Theoretical and experimental study of primary cocoon processing

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Abstract. This study is aimed at studying the influence of basic parameters such as the power of ultrasonic waves, the power of infrared radiation, the drying temperature, the drying time and the drying kinetics of cocoons. We used two special methods to kill and dry the cocoons: infrared and combined (infrared-ultrasound). The results obtained indicate that the cocoon drying process as a whole can be controlled by the period of speed decline. With the infrared method, the drying speed increased with increasing temperature, while the power of infrared radiation did not have a strong effect on the killing process. Ultrasound has shown its positive potential in the primary cocoon processing.

1 Introduction

Realisation of improved highly efficient plant designs solves a number of scientific and technical problems at cocoon processing enterprises. Today in our republic, sericulture and silk production are still considered a pressing problem, since production enterprises do not have modern equipment for the primary processing of cocoons. Killing and drying of cocoons is an important part of cocoon production. At present, different drying equipment for drying cocoons are mainly used in our country, operating with different energy resources, developed by our scientists, researchers and engineers or imported from different countries of the world. However, depending on the equipment and drying methods used, the quality of the final product decreases or increases during the process of dehulling and drying of mulberry silkworm cocoons [1].

Silkworm cocoons are natural protective shells that worms build during their development (Figure 1). These cocoons contain silk threads, which are then used to produce silk. In the process of collecting and primary processing of silkworm cocoons, it is important to follow certain technologies and methods in order to preserve the integrity and quality of silk threads. In Uzbekistan, silk production has a long history and is a traditional branch of the textile industry. There are several enterprises in the country engaged in the primary processing of silkworm cocoons [2].

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In the work of K.R. Avezov, an improved SK-150K unit with new equipment where infrared rays are applied is considered. As a result of preliminary studies by K.R. Avezov, it was established that the suitable option for cocoons washing is exposure to infrared rays [3].

In the work of Professor Z.S. Iskandarov, a device for washing and drying of mulberry silkworm cocoons is considered. This device has a number of infrared emitters in pairs with reflectors provides fast cocoons washing and reduces the total drying time [4].

Z.S. Aripov improved equipment SK-150K, which allows to reduce fuel consumption, air heating time, weight and size of the dryer furnace [5].

Awadd designed, constructed and used a mechanical dryer for killing cocoon silkworms [6].

Zhang et al. studied the effects of heated air temperature, air flow rate of cocoons, and processing time of silkworm cocoons. Changes in humidity, weight and weight of the shells were determined, and the quality of the silk thread of silkworm cocoons after the heat treatment process was assessed [7].

Therefore, this paper investigates and compares two different drying methods (ultrasonic drying and combined drying) for their effectiveness in killing and drying silkworm cocoons.

2 Materials and methods

Bombyx mori cocoons were used in the experiment. Fresh cocoons were stored in a refrigerated chamber at 4.0±0.5 °C. Before drying, cocoons were removed and placed at room temperature for about 15 min. The samples were then spread in a single layer on stainless steel trays and placed in the experimental setup for drying. Using an electronic scale, the whole sample was measured every 30 minutes and the value was recorded to construct drying curves and drying rate curves.

In this experiment we used: "Asia" - a long-wave laboratory infrared drying unit available in the laboratory of the department "Service Technique" of the Mechanical Engineering Faculty of TSTU, with a power of 750W, built-in three infrared emitters of 250 W each [2] and the developed infrared ultrasonic drying unit with an ultrasound frequency of 50 Hz and a IR radiation power of 1000W. Temperature range for both experiments was 60 °C, 65 °C and 70 °C and the ultrasonic exposure time was set to 10 seconds [8].

Instantaneous moisture content was calculated as follows:

\[
M_t = \frac{m_t - m_d}{m_d} \times 100\% \quad (1)
\]

here \(M_t\) is instant moisture content in terms of dry matter; \(m_t\) is instant mass; \(m_d\) is empty weight. Dry mass was determined using a moisture analyzer model MV 200 (the temperature was 102 °C before the mass changed not exceeding 0.1 g.

