# STUDY OF CONTINUOUS SENSING OF THE SPEED OF BELTS IN A HOP DRYER

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***Abstract***
*The article is focused on hop belt dryer and study of sensing of the speed of belts. It contains a schema of the belt dryer and a description of the device for sensing the speed of the belt in the dryer. In measurement was found that the speed of the belts in the dryer is from 0 to 6 mm.s$^{-1}$. Simultaneously was found that the 3rd belt achieved approximately 66 % of the speed of the second belt all the time. The speed of the first and the second belts was different in both hop dryers. From meteodata was found that for belt speed comparison and thereby setting off the hop dryer is the most suitable parameter for humidity. In conclusion, are indicated directions for further research.*

***Key words:*** *speed, hop, belt, dryer.*

## INTRODUCTION

Drying is the extensively used method of the conservation of agricultural materials and food. The success and sustainability of the drying process are assessed based on the quality of the dried products, the specific energy consumption and costs (*Kudra, 2004; Lewicki, 2006; Mujumdar et al., 2014; Myllymaa et al., 2019; Myllymaa et al., 2020; Ziegler et al., 2021*). During drying, water is removed from the dried material as quickly as possible while maintaining product quality and minimizing energy consumption. A universal dryer was not developed because every material insists on specific drying conditions. Many types of dryers (over 400) are used in industry and agriculture, which use different drying methods (*Guine et al., 2011; Tarhan et al., 2011; Mujumdar et al., 2014*). Theoretical and practical aspects of drying various materials are described in the literature. Many studies were accomplished to mathematically model drying and determine the drying kinetics of various vegetables, fruits and medicinal plants. *Zhang et al.* (*2015*) suggested a method of controlling the temperature and relative humidity of the drying medium for the dryer controls system. The topic of numerical models and networks during drying was also deal with, for example, by *Chokphoemphun & Chokphoemphun (2018), Youssefi et al. (2009), Guine et al. (2015), Şahinbaşkan & Köse (2010), Kaveh et al. (2018), Kaveh et al. (2019), KirbaŞ et al. (2019) and Holowaty et al. (2022).*
*Vasiliev et al. (2020)* mention in their contribution that it is necessary to further deal with the issue of drying hops in belt dryers, especially in the area of airflow. In Germany *Raut et al. (2020), Sturm et al. (2020) and Raut et al. (2021)* studied the drying of hop in the dryers.
Hop drying is the last stage of the grower's hop production. The belt dryers are the most widespread among growers in the Czech Republic, which represent 60 % of their total number (approx. 200 units), built mainly in the 1970s. The total capacity of the drying facilities is 9,500 tons of dry hops. However, the growers' production is lower, with approximately 6,000 tons of dry hops. For this reason, it is not worthwhile to build new drying operations, but instead to modernize and innovate existing capacities. This article aimed to provide a method to monitor the average speed of the belt. Information on the speed of the belt together with other data (the hop moisture, the temperature of the drying medium, etc.) will allow the operator to appropriately regulate the drying process of the belt dryer.

## MATERIALS AND METHODS

The belt dryer (Fig.1) contains, among other things, 3 drying belts on which the hops are dried from an input humidity of approx. 80 % to an output humidity of approx. 10 %. The quality of the hops (over-drying or under-drying) depends on the speed of the drying belts, and thus the energy requirement. In older dryers, we often encounter slippage of drying belts. If the movement of the drying belts stops, there is no signalling on the dryer for the operator of the dryer, and the dried product – hops – can thus deteriorate.

One of the key parameters for the drying process is the speed of the drying belt. The principle of sensing the feed rate is known and used. However, in this case, it is a very slow speed of the drying belts up to 10 mm.s$^{-1}$.
It is known from earlier experiments *(Rybka et al. 2017 and Hermanek et al. 2018)* that hops, depending on the variety, are dried to a greater extent on the second belt, while the third belt only tempers the hops. Therefore, it is necessary to focus on monitoring and automating the drying process.

