

I. Wasmuht

Insights into a systematic analysis of novel brewhouse worts in comparison to conventional lauter tun worts and its effects on the brewing process

The present paper, as continuation of the review "Relevant process steps influencing wort and beer composition and quality: A review" [1], deals with the results of a systematic analysis of novel brewhouse worts, based on an integrated, dynamic lautering technology, in comparison to conventional lauter tun worts and its effects on the whole brewing process. In order to balance and compare the influence on the wort composition and the impact of certain ingredients, top- and bottom-fermented beers are produced on a 30-liter scale using the conventional and a novel brewing technology. It is shown that the alternative brewhouse technology and the resulting process influence the entire brewing and fermentation process as well as the finished beer. Compared to the conventional brewhouse, the novel brewhouse system exhibits advantageous differences. Nutrient-rich wort is produced for the yeast and high final fermentation degrees are achieved during the fermentation process. The results show, the new brewhouse technology is a suitable alternative to the existing brewhouse technology.

Descriptors: brewing, rotary disk filter, wort composition, beer composition, processing, fermentation

1 Introduction

In the review "Relevant process steps influencing wort and beer composition and quality: A review" [1] the conventional brewhouse process including the traditional lauter tun as state of the art and the rotary disk filter was thoroughly evaluated. The novel lautering system, the rotary disk filter, is still subject of research. Therefore, a systematic comparison of worts and beers was carried out, in order to evaluate the differences between the lautering processes and their impact on the finished beer using identical raw material conditions. The results are taken from the published doctoral thesis [2]. The novel lautering unit produces wort that differs from conventional and traditionally produced wort [3, 4]. The object of the present work is to record the effects of the novel separation technology on the wort composition, on the subsequent processes and on the resulting beer quality. For the systematic investigation of the worts of the novel brewhouse concept in comparison to conventionally produced worts and their effects on the entire brewing process, lager worts are produced, fermented and bottled in a 30-liter scale. The produced wort and the resulting beer are

analyzed for the fractions shown in table 1. Based on the analyzed ingredients, the differences in wort composition are balanced.

The generated findings based on the results of this work show the technological effects and possibilities of a novel brewing process and serve as a basis for plant and process optimization.

2 Materials and Methods

The processes for mash filtration by means of a rotary disk filter and a lauter tun are compared in the beer production process. A schematic overview of the experimental setup for comparing the brewhouses is shown in figure 1. The same raw materials and quantities of raw materials are used to produce 6 brews per brewhouse, from which 3 top-fermented and 3 bottom-fermented beers are produced. A SafAle K-97 dry yeast [5] is used as the

Table 1 Analyzed ingredients in malt, unboiled wort, half time of wort cooling process wort and in unfiltered beer

Fraction	Ingredients to be balanced
Carbohydrates	Fructose, glucose, maltose, maltotriose, sucrose
Nitrogen fractions	Free amino nitrogen, total soluble nitrogen, magnesium precipitable nitrogen
Lipids	free fatty acids C6 - C18:3
Tannins	Polyphenols, anthocyanogens, tannoids
Minerals	Potassium, sodium, magnesium, calcium, copper, iron, zinc, manganese

<https://doi.org/10.23763/BrSc24-04wasmuht>

Authors

Isabel Wasmuht (ORCID ID: 0009-0002-6937-1216), formally Ziemann Holvrieka GmbH (now Gelita AG), corresponding author: wasmuhti@web.de

