The effect of work of inclined belt conveyors on the quality of hop separation in hop picking line

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ABSTRACT

The article summarizes the results of a two-year research focused on separating impurities in hop picking line by means of inclined belt conveyors. Researchers designed a new version of inclined belt conveyors which were installed in one segment of a parallel hop picking line. In the other segment the current inclined belt conveyors remained. Regarding the product quality, better results were obtained with new inclined belt conveyors where the average content of impurities at the output was 7.73%, contrary to the treatment with current conveyors where the content of impurities was 12.03%. The current inclined belt conveyors had 4.8 times higher losses of hops than the new ones. The economic assessment clearly proves the use of new inclined belt conveyors to be more effective, as the return of the costs for the exchange of six inclined belt conveyors in a picking line makes only 3.13 years at a comparable or even better quality of separation.

Keywords: hop picking line; belt conveyor; hop cones; impurities; quality of work

Czech hops occupy a significant position in the worldwide beer production due to their distinctive characteristics (Rybáček 1991, Krofta et al. 2012). Purchasers put more and more emphasis not only on brewing parameters of hop product, but above all on absolute purity of hop granules in relation to undesirable impurities (Krofta and Ježek 2010). The last separating part of equipment in hop picking line is a section of six inclined belt conveyors which are formed by belt conveyors inclined at an adjustable angle. The role of inclined belt conveyors is to separate remaining hops impurities that are mainly formed by leaves and pieces of vines (Pinzl and Mayer-Diener 2002, Kirchmeier et al. 2005). The separation uses different shape of hop cones and impurities. Hop cones are rounded and therefore they easily roll down against the motion of the conveyor belt. On the contrary, impurities mostly have a different shape and are carried by the conveyor upwards. There are 6 inclined belt conveyors in a section. The material intended for separation is carried onto app. half of the belt of the first inclined belt conveyor where a part of hop cones separates (rolls down) and the remaining mixture passes onto another conveyor. This way the mixture keeps passing till it gets onto the last inclined belt conveyor where the last hop cones should be separated and the remaining impurities should be carried into the waste. As previously mentioned, the angle of incline of each conveyor is possible to set independently in the range of 37 ± 10°. The incline influences the amount of separated cones and the separation efficiency. The operating life of currently used inclined belt conveyors is relatively short (app. 3 years) and also the quality of work, according to growers, is not ideal.

In 2011, based on a design of another belt type and version of driving and driven drums, we assembled experimental measuring equipment and

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carried out a measurement comparing the quality of work of both current and new inclined belt conveyors. The measurement verified that from the point of view of qualitative and economical parameters the quality of the new conveyor achieves improvement in technological procedure of hops processing in hop picking lines. Based on the measurement results, a design of new construction was created and subsequently a prototype of a whole section of inclined belt conveyors was made.

A measurement carried out in 2012 was to verify what effect this change in technological procedure would have on the quality of separating hop cones from impurities in the operating picking line.

MATERIAL AND METHODS

The main task of the measurement in 2011 was to assess the quality of work of inclined belt conveyors set with belts of various lug surface structure (Figure 1). At the same time the costs of inclined belt conveyors production were assessed, with regard to different belt type and guide rolls. These conveyors were designed and made in a way to be able to set and possibly also change the conveyors incline as well as the circumferential belt speed (Srivastava et al. 2006, Weihrauch et al. 2010).

The above described measurement proved that from the point of view of the quality of work and economical parameters, the new inclined belt conveyor achieves an improvement in technological procedure, which was the reason why in 2012 CHMEL-Vent Co. Ltd., Zatec installed a section of six new inclined belt conveyors in one segment of its parallel picking line (Rybka et al. 2012). In the other segment the current inclined conveyors remained, thus enabling comparison of the quality of work of both present and new conveyors during processing the same variety of picked hops, which was Saaz Semi-early Red-bine hops – SSR (Figure 2). The given equipment was operating throughout the harvest season of 2012.

