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Experimental study of liquid evaporation rate from coniferous biomass

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Abstract. The results of experimental studies of moisture evaporation from coniferous wood (spruce, pine) are presented. The dependences of the mass evaporation rate on temperature and time are obtained. The calculation of the accommodation coefficient for the corresponding temperature ranges has been performed. The analysis of temperature regimes of drying of two typical coniferous wood species is carried out.

1 Introduction

Many regions of the planet have an important ecological significance for the world community, since they have a large reserve of renewable forest resources and, as a consequence, a sufficient amount of biomass that can be used as fuel for the generation of thermal and electrical energy. Because of the processing of wood, a large amount of waste appears. Since the forest residues are not practically used, their disposal is associated with high financial costs. Despite these problems, it is well known that waste wood processing can be used to generate thermal and electrical energy [1].

Biomass is a promising energy carrier. Its main advantages - are renewability; ecological cleanliness, in comparison with other types of fuel; neutrality with respect to greenhouse gas emissions [1].

To date, most developed countries are seeking to develop alternative energy [2,3], since classical energy sources are exhaustible. Bioenergetics has more advantages, as biomass is used as a starting material [1], the cost of which is minimal.

However, the use of woody biomass in power engineering is complicated because of the large, as a rule, moisture content of wood. The drying processes of wood are long and energy-intensive. Therefore, the analysis of the regularities of moisture removal processes is one of the main tasks, the solution of which is necessary in the development of technologies for burning woody biomass in the furnaces of steam and hot water boilers.

The removal of moisture from wood under conditions of intense heating is a very complex process, the description of which has not yet been mathematically determined at the level sufficient for carrying out experimental-design work. Even relatively simple processes of evaporation of water droplets at high temperatures have only recently been investigated experimentally [4,5]. The theory of phase transformations (evaporation,

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condensation, boiling) does not even have water droplets at high temperatures. Therefore, the aim of the work is an experimental study of the processes of moisture removal from coniferous wood samples and the determination of the numerical values of the process characteristics necessary for its description in mathematical modeling.

2 Experiment Procedure

The experiment was carried out in a drying chamber, type SU 32. The chamber has a corrosion-resistant stainless steel surface. The working chamber was heated by wire heaters located around it. Such heating panels have good heat transfer and provide uniform heating of working chamber surface. Drying of materials was carried out on two removable shelves.

As experimental samples, biomass of two types (spruce, pine) was used.

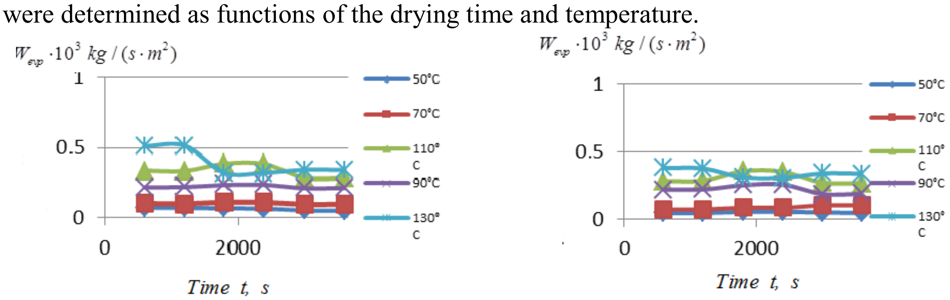
The experiment was carried out in several stages:

• Preparation of a sample of wood weighing 100 grams;
• weighing of the container used for drying, using laboratory scales;
• filling the container with the sample of biomass;
• switching on the drying chamber;
• the required temperature in the drying chamber was set with electric contact thermometer;
• the container with biomass was placed in the drying chamber with time interval (10 minutes).
• after the necessary time elapsed, the capacity was pulled out and its mass was measured;
• processing of experimental data;
• analysis of the results.

Each experiment under fixed conditions was carried out 3 times for the chosen temperature range in the furnace in the same time interval.

3 Results and discussion

In the course of the experiments, the rates of evaporation of two coniferous species of wood were determined as functions of the drying time and temperature.



a) b)

Fig. 1. Dependences of the mass evaporation rate on time (a - spruce, b - pine).

As can be seen from the obtained of dependences, the evaporation of the liquid is stationary in the temperature range 323-363 K for spruce and 323-343 K for pine. This is because at such temperatures for 3600 seconds, the removal of bound moisture does not begin. At temperatures of 383-403 K for spruce and 343-403 for pine, the rate of evaporation decreases after twenty minutes of heating-the first drying period. It corresponds to the step of removing free moisture that covers the pore surface of the material. After this stage, the binding moisture begins to be removed. The increase in the rate of evaporation with the onset of the second period is explained by the fact that the free and bound moisture evaporates, which increases the overall rate of moisture removal.

