doi: 10.17221/35/2017-RAE

Parameters of the drying medium and dried hops in belt dryer

Adolf Rybka[1*], **Petr Heřmánek**[1], **Ivo Honzík**[1], **Karel Krofta**[2]

[1]*Department of Agricultural Machines, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic*

[2]*Hop Research Institute Co., Ltd., Žatec, Czech Republic*

**Corresponding author: rybka@tf.czu.cz*

Abstract

Rybka A., Heřmánek P., Honzík I., Krofta K. (2017): Parameters of the drying medium and dried hops in belt dryer. Res. Agr. Eng., 63 (Special Issue): S24–S32.

An important factor in hop growing is the process of drying. For this purpose belt dryers with follow-up conditioning are the most widespread but they are not ideal. In this respect, an analysis of the drying process was carried out in the belt dryer of Agrospol Velká Bystřice Co., Ltd. for the 'Saaz' hop variety. Drying parameters were monitored by means of fixed sensors, continuously sensing data loggers and samples taken for laboratory analysis (hop moisture, alpha and beta bitter acids, Hop Storage Index (HIS). The process of drying showed that hops are practically dry (10 ± 2.0% of moisture) already at the end of the second belt or possibly at the beginning of the third belt. It was also proved that hops are over-dried (moisture of 4 to 8%) and then they are adjusted by conditioning to the final moisture content of 8–10%. Excessive drying leads to cone disintegration, which makes any manipulation with hops for purposes of further processing difficult and results in greater losses of lupulin.

Keywords: hop cones; drying; conditioning, temperature; moisture

The current state in the field of technology of hop drying and conditioning is not ideal. This refers to both operating costs and qualitative features of the final product. In belt dryers prevailing so far, following stationary picking lines, their drying process is directly linked to the continuous process of harvest. In belt dryers hop cones are dried at a drying air temperature of 55–60°C for 6–8 h coming from original 75–85% of moisture to final 8–10% prior to conditioning. Bracts themselves, however, have moisture content of only 5–6%, while strigs may have a moisture content of up to 30%. Percentage of strig weight to the total cone weight (6–12%) has a great effect on subsequent moisture permeability during the conditioning of hop cones (Kořen et al. 2008). Controlled conditioning requires roughly up to a 1/3 of the total energy requirements needed for hop growing (Doe, Menary 1979).

Stability of alpha bitter acids, being the key hop substance from the point of view of brewing technology, is sufficient at drying temperatures reaching up to 60°C. However, for some heat-labile substances the drying temperatures between 50 and 60°C in the final stage of drying are too high. They lead to irreversible transformations and losses. Such substances are for instance hop essential oils that are contained in the amount of 0.5–3.5%, depending on hop variety (Hofmann et al. 2013; Kumhála et al. 2013). The pilot studies showed a decrease of 15 to 25% of the overall content of essential oils present in the hops prior to drying at the current drying conditions (Kieninger, Forster 1973; Kirchmeier at al. 2005). Besides this amount, the sensory profile changes too, due to a loss of the more volatile components. With special aroma hop varieties, so called "flavour hops", whose

Supported by the Ministry of Agriculture of the Czech Republic, Project No. QJ1510004.

doi: 10.17221/35/2017-RAE

content and composition of essential oils are the key parameters, such losses lead to a reduction in the product quality.

One of the current tasks is a complex innovation of the drying process in the existing belt dryers. The expected economic benefit should be energy and heating medium savings, resulting from reduction of drying time, increase in the facility capacity as well as reduction of the harvest time (Rybáček et al. 1980; Srivastava 2006; Kumhála et al. 2016). The research objective is to provide hop-processing companies with, inter alia, a drying process that had undergone a complex innovation with an emphasis on improving the efficiency of drying and on innovation in conditioning (Podsedník 2001; Hanousek et al. 2008). Related to that is a design and implementation of belt dryers' alterations, including automation of the operations and continuous stability measurement and drying process control. The study objective is therefore also an analysis of the current state of hop drying, conditioning and stabilisation, which precedes the innovation in the entire hop drying process.

MATERIAL AND METHODS

In the hop grower Agrospol Velká Bystřice Co., Ltd. a common belt hop dryer PCHB 750 was chosen in which the temperature and air-conditioning parameters of the drying medium as well as qualitative parameters of dried hops (temperature, moisture, Hop Storage Index (HIS), alpha and beta bitter acids, drying time) were measured. The measured data were subsequently assessed.

