Hop drying process research in industrial dryers

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Abstract. In the conditions of economic sanctions and food embargo in Russia, the issue of import substitution has become acute. Studies are becoming relevant, which improve the production process of hops. Currently, many enterprises use industrial dryers with high performance. The aim of the study is to increase the efficiency of drying hops with the maximum possible reduction of energy costs. The introduction of innovations should be preceded by an analysis of the existing technology of drying hops. Object of research - hop samples taken during and after drying, as well as an industrial dryer. Working measurements were carried out in three-fold repetition. These included determining the temperature and humidity of the drying agent as well as the humidity of the hops. The results of studies have shown that it is possible to achieve significant energy savings in the process of drying hops. This is the scientific novelty. Based on the results, several ways to achieve savings are proposed. To do this, it is necessary to accelerate the movement of the mass of hop cones and optimize the ventilation system. On the basis of this, the possibility of modernizing the duct system to increase the productivity of the dryer is proposed.

1. Introduction
Hops belong to agricultural crops with a small volume of production – the world area of its plantations is more than 51 thousand hectares [1]. Hop growing in Russia and in a number of European countries is an important branch of agricultural production [2]. In recent years, in the conditions of economic sanctions and food embargo in Russia, the issue of import substitution has become acute. These trends are directly related to hop production. Currently, about 90% of commercial hops are imported to the Russian market. The results of the research revealed that the production of Russian hops is mainly localized in the Chuvash Republic [3]. In this regard, today the problems and prospects of development of hop growing as a traditional branch of the Chuvash Republic become actual.

Yields and product quality depend on the timely and proper implementation of technological operations in the production of hops. Given the increasing prices of energy, it is necessary to introduce improved low-cost technologies in the production of hops.

Drying hops and other crops are the object of research of world scientists. For example, as a result of researches the following was found out [4]. The process of drying showed that hops are practically
dry (10 ± 2.0% of moisture) al-ready at the end of the second belt or possibly at the beginning of the third belt.

The aim of the research is to increase the efficiency of drying hops with the maximum possible reduction of energy costs. The novelty of research in improving the parameters of drying hops on existing belt dryers and modernization of drying technology, carried out with the use of advanced digital devices. It is necessary to improve the efficiency and justification of the need for a drying system. The research given in this article can be useful in the design of advanced dryers. Also, in practical use when using and upgrading existing dryers for hops and other crops.

2. Materials and methods
Experimental studies were carried out in existing farms on the belt dryer PHB-750 with productivity of 750 kg of dry hops per hour, which received the greatest distribution among producers of commercial hops in Russia. The schematic diagram of this dryer is shown in figure 1. Green arrows show the direction of movement of the mass of the hop cone, red arrows – the direction of movement of warm air masses, blue arrows – the direction of movement of the spent drying agent.

![Figure 1. Flow diagram of the dryer of PHB-750: 1 – loading conveyor, 2 – first belt, 3 – second belt, 4 – third belt, 5 – air conditioning belt, 6 – fan, 7 – heat generator, 1 – input measuring point, M1 – M10 – measuring points in the workspace, O1 – O6 – outlet measuring points.](image)

The drying tunnel consists of 13 sections, a drive and tensioning station placed on a common mainframe. Sections with a length of 1250 mm are composed of frames and plates connected by bolts and thus constituting the common tunnel. The tunnel is closed, access to the tapes is made possible by means of technological hatches M1-M10. To assess the parameters of the ambient air, a technological hatch I1 was used. In the outlet ducts, there are technological openings O1 – O6, which were used to estimate the parameters of the spent drying agent.

Access to the space below the third belt (necessary mainly during cleaning) is opened by means of a door in the lower part of the side plates, the drive and tension station are placed on the side of the material entering the drying tunnel and on leaving the dryer for air conditioning. Both stations are made of sheet steel and profile material. On the side frames, massive beams are welded for fastening the bearing housings, drums, and tensioning devices and chains.
In the side and end walls there are mounting and test holes for evaluating the course of the tapes and a window for taking samples of the material being dried.

Access to the windows is opened with the help of three ladders, one of which provides access to the overlap of the dryer.

The tapes are a mesh woven from galvanized wire 3 m wide. The connection to the endless band is made with galvanized steel studs and wire. Drive drums rotate using a chain tensioned by tensioning rollers. The drives form an installation assembled from an electric motor and a stepless transmission with a transmission. The stepless transmission is equipped with a tachometer. Bulk and side restrictive boards are made of sheet and shaped steel.

In the course of our research, a total of five series of measurements were made – three for a dryer with diesel fuel and two for a dryer with gas fuel. Research of processes of drying of the hop was carried out in cooperation with representatives of JSC "41 Central plants" (Moscow) in autumn 2018 in hop farms of the Chuvash Republic.