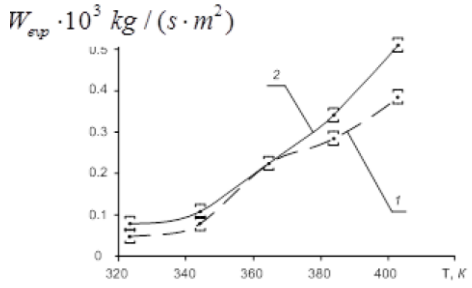


Fig. 2. Dependence of the mass evaporation rate on temperature, at t = 1200 seconds (1 - pine, 2 - spruce).

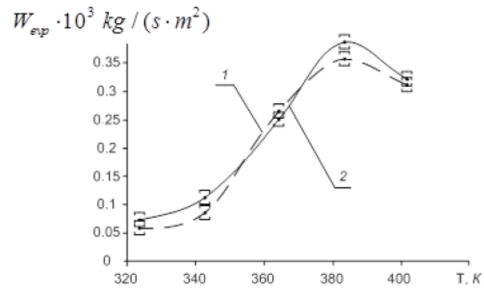


Fig. 3. Dependence of the mass evaporation rate on temperature, at t = 2400 seconds (1 - pine, 2 - spruce).

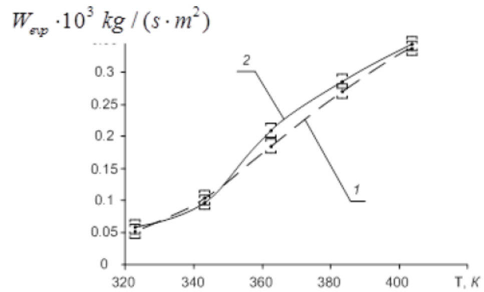


Fig. 4. Dependence of the mass evaporation rate on temperature, at t = 3600 seconds (1 - pine, 2 - spruce).

Analysis of the obtained dependences showed that the rate of moisture removal from the spruce is higher than the rate of moisture removal from pine by an average of 30%. This is explained by the fact that the density of spruce is lower than the density of pine by 10%. From which it follows that the drying of wood spruce is carried out at a lower energy cost. The temperature at which the highest evaporation rate is reached is 403 K.

For the mathematical description of evaporation and condensation processes, different approaches are currently used [6, 7]. The most common is the use of the hypothesis of the possibility of applying the Hertz-Knudsen law obtained for evaporation to vacuum for any density of the medium near the evaporation surface. The coefficient of agreement between the model and the real process is the accommodation coefficient, determination of which is quite a difficult task in any conditions.

The velocity with which gas molecules hit the surface can be calculated on the basis of the kinetic theory from the Hertz-Knudsen equation:

$$W_{evp} = \frac{A \cdot (P^S - P^*)}{\sqrt{\frac{2\pi RT}{M}}}; \quad (3)$$

where W_{evp} - the mass evaporation rate, kg / m2 · s;
P^S - saturated vapor pressure, MPa;
P * - partial pressure, MPa;
R = 8.31 - the universal gas constant, J / mol · K;
M - molecular weight;
T - the temperature of the substance, K;
A - accommodation coefficient.

Using the obtained experimental data and the Hertz-Knudsen law, the accommodation coefficients for moisture removal from biomass were calculated in the temperature range from 323 K to 403 K in the same way as in [8,9].

Tables 1, 2 show the calculated values of the accommodation coefficient in the temperature range from 323 K to 403 K for spruce and pine.

Table 1. Coefficient of accommodation of spruce drying process.

T, K	$W_{evp} \cdot 10^3$, kg/(m²·s)	P^*, Pa	P^s, Pa	$M \cdot 10^3$, kg/mol	R, J / mol · K	Humidity,φ,%	Accommodation coefficient $\cdot 10^6$
323	0.066	6170	12344	18	8.31	50	10.3
343	0.103	15590	31176	18	8.31	50	6.6
363	0.222	35060	70117	18	8.31	50	6.5
383	0.335	71620	143240	18	8.31	50	4.9
403	0.391	135010	270020	18	8.31	50	3.1

Table 2. Coefficient of accommodation of pine drying process.

T, K	$W_{evp} \cdot 10^3$, kg/(m²·s)	P^*, Pa	P^s, Pa	$M \cdot 10^3$, kg/mol	R, J / mol · K	Humidity,φ,%	Accommodation coefficient $\cdot 10^6$
323	0.051	6170	12344	18	8.31	50	8
343	0.087	15590	31176	18	8.31	50	5.6
363	0.22	35060	70117	18	8.31	50	6.4
383	0.301	71620	14324	18	8.31	50	4.4
403	0.34	135010	27002	18	8.31	50	2.7

4 Conclusion

In the course of the experimental studies, the following parameters were determined: the mass evaporation rates of liquid from coniferous wood, the dependence of the mass evaporation rate on temperature was obtained, the accommodation coefficient for the respective temperature ranges was calculated. The temperature regimes of drying two typical coniferous species are analyzed.

The results of the experimental studies carried out are the basis for further refinement of the mechanism of moisture removal from the porous structure of the moisture-containing material and development of the general theory of drying. The dependence of the mass evaporation rate of the wood samples under study on temperature makes it possible to determine the accommodation coefficient in the mathematical expression of the Hertz-Knudsen law.

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