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Assessing the Effects of Packed Beds on Lautering Performance and Wort Quality

The production in a brewery can be considerably affected by the lautering performance. To counteract inefficiencies and accelerate this operation, a novel process strategy is applied and evaluated. The incorporation of additional wall support by using different configurations of packed beds is studied in a laboratory setup. As a result, the compressibility of the filter cake is greatly reduced, and the wort flow through it is improved. Significant lautering time savings of 75% are achieved through a specific type of packing without sacrificing wort quality. These findings might help brewers to modernize the lauter tun and increase production capacity.

Descriptors: Lautering, Mash Separation, Packed Beds, Cake Filtration, Process Strategy

1 Introduction

Mash filtration is one of the several solid-liquid separation steps that are found throughout the brewing process. Nonetheless, its performance and outcome can affect not only the final product quality but also the whole production chain; many variables must be monitored to obtain a wort within the given specifications. Thus, this particular separation process has to be well understood to achieve the desired results.

After the malt has been ground and mashed, the insoluble fraction has to be separated from the liquid one, the beer wort. To accomplish this, small and medium-sized breweries, as well as breweries with a relatively large product diversity, mainly use lauter tuns [1]. The process in this vessel not only comprises filtration but also a sedimentation phase [2]. After transferring the mash to the tun, the coarse fraction of the suspended particles, mainly the husks, reaches the bottom of the tun first. The smaller particles sediment more slowly, and a considerable part of them is therefore separated after the sedimentation [3]. After the preliminary cake formation, the wort begins to flow through the so formed porous medium [4], which must be washed at the end to obtain a profitable amount of extract.

The phenomena relevant to the lautering process can be broken down as represented in table 1. Although simplified, it gives an overview of the different separation mechanisms involved. These overlap and depend on each other, making lautering a challenging engineering task [3]. Furthermore, every process step contributes to the compression of the filter cake due to solid pressure or liquid drag.

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The sub-stages of the separation make lautering very time-consuming despite its widespread use. Moreover, its performance is very difficult to predict [5]. After the process, the remaining spent grains filter cake exhibits high degrees of compression and inhomogeneity. It consists of a layered structure [6], which can become a particular obstacle for wort flow during filtration [7]. The top layer, known as the Oberteig, is composed of fine particles with sizes smaller than 500 µm. Forming a gelatinous structure, it is the cake layer with the highest flow resistance, which slows down the filtration and can even cause production delays [8]. These mechanisms turn the lautering cake into a double-edged sword; the sedimentation of the bottom layers is necessary to retain the fines but simultaneously promotes the Oberteig formation.

With the main goal of optimizing the overall flow rate, shortening the lautering duration without having negative effects on the wort quality or brewhouse yield, many breweries must resort to experience-based process strategies. A point of compromise among the key variables lautering time, filtrate turbidity, and extract content must be set according to particular brewery standards, as depicted in figure 1.

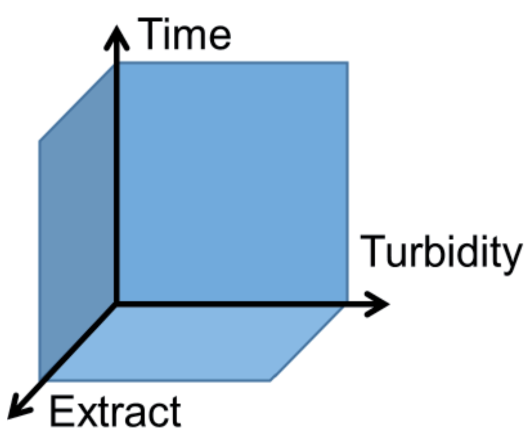

Fig. 1 Key variables of the lautering process.

Since the performance of common cake filtration processes depends on the filter cake's properties [9, 10], such lautering strategies are mainly directed at improving its porosity and permeability. Both variables can be directly related through, e.g., the Kozeny-Carman equation [11]. The traditional methods to counteract lautering inefficiencies depend almost exclusively on using raking knives and hydraulics [12]. The blades of the former actively cut through the spent grains cake and loosen its structure, affecting the cake permeability and therefore the pressure gradient along its height [13]. Even though special care is taken not to destroy the bottom layers in the process [14], using the knives usually leads to increments in the wort turbidity and thus to temporary quality losses. If this effect is counteracted through recirculation, the lautering time is extended, which in turn reduces the process efficiency.

Table 1 Separation mechanisms involved in lautering.

