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Effect of rotors on the parameters of hop drying in belt dryers

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Abstract. This article contains a design and verification for a technical solution aimed at optimising the hop drying process in belt dryer and at increasing the quality of the final product. Above the first belt of our belt dryer two evenly distributed double-arm rotors were installed and tested in operation to improve the permeability of the drying air through a flattened hop layer, as well as to improve the speed of drying. The measurements carried out in operation and comparing the drying process with the rotors switched on and off concluded that by inclusion of rotors the hop layer becomes more permeable, and when switched on, the rotors have a positive effect on faster reduction of the relative humidity and on increase of the drying air temperature. With rotors switched on, the percentage drop in the drying air relative humidity at the third inspection window of the first belt, compared to the first inspection window, was 41% on average (values obtained from data loggers and fixed sensors), the drying air temperature increased by 29%, and the hop moisture content decreased by 12%. Whereas with rotors switched off, the drop in the drying air relative humidity was only by 26% on average, the drying air temperature increased only by 14%, and the hop moisture content decreased by 12%. Based on long-term monitoring of fuel consumption during the whole harvesting season starting 2011 until 2017 inclusive, the average annual consumption of LFO (2011–2014) results in 494 L t^{-1} operating without rotors, and 431 L t^{-1} when operating with rotors (2015–2017). This implies that due to the implementation of rotors, the fuel saving being 13% is significant.

Key words: hop cones, hop drying, belt dryer, quality of hops.

INTRODUCTION

In terms of technology and structure, belt dryers are designed as three belt conveyors mounted one above the other, through which warm air passes and dries the conveyed hops. The drying air temperature ranges between 55 °C and 60 °C and is practically stable for the entire duration of drying, i.e. for 6 or 8 hours. Long-term drying at given temperatures is highly energy-intensive and has also other negative impacts. Our technical solution will enable easier permeability of the drying air, higher drying speed and has a positive impact on the quality of the final product (Doe & Menary, 1979; Aboltins & Palabinskis, 2016; Rybka et al., 2016).

When hop cones are poured into the dryer, on the first belt the layer flattens and hop cone bracts stick together due to surface moisture. That causes lower layer permeability (surface crust is created) for the passing air, thus the drying speed decreases (Jokiniemi et al., 2015; Rybka et al., 2018). After this problem had been eliminated, two double-arm rotors located above the first belt of the dryer were designed, installed and verified in operation following initial experiments (Fig. 1).

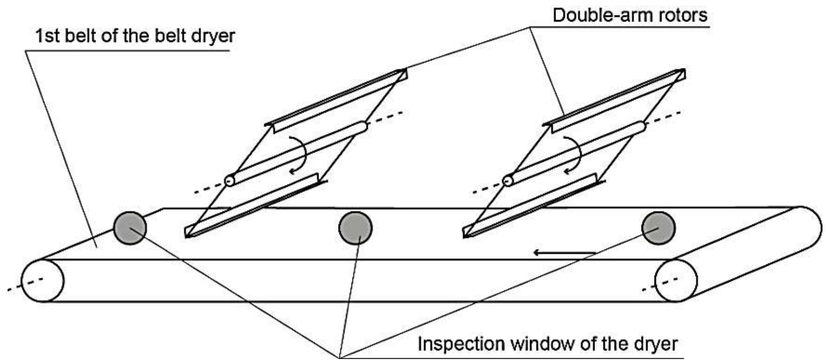

Figure 1. Scheme of placing of two double-arm rotors above the first belt of belt dryer (rotor diameter – 840 mm, rotor rotational frequency – 2.5–3 min^{-1}).

The first rotor is mounted between the first and second inspection window, the second rotor being between the second and third inspection window. Double-arm rotors have their arms fitted with reinforcement at their ends and rotate about their horizontal axis perpendicular to the belt motion (Heřmánek et al., 2018; Podsedník & Ježek, 2018). The rotors arms extend into the lower level of the hop layer moving on the dryer belt (Fig. 2). The shafts are fitted to the vertical walls of the dryer in bearing housings. They are driven by electric motors with transmission gearbox. The rotational frequency of the rotors is selected in a way so that their peripheral speed was greater than the belt speed, however, in order to ensure that the rotors would not push the hops off the belt, thus forming vacant spots without hops above the belt through which the drying air would freely penetrate. This, in turn, would lower the intensity of hop drying. The rotors arms in their actual operation break up and rearrange the flattened layer of hops stuck together, thus enable better penetration of the drying air and faster removal of hop moisture (Rybáček et al., 1980; Srivastava et al., 2006; Ma et al., 2015).

