CONSTRUCTION AND VERIFICATION OF AN EXPERIMENTAL CHAMBER DRYER FOR DRYING HOPS

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Abstract
Hop drying takes a significant part in growers' costs of the final product processing. The current drying technology is based on drying at the drying air temperature of 55-60°C for 6-9 hours to the final moisture content of about 10%. However, the process results in irreversible transformations and losses of, inter alia, heat labile substances contained in hops. The paper describes the design and builds an experimental chamber dryer. The experimental chamber drier was tested at harvest 2015. Assays hop drying were carried out at a temperature of the drying medium 40°C. The research results in the form of an experimental new experimental chamber dryer will be used for testing of drying technologies at lower temperatures of the drying medium.
This is what will make it possible to preserve the quality of aroma as well as other characteristics of the components contained in hops.

Key words: hops, drying, chamber dryer, moisture.

INTRODUCTION

The current state in the field of hop-drying and hop-conditioning technology is not ideal. The process of artificial drying proceeds at the air temperature of 55-60°C for 6-9 hours until the hop final moisture content is approximately 10 %.
Hop-cone drying below 10 % of moisture and following controlled conditioning requires roughly 1/3 of the overall energy requirements. Drying to the final moisture content of 10-12 % with subsequent uncontrolled and natural conditioning (resting chambers) to approximately balanced cone moisture can shorten the way of drying used so far, remove risks of mechanical changes of dried cones and effect positively the quality of brewing as well as other parameters.
Besides brewing parameters there are other heat labile substances contained in hops that are important and for which the current drying temperatures in the final stage of drying are too high. For some special aroma hop varieties, whose content and composition of essential oils are key qualitative parameters, such losses result in a reduced quality of the product. Aroma hops are applied by means of so called dry hopping technique that is widespread especially in the segment of small and restaurant breweries. Based on the above it is concluded that for special hop varieties it is necessary to develop technology and technique suitable for a careful (low-temperature) drying method that would to the extent possible preserve the original composition of hops.
According to the literature in the Czech Republic, no one had a problem hop drying at a lower temperature than 55°C. Drying hops at ambient temperature above 55°C, some authors have discussed (BERNÁŠEK 2007 AND MEJZR 2007). Both authors describe the drying curve and the energy consuption of the drying of hops, wherein the drying air has a temperature of about 60°C. In foreign sources only describe the drying temperature of the drying medium 65 to 68°C (MÜNSTERER, 2006).
The research objective was therefore to design and assemble the experimental chamber dryer including the heater, measurement devices and accessories, allowing hop drying at temperatures below 50°C.

MATERIALS AND METHODS

The aim was to assemble an experimental chamber hop dryer which would enable testing experiments with the drying air temperature, drying air speed or usage of moistened air for a careful drying method.
For the purpose of the experimental measurement, monitoring a drying process at a lower temperature (40 to 45°C) than it is used in current operating dryers, an experimental chamber dryer (Fig. 1) had been designed and produced.

The experimental chamber dryer is in the form of a self-supporting steel structure with inserted wooden boxes measuring 0.9 x 0.9 x 0.3 m for storing dried hops. It is possible to insert up to 3 boxes one above the other into the dryer. The weight of green hops inside one box may be approx. 20 kg.

The dryer is heated by electric hot air aggregate with a maximum thermal input of 18 kW, and the heated air temperature can be set by means of an indoor thermostat to 40-45°C. The heated air is blown into the dryer by a fan. The amount of blown air is possible to regulate through a change in the fan's rotation frequency by means of a frequency converter.

Under and over a layer of hops there are probes to measure the air temperature, relative humidity, excess pressure and speed. The electrical energy consumption is read from the electricity meter.

Over the layer of hops there are 2 axial fans placed to verify the possibility of exhaust (creation of under-pressure) above the measured layer.