The monitored parameters were identified in three different ways:
– by measurement using inserted data loggers,
– by measurement using fixed sensors installed in the dryers,
– by means of a laboratory analysis of the samples.

Each of these methods had different conditions for measuring and different measurement accuracy. Apart from monitoring the dryers, another objective was to assess the used methods of measurement and to compare them.

Fig. 1. Voltcraft DL-121-TH data logger

Fig. 2. Placing a data logger into a protective sieve

Measurement by means of data loggers. For continuous measurement of the air temperature and relative humidity in a layer of hops being dried Voltcraft DL-121-TH data loggers in the hop grower Agrospol Velká Bystřice Co., Ltd. were used (Fig. 1) which enabled to programme the frequency of data storage (Jech et al. 2011).

In our case, the frequency of data storage was set to 5 minutes. The internal memory of a data logger is able to store 32,000 measured data, which is absolutely sufficient. A data logger is integrated together with a sensor in a plastic case and its power is supplied by an inserted battery. The plastic case is fitted with a USB connector at one end via which the stored data are imported into computer.

To protect the data loggers against mechanical damage while carried throughout the dryer as well as against dirt, they were fixed the rigidly in polyurethane foam and inserted between two stainless sieves, half-spherical in form. This was the best guarantee of protection and at the same time the sieves did not impede the air permeability, and hence no measurement error occurred (Fig. 2).

Fig. 3. Comet T3419 sensor

doi: 10.17221/35/2017-RAE

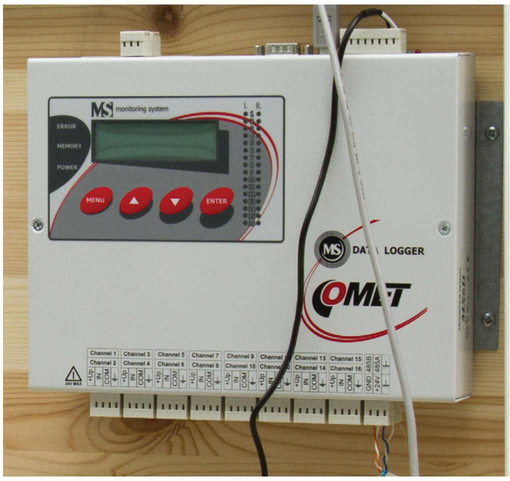

Fig. 4. Comet MS6D multi-channel data logger with a transmitter

The advantage of the data loggers compared to the rigidly fixed sensors in the dryer was that the they were carried together with hops through the dryer, continuously sensing the entire drying process.

They were put into the dryer through the first check window, usually two or three pieces, evenly distributed over the entire width of the belt. They were removed after passing through the dryer and conditioning. Together with the data loggers, a battery-powered LED light was placed into the dryer, which moved together with the hop layer and signalled the moment a data logger reached the position of the check window. Monitoring this light the average belt speed between the check windows was calculated. At the moment when the light reached a check window axis, samples were taken for laboratory testing. This guaranteed that all data from the fixed sensors, data loggers and laboratory samples were read at the same time.

Measurement by means of sensors installed on the dryer wall. On the dryer wall the assembly of Comet T3419 in the hop grower Agrospol Velká Bystřice Co., Ltd. (Fig. 3) temperature and relative humidity sensors was completed. There were always 8 sensors in a row connected to a Comet MS6D multi-channel data logger in the hop grower Agrospol Velká Bystřice Co., Ltd. (Fig. 4). On the dryer, 11 sensors and two multi-channel data loggers had to be installed. All data from the multi-channel data loggers were automatically stored in computer on its hard disc (Fig. 5).

Comet T3419 sensors were installed nearby check windows (Fig. 6). The frequency of reading the values was, similar to the data loggers, set to 5 minutes. The measured values could be read immediately on the connected two-line display, which at the same time showed the actual air temperature (°C) and relative humidity (%). Together with the data reflecting temperature and relative humidity, the exact time of measurement was also stored by means of which the data collected from all the different ways of measuring could be matched up.

Laboratory analyses of the samples. The laboratory analyses monitored the moisture content of all hop samples that was subsequently compared with the drying medium relative humidity measured by means of data loggers and fixed sensors in the dryer. At the same time, the values of HSI, content of alpha and beta bitter acids and DMX in hop cones were determined (Claus et al. 1978; Green, Osborne 1993; Weihrauch at al. 2010).