The moisture content of the material can be easily calculated using the formula below (2):

\[
W_t = \frac{m_t - m_d}{m_0} \times 100\% \quad (2)
\]

here \(W_t\) is moisture content in terms of raw basis; \(m_0\) is initial mass. The initial humidity of the cocoons chosen for the samples was 76±0.05% by weight.

In most sources, the drying rate is determined by formula (3):

\[
DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad (3)
\]

here \(\Delta t\) is time interval.

The experimental data were processed using Excel 2019. Statistical analysis of the results was performed using Statistics 21 and Waller-Duncan mean comparison at \(p<0.05\) using Comsol Multyphiscs 5.5 software [9].
3 Results and discussion

*Drying of mulberry silkworm cocoons in an infrared equipment.* Figures 1 and 2 show the effect of temperature on the drying characteristics of cocoons at 60, 65, 70 °C and the drying time was 15, 12, 10 min, respectively.

![Fig. 1. Changes in moisture content in cocoons depending on temperature.](image)

![Fig. 2. Changing the drying speed of cocoons depending on temperature.](image)

Naturally, as the temperature increases, the processing time will decrease and the drying speed will increase accordingly. Figure 3 shows energy consumption during cocoon processing depending on temperature. At dryer temperatures of 60°C, 65°C and 70°C, energy consumption was 0.19, 0.15 and 0.12 kWh, respectively. Energy consumption at 70°C was lowest with an average of 21% lower than at 60°C. Although the device consumes more power depending on the time the temperature is maintained, shortening the processing time has an effective effect and reduces power consumption. This means that higher temperature speeds up the drying process and saves energy, and it can be said that higher temperature corresponds to drying the cocoons [10].
Fig. 3. Energy consumption for drying cocoons depending on temperature.

Drying of mulberry silkworm cocoons in an infrared ultrasonic equipment. Figure 4 shows the change in moisture content of cocoons at different temperatures and exposure to ultrasound at drying temperatures of 60, 65 and 70 °C.

Fig. 4. Change of moisture content in cocoons at different temperatures and exposure to ultrasound.

Figure 5 shows the change in moisture content of cocoons at different temperatures and exposure to ultrasound. It should be noted that the piezoelectric ultrasonic emitters used in the equipment are periodically exposed to the raw material, the interval between each exposure is 5 seconds. Infrared radiation allows heat to be transferred directly inside the material, which accelerates the process of moisture evaporation. Ultrasonic waves, in turn, contribute to a more even distribution of heat and increase the rate of moisture evaporation. The combination of these two methods allows to achieve faster and more efficient drying, while reducing energy consumption [11].
Fig. 5. Variation of cocoons drying rate at different temperatures and ultrasound exposure.

Figure 6 shows the energy consumption for drying cocoons as a function of temperature (60, 65 and 70 °C) for combined drying.

Fig. 6. Energy consumption for drying cocoons as a function of temperature and ultrasonic exposure.

Energy consumption was significantly lowest at a drying temperature of 70 °C, indicating that the energy expended at a temperature increase of about 10 °C was less energy than that expended at 60 °C. Obviously, 70 °C is a more suitable temperature for infrared ultrasonic drying of mulberry silkworm cocoons in terms of energy consumption [12].

4 Conclusion

Infrared radiation allows heat to be transferred directly into the material, which speeds up the moisture evaporation process. The ultrasonic waves, in turn, contribute to a more even heat distribution and increase the rate of moisture evaporation. The combination of these two methods results in faster and more efficient drying, while reducing energy consumption. This is because ultrasonic waves can affect the microstructure of mulberry cocoons. Optimal conditions for drying mulberry cocoons are: drying temperature 70 °C, ultrasound power 50 Hz, drying time on average 5 minutes, which leads to energy saving and high quality of the final product.
References

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