Fig. 1 clearly shows that the heated air is directed into the fan's intake. In between the fan outlet and the dryer there is a short supply pipe which directs and distributes the supplied air over the entire width of the dryer. The supply pipe is followed by a bottom-mount drying chamber that is fitted with flaps to direct the air stream. This way ensures a uniform circulation over the overall coverage area of the dryer. The air flow uniformity gets even better after inserting drying hops, for a layer of drying hops creates resistance to the air flow resulting in a slight overpressure under the layer.

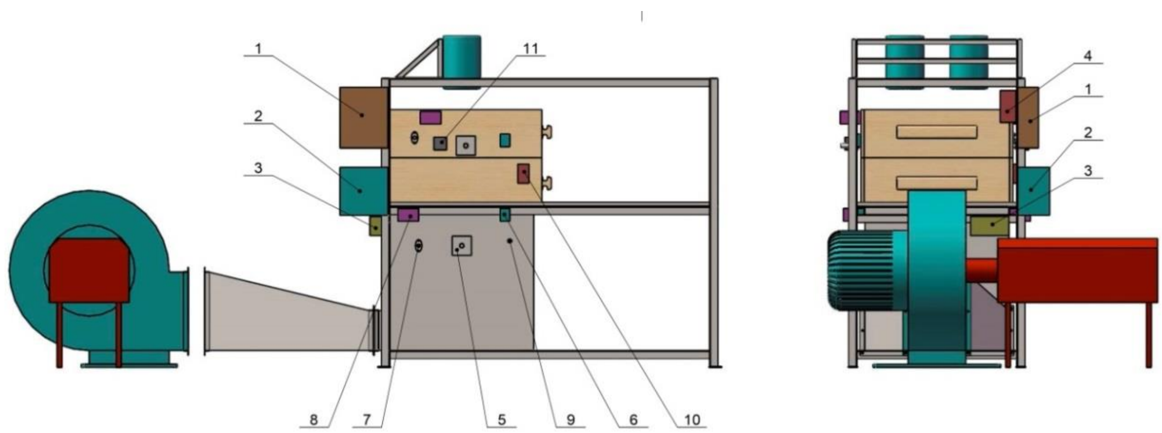

Fig. 1. – Distribution of control elements and sensors on the experimental chamber dryer
1-fuse box, 2-frequency converter, 3-electricity meter, 4-thermostat, 5-air temperature and relative humidity data logger probe, 6-display unit for the air temperature and relative humidity data logger, 7-air speed probe, 8-air speed probe display unit, 9-pressure gauge probe, 10-pressure gauge probe display unit, 11-hygrometer

By contrast, to create underpressure, thus reaching a forced drawing off of the air passing through the hop layer, there are two axial fans in the upper part of the dryer.

Measurement methodology

The thermostat of the hot-air aggregate was set to 45°C, and the radial fan rotation frequency was set by the frequency converter so that the drying air temperature was kept between 40 and 45°C.

Into one wooden box (Fig. 2) green hops were put of the total weight of approx. 20 kg. The box was inserted into the dryer and another empty box, which prevented hops from rising during the process of drying, was placed above it. At the same time, sensors of the air speed, temperature and humidity were placed on the walls of the upper box. The same sensors were placed also under the lower box with hops.

During the measurement we monitored:

- air temperature and relative humidity under the layer of hops – 2x data logger COMET R0110,
- air speed under the layer of hops – 2x probe GREISINGER GIA 2000/GIR 2002,
- air pressure under the layer of hops – pressure gauge GREISINGER 3100,
- air temperature and relative humidity over the layer of hops – 2x data logger COMET R0110,
- air speed over the layer of hops – 2x probe GREISINGER GIA 2000/GIR 2002,
- temperature of blown air – thermostat FAMATEL,
- energy consumption – electricity meter NOARK EDN 3412,

- radial fan rotation frequency– frequency converter.

The values read from individual sensors were recorded every 15 minutes, and every two hours a sample was taken to provide for the hop moisture detection and another samples for laboratory analyses.