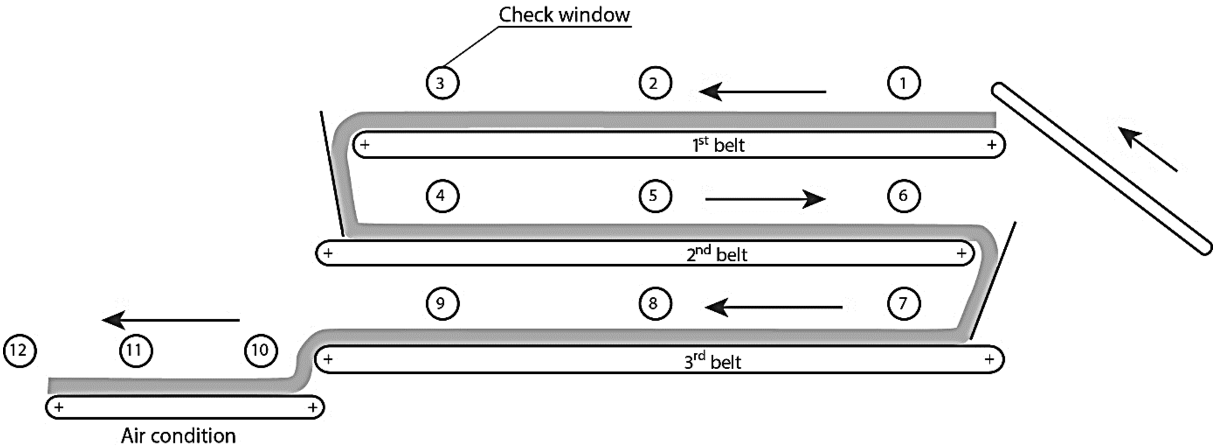

**Fig. 1** The scheme of belt dryer PCHB 750

Measurements were carried out on two belt dryers PCHB 750 in companies – Lupofyt Co., Ltd. in Chrášťany and Agrospol Velká Bystřice Co., Ltd. The Saaz variety, the leading variety of Czech hop growing, was mainly used during the measurements. As a delicate aromatic variety, it requires specific drying conditions that differ from hybrid varieties.
During the experiments, the following equipment was installed in the PCHB 750 dryer:

- the sensor (wheel) of the speed of the drying belts (for the speed from 0 to 10 mm.s$^{-1}$) in the belt dryer of hops (Fig. 2), which was manufactured by SKV Co., Ltd. in Dvůr Králové nad Labem according to the suggestion of the authors of the article,
- the evaluation centre (Fig. 3) for continuous sensing and evaluation of the speed of all drying belts in the belt dryer of hops, the manufacturer was SKV Co., Ltd. in Dvůr Králové nad Labem according to the specifications and parameters of the authors of the article,
- the device for fastening to a belt dryer, which was designed and manufactured at the Czech University of Life Sciences in Prague,
- the connecting and electrical material.

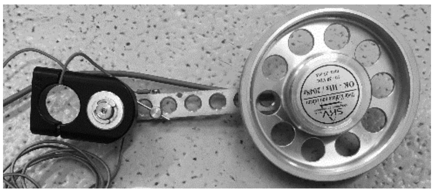
**Fig. 2** The sensor (wheel) of the speed of the drying belts

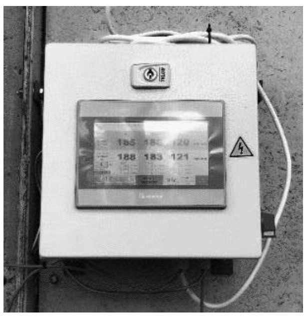
**Fig. 3** The evaluation centre

The methodology of the experiment was based on the collection of process parameters from sensors installed on the hop dryer, i.e., the instantaneous and average speed of the belt. Furthermore, available meteorological data from individual areas – Chrášťany near Rakovník and Velká Bystřice – were used. Subsequently, the values were analysed.

## RESULTS AND DISCUSSION

According to measurements at the belt dryer in 2020, the speed of the second belt varied between 2.4 and 3.8 mm.s$^{-1}$. For the experiments that were carried out during the drying period in 2021, we used a modified device. The modification consisted of the possibility of choosing a period for which the average speed of the belt will be measured. This value is adjustable in the range from 0 to 600 s. When measuring in 2021, we looked for a suitable setting for the average belt speed per time interval (60 s, 120 s, 300 s and 600 s). For our measurements on both dryers, we set the measurement for 60 s. An example of measured data is shown in Table 1. The measured data from the speed sensors are displayed as the current instantaneous belt speed and the average belt speed.