Figure 2. Rotor installed above the first belt of belt dryer.

MATERIALS AND METHODS

1. Measurement by inserted data loggers

To measure the temperature and relative humidity inside the hop layer continuously we used VOLTCRAFT DL-121-TH data loggers (Fig. 3) which enable to programme the frequency of data storage (Jech et al., 2011; Vitázek & Havelka, 2013). In the present case this frequency was set to 5 minutes. The data logger internal memory has its storage capacity of 32,000 measured data, which is absolutely sufficient. The data logger was integrated together with a sensor in a plastic casing and supplied by an inserted battery. The plastic casing had been fitted with a USB connector at one end via which the stored data were imported to a computer (Kumhála et al., 2016).

Figure 3. VOLTCRAFT DL-121-TH data logger.

To protect the data loggers against mechanical damage while carried throughout the dryer as well as against dirt we fixed the data loggers rigidly in polyurethane foam and inserted them 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, hence no measurement error occurred (Fig. 4).

Figure 4. Placing of a data logger into a protective sieve.

Three data loggers were placed through the first inspection window onto the first (upper) belt of the dryer, two of them approx. 0.5 m far from both left and right wall, and one in the middle. The data loggers were inserted into a hop layer. The advantage of data loggers, compared to rigidly fixed sensors in a dryer, is that they pass through the dryer together with the hops, continuously sensing the whole drying process.

All the determined values relate to an individual hop layer passing separate inspection windows on the first belt (1^{st}, 2^{nd} and 3^{rd} window) with rotors being switched on and then off.

2. Measurement by fixed sensors

On the dryer wall the assembly of Comet T3419 temperature and relative humidity sensors (Fig. 5) was completed. The sets of sensors were connected to a Comet MS6D multi-channel data logger (Fig. 6), from which all data were automatically stored in the computer on its hard disc.

Figure 5. Comet T3419 sensor with transmitter.

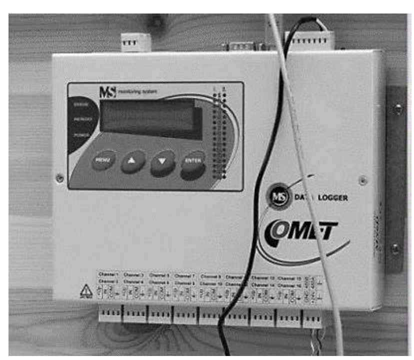

Figure 6. Comet MS6D multi- channel data logger.

The sensors had been installed nearby the inspection windows (Fig. 7). Inspection windows are part of the belt dryer basic equipment and they are intended for the purposes of visual and sensor monitoring of the drying process.

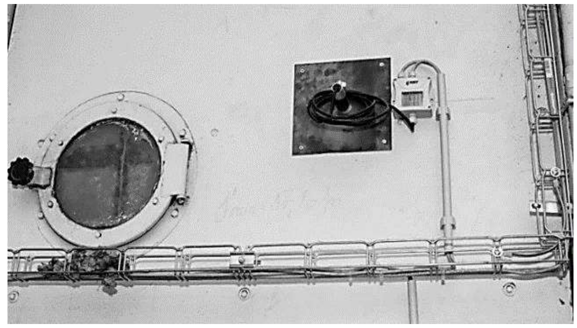

Figure 7. Sensor with a transmitter and display nearby an inspection window of the dryer (inspection window – on the left, fixed sensor – on the right).

The frequency of reading the values was in a way similar to the data loggers set to 5 min. Immediate measured values could be read on the connected two-line display, which at the same time showed the actual temperature in °C and relative humidity in %. 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.

3. Laboratory analysis of samples

The laboratory analyses monitored the moisture content of all hop samples, which was subsequently compared to the drying medium relative humidity measured by means of data loggers and fixed sensors in the dryer. The moisture content in the hops was determined by the Mettler-Toledo HE53 moisture analyser (Fig. 8) from the inspection windows individual samples taken in a synchronised manner with passing data loggers. The measurements were carried out 3 times and the resulting values were compared against each other (Henderson & Miller, 1972; Forster & Gahr, 2013).