From the point of view of construction, the current inclined belt conveyors are formed by a steel frame which is fitted with a driving and a driven drum at both ends (Figure 3). There is a belt stretched over both drums, creating a short belt conveyor. Inclined belt conveyors are placed in a way that we were able to set their incline. The belt which is currently used on inclined conveyors is made of rubber and on its surface there are lugs in the form of truncated cones evenly distributed in a square net. The belt guiding is ensured by a central high ridge welded from below (Portner 2011). The designed belt is made of PVC and has lugs on its surface which are formed by longer segments arranged in slanting lines. The belt guiding is ensured by two guide wedges on its edges. Separation of biological hop impurities, which are mainly leaves, pieces of hop bines, and leafstalks, is significantly influenced by the profile of the inclined conveyor's belt surface. The belt moves at a constant frame speed, hop matter falls onto the belt at a right angle, therefore not having any speed in the direction of the belt at the very moment of its falling on the belt. The inclined belt conveyor divides the mixture into two fractions. The particles with a higher coefficient of friction, actually all biological hop impurities or possibly also smaller-sized stones and clods (angular or flat mixture components), which get stuck between the rubber lugs, start moving upwards after carried onto the belt. Those mixture particles, which apply rolling friction instead of sliding friction (namely hop cones) start moving downwards once on the belt. An adjustable belt incline plays a significant role in the quality of work of inclined belt conveyors (Neubauer et al. 1989).

The method of the measurement comparing quality of work of the current and the new inclined belt conveyors:

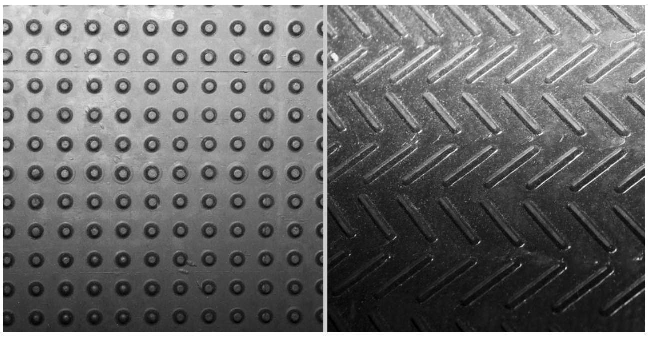

Figure 1. On the left – surface of currently used belt, on the right – new belt

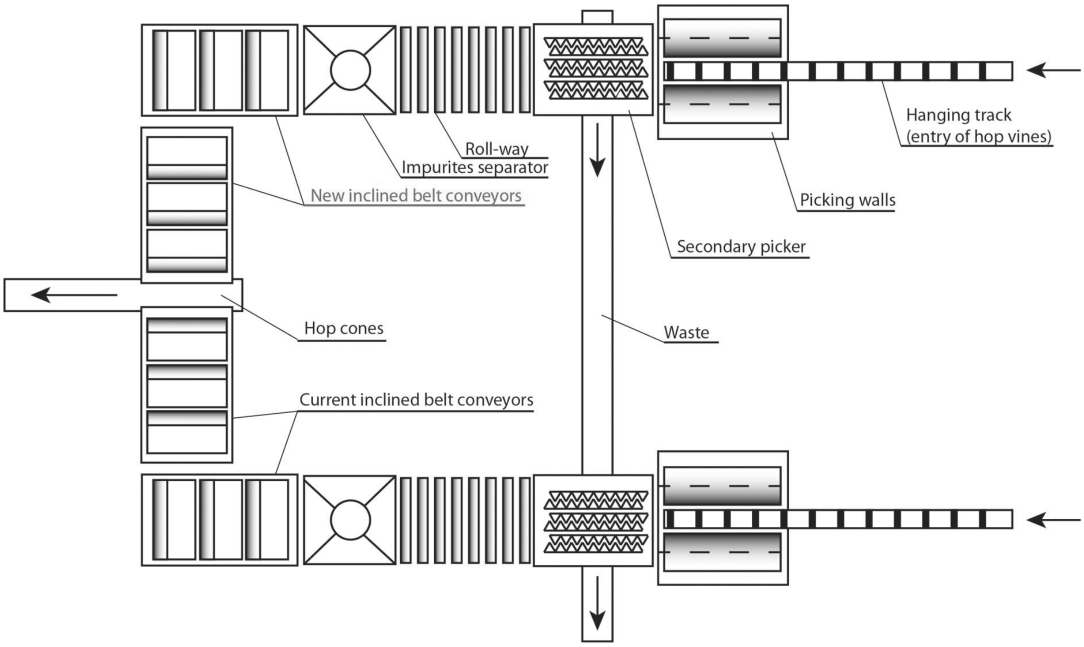

Figure 2. Scheme of technological arrangement of picking line

– check the incline of the current inclined belt conveyors (the optimum incline according to experience of operators from last years to reach the best separation quality, the first inclined belt conveyor – incline 39°; 2^{nd} – 41°; 3^{rd} – 44°; 4^{th} – 37°; 5^{th} – 40°; 6^{th} – 42°),
– set the incline of the new inclined belt conveyors (based on the experiments in 2011, 1^{st} – 36°; 2^{nd} – 40°; 3^{rd} – 42°; 4^{th} – 36°; 5^{th} – 39°; 6^{th} – 42°),
– assess the technical maturity of the hops harvested in the period of sampling and proportion of impurities in the hop matter coming onto inclined belt conveyors,
– take 5 samples (one set of the measurements) at the output of the picking line before the dryer (sampling time 60 s) and sort them manually to hop cones and impurities, weigh accurate to 1 g,
– take 5 samples (one set of measurements) of the waste separated on the inclined belt conveyors (sampling time – 60 s) and sort them manually to impurities and hop cones, weigh accurate to 1 g,
– perform the same sampling and assessing procedure with both the current and the new inclined belt conveyors,
– repeat the measurement sets five times in one day, each time keeping the interval of one hour (between 9.00–13.00 o'clock),
– statistically evaluate the stated measurement sets,

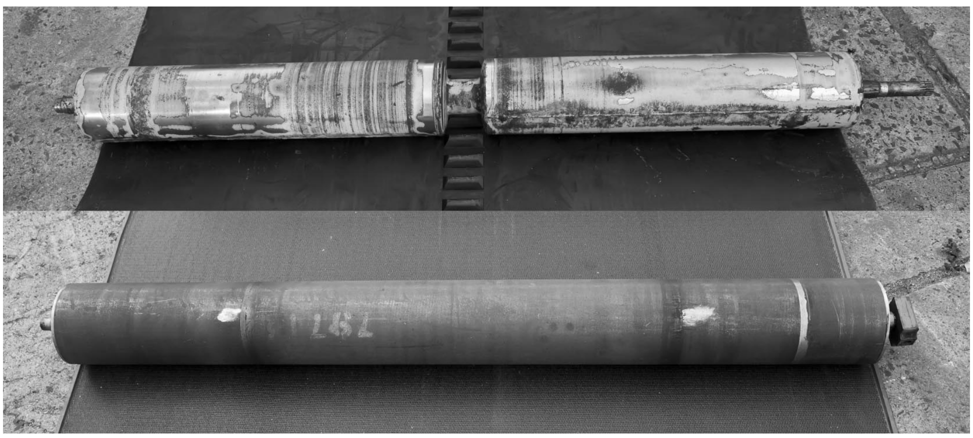

Figure 3. Drum of a current (up) and a new (down) inclined belt conveyor

– compare from the economic point of view the current and the new inclined belt conveyors (production costs and operating life).

RESULTS AND DISCUSSION

The operating experiments were accomplished on 23. 8. 2012 and they strictly accepted the chosen methods.

Before the measurement itself we assessed the technical maturity of the harvested hops. The colour of cones was bright yellow-green with a natural gloss, an absolute majority of cones was closed and elastic when squeezed, the smell was strong and typical for SSR, lupulin was of a bright lemon-yellow colour; proportion of biological impurities (leaves, pieces of hop bines, leafstalks) ranged between 15.26% and 20.24% with the current inclined belt conveyors, between 9.79% and 11.42% with the new inclined belt conveyors, non-biological impurities were not present.

