

Theoretical analysis of the technological process of hop drying

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Abstract. This article is aimed at the current questions concerning hop drying, a process which represents a significant part of energy consumption for hop producers. The water content drops during hop cone drying from the original approx. 80% of moisture to 8 or 10%. The drying medium is heated air, and the maximum drying temperatures range between 55 °C and 60 °C, remaining practically stable for the entire duration of drying. Hops are exposed to these temperatures for 6 to 8 hours. The current old and ageing belt dryers record large losses. Their modernisation and particularly new drying technologies need to derive from perfect knowledge of thermal characteristics of materials and drying devices. The drying process and the actual implementation necessarily depend on the knowledge of the entire process calculation that is why the paper introduction outlines simplified issues concerning a ‘theoretical dryer’ following the h-x chart. An experimental measurement was carried out in an operating belt dryer. It included measurements of the drying medium thermal and moisture parameters and of the drying hop qualitative parameters. These drying parameters were monitored by means of continuously recording data loggers and of a laboratory analysis of the samples (hop moisture content, alpha bitter acids, Hop Storage Index). The drying process revealed that hops are practically dry ($10 \pm 2.0\%$ of moisture content) already at the end of the second belt or possibly at the beginning of the third belt. It was also proven that hops are excessively dried (moisture content of 4 to 8%), adjusted to their final moisture of 8–10% through conditioning. Excessive drying results in considerable hop-cone shatter which makes the hop manipulation difficult during further processing, leading to larger losses of lupulin.

Key words: hop, hop drying, belt dryer.

INTRODUCTION

The current state in the field of hop drying and hop conditioning technology is not ideal, as regards the operating costs as well as qualitative properties of the final product. The belt dryers prevailing so far, following stationary picking lines, derive their drying process from continuous progress of the harvest. In a belt dryer hop cones are dried at a temperature of the drying air ranging between 55–60 °C for 6–8 hours from the initial 80% moisture content to 8 or up to 10%. Drying hop cones below 10% of moisture content and following controlled conditioning require approximately 1/3 of the overall energy requirements necessary for hop growing (Doe & Menary, 1979).

The following outlined simplified process referring to ‘theoretical dryer’ based on the h-x chart only introduces the matter but does not cover the problem linked to hop

drying as a whole. For the real dryer psychrometric mechanisms need to be considered, as well as thermal energy savings, recirculation and recovery (Srivastava et al., 2006).

The process between the initial and final state of the hops and air is illustrated in the Molliere h-x diagram by isobaric air heating (0–1) and its isenthalpic humidification (1–2) through the moisture released from the hops. This process is called ‘theoretical dryer’ (Fig. 1).

The weight of dried-off moisture content is determined from weights of the input and output hops M_1 and M_2 , with a proportion of hop moisture content w_1 and w_2 and specific hop moisture u_1 and u_2 (Henderson & Miller, 1972; Aboltins & Palabinskis, 2016):

$$M_w = M_1 - M_2 = M_1 \frac{w_1 - w_2}{100 - w_2} = M_2 \frac{w_1 - w_2}{100 - w_1} = M_{dm}(u_1 - u_2) \quad (1)$$

where: M_w – weight of the dried-off moisture, kg d.o.m.; M_1, M_2 – weight of the input and output hops, kg; w_1, w_2 – hop moisture content wet basis, % w.b.; M_{dm} – dry matter weight determined in accordance with the standard (ISO), kg; u_1, u_2 – hop specific moisture, kg kg⁻¹.