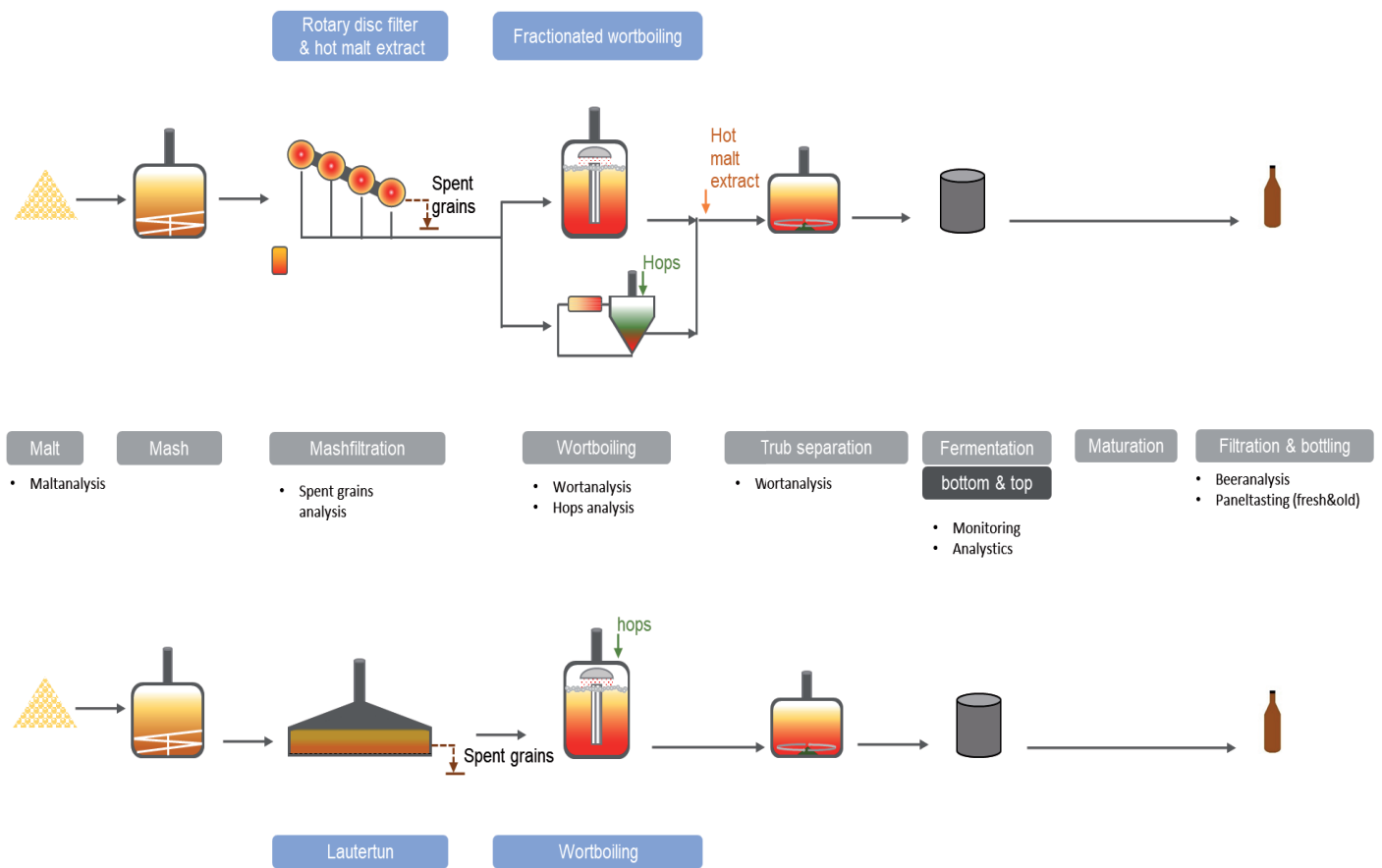


Fig. 1 Experimental setup brewhouse comparison

top-fermenting yeast; a SafLager W-34/70 dry yeast [6] is used as the bottom-fermenting yeast. To prepare the brews, 5 kg of milled malt (Pilsner barley malt) is mashed with 20 l water. For all brews an infusion mashing process is used: 62 °C for 45 minutes, heating, 72 °C for 30 minutes. Lauter tun mashes are mashed-off at 78 °C; rotary disk filter mashes are mashed-off at 72 °C. Three times sparging of 6 liters each are added. The analyses used to determine the resulting worts and beers are recorded in table 2.

Worts and beers are made at the pilot brewery of Geisenheim University. The university brewery corresponds to a conventional brewery in its design and process and has a production volume of 30 liters. It has a water heater (WWB), a cereal cooker (RFK), a mash tun (MPF), a lauter tun (LB), a wort kettle (WPF), a whirlpool (WHP), a

starting vessel (AT), ten fermentation tanks, four pumps, and piping routes. The flow diagram is shown in figure 2 and figure 3 below.

In order to be able to demonstrate the novel brewhouse on a 30-liter scale, the university brewery is expanded to include the necessary components of the novel brewhouse (fractionated wort boiling with external isomerization, rotary disk filter, and addition of a hot malt extract). For this purpose, a rotary disk filter was installed on the scale of the brewery. It consists of three identical modules located next to each other in a plexiglass housing (see Fig. 4, see page 59). Each module has an inlet, two wort outlets, a residue discharge and an outlet for the spent grains. The flow diagram of the plant is shown in figure 5 (see page 60). An electrically operated boiling kettle with a capacity of 30 l was used as a

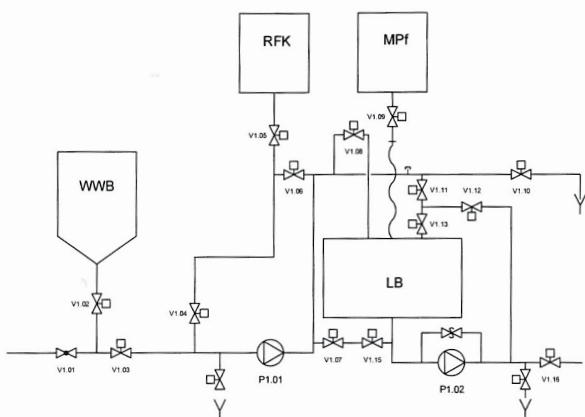


Fig. 2 Schematic diagram of pilot brewery (part 1) [8]

