisture content of broken-up wood increases rapidly.

It is evident from carried out investigations that the modified Henderson’s equation can be used in simulation of storing and drying processes of broken-up wood, since it well reflects the investigations results on this material (Fig. 4). Besides, these dependences are similar to the ones presented in other publications of similar investigations on the behaviour of other biological hygroscopic materials under various environmental conditions.

Figure 3 presents dependence between temperature of sample of moisture content 14.5% and relative ambient air humidity. As it is evident from the diagram, relative ambient air humidity increases when the broken-up wood sample temperature is increased.

The obtained results of investigations were compared to an isotherm drawn with the use of modified Henderson’s equation of the following form:
CONCLUSIONS

1. To avoid dry mass losses of wood material during storing it is important to learn about basic characteristics of process parameters, namely: the wood moisture content and relative air humidity under variable ambient temperature.

2. It is evident from the presented diagram that at relative air humidity of 90% a rapid increase in broken-up wood moisture content occurs.

3. It is evident from carried out investigations that the modified Henderson’s equation can be used in simulation of storing and drying processes of broken-up wood, since it well reflects the investigations results on this material.

4. Working out of modified form of Henderson’s equation would enable to develop a mathematical model for computer simulation of various storing conditions of the wood designed for energetic purposes.
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Streszczenie: Kilka aspektów wykorzystania biomasy w odniesieniu do braków energii. Przedstawiono procesy występujące podczas składowania rozdrobnionego drewna z przeznaczeniem na cele energetyczne. W wyniku przeprowadzonego eksperymentu otrzymano zależność zmian temperatury przechowywanego materiału i wilgotności względnej otaczającego powietrza. Zmodyfikowane równanie Hendersona może być wykorzystane do symulacji procesów przechowywania i suszenia rozdrobnionego drewna, ponieważ dobrze odzwierciedla wyniki badań tego materiału. Ponadto pozwala ono na przeprowadzenie symulacji komputerowej warunków składowania rozdrobnionego drewna z przeznaczeniem na cele energetyczne.

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