**Tab. 1** An example of measured data of average belt speed in a hop dryer (Agrospol Velká Bystřice Co., Ltd.)

| date | time | speed of belt 1 | speed of belt 2 | speed of belt 3 |
|---|---|---|---|---|
| month.day.year | h:min:s | mm.s$^{-1}$ | mm.s$^{-1}$ | mm.s$^{-1}$ |
| 08.23.2021 | 13:00:57 | 4.57 | 1.58 | 1.03 |
| 08.23.2021 | 13:02:57 | 4.57 | 1.58 | 1.03 |
| 08.23.2021 | 13:04:57 | 4.55 | 1.57 | 1.03 |
| 08.23.2021 | 13:06:57 | 4.53 | 1.55 | 1.03 |
| 08.23.2021 | 13:08:57 | 4.53 | 1.57 | 1.03 |
| 08.23.2021 | 13:10:57 | 4.55 | 1.58 | 1.03 |

We obtained meteorological data from the harvest period: temperature [°C], dew point [°C], humidity [%], speed of wind [m.s$^{-1}$] and pressure [hPa].

In the analysis, we examined and compared various meteorological data with belt speed values. Firstly, we removed the stopping, standing, and starting motion of the belts. We did not include the results of the measured values of the average speed of all three belts in the graphs below for the sake of clarity. From a technological point of view, the inclined belt for the supply of fresh hops and the first belt of the dryer are driven from one source. The second and third belts are driven from the second source. The third belt reached approximately 66 % speed of the second belt. The speed of the second belt was different for both dryers. Compared to the speed of the first belt, the speed of the second belt in the dryer Lupofyt Co., Ltd. was 98 % and, in the dryer Agrospol Velká Bystřice Co., Ltd. was approximately 30 %.

For comparison, we selected humidity from all meteodata. The results of the speed of the first belt and the humidity of the air for the entire period of drying of hops after their harvest are shown in the graphs in Figure 4 (Lupofyt Co., Ltd.) and Figure 5 (Agrospol Velká Bystřice Co., Ltd.).

The graphs in Fig. 4 and 5 show the dependence of the average speed of the first belt of the hop dryer on humidity. The interpretation of the measured values shows that when the humidity increased, the speed of the belt decreased and vice versa. The dependence is most evident in the graph in Fig. 5. Belt speed regulation was not based on automatic regulation of the drying process but based on manual control by the operator of the dryer, which we want to eliminate in the future and fully replaced with automation. Manual control has so far been based on the experience of the operator and is implemented based on the moisture of the hops leaving the dryer and with a certain time delay. The obtained data were not subjected to a statistical evaluation, as only the results for one year of measurement are available so far. According to the measured values, it is also possible to conclude that speed sensors only on the first and second belt are sufficient. However, in the case of the third belt, the malfunction will not be signalled, and the operator must find out by looking into the control windows.

*J. Münsterer (2020)* dealt with a detailed study of drying hops in chamber and belt dryers. In the study, he states that it is necessary to change the speed of the belts in the dryer in order to regulate the hop layer. However, there was no published article about measuring and visualizing the speed of the belts during drying of hops in a belt dryer.

For further measurements, it will be necessary to obtain current meteorological data and compare them with measured data from speed sensors during the drying period on individual days. This assesses the effect of humidity and speed of belts in the dryer. The next task will be to solve the visualization of the measured values in the control device in the dryer. Next, we will focus on the possibility of monitoring the passage of the hop mass through the dryer when changing varieties, plots, etc.