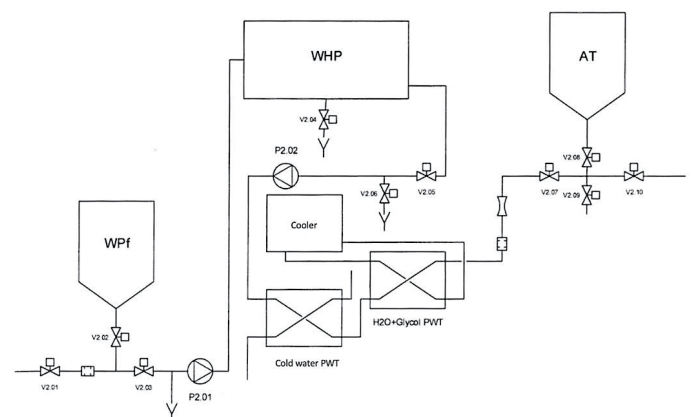


Fig. 3 Schematic diagram of pilot brewery (part 2) [8]

separate wort boiling vessel for hop boiling within the novel brewhouse setup.

3 Results and Discussion

Since the use of a rotary disk filter for solid-liquid separation in the brewing process represents a novel type of mash separation, it is necessary to begin with a theoretical consideration for modeling the separation process. As described in the review the filtration principle is based on dynamic sieve filtration without the build-up of low differential pressure. The rotational movement of the sieves prevents the build-up of a filter cake; only a cover layer similar to cross-flow filtration is formed. The tangential overflow is generated by the rotation of the sieve disks. In contrast to membrane modules, which are used for cross-flow filtration, the wall shear stress in the disk filter depends on the rotation speed and the suspension volume [9]. This makes it possible to generate high wall shear stresses with a low filtration pressure difference and to keep the formation of the covering layer as low as possible. This can be supported by a turbulent flow, which is favored by shearing or flow breakers. Turbulent flow is particularly necessary for high solids concentrations [9]. The speed of the rotating sieve disk determines the tangential overflow velocity, which depends on the solids load of the suspension. In principle, the build-up of a covering layer should be avoided but for the filtration effect of the rotary disk filter, it is necessary to build up a covering layer (= spent grains layer). Without this layer, the mash flows over the transition to the next module without sufficient dehumidification. This behavior can be observed in particular in combination with mashes without husks. Consequently, the build-up of a low covering layer is necessary for sufficient separation of the mash, depending on the distributed particle size. Depending on the suspension, the mash flow rate and the setting of the speed of the filter disks in the rotary disk filter must be adjusted. Extraction, realized by the addition of water, takes place in the transitions to the next modules. In this process, the spent grains are resuspended and mixed again. The dissolved ingredients diffuse into the sparging water. It is a solid/liquid extraction, which runs discontinuously, since the sparging liquor is added in each transition. The separation and remixing with

Table 2 Analysis methods

Analysis	Parameter	Method
pH value	-	MEBAK WBBM 2.13 (MEBAK = Central European Commission for Brewing Analysis; WBBM = Wort, Beer and Beer-based Beverages)
extract	mas.%	WBBM 2.9.6.3
visual iodine value	- (Coloring)	WBBM 1.2.2
photometric iodine value	- (Extinction)	WBBM 2.3
color	EBC	WBBM 2.12.1
turbidity	EBC	WBBM 2.14.1.2
Sugar spectrum	g/l	BLQ LS-HPLC 002_2 2018-07 (BLQ = Research Center Weihenstephan for Brewing and Food Quality)
FAN	mg/100ml	WBBM 2.6.4.1.1
Total soluble nitrogen	mg/100ml	WBBM 2.6.1.1
Fatty acids C6-C18:3	mg/100ml	BLQ DGF,C-VI 11e
Polyphenols	mg/l	WBBM 2.16.1
Anthocyanogens	mg/l	WBBM 2.16.2
Tannoids	mgPVP/100g mgPVP/l	MEBAK II 2.17.3 1987
Minerals	mg/l	WBBM 2.24.12
Bitter units	BE	WBBM 2.17.1
Nitrogen - MgSO ₄ precipitable	mg/100ml	WBBM 2.6.3.1
Spent grains by pressing	mas.%	MEBAK II 1.4.3.1
Spent grains convertible extract	mas.%	WBBM 1.4.4.1
Spent grains soluble extract	mas.%	WBBM 1.4.3.2
Spent grains water content	%	WBBM 1.4.2
Final attenuation	%	WBBM 2.8.1
Foam stability (SFT)	SKZ	WBBM 2.18.2
Activity alpha-amylase	SKB-U/ml	Sandstedt-Kneen-Blish-Methode [7]