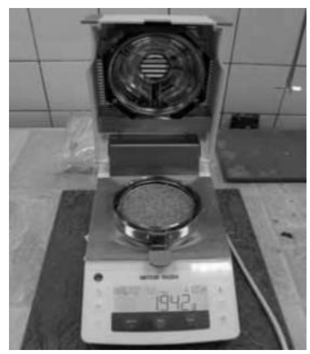

Figure 8. Mettler-Toledo HE43 moisture analyser.

We monitored the drying process on the 1st belt of the PCHB 750 belt dryer. All the values determined are related to specific hop layer passing individual inspection windows on the first belt (1st, 2nd and 3rd window) with the rotors switched on and off. The entry thickness of the hop layer on the first belt was 0.3 m, the drying temperature in 2016 was 58 °C and in 2017 it was 59 °C, and the initial hop moisture was 83–85%. The first belt speed was 0.0031 m s^{-1}. The drying air temperature and relative humidity were continuously monitored by means of three data loggers with a measurement frequency of 5 min. The data loggers had been inserted in a row (in the middle and at the edges of the belt) into a moving hop layer at the first inspection window and removed at the third inspection window. The measurements in 2017 were compared with the data obtained from the fixed sensors placed nearby the inspection windows slightly above the hop layer. The moisture content of hops was determined by means of the Mettler-Toledo HE53 moisture analyser using samples taken at given times at individual inspection windows (Chyský, 1977; Krofta, 2008; Mitter & Cocuzza, 2013).

RESULTS AND DISCUSSION

Measurement in 2016

During drying, the rotors were switched off for 50 min at three cycles (Table 1). Simultaneously with switching off the rotors, the data loggers were inserted into the dryer that measured the drying process between the 1st and 3rd inspection window of the first belt. These measurements were compared with the data obtained from the data loggers during drying with the rotors switched on in one cycle. The measurement results are shown in Table 1 and illustrated in graphs of Figs 9–11.

Table 1. Parameters of the drying process – 2016

Measurement date: 23.8.2016	Variety: Saaz	PCHB 750 belt dryer		
			Fixed sensors	
Inspection window	Rotors switched on, off	Reading time	Drying air temperature	Relative humidity of drying air
		h:min	°C	%
1	on	14:00	33.4	98.5
2	on	14:29	42.5	35.8
3	on	14:50	47.8	32.5
1	off	7:32	30.9	87.9
2	off	8:01	36.5	56.0
3	off	8:22	39.4	44.8
1	off	8:48	31.4	76.0
2	off	9:17	36.5	56.0
3	off	9:38	41.2	42.3
1	off	10:30	33.4	70.6
2	off	10:59	36.5	45.0
3	off	11:20	41.5	39.5

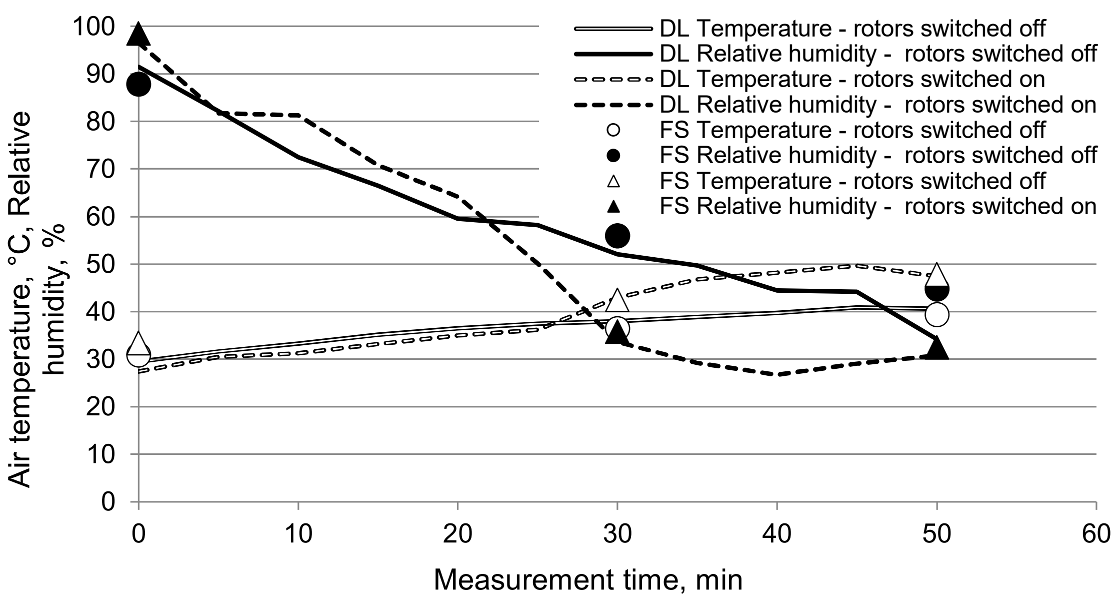

Figure 9. Dependence of drying air temperature and relative humidity on measurement time (time: 7:32–8:22 h); DL – data loggers, FS – fixed sensors.