The measurement results are processed in tables and arranged clearly in graphs. In the graphs (Figure 4) we compare the percentage share of impurities in taken samples of hop cones with percentage share of hop cones in samples of waste taken after the inclined belt conveyors, both the current and new. The graphs already present the average values for each set of the measurements, where the coefficient of variation representing the variance of always five values within individual sets of the measurement ranged between 8% and 15% in all cases.

When assessing the quality of work of both inclined conveyors sections we focused above all on the content of impurities at the input and output of the inclined conveyors, and on the content of hop cones separated on the inclined conveyors as waste, which is considered a loss (Figure 5). In case of the product purity both at the input and output of the inclined conveyors there were recorded significant differences between both treatments (Table 1). From the point of view of the product quality, better results were shown with new inclined belt conveyors, where the average content of impurities at the output was 7.73%, contrary to the current conveyors, where the measured content of impurities was higher, namely 12.03%. However, we must consider the fact that the input material with the current inclined conveyors contained 18.86% of impurities on average, and with the new conveyors only 10.29%. These data prove that the current inclined conveyors separated 6.83% of impurities and the new ones only 2.56% of impurities. The current inclined conveyors then separated 2.67 times more impurities, without increasing the content of hops in the waste in any provable way.

As in the given case we were assessing the effect of two factors (technology and place of sampling) influencing the resulting feature, it was necessary to use the two-way analysis of variance, which assessed at the same time the influence of the inclined belt conveyors on the average weight of impurities and hops according to the *F*-test ($F = 129.82$), together with the influence of sampling place on the average weight of impurities and hops according to the *F*-test ($F = 617.95$). For both cases an alternative hypothesis was accepted by comparing the value of the calculated level of significance *P* and the determined level of significance $\alpha = 0.05$. In both cases the *P* value was notably

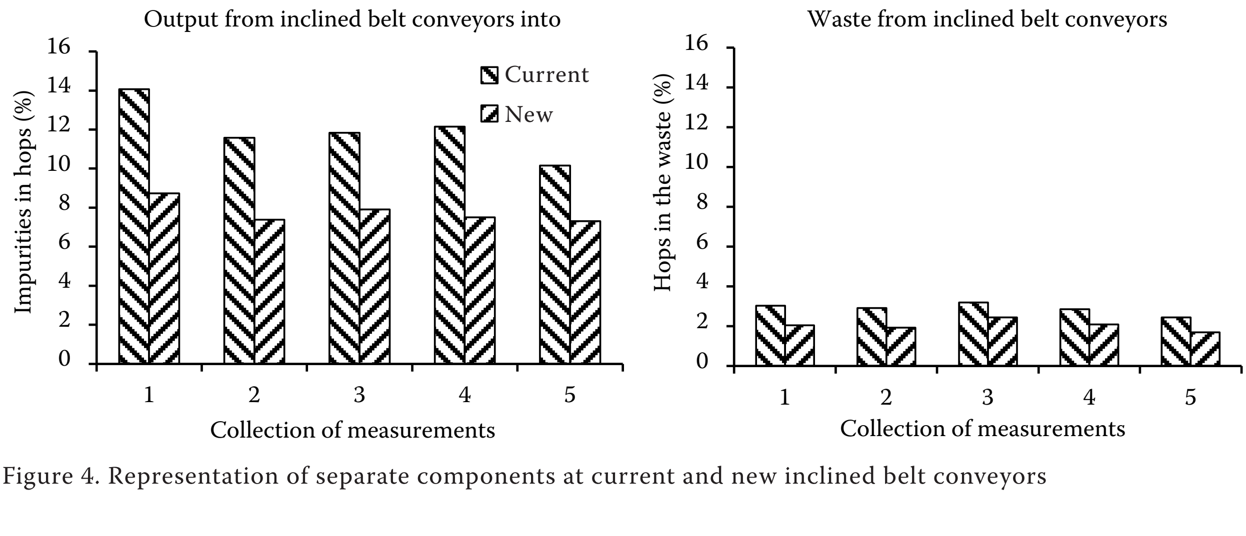

Figure 4. Representation of separate components at current and new inclined belt conveyors