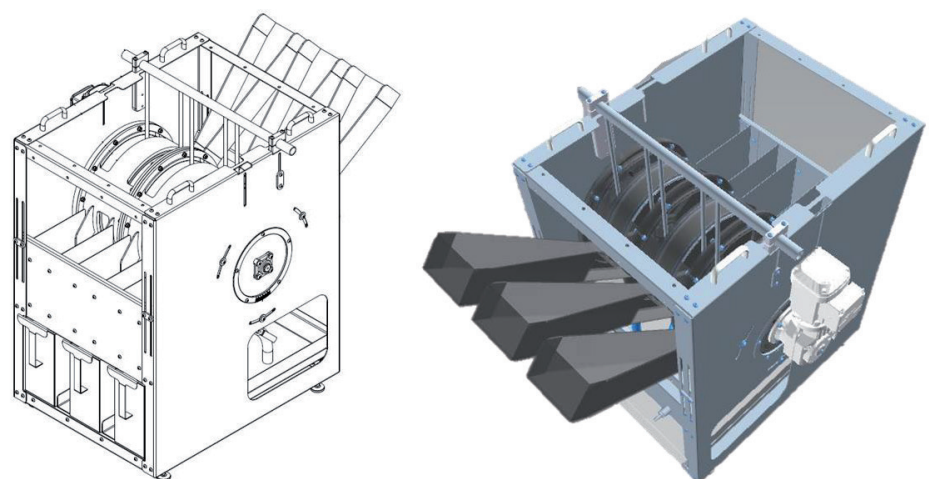


Fig. 4 Schematic diagram of the pilot plant rotary disk filter

water corresponds to the schematically dilution wash (shown in part 1 [1]): it is a 4-stage dehumidification and a 3-stage mixing [10]. The wort fractions running off can therefore be calculated by means of the model of a dilution wash. The following diagram (Fig. 6, see page 60) is based on the rotary disk mash filtrations of the brewhouse comparison.

