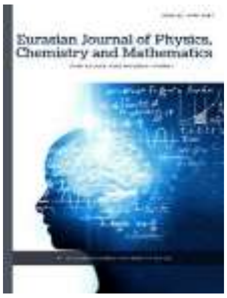

Kinetics and Thermodynamics of Grape Cake Drying

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ABSTRACT

In this work, several different drying methods were used to organize deep processing of grape residues collected at grape processing plants using waste-free technology. The initial moisture content of grape cake is 49,36 ± 3,45%. Grape cake composition is considered a good raw material for the production of biofuel products of the second generation. During the experiment, the drying efficiency of a vacuum dryer, conventional drying and drying in the open sun were studied.

Keywords: drying, storage, temperature, humidity, time, grape cake, food

The drying process in a vacuum dryer was carried out at two different temperatures. For materials sensitive to heat damage, a vacuum dryer can be used to reduce the drying temperature and pressure in order to maintain the physico-chemical properties of the grape pomace. The work shows the effect of different temperatures on the kinetics of drying grape pomace. As expected, the moisture content decreased during the drying process. The highest temperature resulted in the shortest drying time. Equilibrium moisture content was achieved at different times during the process. After drying for 12 hours at 35°C, and 3 hours at 70°C, the equilibrium moisture content of the cake was about 8.32 ± 0.96%. As mentioned earlier, the drying kinetics were described using the Peleg model. The Peleg model constants obtained as a result of mathematical modeling at various drying temperatures are shown in Table 1.

Table 1 – Methods for drying grape pomace (n=3)

Метод сушки	K_1, ч %$^{-1}$	K_2, %$^{-1}$	R^2	R_0, % ч$^{-1}$
Вакуумная сушка (35 °C)	2,166±0,766	1,609±0,120	0,957	0,462
Вакуумная сушка (70 °C)	0,275±0,167	1,482±0,106	0,974	3,634
Обычная сушка (70 °C)	0,419±0,073	1,129±0,019	0,998	2,385
Сушка на открытом солнце	4,311±0,822	1,192±0,055	0,991	0,242

Note:
(K1, K2) – Peleg equation;
R2 – coefficient of determination;
R0 – desorption rate.

Table 1 shows the constants of the Peleg equation (K1, K2), the coefficient of determination (R2) and the rate of desorption (R0) for various methods of drying grape pomace. The constant K1 is related to the rate of mass transfer, where the higher K1, the lower the initial rate of water desorption. The constant decreased with increasing temperature, which indicates an increase in the rate of water desorption. The second constant K2 is related to the maximum water absorption capacity, where the lower K2, the higher the water absorption capacity [1]. Peleg [2] proposed an empirical equation for describing the sorption characteristics of various food materials. The use of short-term experimental data to predict the equilibrium moisture content of foodstuffs is the main advantage of the model. The drying process model is shown as [2]:

$$M_t = M_0 - \frac{t}{K_1 + K_2 t} \quad (1)$$

where M_t is the moisture content in terms of dry matter at time t, M_0 is the initial moisture content in terms of dry matter, t is time, K_1 is the Peleg rate constant (h %-1), K_2 is the Peleg capacitance constant (%- 1).

The Peleg rate constant K_1 refers to desorption at the beginning (R0), i.e. R at t=t0:

$$R = -\frac{1}{K_1} \quad (2)$$

Linearization of equation (1) gives:

$$\frac{m}{M_m - M_0} \text{знак равно } K_1 - K_2 m \quad (3)$$

It can be seen from Table 1 that with increasing temperature there is a slight decrease in the values of the K2 constant. The obtained coefficients exceeded 0.95, which indicates that the Peleg equation corresponds to experimental data and is suitable for describing the decrease in moisture content in grape pomace [3]. As can be seen from all the results, the desorption rate was the highest for the vacuum dryer drying process at 70°C, which means that the drying of grape pomace was the fastest at this temperature. The use of a higher temperature resulted in a higher desorption rate. Comparing the desorption rate of the cake, it can be seen that the lowest drying rate was in the open sun, and the highest drying rate was during vacuum drying at a temperature of 70 °C.

In addition, the Peleg constant (K1) can be used to calculate the activation energy and thermodynamic parameters such as differential enthalpy, entropy and Gibbs energy (activation energy 52.095 kJ mol-1 and hydration coefficient equal to 73.729 h-1). These thermodynamic parameters characterize the drying process (thermodynamic parameters of cake in a vacuum dryer at 35 °C - 135.047 kJ mol-1, at 70 °C - 144.776 kJ mol -1).

Enthalpy is a thermodynamic property of a system and is related to the energy required to remove water associated with a product during the drying process. The differential enthalpy decreased with increasing temperature. At lower temperatures, differential enthalpy values were higher, indicating that more energy was required to accelerate drying. The values were positive for grape pomace, indicating an endothermic process, i.e. about the need to supply heat to the system. Similar results were obtained in the study [4].