Determination of the hop moisture content. The hop moisture content was determined gravimetrically as a weight loss of a defined amount of water during drying at a temperature of 105°C for 60 min. The measurement was carried out in a hot-air laboratory chamber dryer with forced air circulation. The resulting moisture content is expressed as a weight percentage. Dried hops generally contain 10 ± 2.0% of water (Henderson, Miller 1972; Henderson 1973).

Determination of HSI of hop cones. Hop Storage Index is a dimensionless parameter that characterizes hop aging rate during storage and during processing after harvest. Its numeric value is calculated as the absorbance ratio of toluene extract of hops under alkaline methanol conditions at wavelengths of 275 and 325 nm. In green hops the value

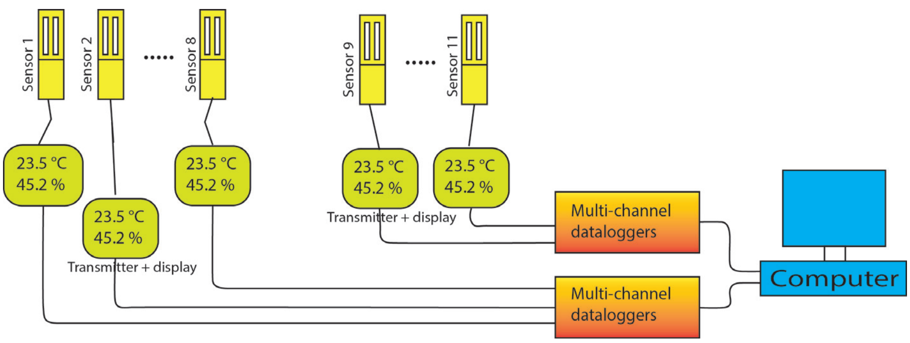

Fig. 5. Wiring diagram of sensors, multi-channel data loggers and a computer

doi: 10.17221/35/2017-RAE

Table 1. Overview of the measurements results

Date	Measurement No.	Hop variety	DL No.	DL time (hh:mm) insertion	DL time (hh:mm) removal
Aug 23, 2016	1	Saaz	2, 3	06:15	19:15
Aug 25, 2016	2	Saaz	4, 5, 6	06:06	19:07

DL – data logger

of this index is 0.20–0.25, immediately after drying it ranges between 0.25 and 0.30. During further storage its value increases continuously and irreversibly. In old hops, the HSI values can be measured in the range from 1.0 to 2.0.

Determination of the content of alpha and beta bitter acids and DMX in hop cones. Alpha bitter acids are determined by liquid chromatography following the EBC 7.7. alpha test method. Hop resins extracted into the ether phase are split in chromatographic HPLC column with reverse phase in the mobile phase of the defined composition (methanol-water-phosphoric acid). Analytes are detected at a wavelength of 314 nm. Simultaneously, it is also possible to determine the content of xanthohumol prenylflavonoids and desmethylxanthohumol (DMX) if the analytical signal is detected at

Fig. 6. Sensor with a transmitter and a display nearby a check window in the dryer