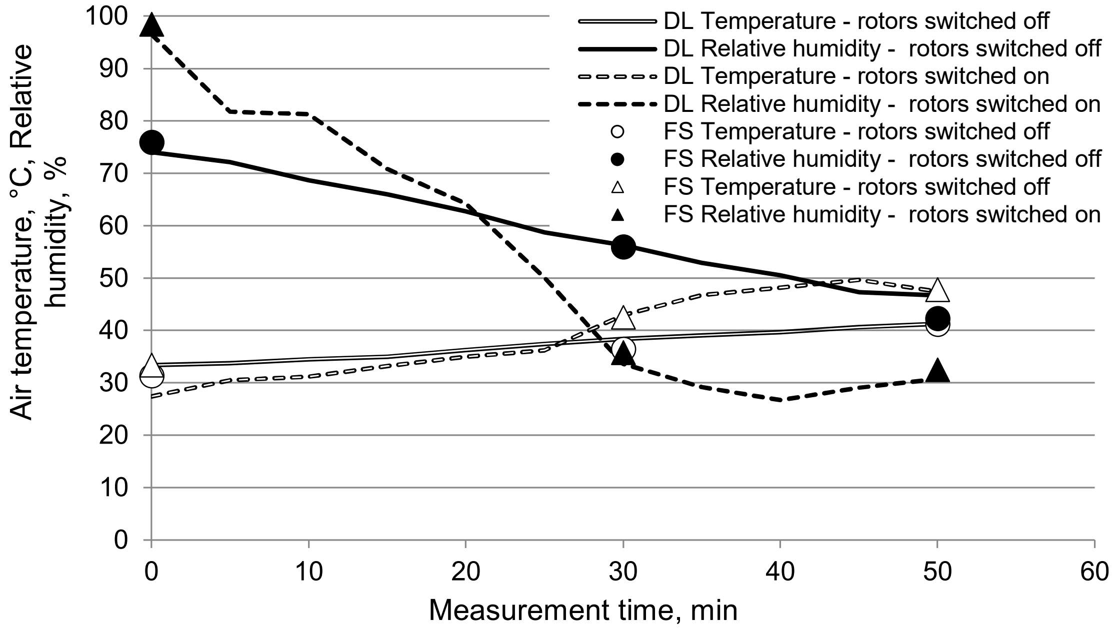

Figure 10. Dependence of drying air temperature and relative humidity on measurement time (time: 8:48 – 9:38 h); DL – data loggers, FS – fixed sensors.