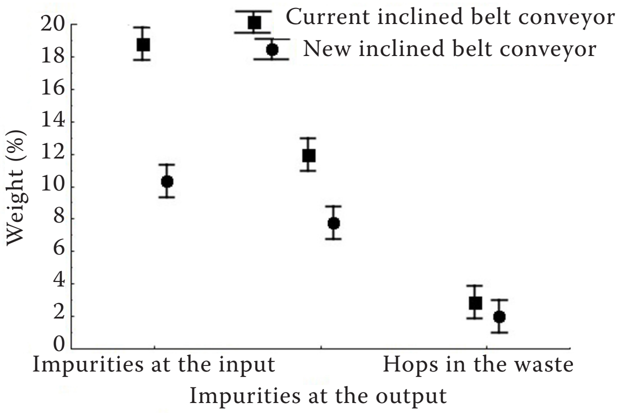

Figure 5. Procentages proportion of the weight of impurities at the input and output of inclined belt conveyors and of hops in the waste (columns denote 95% confidence intervals)

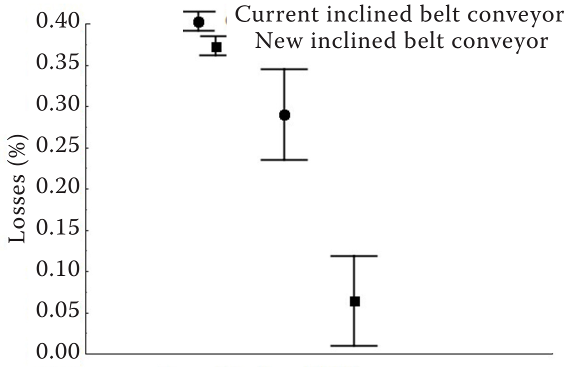

Figure 6. Percentage proportion of the weight of hop cones in the waste to the waste of hop cones at entry to current and new inclined belt conveyors (columns denote 95% confidence intervals)

lower than the determined level of significance α. Therefore it was necessary to carry out a more detailed assessment of the analysis of variance as for the average weight determined according to the sampling place, as for the average weight determined according to the type of inclined belt conveyors. The detailed assessment applied the Tukey's method with a schematic depiction of the homogenous groups (Table 1). Those averages with stars in the same column do not differ statistically significantly (on the chosen level of significance α = 0.05), contrary to those with stars in a different column whose averages differ significantly. The graphic depiction of averages with 95% confidence intervals can be seen in Figure 5.

After assessing the losses we find out that the current inclined belt conveyors show much worse results (Figure 6, Table 2). The current inclined conveyors have 4.8 times higher losses of hops that the new ones. Specifically, we recorded losses of 0.29% compared to 0.06% with the new inclined conveyors (ratio of the weight of hops in the waste to the weight of hops at the input of inclined belt conveyors).

In the case of comparing the average values of hops losses both at new and current inclined belt conveyors through the method of T-test, the basic condition of homogeneity of variances for the use of the classic T-test was not fulfilled in our case. The calculated value of the F-test ($F = 41.48623$) corresponds to the level of significance $P = 0.003272$ (Table 2) which is lower than our determined value of the significance level α = 0.05 and the variances on this level differ substantially. Thus we tested the given sets as independent samples. The new value of the two-sided $P = 0.002736$ for sets with different variances is significantly lower than the determined value α = 0.05 (Table 1), thus on the significance level α = 0.05 (as well as on the significance level α = 0.01) reject the

Table 1. Tukey's test of homogeneous groups to depict statistically provable differences in recorded values of the weight of impurities and hops