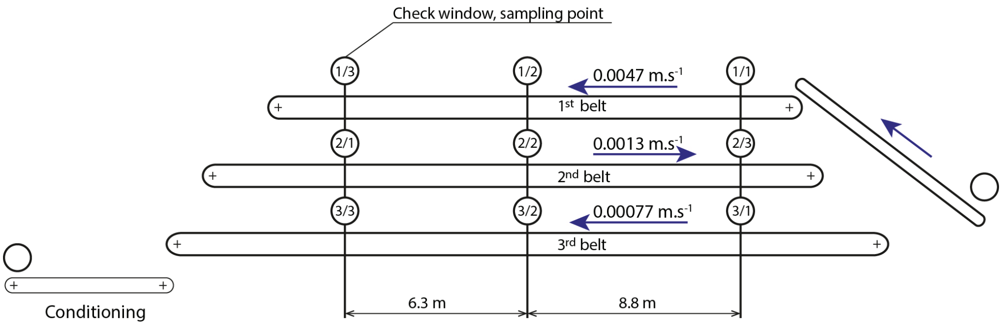

Fig. 7. Speed of the dryer's belts and sampling points

Table 2. Parameters of the drying process - measurement No. 1

Sampling point			Before entering the dryer	1st belt			2nd belt			3rd belt			End of conditioning
Belt speed (m/s)				0.0047			0.0013			0.00077			
Sampling window				1	2	2	1	2	3	1	2	3	
Sampling time (hh:mm)			06:14	06:24	06:55	07:16	07:34	08:53	10:46	11:16	14:25	16:40	18:10
Measurement time		(min)		10	41	62	80	159	272	302	491	626	
Sensors	temperature	(°C)	–	28.4	34.0	39.7	44.9	54.2	60.4	50.3	66.0	62.6	–
	rel. humidity	(%)		88.8	40.5	43.7	30.6	15.7	11.7	24.2	8.1	8.8	
Datalogger DL2	temperature	(°C)	–	26.7	40.4	44.6	33.6	42.2	58.0	56.0	66.2	64.0	–
	rel. humidity	(%)		96.7	42.0	37.5	66.7	4.1	15.6	18.0	9.9	9.9	
Datalogger DL3	temperature	(°C)	–	28.1	45.4	50.2	34.6	36.8	53.5	52.6	66.8	63.7	–
	rel. humidity	(%)		96.4	25.3	24.0	67.9	56.4	19.9	22.6	9.6	10.1	
Dataloggers – average values	temperature	(°C)	–	27.4	42.9	47.4	34.1	39.5	55.8	54.3	66.5	63.9	–
	rel. humidity	(%)		96.6	33.7	30.8	67.3	48.3	17.8	20.3	9.8	10.0	
Laboratory analyses of hops	moisture	(%)	79.5	77.8	71.4	64.7	50.6	19.5	6.4	7.0	5.0	5.2	8.8
	HSI	(–)	0.243	0.258	0.238	0.235	0.252	0.250	0.270	0.277	0.297	0.311	0.311
	alpha	(%)	4.31	4.33	3.98	4.22	3.64	2.98	3.38	2.99	2.98	3.16	2.94
	beta	(%)	7.08	6.96	6.82	6.69	6.32	4.62	5.38	4.97	4.95	5.04	4.90

doi: 10.17221/35/2017-RAE

a wavelength of 370 nm. To quantify alpha bitter acids an external standard (ICE 3:2017) was used, the composition of which is regularly verified by international ring tests. To quantify xanthohumol, an acidified methanol solution of pure substance is used (Ono et al. 1984; Krofta 2008).

RESULTS AND DISCUSSION

In-process measurements presented in Table 1 were carried out in operation of Agrospol Velká Bystřice Co., Ltd. Due to a large harvest in 2016, hops had to be dried in thicker layers and therefore for a longer time than usual. Instead of the regular 8 h including conditioning, the drying time stretched to 12 h including conditioning where hops stay for about 1 hour. The speeds of individual belts in the belt dryer are shown in Fig. 7.

Measurement No. 1

Fig. 8 depicts the course of values measured by two data loggers. As the graph shows, the courses are practically identical with both data loggers, meaning that the drying process is even over the whole width of the belt. In the subsequent processing of the measured values, the average value was determined on the basis of the values recorded by the data loggers, and the result was compared with the measurement using fixed sensors as well as with the results of laboratory analyses of hop moisture (Table 2, Fig. 9). The samples for laboratory analyses were taken from individual windows in the belt dryer and at the end of conditioning.

Apart from the hop cone moisture, values of HSI, alpha and beta bitter acids were obtained from the laboratory analysis (Fig. 10).

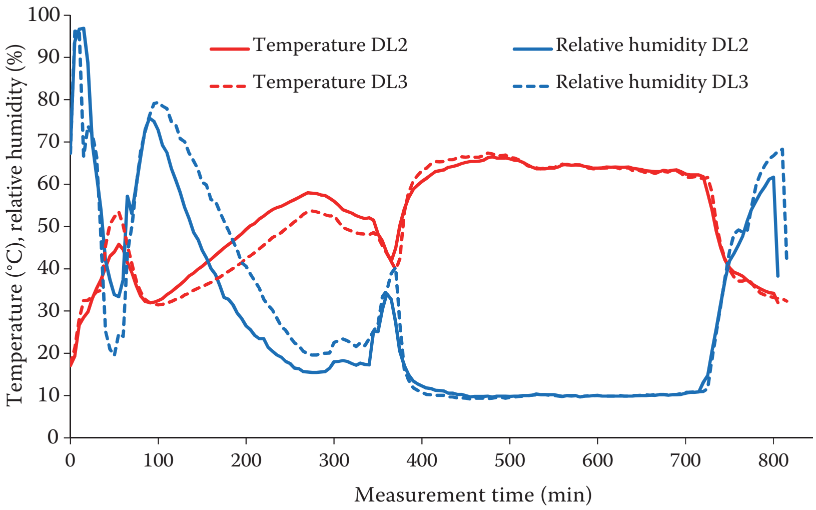

Fig. 8. Data loggers – dependence of air temperature and relative humidity on the measurement time