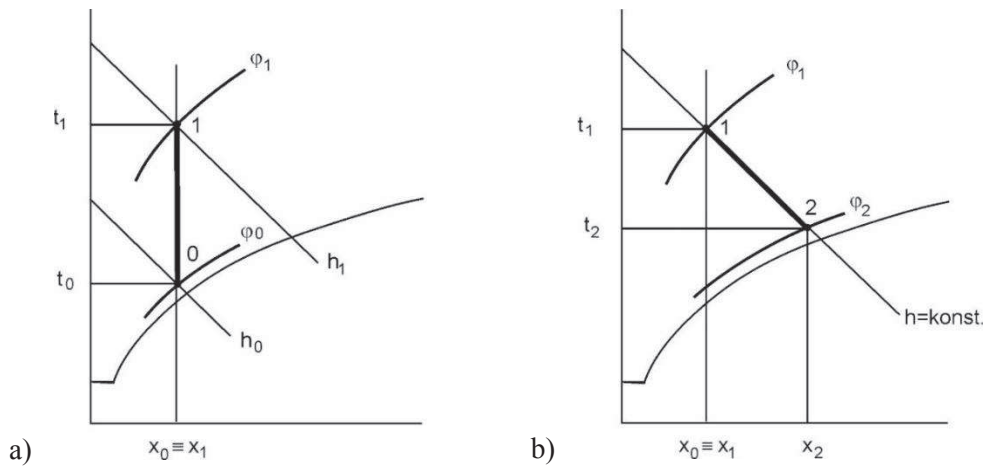


Figure 1. Theoretical dryer: a) air heating; b) air moistening; t_0, t_1, t_2 – air temperature, °C; x_0, x_1, x_2 – hop moisture content dry basis, kg kg⁻¹ d.b.; ϕ_0, ϕ_1, ϕ_2 – relative humidity; h, h_0, h_1 – enthalpic, kJ kg⁻¹.

The initial moisture content of the hops is $M_1 - M_{dm}$ and the humidity of the air is $M_{da} \cdot x_0$ when entering the dryer, becoming $M_2 - M_{dm}$ and $M_{da} \cdot x_2$ respectively, while leaving the dryer, where: M_{da} – the weight of dry air, kg d.a.

The remainder is the evaporated moisture carried away by the outlet air:

$$M_w = M_1 - M_2 = M_{da} = M_{da}(x_2 - x_0) \quad (2)$$

Specific air requirements – λ :

$$\lambda = \frac{M_{da}}{M_w} = \frac{1}{x_2 - x_0}, \frac{\text{kg d.a.}}{\text{kg d.o.m.}} \quad (3)$$

The outlet hop moisture content dry basis x_2 is determined by state 2 which is the intersection of enthalpic humidification (1–2) with the relative humidity curve φ_2 and with the air isotherm t_2 which is usually determined from the admissible temperature of hop warming, i.e. the temperature which when exceeded causes a damage to the physico-chemical hop properties and which in practice is 60 °C. The dependency of the hop specific moisture on time is the drying curve. Its derivation is the drying rate speed curve. Both curves illustrate in a concise manner the drying process in time. Shortening the drying time by up to a half the usual time will lead to substantial energy savings (Chyský, 1977; Jokiniemi et al., 2015).

Currently used belt dryers are ageing, as they were implemented in the 70s and 80s of the last century (Rybáček et al., 1980). The overall drying capacity now amounts to 9,500 tons of dry hops which exceeds by 38% the total production being approx. 6,000 tons of dry hops. Consequently, there is no need to build new hop dryers, but only to focus on modernization and automation of drying process as a whole within the current drying technologies. The objective of this paper is, following the theory, the analysis of the current state of drying, conditioning and stabilization of hops, which in terms of content precedes the innovation in the entire process of hop drying.

MATERIALS AND METHODS

The measurements were carried out in PSCH 325 belt dryer being parts of the plants of the Research Farm in Stekník, Hop Research Institute Co. Ltd. Žatec.

The measured parameters were the temperature and moisture parameters of the drying medium, and the qualitative parameters of the hops being dried – temperature, moisture content, drying time (Hanousek et al., 2008). Given the large extent of the measured values, only selected results are presented in this paper. Further results are available from the authors.

The monitored parameters were determined in two ways (Ma Xu et al., 2015):

- through measuring by means of inserted data-loggers Voltcraft DL-121-TH,
- through a laboratory analysis of the samples.

The data-logger was integrated together with the sensor in a plastic case and powered with a battery. The plastic case was fitted with a USB connector at one of its ends, via which the stored data were imported into the computer (Fig. 2).