Fig. 2. – A wooden box partially filled with hops

RESULTS AND DISCUSSION

The measurement was made on the premises of Chmelařství, Cooperative Žatec, the Machinery Plant. To verify the structure and measuring apparatus, varieties Vital and Kazbek had been selected. The measurement results for the variety Kazbek are presented below.

The product input and output values are presented in Tab. 1.

Tab. 1. – Input and output values for Kazbek variety

Parameter	Input values	Output values
weight of green hops in the box	19 kg	5.2 kg
layer height of green hops in the box	0.25 m	0.21 m
hop moisture content	75.0%	11.4%

The graph in Fig. 3 illustrates progress of drying including values from embedded sensors on the experimental chamber dryer, and hop moisture measured from the samples. Approximately at a time of 600 min the air inlet was cut and hops remained in the wooden box over the entire night. This procedure simulated a resting chamber to balance the moisture between hop bracts and spindle.

Hop moisture was determined through gravimetric analysis in the laboratory chamber dryer of Hop Research Institute Co., Ltd, Žatec with forced air circulation according to the EBC 7.2 method. Following this method, the weighed hops are dried at a temperature of 105°C for 1 h. Drying time for hops with moisture content over 30 % shall be extended to 1.5 h. With the samples we also monitored the hop storage index (HSI) which had been determined by the official EBC 7.13 spectrophotometric method from a hop toluene extract. Alpha bitter acid content was measured by means of liquid chromatography according to the EBC 7.7 method (KROFTA 2008; WEIHRAUCH ET AL., 2010). The measured value was then converted to an absolutely dry matrix for all the points of the drying curve.

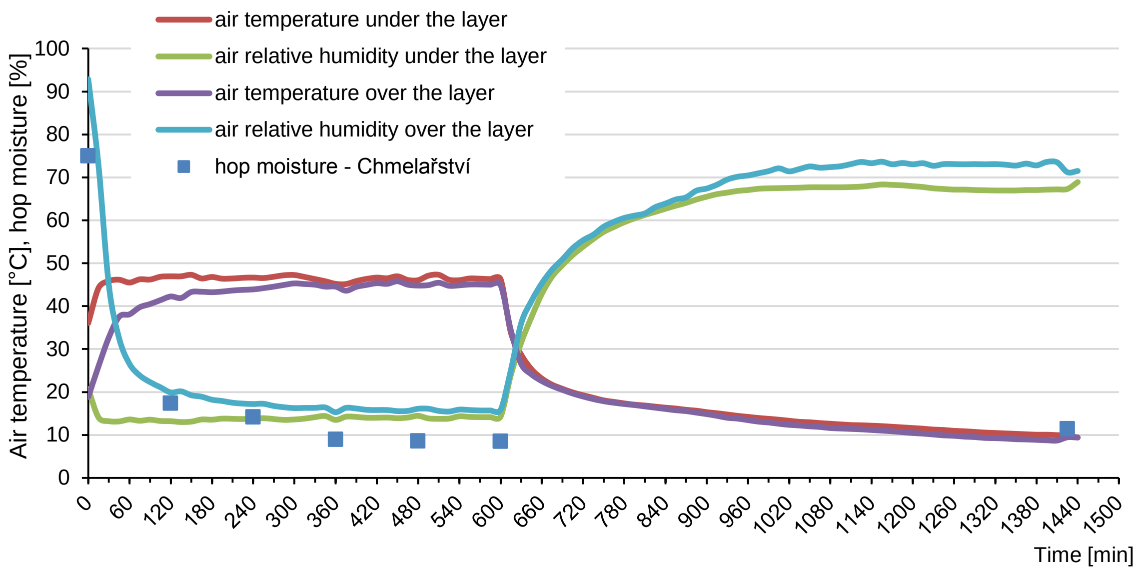

Fig. 3. – Air temperature and relative humidity and hop moisture during the drying process

At the start of the drying process, three data loggers VOLTCRAFT DL-121-TH had been inserted into approximately half of the hop layer (SRIVASTAVA ET AL., 2006). These are described in the article "RYBKA ET AL, 2015. Analysis of the technological process of hop drying in belt dryers". Since they were buried under a pile of hops, the values they recorded corresponded better to the progress of hop moisture in comparison with the probes placed under and over the layer. The graph in Fig. 4 depicts the average values obtained from data loggers.