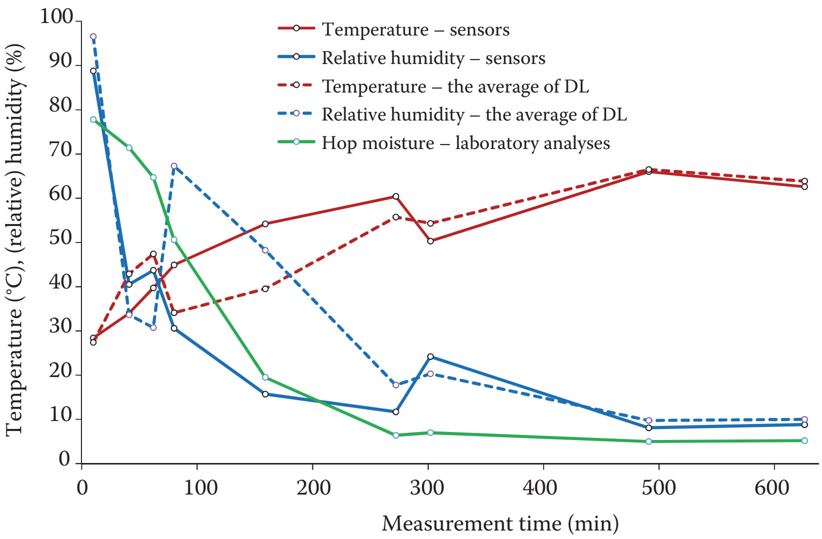

Fig. 9. Data loggers, fixed sensors and laboratory analyse

doi: 10.17221/35/2017-RAE

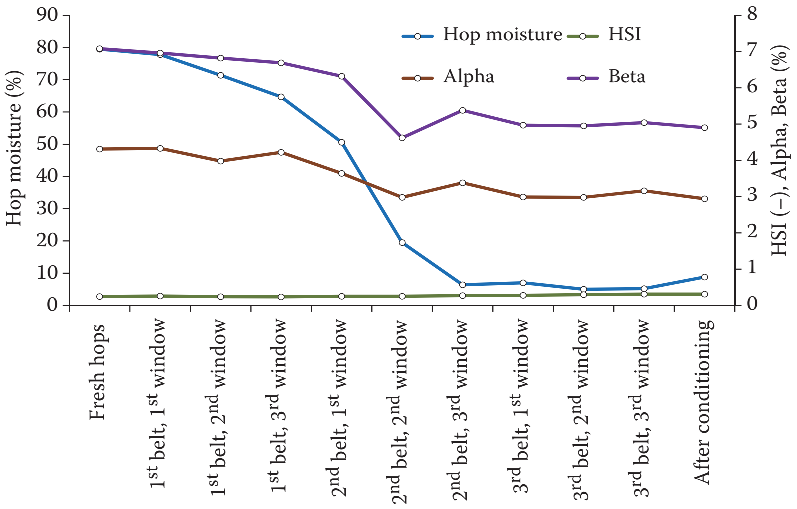

Fig. 10. Laboratory analyses – hop moisture, HSI, alpha and beta bitter acids during the drying process

Measurement No. 2

The measurement procedure as well as processing of the results was similar to the measurement N° 1. This measurement referred to the same variety and its objective was to assess repeatedly the variability of courses of the individual parameters during the process of drying in belt dryer (Table 3, Figs 11–13).

Fig. 11 illustrates the courses of the measured values from three data loggers which were located in the belt dryer approx. 1 m from both edges and in the middle of the belt. Like Fig. 8, the graph in Fig. 11 clearly shows that the courses are almost identical with all three inserted data loggers, which means that the drying process is even over the whole width of the belt and further analysis may draw on their average values. Table 3 and Fig. 12 show a comparison with the measurement using fixed sensors and with the results of hop moisture laboratory analyses. The graph in Fig. 13 also shows courses of values of HSI, alpha and beta bitter acids.