Mechanism	Features	
Sedimentation	Particle classification due to size and density	Cake compression
Cake filtration	Solids accumulate on the filter medium	
Depth filtration	Impurities are retained inside a porous medium	
Permeation	Liquid flows through a pore network	
Extraction	Solubles diffuse and are washed away	

In the last few decades, the lauter tun performance has been increased enormously from 6 to 14 brews per day [15]. Experience has generated best practices in this regard, e.g., that the peripheral speed of the raking mechanism should be kept low but uniform [14, 16]. This way, the cut is controlled more precisely, and the shaft is stressed more evenly. Furthermore, the knife geometry has been optimized repeatedly, achieving thrust reduction inside the cake and denser knife arrangements [17, 18]. In 2019, an additional component for the raking machine was introduced, which cuts the cake horizontally and thus helps partially blend the Oberteig into the lower layers [19]. While this represents a step further in achieving a more homogeneous flow resistance, an entirely new concept has not yet been established. For this reason, it can be discussed whether the basic lauter tun design with raking device is optimal for loosening the cake and controlling the filtration process. Its effects on the flow conditions in the spent grains cake are still scarce in the literature.

Nevertheless, innovative alternate methods to enhance the lautering cake permeability have been proposed in recent investigations. The method of air sparging, commonly applied to remove scaling on cross-flow membranes [20], was adapted by Tippmann et al. in an experimental lauter tun [4]. Through the installation of a nitrogen bubble distribution system at the bottom, they observed two positive effects for the process: filtrate flow rate was greatly increased, and part of the unwanted aroma compounds in the suspension was removed. Analogous to the traditional raking knives, the fine bubbles loosened the compressible filter cake, preventing blockage and lowering its flow resistance. This approach achieved considerable time and energy savings.

Bandelt Riess et al. [21] studied the effects of diverse flocculants on the fine mash particles through a jar-test procedure. The effective concentration of each agent was determined to agglomerate the particles and form stable flocs. Thus, their sedimentation behavior was changed, and the lautering process was notably accelerated after building a more porous spent grains filter cake. The dosage of every tested flocculant achieved to halve the process duration.

The method published by Hennemann et al. proposes to remove the Oberteig during lautering altogether [22]. This strategy is based on the overhead extraction of the fine particle fraction with a pumping mechanism. In the absence of the gelatinous structure, the first wort was swiftly separated, and significant time savings were achieved. Moreover, a low cake compression degree was observed. The extracted fraction was centrifuged in parallel to make up for yield losses, which led to an overall improvement of the lautering performance. Even so, the abovementioned alternatives have not been established yet.

This article assesses transferring a novel filtration strategy that can give traditional lautering methods an innovative perspective to the brewhouse. According to recent findings by Bandelt Riess et al., using packed beds of rings, which are normally found in absorption or rectification columns, is a way of effectively incorporating additional wall support into a filter cake. Their experimental observations when separating selected suspensions indicate that these packings provide a permeable structure with high porosity for the cake to accumulate and reduce filter cake compressibility, considerably improving filtrate flow [23]. Moreover, it was found that the porous medium's resistance to compressive stress is further improved for highly compressible solids [24].

Considering the particular properties of the spent grains cake, a great application potential could arise from using packings while lautering. Furthermore, the observed advantages could eventually be achieved with the raking mechanism already present in the standard lauter tun by redesigning its knives to resemble a viable support structure. This would considerably improve the equipment performance and brewhouse yield. However, a successful lautering process has to meet multiple criteria simultaneously, which demands specific evaluation methods and breaks new ground for the packing strategy. In consequence, this study takes a systematic experimental approach to assess the influence of packed beds on lautering performance and wort quality. Added wall support is used to manipulate the cake structure and achieve significant filtration time savings without violating the product specifications.

2 Materials and Methods

Pilsner malt (variety Laureate, Malteurop GmbH) was used for all experiments. This malt harvested in 2017 exhibited an extract of 81%. It was conditioned with 2% demineralized water before being ground twice with a two-roller mill (model 16/16, Künzel