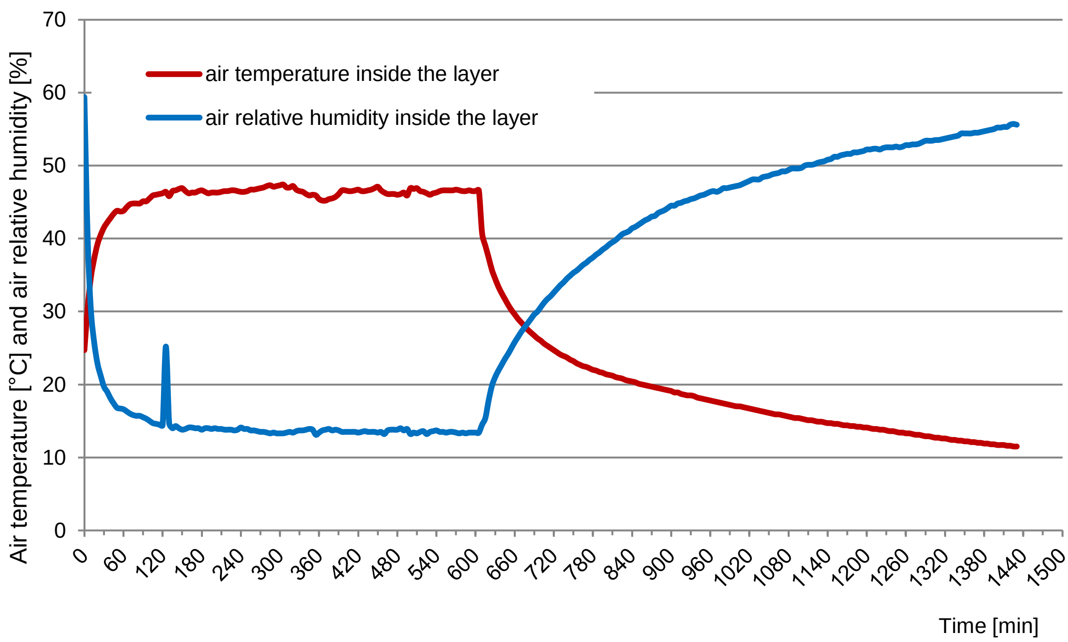

Fig. 4. – Air temperature and relative humidity measured by data logger DL-121-TH

The graph in Fig. 5 gathers all the values of the air temperature and relative humidity as well as hop moisture measured and determined by the analysis for Kazbek variety. Another two graphs (Fig. 6 and 7) illustrate variability in the air speed under and above the dry hop layer on one hand, and cumulation of electric energy consumption during the process of drying.