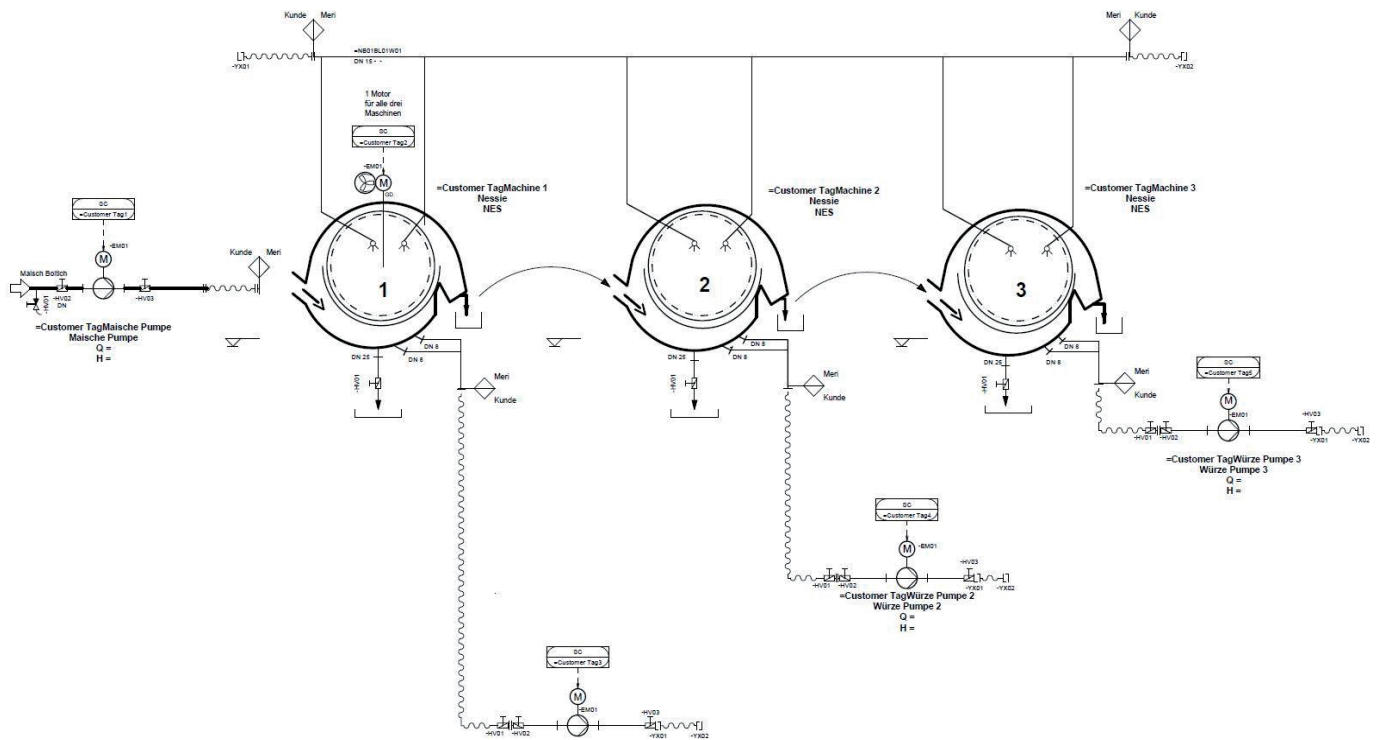


Fig. 5 Flow diagram pilot plant rotary disk filter

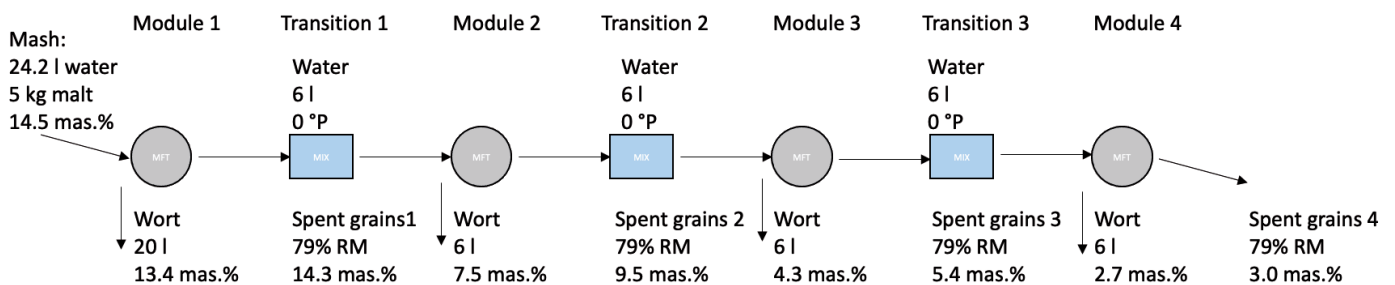


Fig. 6 Schematic diagram of the dilution wash of the rotary disk filter for mash filtration; mixing stages (MIX) and dehumidification stages (MFT), RM = residual moisture

The suspension to be separated is the produced mash, the resulting filtrate is the wort and the dehumidified residue are the spent grains, which are resuspended again with sparging liquor for further washing. 5 kg of milled malt is mixed with 24.2 liters of water, mashed and fed to the first module of the rotary disk filter. The mash volume is 27.95 liters, assuming that 1 kg of malt grist displaces 0.75 liters of mash. Three times sparging with 6 liters of water each are added. It is assumed that the dehumidification in each module is always reduced to 79 % residual spent grains after the collected wort volume corresponds to the added sparging water. To calculate the spent grains volume, it is assumed that 1 kg of spent grains corresponds to a volume of 1.78 liters. Losses are not taken into account.

There is always a difference in extract between the draining wort and the spent grains of the individual stages. In solid/liquid extraction, as it takes place here, there is no phase equilibrium, as the solid in its capillaries contains partly undissolved extract and the solvent remains adsorbed on the solid surface [11]. A so-called quasi-equilibrium is established when the liquid in the capillaries

has the same concentration as the free liquid. The time required to achieve this equilibrium depends on the type, particle size and porosity of the solids, the absorption capacity of the solvent and the temperature [11]. Part of the dissolved extract remains adsorbed on the surface of the solids and can only be reduced by repeated or increasing flow [11]. During mash filtration in the rotary disk filter, the extract of the spent grains-mash mixture dissolved by the extraction taking place in the transition runs off as wort without pressure and without further flow through the sieves. Due to the turbulent mixing of the spent grains-mash mixture in the transition with the sparging liquor, it can be assumed that intensive mixing and thus a quasi-equilibrium is achieved. Nevertheless, partially adsorbed extract remains in the spent grains. The extract in the spent grains is determined by pressing the spent grains and measured in the drained liquid. The extract in the capillaries is dissolved out during the pressing process and enters the draining liquid. Consequently, a difference in extract between the wort and the spent grains can be attributed to this.

In the first step, module 1, the mash is only dehumidified. The wort

flows off unhindered at a concentration of 13.4 mas.%, leaving behind 7 kg of spent grains or 12.46 liters with an extract (spent grains pressings) of 14.3 mas.%. The spent grains are mixed with 6 liters of water. As this is a dilution wash, the theoretically measurable concentration of the wort running off in the next module (module 2) must be calculated according to the dilution wash described in part 1 [1]. The wort concentrations of the subsequent modules are calculated equivalently. The formulas are further developed with the collected data and are shown below.