Table 3. Parameters of the drying process – measurement No. 2

Sampling point			Before entering the dryer	1st belt			2nd belt			3rd belt			End of conditioning
Belt speed		(m/s)		0.0047			0.0013			0.00077			
Sampling window				1	2	3	1	2	3	1	2	3	
Sampling time		(hh:mm)	05:55	06:06	06:40	07:02	07:25	08:46	10:36	11:29	14:45	16:55	18:17
Measurement time		(min)	0	11	45	67	90	171	281	334	530	660	774
Sensors	temperature	(°C)	–	32.9	39.0	39.8	43.0	51.9	58.4	57.9	64.7	62.0	–
	rel. humidity	(%)		79.3	48.9	43.5	35.9	18.7	14.3	11.4	8.2	9.0	
Datalogger DL4	temperature	(°C)	–	24.7	50.5	48.4	35.5	51.9	63.6	60.3	65.2	6.5	–
	rel. humidity	(%)		95.7	24.3	27.4	57.5	22.4	11.6	11.1	8.9	9.8	
Datalogger DL5	temperature	(°C)	–	25.8	44.1	44.5	33.4	45.9	61.9	56.4	65.7	63.3	–
	rel. humidity	(%)		96.9	35.4	47.0	69.4	33.1	14.2	15.7	9.5	10.3	
Datalogger DL6	temperature	(°C)	–	26.2	41.7	40.5	33.2	45.9	59.5	56.4	65.5	62.7	–
	rel. humidity	(%)		96.4	43.4	60.7	70.8	35.6	16.4	15.4	9.4	10.4	–
Dataloggers – average values	temperature	(°C)	–	25.6	45.4	44.5	34.0	47.9	61.7	57.7	65.5	62.8	–
	rel. humidity	(%)		96.3	34.4	45.0	65.9	30.4	14.1	14.1	9.3	10.2	
Laboratory analyses of hops	moisture	(%)	77.8	75.9	65.9	58.2	49.2	36.4	10.8	6.2	5.8	5.8	9.4
	HSI	(–)	0.237	0.244	0.229	0.240	0.242	0.241	0.254	0.271	0.278	0.296	0.296
	Alpha	(%)	6.17	6.07	6.00	6.25	5.40	6.30	5.06	5.17	5.37	5.71	5.54
	Beta	(%)	5.36	5.49	5.75	5.65	4.73	5.41	4.52	4.49	4.65	4.90	4.71

doi: 10.17221/35/2017-RAE

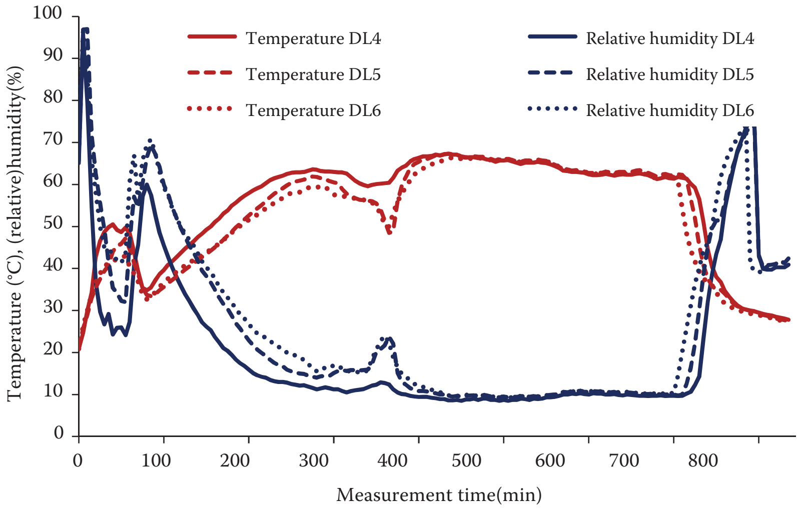

Fig. 11. Data loggers (DL) – dependence of air temperature and relative humidity on measurement time