The advantage of data-loggers compared to fixed sensors in a dryer is that they pass together with hops through the dryer (Fig. 3), continuously recording the entire drying process. The following graphs are based on the average values received from the employed data-loggers.



Figure 2. Inserting a data-logger into a protective sieve.



Figure 3. Deployment of data-loggers to dryer width.

Hop samples were being taken throughout the process of drying, following a pre-determined schedule, and then were submitted to a laboratory analysis. The analysis allowed for identification of the Hop Storage Index (HSI), the content of alpha bitter acids, and the hop sample moisture content was also determined (Krofta, 2008). The HSI is used to estimate losses of alpha bitter acids during storage and handling. It could be used as an indicator of 'hop freshness' for brewing.

The first sample was always fresh green hops taken immediately after picking. Other samples were taken at check window points (Fig. 4) by individual belts, three samples from each belt (Jech et al., 2011). Last samples were taken prior to and after the conditioning, and one more sample prior to baling.

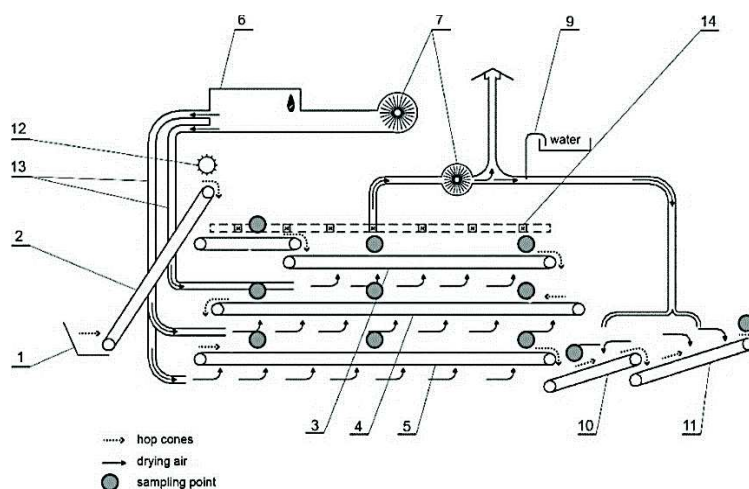


Figure 4. Scheme of the belt dryer with indicated sampling points: 1 – hopper; 2 – inclined wire mesh belt; 3(4,5) – upper (middle, lower) drying wire mesh belt; 6 – hot-air aggregate; 7,8 – fan; 9 – humidifier; 10(11) – first (second) wire mesh belt of the conditioning chamber; 12 – straightening roll; 13 – distribution air pipes; 14 – suction openings.

In Stekník the monitored hops were mainly of the Saaz hop variety. The hop moisture content was determined in the laboratory dryer of the Hop Research Institute Co. Ltd. Žatec with forced air circulation according to the EBC 7.2 method. The HSI was

determined using the EBC 7.13 conventional spectrophotometric method from a toluene hop extract. The content of alpha bitter acids was measured by liquid chromatography according to the HPLC EBC 7.7 method. Tables and graphs were created reflecting the results of the hop sample laboratory analyses.

RESULTS AND DISCUSSION

The graph in Fig. 5 clearly shows the whole drying process is recorded when measured continuously. Around the 90th minute the temperature dropped and the relative humidity increased due to the dryer failure and following forced interruption of operation.

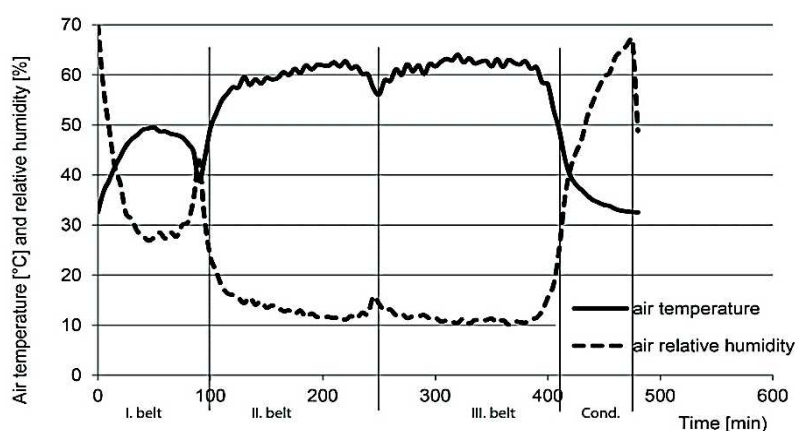


Figure 5. Air temperature and air relative humidity of the Saaz hop variety measured by means of data-loggers: I. belt – upper b.; II. belt – middle b.; III. belt – lower b.; Cond. – conditioning chamber.