Entropy is a thermodynamic property that can be related to the level of disorder between water and product. During the drying process, entropy becomes more negative as the drying temperature increases. A negative change in entropy indicates a decrease in the disorder of the isolated system. The Gibbs free energy increases with increasing temperature. For all materials dried in the vacuum dryer, the Gibbs energy values were positive, indicating that the process was not spontaneous. In principle, the drying process requires the addition of energy from the environment to help reduce the moisture content [4].

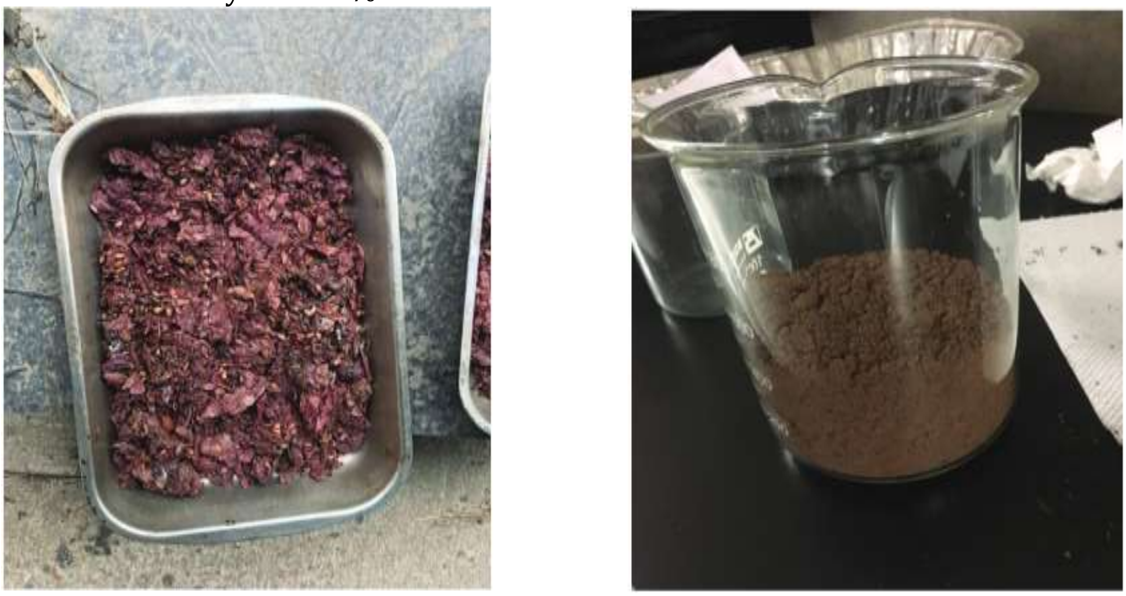
Vacuum drying method has proven to be an effective drying method in industry due to energy savings i.e. Drying requires less energy. On the other hand, this method requires additional equipment, which includes higher operating costs, and process control becomes more difficult due to maintaining lower pressure [5]. Considering the lower operating costs, another method for drying grape pomace was conventional drying at 70°C, since this temperature was the most effective for vacuum drying. In a conventional dryer, heat is transferred by conduction, and it took 7 hours to reach equilibrium moisture content (Table 2), and the content was about 4-8% for all materials, which was the same as in vacuum drying.

Table 2 - Drying conditions for ongoing processes

Показатели	Процесс сушки		
	Вакуумная сушка	Обычная сушка	Сушка на открытом солнце
Температура, °C	35, 70	70	25-35
Давление, атм	0,098	0,098	атм
Время высыхания, ч	3-12	7	24

Due to the huge amount of grape pomace produced over several weeks during the grape ripening period, these methods can become a bottleneck due to the power of the equipment. An alternative method may be drying in the open sun, since it does not require special equipment and energy consumption, but it should be taken into account that the conditions of temperature and air humidity are not constant; so it may take much longer. Therefore, the open sun drying method was also used in this work. The average temperature when drying in the open sun was 30 °C, and the humidity was 40%. This method was carried out for 24 hours to achieve equilibrium moisture content, which was approximately the same as for previous methods.

Peleg constants, desorption rate and equilibrium moisture content for drying in a conventional dryer and drying in the open sun are given in Table 1. Comparing drying in a vacuum dryer and in a conventional dryer at 70 ° C, it can be noted that the desorption rate had higher values during drying in a vacuum dryer. On the other hand, the desorption rate was lowest when drying in the open sun.



a b

Picture 1 - Change in the texture of the cake: a - dried in the oven, b - after grinding

Considering all the results obtained with various drying methods, the most suitable method for pressing the grapes was drying in a vacuum dryer at a temperature of 70 °C. But, given the large number of grape cakes resulting from the year-round processing of grape varieties, the method of drying grape cakes in the sun was chosen in order to prevent pollution of the environment and ecology and use the secondary product for experiments throughout the year. According to the results of the analysis, sun-dried grape cake was found suitable for processing to obtain the second generation of bioethanol.

The dried samples are crushed to particles of 1-2 mm using a laboratory device U1 EML (Russia). Then they are passed through two mills, the first to obtain a more uniform consistency, and the second to obtain the second to achieve the required size (mesh with a hole of 1-2 mm). The change in the cake texture after this treatment is shown in Figure 1

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