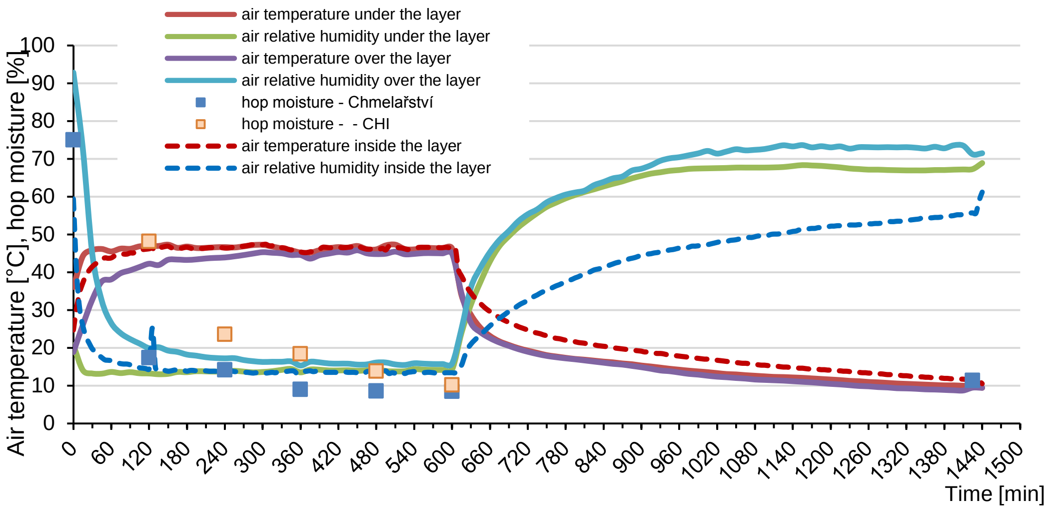

Fig. 5. – Cumulative graph for Kazbek variety

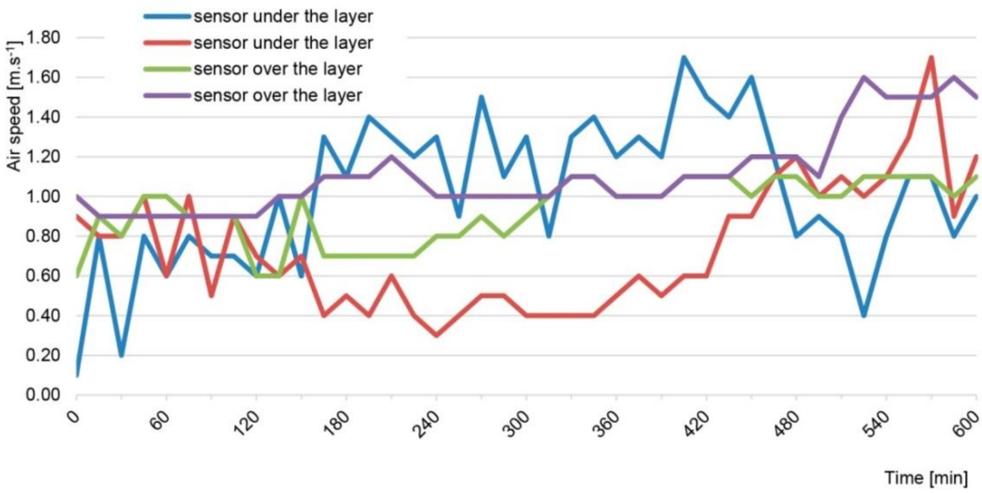

Fig. 6. – Air speed during the drying process

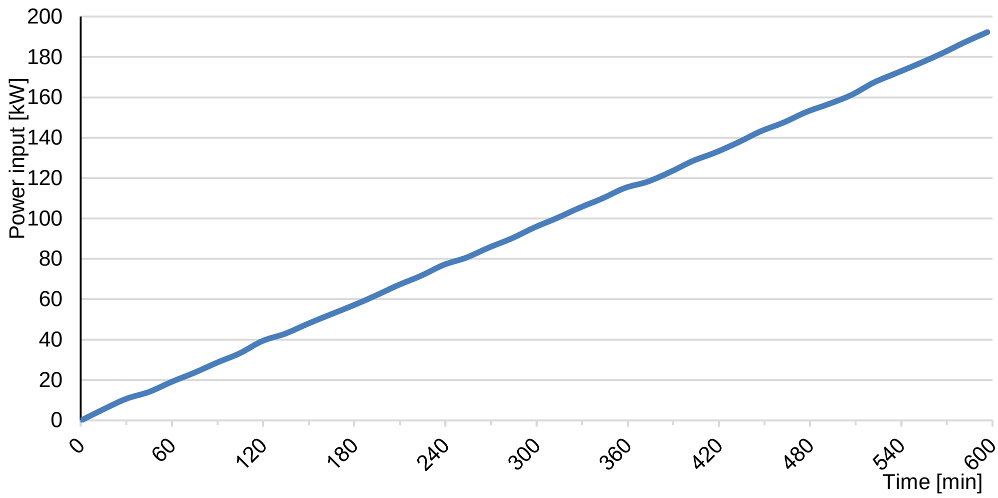

Fig. 7. – Cumulation of electric energy consumption during the process of drying

During the drying process samples were taken for purposes of laboratory analyses. Results of the sample laboratory analyses are presented in Tab. 2. The laboratory analyses focused, inter alia, also on essential oils, xanthohumol (X) and desmethylxanthohumol (DMX). High drying temperatures result in significant losses of the mentioned xanthohumol and desmethylxanthohumol. The analyses results are shown in Tab. 2.

Tab. 2. – Results of laboratory analyses of Kazbek variety samples during the drying process

Sampling time [min]	Hop moisture [% weight]		HSI	Alpha [%DM wgt]	X	DMX
	probe (Chmelařství)	gravim. (CHI Žatec)				
0	17.4	48.2	0.233	8.96	0.37	0.26
120	14.2	23.6	0.240	8.35	0.36	0.23
240	9.0	18.4	0.246	8.22	0.34	0.24
360	8.6	13.8	0.242	8.78	0.37	0.25
480	8.5	10.2	0.247	8.00	0.34	0.22

The task of research project (NAZV MZe) solution in its first year was to analyse the drying process in a designed experimental chamber dryer, which should result, in the following years of the project solution, in an optimal structural solution of the chamber dryer, leading to a design and development of a new line for gentle drying of selected hop varieties. Throughout the 2015 harvest season, continuous measurements of the drying process were being carried out, including verification of various measuring devices and methods in the experimental chamber dryer.

The air speed distribution both under and above the hop layer was very uneven and no correlations between patterns of the air relative humidity and hop moisture can be deduced from graphic waveforms.

The cumulation of electric energy consumption had linear progress.