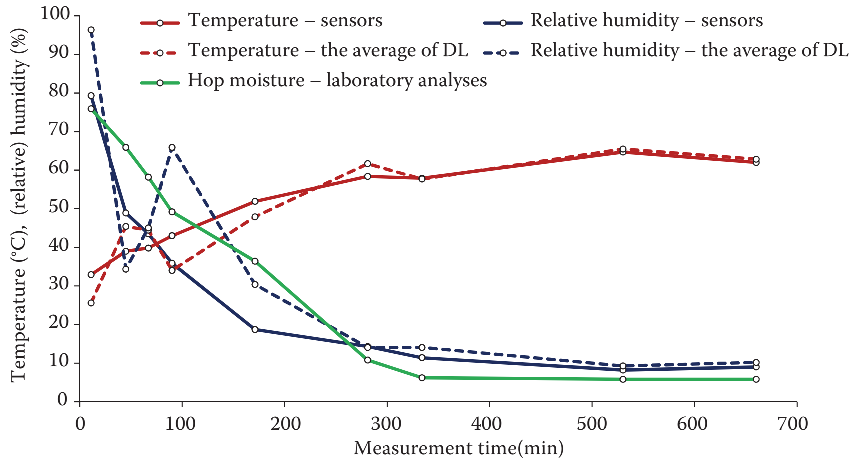

Fig. 12. Data loggers (DL), fixed sensors and laboratory analyses

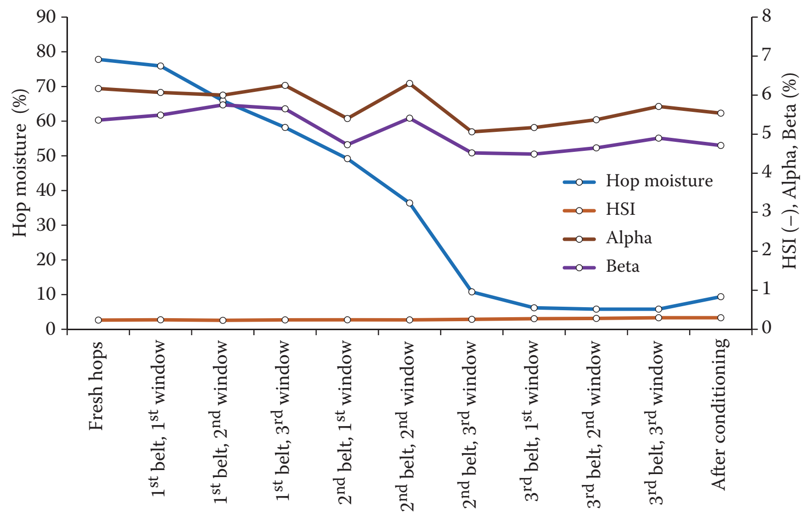

Fig. 13. Laboratory analyses – hop moisture, HSI, alpha and beta bitter acids during the process of drying

CONCLUSION

Uniformity in drying over the whole width of the drying belt. The graphs in Figs 8 and 11 depict the course of measured values from two or possibly three data loggers evenly distributed over the whole width of the drying belt. Both graphs clearly show that the course of the drying air temperature and relative humidity is practically identical, which means that the drying process is uniform over the whole width of the belt. This uniformity in drying over the belt width can be confirmed also with the first belt

doi: 10.17221/35/2017-RAE

where the course of values of the air temperature and humidity is abruptly unbalanced throughout both measurements. From values obtained from the data loggers the average value was determined and the result was compared with the measurement by means of fixed sensors and with the results from laboratory analyses of hop moisture. Analysing the three sources of values is necessary for the design of automatic regulation of dryers.

In Figs 9 and 12, concentrated in one graphical representation there is a course characterizing changes in the drying medium parameters together with attached dependence of hop moisture on the measurement time. The air temperature and relative humidity during the process of drying are represented by average values from the data loggers and values from the fixed sensors. As can be seen from the graphs, the courses from both sources approximate closely and also that with drying time the air temperature logically increases and its relative humidity decreases. At the moment when hops fall over from the first to the second belt and from the second to the third belt, both values abruptly change compared to their overall course. A probable cause is a disruption of matted hop layer including their surface crust when falling over onto another drying belt thereby the monitored parameters transiently change.

Hop moisture, determined from laboratory samples, logically decreases depending on the measurement time. A considerable drying productivity is shown on the first and second belt. The required hop moisture content of approx. 10% is reached practically in all cases at the level of the third window of the second belt. On the third belt the hops are excessively dried, a fact that is justified by the grower as a certain insurance against poor-quality drying, and prevention against occurrence of nests of moist hops that irregularly occur when drying hops with high initial moisture. This implies higher energy consumption, hops are disintegrated due to over-drying, and subsequent conditioning might not bring them back into the shape of closed cones. It makes any further manipulation with hops difficult and leads to greater losses of lupulin. Related to a view of the technological drying process without classic conditioning and installation of resting chambers, adjustment of drying parameters is possible, heading towards possible acceleration of belt motion or towards a change in the height of the hop layer that is being dried in such a way so that the required hop moisture content (approx. 10%) was achieved only towards the end of the third belt.

The graphs in Figs 10 and 13 show the results of the laboratory analyses of hop moisture, HSI, alpha and beta bitter acids during the process of drying. An increase of the HSI values should be minimal during drying and, conversely, the values of alpha and beta bitter acids should decrease minimally. On the basis of an overall assessment it can be concluded that the process of drying in the given belt dryer has a minimal effect on the course of the given values.