Measurement	Place	Inclined belt conveyors	Average (%)	Differences (α = 0.05)
1	hops in waste	new	2.04	****
2		current	2.88	****
3	impurities at the input	current	18.82	****
4		new	10.34	****
5	impurities at the output	current	11.96	****
6		new	7.77	****

Table 2. Tukey's test of homogeneous groups to depict statistically provable differences in recorded values of hops losses

Inclined belt conveyors	Average (%)	*t*	Degree of freedom	*P* two-sided	Standard deviation	*F*-variances ratio	*P*
New	2.56	6.3173	4.19	0.002736	0.2331	41.48623	0.00327
Current	6.83				1.5016		

null hypothesis about the equality of averages of both sets, it follows that on our determined level a statistically significant difference was proved between average losses of both new and current inclined belt conveyors. A graphic depiction of the averages with 95% confidence intervals are to be seen in Figure 6. Statistical assessment was carried out through Statistica v.10 program (Tulsa, USA) by StatSoft company.

Besides the qualitative indicators of change in technology of picking line, the economic indicators were also compared. The economic assessment was carried out on the basis of comparing the production costs on the one hand, and on the basis of the operating life of both current and new inclined belt conveyors on the other.

Current inclined belt conveyors are produced by Chmelarstvi, druzstvo Zatec (cooperative for hop mechanization), in Zatec, where also the spare parts for new inclined conveyors were made. This made possible to compare the production costs of both variants (Table 3). The production costs of the whole inclined belt conveyor (2 drums + 1 belt) are 463 € for the current make and 483 € for the new one, which represents a costs increase by 20 € for the new version. Another assessed criterion was the operating life of both versions. The operating life of the current belt is according to the producer's long-standing experience only 3 years. Such a short life is caused partly by the belt material (rubber), but above all by an uneven loading and strain in the belt caused by the welded central ridge. The main disadvantage of the separating belts' central guiding is a frequent cracking of driving and driven drums due to a combined torsion – bending stress of drum shaft, where due to the central ridge the central part is shortened and at belt stretching occurs a higher prestress in the centre rather than on the sides leading not only to shafts damage when in operation, but also to damage of joint followed by damage of belt. The operating life of new belt is guaranteed by the producer over 15 to 20 years. For the purpose of our calculation we used the lower estimation. A longer life is secured by the material (PVC) which resists the ageing process unlike rubber, and by new version of guide wedges which do not cause any undesirable stress inside

Table 3. Comparison of costs, operating life and calculation of return on investment in new model

	Unit	Inclined belt conveyor			
		current		new	
		drum	belt	drum	belt
No of pieces	pcs	2	1	2	1
Price for 1 piece	€	112	239	108	267
Total price	€	224	239	216	267
Total for 1 inclined belt conveyor	€	463		483	
Operating life	year	3		15	
No of inclined belt conveyors in a line	pcs	6		6	
Costs of inclined belt conveyors exchange (new for current)	€			2 898	
Costs of repair for 1 year	€	926		0	
Savings over 15 years	€	13 890			
Exchange costs return	year	3.13			

the belt as they are placed on the belt edges and have a much smaller cross-section than the current belts. The specific weight of the new belt is app. by 25% lower compared to the current one, therefore the belt structure is also less stressed during the operation.

The abovementioned measurement results prove that new inclined belt conveyors show better results compared to current inclined belt conveyors, mainly in the case of a smaller share of hop cones present in the waste.

The amount of impurities in the sample where was supposed to be only hops ranged from 10.15% to 14.07% with current inclined conveyors, whereas with new inclined conveyors the values were from 7.31% to 8.73%. On the contrary, the amount of hop cones in the sample where was supposed to be only impurities, ranged between 2.44–3.19% with current inclined conveyors, and between 1.69–2.44% with new ones.

The economic assessment clearly proves the use of new inclined belt conveyors to be more effective, as the costs return for the exchange of 6 inclined belt conveyors in a picking line makes only 3.13 years at a comparable quality of separation.

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