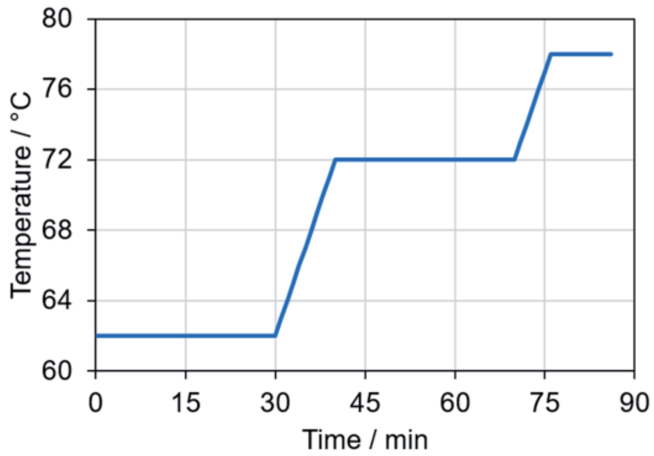

Fig. 2 Temperature program of the mashing process

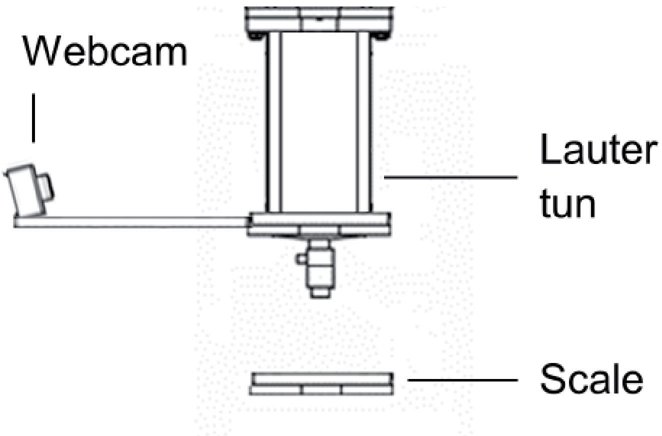

Fig. 3 Experimental lautering setup.

Maschinenbau GmbH) with the grinding gaps 1 and 0.4 mm. The particle size distribution was monitored through sieve analyses according to MEBAK standards [25]. All grist samples (500 g) were mashed with 2 liters of demineralized water in a mashing reactor LR-2000.70 (IKA Works, Inc.) according to the infusion temperature program depicted in figure 2.

The lautering procedures were carried out in a laboratory lauter tun with a 10 cm diameter glass housing and a slotted brass bottom with 13.8% open area, common in the industry. The transparent vessel allowed identifying the process sub-stages as well as observing the filter cake height and structure. While heating the tun with water at 80 °C, the infusion was terminated, and the mash was transferred and allowed to settle for 10 min before opening the outlet valve and starting the separation. The filtered wort mass was monitored online using an automated precision scale (KB 10000-1N, Kern & Sohn GmbH), and all experiments were recorded with a webcam [12]. The setup is illustrated in figure 3.

The first 400 g of trub wort were recirculated to produce a clear filtrate. After collecting about 1,250 g of liquid (first wort), the raking device of the tun was lowered to loosen the cake before starting the sparging procedure. The spent grains cake was subsequently washed with 1.5 liters sparging water, adding about 375 mL every five minutes. Once 3,100 g wort were produced, the lautering process was terminated. In the end, the filtrate quality was characterized by measuring its extract content with an Alcolyzer analysis system (Anton Paar GmbH) and turbidity with a LabScat 2 photometer (Sigrist-Photometer GmbH; transmission and scattering at 90° and 25° from a single light source). The results of this method were used as a reference. All experiments were performed threefold to ensure their reproducibility.

To assess the effects of wall support on the separation process, a preliminary series of experiments was planned to screen for the most viable option. This series truncated the reference method at the first wort stage: after collecting 1,500 g of liquid without raking, the experiment was stopped, and the filtrate quality was characterized as described above. The screening results obtained without and with packings were compared based on lautering time, wort turbidity, and extract content to select the most promising variation and repeat the sparging procedure under those conditions.

Fig. 4 Used packing components. Left to right: Raflux rings random, structured, and a Top-Pak.

Table 2 Properties of the packings

Type	Raflux (random)	Raflux (structured)	Top-Pak
Diameter [mm]	25	100	80
Length [mm]	25	25	80
Wall thickness [mm]	0.5	0.5	1
Quantity [–]	38	1	2

For the insertion of additional wall support, different commercial packed bed components and configurations were tested in the lautering tun. Steel Raflux rings 25-4 (RVT process equipment GmbH) and Top-Paks (VFF GmbH) were used. In addition to using the Raflux rings as a random packing, a structured bed was fabricated by expanding ten of them and welding them together to fit the diameter of the tun. The packings are pictured in figure 4, and their properties are presented in table 2. They were placed into the lauter tun after the mash sedimentation step. This allowed the lower cake layers to form beforehand, preventing the inserts from completely reaching the bottom. The Raflux (random) and Top-Pak packings had heights slightly above the one of the spent grains cake, whereas the Raflux structure was lowered to the Oberteig level and maintained there. The rest of the experiment was then carried out following the reference procedure.