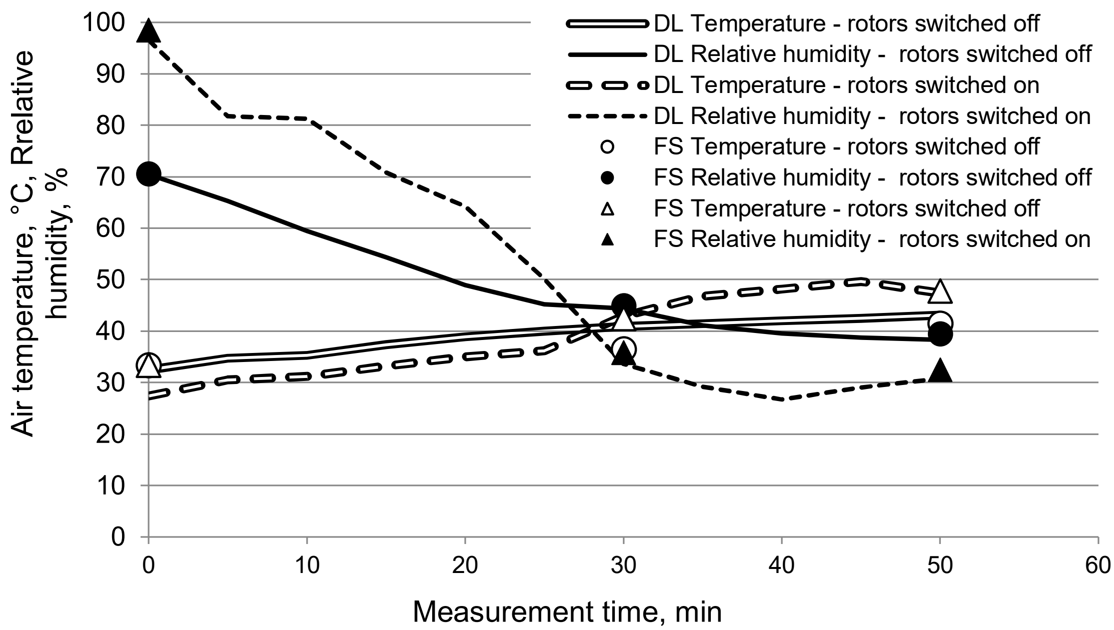

Figure 11. Dependence of drying air temperature and relative humidity on measurement time (time: 10:30–11:20 h); DL – data loggers, FS – fixed sensors.

Measurement in 2017

Table 2 presents the basic parameters and results of the measurement which are also documented in the graph of Fig. 12. The measurements using data loggers were in 2017 extended by temperature measurements and drying air relative humidity measurements by means of fixed sensors, and by determination of the hop moisture content by means of a moisture analyser.

Table 2. Parameters of the drying process – 2017

Measurement date: 29. 8. 2017	Belt dryer PCHB 750					Variety: Saaz
Sampling point	1st belt					
Rotors	Rotors switched on			Rotors switched off		
Inspection window	1	2	3	1	2	3
Sampling time, h:min	10:00	10:47	11:22	13:00	13:47	14:22
Measurement time, min	0	47	82	0	47	82
Data loggers – drying air temperature, ºC	31.1	37.7	41.5	36.3	41.0	40.7
Data loggers – drying air relative humidity, %	69.3	47.2	40.2	43.1	33.3	33.2
Fixed sensors – drying air temperature, ºC	29.2	34.3	36.5	30.8	35.1	35.6
Fixed sensors – drying air relative humidity, %	87.7	57.2	53.0	72.6	52.8	50.9
Hop moisture, %	75.4	70.3	66.1	68.1	62.0	60.1

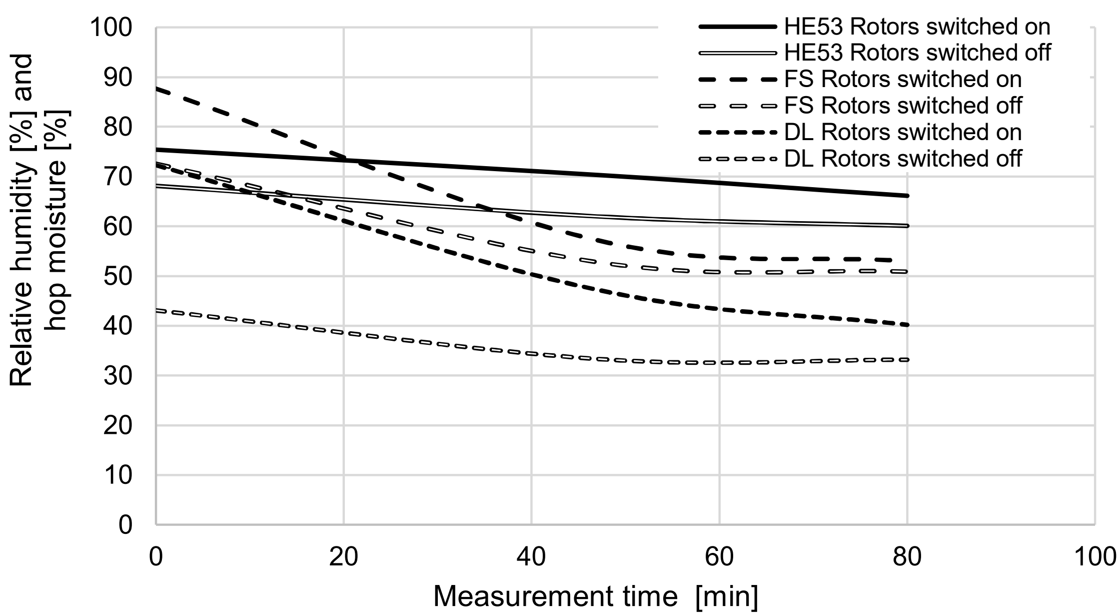

Figure 12. Dependence of drying air relative humidity and hop moisture on measurement time; HE53 – moisture analyser Mettler-Toledo HE53, DL – data loggers, FS – fixed sensors.