The thermal regime was roughly violated in the diesel fuel dryer, which negatively affected the quality of marketable hops (temperature reached 90°C). As emphasized by various authors, this is unacceptable [5], so we used averaged data at steady state.

Ambient temperature 19°C, ambient humidity 65 to 75%. Considering that the atmosphere surrounding the hop cones in dryers vary with time and position, a specific study was conducted to analyze the behavior of analytical solutions under such variable conditions [6].

The data obtained were stored on a digital medium and subsequently processed.

Gas flow measurement was carried out on a dryer by reading the standard flow meter and pressure gauges. Measurements were carried out for four hours, at the stage of heating the dryer and in the drying mode. The first hour of measurement was followed with an interval of 10 minutes, then 20 minutes and 40 minutes.

The humidity of air in the masses of raw hops was measured by a hygrometer, its readings completely coincided with the standard hygrometer, used on industrial dryers of many types.

The flow rate inside the chamber was measured using an anemometer, which was inserted at arm's length through 9 portholes numbered in the course of hops movement. A supply fan is used as part of a dryer with a capacity of 42 thousand m³/h, i.e. it is redundant and operates at 30%.

The method of determining the volume-mass characteristics of hops was given earlier [7].

To determine the dependence of humidity changes in the drying process of hops, it is necessary to study the dynamics of changes in the mass of the sample during its drying [8]. The mass of the hops sample is defined as

\[ M = M_C + M_B, \]  

where \( M_B \) is the mass of dry matter in the sample, kg; \( M_C \) is the mass of water in the sample, kg.

If we take the total mass of the material \( M \) for 100%, the amount of moisture in it, expressed as a percentage of the total weight, will be characterized as relative humidity related to the weight of the wet material:

\[ \omega_0 = \frac{M_B}{M} \cdot 100\% = \frac{M_B}{M_C + M_B} \cdot 100\%. \]  

Accordingly, in the ideal case in the absence of moisture \((M_B = 0)\), dried hops become completely dry, with \( \omega_0 = 0 \). It can also be noted that at \( M_C = 0 \) the material will be pure water, in which case \( \omega_0 = 100\% \). Thus, the parameter \( \omega_0 \) varies from 0 to 100%.

Then, the dependence of the weight of dry matter \( M_C \) moisture on the total weight \( \omega_0 \) looks like

\[ M_C = M \frac{100 - \omega_0}{100}. \]  

To study the dynamics of the drying process, we take the initial mass of the wet hop sample as \( M_1 \). Accordingly, the sample will have moisture \( \omega_{01} \). After complete drying of the hops sample, we take its mass as \( M_2 \) and the humidity as \( \omega_{02} \).
The dry matter content of the material prior to drying is determined by (3) as

\[ M_{c_1} = M_1 \frac{100 - \omega_{b1}}{100}. \]  

The dry matter content of the material after drying, respectively, is expressed as

\[ M_{c_2} = M_2 \frac{100 - \omega_{b2}}{100}. \]  

It is known that during drying there is moisture evaporation, thus the content of absolutely dry substance does not change \([9]\), or

\[ M_{c_1} = M_{c_2}. \]  

Thus, by combining (4), (5) and (6), we obtain

\[ M_1 \frac{100 - \omega_{b1}}{100} = M_2 \frac{100 - \omega_{b2}}{100}, \]  

or

\[ \frac{M_1}{M_2} = \frac{100 - \omega_{b1}}{100 - \omega_{b2}}. \]  

Using the ratio (8) it is possible to estimate the weight and humidity of hops before and after drying. The amount of moisture evaporated from the dried hops can be expressed as

\[ M_\beta = M_1 - M_2, \]  

or, subject to (8),

\[ M_\beta = M_2 \frac{\omega_{b2} - \omega_{b1}}{100 - \omega_{b2}} = M_1 \frac{\omega_{b1} - \omega_{b2}}{100 - \omega_{b1}}. \]  

Using the expression (10), the amount of moisture in the initial hop samples was determined by substituting the mass values obtained by high-precision scales. While achieving the complete drying of the samples and considered \( \omega_{b2} \approx 0 \).

3. Results and discussion

3.1. Experimental determination of evaporated moisture in hops

For experimental determination of evaporated moisture for a certain time of drying of hops in laboratory conditions three containers of identical capacity and the minimum difference in weight are taken. The research conditions were as follows: Ambient temperature 19 °C, ambient humidity 65 to 75%. These containers were filled with hops lying in the air in the room and weighed on electronic scales with an accuracy of up to the fourth decimal place, and then placed in a preheated to a temperature of 60±3°C drying Cabinet. After an interval of 1 hour, the samples were taken out and weighed. According to the results of drying data on the weight of hops in a given time interval (figure 2).