Calculation of the saturation of the steps:

$$S = \frac{v_1}{v_\alpha} = \frac{\text{Volume after dehumification}}{\text{Volume before dehumification}} = \frac{12,46 \text{ L spent grains}}{(12,46 \text{ L spent grains} + 6 \text{ L water})} \approx 0.67$$

(Eq. 1 Calculation of the saturation of the steps; S = saturation, v = volume)

Calculation of the wash ratio of the stages:

$$W = S \frac{m_{1WF}}{m_{1RF}} = S \frac{\text{Mass water}}{\text{Mass spent grains}} = 0.67 \frac{6 \text{ kg}}{7 \text{ kg}} \approx 0.58$$

(Eq. 2 Calculation of the wash ratio of the stages; S = saturation, m = mass, WF = washing liquid, RM = residual moisture)

Calculation of the concentration of the drained wort of module 2:

$$C_{\text{Module 2}} = C_{\text{spent grains1}} \frac{1}{1+\frac{W}{S}} = 14.3 \text{ mas. \%} \frac{1}{1+\frac{0.58}{0.67}} = 7.70 \text{ mas. \%}$$

(Eq. 3 Calculation of the concentration of the drained wort of module 2; c = concentration, W = washing ratio, S = saturation)

Calculation of the concentration of the drained wort of module 3:

$$C_{\text{Module 3}} = C_{\text{spent grains2}} \frac{1}{1+\frac{W}{S}} = 9.5 \text{ mas. \%} \frac{1}{1+\frac{0.58}{0.67}} = 5.12 \text{ mas. \%}$$

(Eq. 4 Calculation of the concentration of the drained wort of module 3; c = concentration, W = washing ratio, S = saturation)

Calculation of the concentration of the drained wort of module 4:

$$C_{\text{Module 4}} = C_{\text{spent grains3}} \frac{1}{1+\frac{W}{S}} = 5.4 \text{ mas. \%} \frac{1}{1+\frac{0.58}{0.67}} = 2.91 \text{ mas. \%}$$

(Eq. 5 Calculation of the concentration of the drained wort of module 4; c = concentration, W = washing ratio, S = saturation)

The theoretically calculated values are within the range of the actual measurable values. The wort from module 2 measures 7.5 mas.%; the calculated value is 7.70 mas.%. The wort from module 3 has a measurable extract of 4.3 mas.%; according to the theoretical analysis it is 5.12 mas.%. The drained wort from Modul measures an extract of 2.7 mas.%; the calculation results in 2.91 mas.%. Since these are average values, fluctuations around the measurable value cannot be ruled out. The confidence intervals of the measured wort concentrations at module 2 and 3 are 0.3 – 0.4. Taking this fluctuation into account, the theoretical calculation of the dilution wash is correct and can be used to calculate the wort fractions of the rotating disk filter.

The results of the novel separation process compared to the lauter tun is to be seen in the spent grain analysis, shown in table 3.

At 2.98 % extract and a pH value of 6.76, the pressings of the spent grains from the rotary disk filter tends to show higher values than the pressings of the spent grains from the lauter tun. The increased extract in the spent grain pressings can also be found in the soluble

Table 3 Spent grain analysis; n = 6

Spent grain analysis	Unit	Lauter tun	Rotary disk filter
Water content	%	82.1	79.3
Extract	mas.%	2.43	2.98
pH value	-	6.62	6.76
Convertible extract	mas.%	0.67	0.54
Soluble extract	mas.%	1.65	2.72

extract of the rotary disk filter spent grains. Although the mixing in the transitions of the rotating disk filter is more intensive than the flow of spent grains in the lauter tun and the free wort runs unhindered through the filter disks, the free extract remains in the spent grains.

The convertible extract of the novel brewhouse averages 0.54 mas.%, that of the conventional brewhouse 0.67 mas.%. Generally, the convertible extract depends largely on the malt, the milling and the mashing process. The tests carried out involved the same malt, the same grist and the same mashing process, but with different mashing temperatures. For mash filtration using the lauter tun, mashing is carried out at 78 °C. The mash is not subject to any further stirring in the lauter tun. For mash filtration using the rotary disk filter, mashing is continuous. The mash is continuously fed to the rotary disk filter and stirred at 72 °C for the duration of mash filtration until separation is complete. It has to be assumed that the enlarged mashing time reduces the convertible extract and increases the soluble extract. As a result, low convertible extract values are achieved in the spent grains during mash separation using the rotating disk filter. However, the released extract cannot be washed out and remains in the spent grains as increased soluble extract. It has to be assumed that the contact time of the spent grains with the spent grains is too short in the transition to wash out the extract. To reduce the loss of extract in the spent grains, the contact time must be extended. On average, the rotary disk filter spent grains contain 3.4 % less water in comparison. The rotational movement of the filter disks prevents the sieves from blocking, just allowing building up a small layer of spent grains so that the wort flows through the filter disks. The wort is not retained in the spent grains. As a result, the spent grains are dewatered slightly more in the rotating disk filter than in the lauter tun.

In table 4, the analyzed ingredients of the brews are compared (sugars, proteins, fatty acids, minerals and tannins) and are shown in comparison of the two brewhouses.

Rotary disk filter worts exhibit increased turbidity compared to conventional worts. The wort turbidity makes the determination of fatty acids more difficult. The measured values nevertheless confirm the tendency that the fatty acid concentrations in the wort correlate positively with the wort turbidity [12, 13, 14].