Long-term monitoring of fuel consumption

A significant outcome of all the measurements lay in long-term monitoring of fuel consumption when drying with and without rotors, always over the length of the harvesting season from 2011 to 2017 inclusive (Table 3).

Table 3. Fuel consumption in the PCHB 750 hop belt dryer

Year	Total consumption LFO, L	Dry hops, t	Average consumption of LFO per 1 t of dry hops, L t^{-1}		Note
2011	21 949	42.48	517		
2012	12 300	30.90	398		
2013	22 200	43.87	506		
2014	24 100	45.90	525		
2011–2014	80 549	163.15		493.70	without rotors
2015	13 600	32.94	413		
2016	29 369	69.47	423		
2017	28 444	63.30	449		
2015–2017	71 413	165.71		431.00	with rotors

DISCUSSION

The graphs in Figs 9–11, documenting the measurement from 2016, show that despite a significant impact of the initial hop moisture content, the relative humidity is lower and the air temperature is higher always after about 30 mins, i.e. from the 2nd inspection window. It can therefore be concluded that lower relative humidity and higher air temperature inside a hop layer are caused by rotors by disrupting its surface layer, that are placed between the 1st and 2nd and between the 2nd and 3rd inspection window. Such hop layer becomes more air-permeable, therefore the relative humidity inside the dried layer declines and its temperature rises causing the moisture in hop cones to dry out faster. When preliminarily measuring the layer height at individual inspection windows it was found out that with rotors switched off the hop layer is overall more compact, with a more solid surface, and it is apparent that the drying air penetrates through this layer with difficulty. The drying air temperature and relative humidity were measured by data loggers (continuous measurement) and fixed sensors independently of one another. These were placed above the hop layer nearby the inspection windows. The graphs document that the data obtained from the fixed sensors are practically identical to the continuous measurement by means of data loggers with rotors switched both on and off.

Table 2 and Fig. 12 document the measurement results from 2017. The measurement data obtained from data loggers (drying air temperature and relative humidity) in Table 2 represent the average data from three data loggers placed in a row. The values from individual data loggers placed in a row differed minimally, thus confirming a presumption about drying process being even over the whole width of the dryer. For reasons of clarity, drying air temperature courses have been excluded from the graph in Fig. 12.

As resulted from the in-process measurement (Table 2), the rotors on the first belt of the belt dryer have a positive impact on the efficiency of hop drying. The percentage drop in the drying air relative humidity at the third inspection window of the first belt was, compared to the first inspection window with the rotors switched on, 41% on average (values from both the data loggers and fixed sensors), while the drying air temperature increased by 29%, and the moisture content in hops decreased by 12%. Whereas with the rotors switched off, the drop in the drying air relative humidity was only 26% on average, the drying air temperature increased only by 14% and the hop moisture content decreased by 12%.

Based on the multi-annual monitoring, the average annual LFO (Light fuel oil) consumption (years 2011–2014) is 494 L t^{-1} when operating without rotors and 431 L t^{-1} with rotors (years 2015–2017). This implies significant fuel savings of 13% by using rotors.

CONCLUSION

The experiments in a belt dryer comparing drying with its rotors switched on and off above the first belt show that by involving rotors in the technological process a hop layer becomes more air-permeable and they also have a positive impact on faster decrease in the relative humidity and increase in the drying air temperature. By inclusion of rotors, the relative humidity of the passing drying air dropped by 14% compared to the operation with the rotors switched off, the drying air temperature on the contrary increased by 15%, and the hop moisture decreased by 0.6%. This comparison of results, however, may be influenced by the variable moisture of the hops coming into the dryer. It is ideal when hops on entering the dryer have identical moisture content for both variants of the measurement. Therefore, it will be appropriate to carry out repeated measurements in the following harvesting seasons. The inclusion of rotors also significantly positively reflected in the long-term monitoring of fuel consumption. After several seasons of monitoring, the average annual savings of LFO when using rotors is 63 L t^{-1} of dry hops, which corresponds to 13%.

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