3 Results and Discussion

The webcam attached to the experimental setup allowed for a detailed visual characterization of the lautering procedure. During the reference first wort experiments, the process sub-stages mentioned in table 1 were identified and are pictured in figure 5. Significant differences are observed when comparing the heights of the sedimented and compressed filter cakes. Potential applications of this method for detecting extreme degrees of cake compression during lautering have been discussed by Engstle et al. [12].

The online measurements with the automated scale provided data to analyze lautering time and monitor flow rate. First wort experiments were used to screen for the most viable option among the tested configurations. The wort mass curves obtained without and with packed beds are shown in figure 6.

The black curve represents the mean values of the reference experiments for this series, and the colored curves show the ones in the presence of packings. The standard deviation bars suggest a high reproducibility of the lautering procedure. A substantial lautering time reduction was achieved through all the tested packings. The randomly placed Raflux rings originated the greatest change in wort flow, closely followed by the Top-Paks. The slope of both curves shows that the filter cake resistance was significantly reduced in relation to the reference. Using the Raflux structure had a positive effect as well, but a high flow resistance can still be observed. Nevertheless, it is necessary to look at the bigger picture to properly compare the lautering performances, taking all the variables in figure 1 into account. Table 3 summarizes the obtained results, including the wort quality analyses and expected values based on the work of Narziß and Back [26].

The reference lautering procedure performed according to the expected behavior. Comparing the extract yield of the different runs, no relevant differences are found between them, making turbidity the other decisive factor for these experiments. Even though the random insertion of Raflux rings greatly accelerated the separation, this also resulted in a wort of very high turbidity, rendering their use disadvantageous in this application.

Fig. 5 **Sub-stages of the lautering process identified during the reference procedure. From left to right: initial mash, sedimented cake, filtration and permeation, final cake compression.**

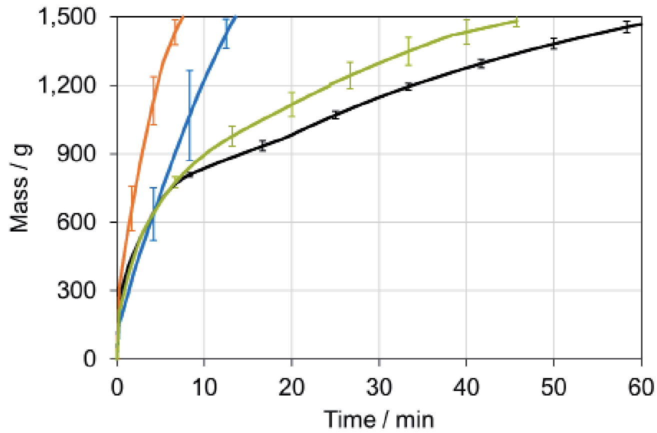

Fig. 6 **Filtrate mass over time for the first wort experiments. From right to left: Reference (black), Raflux structure (green), Top-Pak (blue), Raflux random (orange)**

Table 3 **First wort performance results.**

Experiment	Duration [min]	Turbidity [EBC]	Extract [°P]
Literature [26]	40 – 75	< 30	14 – 16
Reference	64 ± 5	20 ± 8	14.5 ± 0.2
Raflux random	8 ± 1	100 ± 16	14.5 ± 0.1
Raflux structure	45 ± 5	25 ± 4	14.8 ± 0.1
Top-Pak	14 ± 3	20 ± 10	14.8 ± 0.2

The run with the Raflux structure produced a wort within specifications and a time reduction of 30%, making it attractive for a scale-up. The benefit of this experiment was the aimed support of the Oberteig, which lowered its flow resistance without affecting the layers below. This result confirms that the fine particles pose the biggest impediment during lautering and process improvements can be derived from targeting them [8, 21].

However, the system containing Top-Paks was the one that achieved the best overall performance. The packing considerably reduced process time (by 78%) without compromising filtrate quality in any way. Therefore, it was chosen as the most promising one for

Fig. 7 Filter cakes after lautering (left to right) without and with Raflux rings and Top-Paks

potential applications and used in the sparging procedure as well. Like the Raflux structure, this packing lowered the flow resistance of the Oberteig but also of the layers directly below it without reaching the bottom of the lauter tun, which helped to keep the turbidity constant. Thus, the key to this method is focusing the wall effects in a strategic portion of the filter cake, where the separation efficiency is not affected.