Although the higher wort turbidity of the novel produced wort with the accompanying increased concentrations of wort components leads on the one hand to improved nutrient supply to the yeast during fermentation, on the other hand trub separation is shifted to the cold area and green beer transfer is made more difficult. The extent to which wort turbidity can be lowered without affect-

Table 4 Comparison of wort and beer composition from the novel brewhouse (NE) in relation to the conventional brewhouse (CONV) of unboiled wort, half time of wort cooling process wort and in unfiltered beer; wort n = 6, beer n = 3, calculated to 12°P

Parameter	Unit	Unboiled wort		Half time wort cooling		Beer bottom fermented		Beer top fermented	
		CONV	NE	CONV	NE	CONV	NE	CONV	NE
pH-value	-	5.81	5.79	5.71	5.81	4.45	4.39	4.36	4.38
Iodine value	-	0.50	0.57	0.40	1.43	0.44	0.08	0.13	0.11
Color	EBC	12.4	9.3	16.1	13.0	7.3	6.0	7.2	6.6
Turbidity	EBC	54	126	40	60	5	3	5	6
Real attenuation	%	-	-	66	70	-	-	-	-
Final attenuation	%	-	-	81	86	81	85	77	84
Bitter units	EBC	-	-	30	20	18	15	14	12
Foam stability	SKZ	-	-	-	-	115	112	102	92
Sugar									
Fructose	g/l	0.79	0.69	0.85	0.88	0.09	0.11	0.09	0.10
Glucose	g/l	6.93	6.17	6.88	6.62	0.09	0.11	0.09	0.10
Sucrose	g/l	4.49	4.07	4.40	4.24	0.09	0.11	0.09	0.10
Maltose	g/l	57.53	52.85	56.76	53.08	1.89	1.02	2.03	0.83
Maltotriose	g/l	14.40	12.95	13.18	13.81	0.70	0.71	5.48	3.54
Protein									
FAN	mg/100 ml	17.5	17.3	17.1	16.3	6.9	3.6	4.9	3.8
total soluble N	mg/100 ml	104.5	101.2	98.5	96.0	69.0	60.8	63.4	56.7
MgSO4 precipitable N	mg/100 ml	25.2	24.0	22.4	22.9	18.8	20.9	13.7	14.6
Fatty acids									
Caproic acid	mg/100 ml	0.00	0.02	0.03	0.01	0.00	0.00	0.00	0.00
Caprylic acid	mg/100 ml	0.01	0.14	0.02	0.00	0.01	0.01	0.19	0.20
Capric acid	mg/100 ml	0.01	0.00	0.03	0.08	0.01	0.00	0.00	0.00
Lauric acid	mg/100 ml	0.00	0.27	0.00	0.00	0.01	0.01	0.01	0.00
Myristic acid	mg/100 ml	0.05	0.12	0.07	0.08	0.00	0.00	0.01	0.00
Palmitic acid	mg/100 ml	1.09	5.37	1.29	2.11	0.05	0.02	0.02	0.05
Stearic acid	mg/100 ml	0.10	0.34	0.14	0.19	0.05	0.02	0.03	0.02
Oleic acid	mg/100 ml	0.21	0.53	0.73	1.01	0.03	0.01	0.02	0.01
Linoleic acid	mg/100 ml	0.86	3.94	1.84	1.53	0.04	0.02	0.02	0.04
Linolenic acid	mg/100 ml	0.08	0.41	0.25	0.64	0.00	0.00	0.00	0.00
Total	mg/100 ml	2.41	11.13	4.38	5.58	0.20	0.09	0.29	0.33
Tannins									
Polyphenols	mg/l	165	84	196	157	163	152	164	145
Anthocyanogens	mg/l	75.4	33.6	71.3	69.8	59.5	33.6	60.7	48.9
Tannoids	mgPVP/l	98	25.1	85	56	34	21	36	20
Minerals									
Calcium	mg/l	44.2	55.6	43.8	51.9	42.5	57.4	37.2	54.8
Magnesium	mg/l	100.2	100.4	99.3	98.5	102.1	106.3	94.3	97.6
Potassium	mg/l	546	540	577	547	510	456	497	446
Sodium	mg/l	41.4	38.1	43.7	52.2	31.7	35.3	39.6	40.4
Iron	mg/l	0.05	0.07	0.03	0.07	0.02	0.02	0.02	0.05
Zinc	mg/l	0.15	0.40	0.12	0.21	0.01	0.01	0.01	0.01
Manganese	mg/l	0.15	0.26	0.14	0.17	0.14	0.22	0.13	0.23
Copper	mg/l	0.26	0.30	0.11	0.07	0.08	0.07	0.09	0.08
Aluminum	mg/l	0.05	0.05	0.04	0.05	0.04	0.05	0.04	0.05

ing the concentration of value-giving ingredients for the yeast was investigated. For this purpose, rotary disk filter worts were produced on a 10 hl scale and selectively centrifuged to investigate the effects on wort constituents. It is advantageous to centrifuge the wort of the wort kettle in the novel brewhouse during boiling. The process time to produce a brew is not affected. The important wort ingredients for the yeast are retained and are available to the yeast during fermentation. Separation of particles from the wort without affecting the wort quality is possible. Consequently, the use of the centrifuge is a suitable method for separating the wort particles as well as the hot trub.