With an increase in the drying time of hops, the moisture content in it decreases, and therefore, the weight of the received sample decreases. At the same time, during the first hour of drying, the samples lose an average of 0.29 g in weight. Further, the evaporation rate decreases, and within 6 h the mass loss is 0.06 g, which is 0.5% of the initial mass of the sample (figure 2). It follows that further drying is impractical. At the same time, to reduce the relative humidity of the material by the same amount, it is necessary to remove different amounts of moisture, and the higher the humidity of the hops, the more moisture must be evaporated at the beginning of drying.
3.2. Gas flow measurement
Gas flow measurement was carried out by reading the standard flow meter with the error no more than 1%. Measurements were carried out for ten hours, at the stage of heating the dryer and in the drying mode. The measurements were followed with an interval of 10 minutes. The graph (figure 2) shows the gas fuel consumption of the dryer. According to the initial data, the maximum consumption is $Q=175 \text{ m}^3/\text{h}$. The graph shows that the heating mode is used by no more than 50%, and in the drying mode – about 25% of the possible thermal power. The results show (figure 3) that at the initial stage of the dryer heating of the heating system takes place, and requires an increased rate of gas consumption. As the steady-state enters, the gas flow rate approaches the nominal, and at the end of the drying cycle, it is lower than the nominal one, since the dehumidification rate decreases and the previous heat quantity is no longer required. Around the 45th minute, there is a significant decrease in temperature.

3.3. Hops humidity measurement
Figure 4 shows an example of a single measurement taken with samples taken from the technological openings of the $M_1 - M_{10}$ dryer, as well as at the input $I_1$ into it. In addition to the moisture content of $Wh$ in the hop, the graph shows the values of relative humidity $w$ and air temperature $t$. The humidity of hops on the upper belt ($M_1 \ldots M_3$) changes slightly compared to the initial value, on the middle layer ($M_4 \ldots M_6$) it changes significantly, on the lower layer ($M_7 \ldots M_9$) it almost does not change, being at around 8-10%. This can be explained by the fact that petals of cones dry on the top layer, which opens at the end of the upper belt of the dryer, and then evaporation from the rod of the cone begins on the middle belt, where the bulk of the moisture is located. It can be concluded that the hops are dried to a value of about 10% humidity at the end of the second layer.

3.4. The flow rate measurement
The flow rate inside the chamber was measured using an anemometer through 9 windows numbered in the direction of movement of the hops ($M_1 - M_9$). The flow rate over the hop does not exceed 0.6 m/s (figure 5). The air accelerates in the lower channel in the hop discharge port. When comparing the graphs shown in Figures 2 and 4, it can be seen that the air velocity above the hop layer, equal to 0.3-0.4 m/s, is sufficient for intensive drying of the hop layer. Measurements show that the hops are already dried on the lower tier (at points $M_7 - M_9$) and are to some extent over-dried, which means an unjustified loss of energy spent on heating the air for drying. It is also recommended to reduce the performance of the supply fan in order to save energy. The obtained indicators allow us to review the existing modes of drying of hops with a belt dryer and indicate that they have reserves for reducing energy consumption.
Figure 4. Graph of moisture content of hop (Wh, %), relative humidity (w, %) and drying agent temperature (t, °C) in points I₁ and M₁-M₁₀.

Figure 5. Airflow rate v in the chamber in points M₁-M₉, m/s.

4. Conclusion

The drying process in working industrial dryers shows that hops reach moisture targets long before the drying cycle is complete, so the drying efficiency can be significantly improved. It has been established that it is possible to achieve a significant reduction in energy costs when drying hops. Experiments have proved the original possibility of increasing the efficiency of drying hops while reducing energy costs. The following ways to improve hop drying parameters on existing dryers are being considered.

Modernization of drying technology with the use of advanced digital devices. Equipping the dryer with modern digital temperature and humidity sensors will strengthen the control over the quality of hops. It will also allow the operator to make a timely decision on unloading.
Drying and conditioning is not necessary. Since it was found that hops are largely dried already in the middle of the drying cycle. The modernization of the duct system will allow more rational distributing of the supply air flows. This will have a positive impact on the uniformity of drying hops, and also contributes to the replacement of the fan to a less productive one. This will save energy resources.

The research given in this article can be useful in the design of advanced dryers. Also in practical use when using and upgrading existing dryers for hops and other crops. The research materials open up opportunities for further study of the issue of industrial dryer’s modernization for hops and other crops, experiments on the ventilation and heating system. The possibility of supplementing the hop dryer with infrared heaters is also considered, since their effectiveness has been proven [10].

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