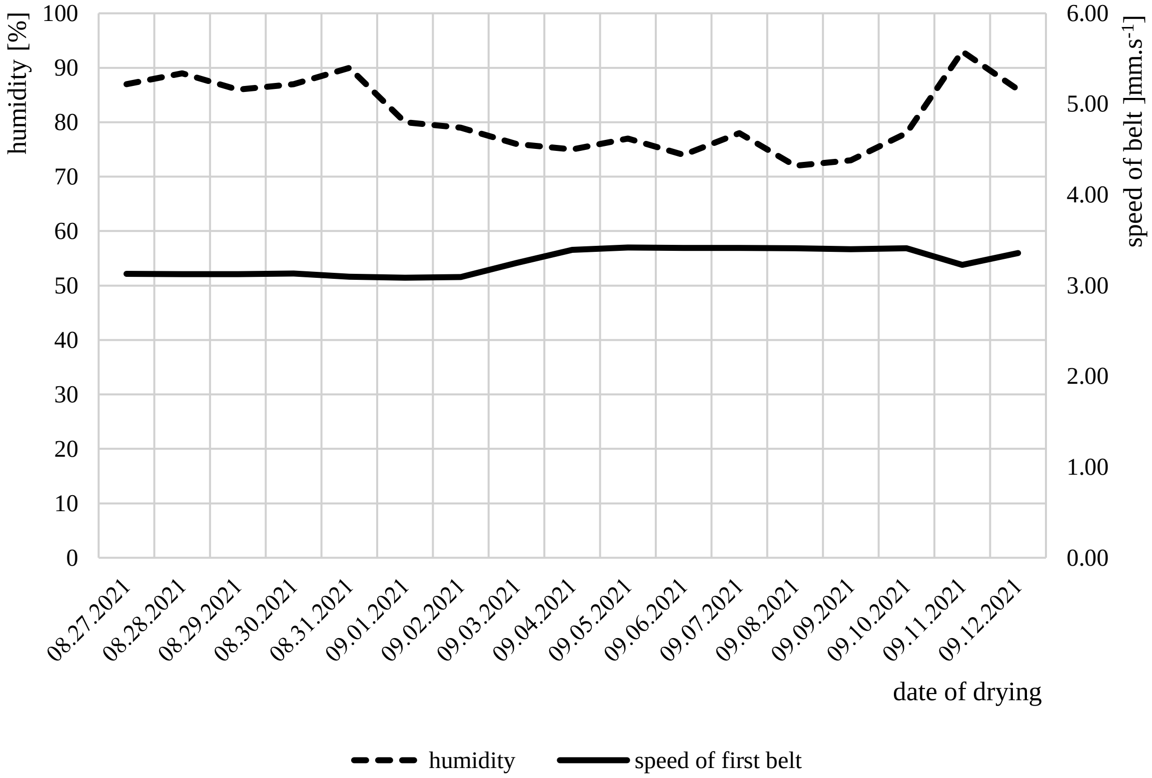


**Fig. 4** Measured data from Lupofyt Co., Ltd.

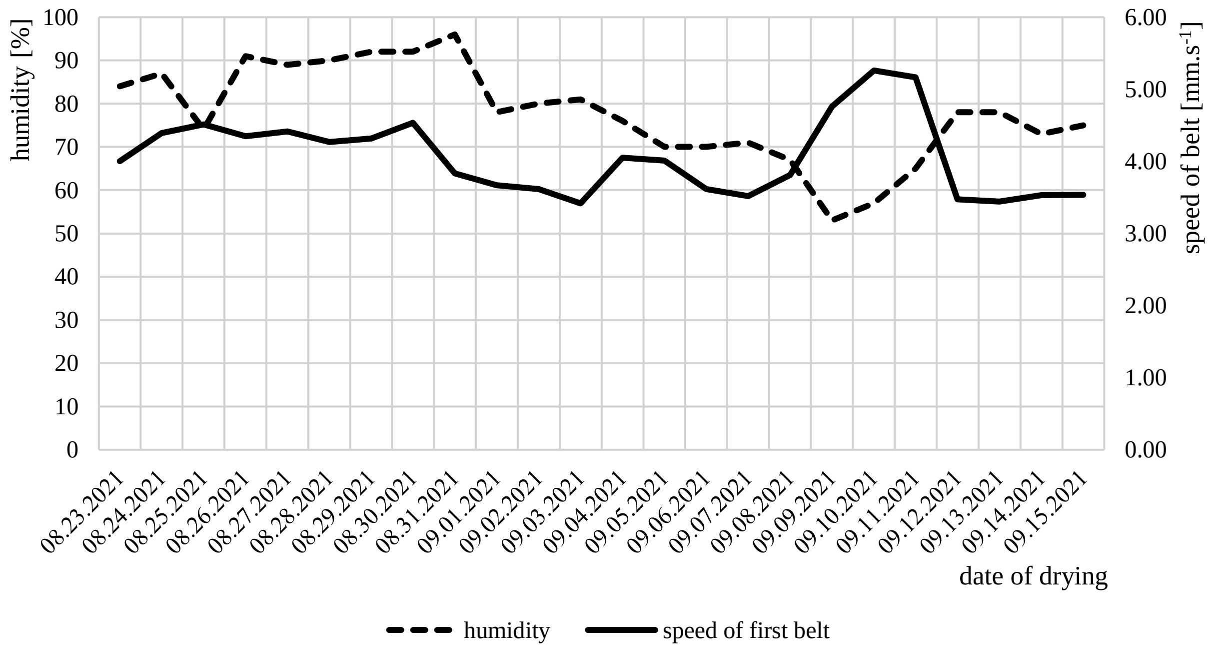


**Fig. 5** Measured data from Agrospol Velká Bystřice Co., Ltd.

## CONCLUSIONS

Continuous sensing of the speed of the dryer belts will help to signal slippage or unexpected stoppage of the dryer belts. The advantage of continuous sensing of the speed of the drying belts is an increase in the quality of hops, safety when working in the dryer, the introduction of signalling for the operator and subsequent use for the automation of the hop drying process. The speed data will be transmitted to the computer and subsequently, it will be possible to use it for precise adjustment of the movement of the drying belts of the belt dryer. Another advantage lies in the possibility of using motion sensing devices in post-harvest technologies of other crops, e.g., when processing vegetables and sensing slow speeds of various mechanisms. The uniqueness of the solution results from the fact that there is no mechanism or device used in hop dryers to continuously monitor the speed of the drying belts. The automation of the drying process is achieved by mounting the designed sensor and connecting it to the control of the dryer.

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## REFERENCES

1. Guiné, R., P., F. (2011). Influence of Drying Method on Some Physical and Chemical Properties of Pears, International Journal of Fruit Science, 11:3, 245-255, DOI: 10.1080/15538362.2011.608295.
2. Guiné, R., P., F., Barroca, M., J., Gonçalves, F., J., Alves, M., Oliveira, S., & Mendes, M. (2015). Artificial neural network modelling of the antioxidant activity and phenolic compounds of bananas submitted to different drying treatments. Food Chemistry, 168, 454-459. DOI:10.1016/j.foodchem.2014.07.094.
3. Hermanek, P., Rybka, A., & Honzik, I. (2018). Determination of moisture ratio in parts of the hop cone during the drying process in belt dryer. Agronomy Research, 16 (3), 723 – 727. DOI: 10.15159/AR.18.076