Experiments in the laboratory chamber dryer showed that the drying time at the drying air temperature lower than 60°C is approximately 4 to 5 hours to reach cone moisture of 10 % needed for conservation of hops by pressing into sacks or square bales. This is approximately half the drying time compared to belt dryer. It follows that in belt dryer hops are exposed to allowable temperature for a very long time. Shortening the drying process to a half time would, inter alia, mean a considerable energy savings.

CONCLUSIONS

Hop drying at lower temperatures of the drying air (to 45°C) proved applicability of this concept in hop drying. A problem occurred in hop moisture measuring by means of a special probe supplied by Chmelařství, cooperative Žatec. A check determination of hop moisture in the laboratory of Hop Research Institute Co., Ltd., Žatec pointed to significant differences. As a consequence, the process was terminated early, since the special probe recorded an incorrect value of hop moisture (8.7 % of weight). The actual moisture value was almost 25 %. The cause of these false results in measuring hop moisture by the probe was an incorrect methodical procedure (the measurement was conducted too shortly after inserting the probe into a layer of pressed hops).

For practical use, and further experiments will be necessary to ensure:

- optimum ripeness hops depending on the variety,
- uniform distribution hops within the dryer including an optimal height of the layer of hops,
- temperature of the drying medium a maximum of 40 to 45°C,
- uniform distribution of the drying medium within the dryer,
- continuous monitoring of temperature and moisture of hops,
- continuous monitoring of temperature, humidity and velocity of the drying medium,
- control the speed and temperature of the drying medium,
- uniform final moisture of hop between 8-10 %,
- option air and moisture balancing hops,

documentation of the measured values.

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