References

Claus H., Van Dyck J., Verzele M. (1978): Photometric constants of hop bitter acids. Journal of the Institute of Brewing, 84: 218–220.

Doe P.E., Menary R.C. (1979): Optimization of the hop drying process with respect to alpha acid content. Journal of Agricultural Engineering Research, 24: 233–248.

Green C.P., Osborne P. (1993): Effects of solvent quality on the analysis of hops. Journal of the Institute of Brewing, 99: 223–225.

Hanousek B., Rybka A., Bernášek K. (2008): Hodnocení práce česačky chmele PT 30/15 a sušení chmele v pásové a komorových sušárnách v r. 2007 (Evaluation of hop picker line PT 30/15 and hop drying in belt and kiln dryers in 2007). In: Ekonomicko-technologický seminář k problematice pěstování chmele (Economic-technological seminar about hop production problems). Hop Research Institute Co. Ltd., Žatec, Czech Republic, Febr 27, 2008: 43–61

Henderson S.M. (1973): Equilibrium Moisture Content of Hops. Journal of Agricultural Engineering Research, 1: 55–58.

Henderson S.M., Miller G.E. (1972): Hop Drying – Unique Problems and Some Solutions. Journal of Agricultural Research, 17: 281–287.

Hofmann R., Weber S., Rettberg S. (2013): optimization of the hop kilning process to improve energy efficiency and recover hop oils. Brewing Science, March/April, 66: 23–30.

Jech J., Artim J., Angelovič M., Angelovičová M., Bernášek K., Honzík I., Krčálová E., Kvíz Z., Mareček J., Polák P., Poničan J., Ružbarský J., Rybka A., Sloboda A., Sosnowski S., Sypula M., Žitňák M. (2011): Stroje pre rastlinnú výrobu 3 – Stroje a zariadenia na pozberovú úpravu rastlinných materiálov a na ich skladovanie (Machines for Crop Production 3 – Machinery and Equipment for Post-harvesting and Treatment of Plant Material). Prague, Profi Press Co. Ltd.

Kieninger H., Forster A. (1973): Brauwiss, 26: 214–217.

Kirchmeier H., Rodel G., Demmel M. (2005): Verfahren zur Abtrennung von Drahtstucken bei der Hopfenernte. Landtechnik, 60:148–149.

doi: 10.17221/35/2017-RAE

Kořen J., Ciniburk V., Podsedník J., Rybka A., Veselý F. (2008): Sušení chmele na pásových sušárnách (Hop drying in belt dryers). Metodika pro praxi (Methodics for practice). Žatec, Czech Republic, Hop Research Institute Co. Ltd. (in Czech).

Krofta K. (2008): Hodnocení kvality chmele (Evaluation of hop quality). Metodika pro praxi (Methodics for practice). Žatec, Czech Republic, Hop Research Institute Co. Ltd.

Kumhála F., Kavka M., Prošek V. (2013): Capacitive throughput unit applied to hop picking machine. Computers and Electronics in Agriculture, 95: 92–97.

Kumhála F., Lev J., Kavka M., Prošek V. (2016): Hop-picking machine control based on capacitance throughput sensor. Applied Engineering in Agriculture, 32: 19–26.

Ono M., Kakudo Y., Yamamoto Y. (1984): Quantitative analysis of hop bittering components, its application to hop evaluation. Journal of the American Society of Brewing Chemists, 42: 167–172.

Podsedník J. (2001): Hop harvesting technology in the Czech Republic 1996–2000. In: Proceedings of the Technical Commission I.H.G.C. of the XLVIIIth International Hop Growers Congress. Canterbury, England.

Rybáček, V., Fric V., Havel J., Libich V., Kříž J., Makovec K., Petrlík Z., Sachl J., Srp A., Šnobl J., Vančura M. (1980): Chmelařství (Hop production). Prague, SZN.

Srivastava A.K., Goering C.E., Rohrbach R.P., Buckmaster D.R. (2006): Engineering Principles of Agricultural Machines. Michigan, ASABE.

Weihrauch F., Baumgartner A., Felsl M., Kammhuber K., Kneidl J., Lutz A., Neuhof-Buckl E., Petzina C., Sperr B., Weihrauch S., Wyschkon B. (2010): The influence of aphid infestation during the hop growing season on the quality of harvested cones. EBC Hop Symposium, Wolnzach, Germany.

Received for publication April 6, 2017
Accepted after correction July 17, 2017