4. Holowaty, S., A., Schmalko, M., E., & Schvezov, C., E. (2022). Modeling of a double pass belt conveyer dryer of yerba mate, Drying Technology, 40:5, 938-947. DOI: 10.1080/07373937.2020.1839488
5. Chokphoemphun, S., & Chokphoemphun, S. (2018). Moisture content prediction of paddy drying in a fluidized-bed drier with a vortex flow generator using an artificial neural network. Applied Thermal Engineering, 145, 630-636. DOI:10.1016/j.applthermaleng.2018.09.087.
6. Kaveh, M., Amiri Chayjan, R., Taghinezhad, E. et al. (2019). Modeling of thermodynamic properties of carrot product using ALO, GWO, and WOA algorithms under multi-stage semi-industrial continuous belt dryer. Engineering with Computers, 35, 1045–1058. DOI: 10.1007/s00366-018-0650-2
7. Kaveh, M., Sharabiani, V., R., Chayjan, R., A., Taghinezhad, E., Abbaspour-Gilandeh, Y., & Golpour, I. (2018). ANFIS and ANNs model for prediction of moisture diffusivity and specific energy consumption potato, garlic and cantaloupe drying under convective hot air dryer. Information Processing in Agriculture, 5(3), 372-387. DOI: 10.1016/j.inpa.2018.05.003.
8. Kırbaş, İ., Tuncer, A., D., Şirin, C., & Usta, H. (2019). Modeling and developing a smart interface for various drying methods of pomelo fruit (Citrus maxima) peel using machine learning approaches. Computers and Electronics in Agriculture, 165. DOI: 10.1016/j.compag.2019.104928.
9. Kudra, T. (2004). Energy Aspects in Drying. Drying Technology, 22:5, 917-932. DOI: 10.1081/DRT-120038572.
10. Lewicki, P. (2006). Design of hot air drying for better foods. Trends in Food Science & Technology, 17:4, 153-163. DOI: 10.1016/j.tifs.2005.10.012.
11. Mujumdar, A., S. et al. (2014). Handbook of Industrial Drying. CRC Press.
12. Münsterer, J. (2020). Trockung und Konditionierung von Hopfen. LFL Information. Wolnzach. (in Germany).
13. Raut, S., Gersdorff, G., J., E., Münsterer, J., Kammhuber, K., Hensel, O., & Sturm, B. (2020). Impact of Process Parameters and