Fig. 6 presents an example of one measurement carried out with samples from a laboratory dryer. Besides hop moisture content, the graph also depicts the HSI progresses. The graph confirms the previously mentioned changes in the hop moisture content depending on hop passage through the dryer. A conclusion can be drawn that hops are dried to approx. 10% of moisture content already at the end of the second belt. The laboratory analyses also indicate that only minimum changes occur both in alpha bitter acids and the HSI after the hops have passed through the belt dryer (Henderson, 1973).

The reports from travels to important hop-growing areas in the USA, Germany and China provided by hop experts showed that in these countries hops have been dried and processed in a similar way, therefore we may assume similar outputs from the measurement. Foreign research centres do not deal with these particular issues, which is the reason why there are no comparable results available for possible discussion.

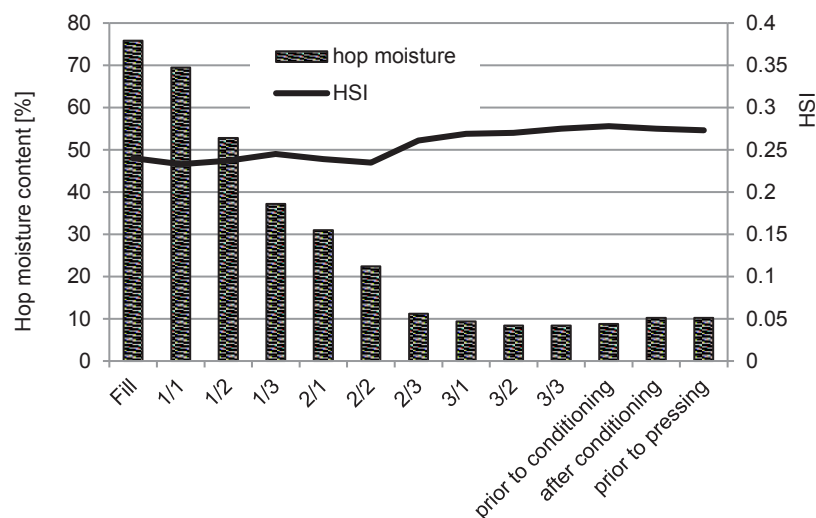


Figure 6. Changes in the hop moisture content and HSI with samples of the Saaz hop variety: Fill – hopper; 1/1 – 1st (upper) belt and 1st window... 3/3 – 3rd (lower) belt and 3rd window.

CONCLUSION

The progress of drying in the operating belt dryer showed that hops are practically dry ($10 \pm 2.0\%$ of moisture content) already at the end of the second belt, or possibly at the beginning of the third belt. Hop drying in the belt dryer proved that hops are considerably over-dried (4 to 8% of moisture content) and are subsequently adjusted to the final moisture content of 8–10%. According to the company staff this state is intentional, working as prevention against the occurrence of nests of moist hops, which occur on irregular basis when drying hops with high initial moisture content. Over-drying results in extensive hop cone shattering, rendering the manipulation with hops for further processing more difficult and leading to larger losses in the lupulin content.

Further research activity will focus on data visualization as well as on automation of the entire drying process control including curing in belt dryers. The experiments will be aimed both at increasing the quality of the final hop product and also at saving the heating medium and electricity.

As indicated in the above, there is great room for improvement in the whole drying process, both in terms of energy and the quality of the final hop product. A complex innovation in the hop drying process in the current belt dryers is very much needed and logically we may assume savings of heat medium and electric energy, resulting from shortening the drying time, increasing the capacity of the facility, and shortening the harvest time.

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