The webcam was used to obtain visual results of these experiments as well. Some of the spent grains cakes are pictured in figure 7. The center image displays a highly porous network that has formed discontinuously around the Raflux rings. Since this packing reached the bottom of the tun, the lower layers were destroyed, and retaining the fine particles became impossible, explaining the measured quality loss. The increase in porosity is not as evident in the cake containing Top-Paks (shown right), but it does exhibit a significant height difference when compared to the reference. This hints at pores distributed within the structure and a greatly reduced degree of compression.

Using the packing prevented the filter cake from collapsing and made it more permeable, which reflects previous experimental results [23, 24]: As this strategy was first tested on model systems, it was shown that added wall support provides friction, which greatly increases the systems' resistance to compressive stress. Moreover, it was observed that this is linked to permeability improvements for compressible solids. Hence, the effects were magnified here as a result of the lautering cake's extreme compressibility, setting a very favorable scenario for the packing application.

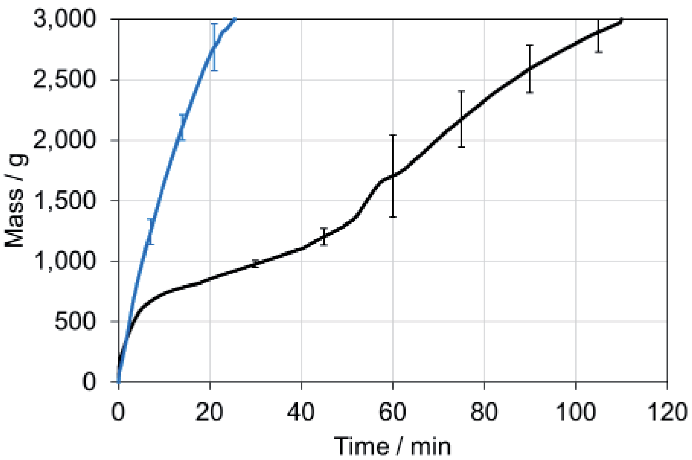

Fig. 8 Filtrate mass over time for the full lautering experiments. Reference (black), Top-Pak (blue)

Similar to the previous experiment series, figure 8 presents the wort mass curves obtained from the lautering procedures (reference and Top-Pak insertion) with sparging phase. Table 4 summarizes the values of the key variables and includes the literature data [26]. Additionally, the post-process MEBAK analyses for last runnings and total available extract in the spent grains (washable and soluble) were considered.

After following the same course as in the first wort procedure, the black reference curve shows a change in flow after 50 min, when the raking device was lowered. This allowed for a relatively constant throughput until the procedure was stopped. It also performed according to the expected values. Regarding the lautering with Top-Paks, the sparging phase did not affect the cake permeation in relation to the first wort experiment: both wort mass and extraction time were doubled. Furthermore, raking was not necessary. As before, a substantial lautering time reduction was achieved through the packing, this time by 75%, by counteracting filter cake compression and decreasing flow resistance. Comparing the wort qualities, slight decrements were measured when using the packing, suggesting that this strategy can still be improved or that a new time–quality compromise should be found. The post-process analyses indicate that optimizing the sparging phase with packing would contribute to the yield. However, the values are still within the given specifications, showing promise for scale-up and validation.

Thus, it has been found that using a static packing that provides structural support in the spent grains cake instead of raking knives can lead to significant lautering time savings without changing wort quality. This has a lot of application potential, for which further studies should be considered, including more variables, such as hygiene, packing material, and carry-over.

Table 4 Lautering performance results.

Experiment	Duration [min]	Turbidity [EBC]	Extract [°P]	Last runnings [°P]	Available extract [°P]
Literature [26]	≤ 120	< 30	10 – 12	< 3	1.6
Reference	114 ± 5	13 ± 6	11.3 ± 0.1	1.2 ± 0.1	1.4 ± 0.2
Top-Pak	28 ± 4	19 ± 6	10.8 ± 0.1	1.9 ± 0.1	1.6 ± 0.2

4 Conclusion and Outlook

An innovative process engineering strategy was developed, and its effects on lautering performance were evaluated to increase production efficiency. Since the spent grains cake can often become an obstacle for wort flow, different configurations of packed beds were tested to incorporate more wall support into the lauter tun. This way, cake compression was avoided, and the resulting filter cakes were more porous and permeable, considerably increasing throughput. After a screening of possible configurations, a viable option using Top-Paks was found, which accomplished a substantial increase in lautering performance without resorting to raking. Hence, these results might help to rethink the current lauter tun design and ultimately raise the number of brews per day.

Considering that the observed improvements were caused by using a component from another kind of application, future work should aim for a tailored lautering tool to obtain even more favorable results. Once this is achieved, a scale-up of the strategy would directly help breweries to improve their lautering processes.

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