Bulk Properties on Quality of Dried Hops. Processes, 8(11), 1507. DOI: 10.3390/pr8111507.
14. Raut, S., Gersdorff, G., J., E., Münsterer, J., Kammhuber, K., Hensel, O. & Sturm, B. (2021). Influence of pre-drying storage time on essential oil components in dried hops (Humulus lupulus L.). Journal of The Science of Food Agriculture, 101, 2247-2255. DOI: 10.1002/jsfa.10844.
15. Rybka, A., Hermanek, P., Honzik, I., Krofta, K. (2017). Parameters of the drying medium and dried hops in belt dryer. Research in Agriculture Engineering, 63, 24–32. DOI:10. 17221/35/2017-RAE.
16. Sturm, B., Raut, S., Kulig, B., Münsterer, J., Kammhuber, K., Hensel, O., & Crichton, O., J., S. (2020). In-process investigation of the dynamics in drying behavior and quality development of hops using visual and environmental sensors combined with chemometrics. Computers and Electronics in Agriculture, 175. DOI: 10.1016/j.compag.2020.105547.
17. Myllymaa, T., Holmberg, H., & Ahtila, P. (2019) Techno-economic evaluation of biomass drying in moving beds: The effect of drying kinetics on drying costs. Drying Technology, 37:10, 1201-1214. DOI: 10.1080/07373937.2018.1492615.
18. Myllymaa, T., Holmberg, H., & Ahtila, P. (2020). Economic Evaluation of Drying of Soot Sludge and Sawdust Mixture at Low Temperatures Using the Characteristic Drying Curve Method. ChemEngineering, 4(1):6. DOI: 10.3390/chemengineering4010006.
19. Şahïnbaşkan, T., & Köse, E. (2010). Modelling of time related drying changes on matte coated paper with artificial neural networks. Expert Systems with Applications, 37(4), 3140-3144. DOI: 10.1016/j.eswa.2009.09.068.
20. Tarhan, S., Telci, I., Tuncay, M., T., & Polatci, H. (2011). Peppermint Drying Performance of Contact Dryer in Terms of Product Quality, Energy Consumption, and Drying Duration. Drying Technology, 29:6, 642-651. DOI: 10.1080/07373937.2010.520421.
21. Vasiliev, A., O., Andreev, R., V., Smirnov, M., P., Pushkarenko, N., N., & Zaitsev, P., V. (2020). Hop Drying process Research in industrial dryer. IOP Conference Series: Earth Environmental Science, 433. DOI: 10.1088/1755-1315/433/1/012032.
22. Youssefi, S., Emam-Djomeh. Z., & Mousavi, S., M. (2009) Comparison of Artificial Neural Network (ANN) and Response Surface Methodology (RSM) in the Prediction of Quality Parameters of Spray-Dried Pomegranate Juice, Drying Technology, 27:7-8, 910-917. DOI: 10.1080/07373930902988247.
23. Zhang, W., Ma, H., & Yang, S., X. (2015). A neuro-fuzzy decoupling approach for real-time drying room control in meat manufacturing. Expert Systems with Applications, 42(3), 1039-1049. DOI: 10.1016/j.eswa.2014.09.013.
24. Ziegler, T., Jubaer, H., & Teodorov, T. (2021). Bottlenecks in continuous hops drying with conveyor-belt dryer, Drying Technology. DOI: 10.1080/07373937.2021.1950168.

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