The unboiled wort, the cast out wort and the half time of cooling worts of the novel brewhouse have higher photometric iodine values than the worts of the conventional brewhouse. To lower the photometric iodine value after boiling in novel brewhouse worts, a hot malt extract is dosed to the wort after boiling. To measure the enzyme activity of alpha-amylase, the measurement of SKB - U/ml is used. This indicates the enzyme concentration which is capable of starch degradation [15]. Here, the hot malt extract was shown to have an enzyme activity of 2 SKB-U/ml. Compared to a technical enzyme of 10,000 SKB-U/ml, this is significantly lower. There is not sufficient enzymatic activity of the hot malt extract for post-saccharification compared with technical enzymes. The experiments also show that a lowering of the photometric iodine value in the novel brewhouse occurs with and without the addition of the hot malt extract. A reduction in the photometric iodine value can also be measured in the conventional brewhouse. Zarnkow [16] showed the likewise decreasing course of the photometric iodine value in a conventional brewhouse. In addition, it was found that iodine values measured photometrically in breweries often tend to be higher than 0.5 ΔE [17]. Consequently, high photometric iodine values are to be considered normal. For a precise investigation of the starch molecules present and a possible conversion, an exact differentiation is required; the summary consideration via the photometric iodine value is insufficient. In addition, the photometric iodine value is related to the turbidity as well as the tendency to turbidity in the beer. It can be assumed that in the case of an iodine-normal mash or wort, the measured iodine value as a sum parameter generally records sugar and starch molecules, which are irrelevant for the brewing process since these molecules are obviously naturally degraded via the process. A more specific analytical method is required for a more detailed investigation of these molecules and to predict the effects on the brewing process.

The sugar spectra of the novel and conventionally produced worts are similar. The sugar spectra of the two wort types change only slightly during boiling. An examination of the sugar spectrum after fermentation shows that the simple sugars and sucrose of the two wort types have been consumed by the yeast to the same extent. Differences are found in the maltose and maltotriose. The beer from the conventional brewhouse has higher concentrations of maltose and maltotriose compared to the beer produced in the new way. In contrast, during fermentation of the wort of the novel brewhouse, most of the sugars, including the disaccharide maltose and the trisaccharide maltotriose, were metabolized by the yeast. The higher uptake of sugars compared to the fermentation of the conventional wort is also reflected in the final fermentation degree of the beers of the novel brewhouse. During fermentation of the

novel wort, the propagation rate of the yeast is increased. During increased propagation, the nutrient requirement of the yeast is also increased. Thus, for energy production, the yeast breaks down not only the simple sugars and maltose, but also maltotriose, which is energy-consuming due to mass transfer. In addition, the wort turbidity must also be taken into account at this point. The increased turbidity and the associated increased solids content in the wort keep the yeast cells in suspension by attaching to the wort particles [13]. This increases the availability of the sugars present for the yeast. The yeast is able to absorb more sugar in the newly produced wort. Consequently, the total sugar content in the newly produced beer is lower and the final degree of fermentation is higher.

The analyses carried out to determine the protein fractions present show that the worts do not differ in the content of free amino nitrogen, total soluble nitrogen and magnesium precipitable nitrogen. The free amino nitrogen of the novel and the conventionally produced worts is within the applicable guideline values for a sufficient supply of the yeast during fermentation [18]. Although there is sufficient free amino nitrogen and soluble nitrogen in the half time of cooling worts of both brewhouse systems to supply the yeast during fermentation, the yeast in the conventionally produced wort is apparently undersupplied. Increased amounts of the nitrogen fractions remain in the conventionally produced beer. In the novel produced wort, it is possible for the yeast to absorb the nitrogen fractions present.

In worts and beers of the novel brewhouse, a significantly lower tannin spectrum is present than in comparison with the conventional brewhouse. The low concentration of tannins is due to the speed of mash separation. The longer the separation takes and the resulting thermal stress, the more tannins are released and pass into the wort. As separation using the rotary disk filter takes 30 minutes less time compared to the lauter tun, this also explains the low tannin concentration. Compared to a total polyphenol concentration with increasing PVPP administration as described by *Schlenker* et al. [19], the tannin spectrum of the beers of the novel brewhouse is similar to that of a PVPP-stabilized beer. As a result, the beers of the novel brewhouse, since these are omitted as reaction partners for the protein-phenol compounds, exhibit an extended chemical-physical shelf life. The extended shelf life can be put at 38 % compared with the conventional brewhouse. The tannin spectrum of the newly produced beers corresponds to an already stabilized tannin spectrum after a 20 g/hl PVPP dosage. Consequently, further stabilization of the tannin side by means of PVPP is not necessary.

The wort and the beers of the novel brewhouse show a lighter color than those of the conventional brewhouse. This color difference is due to the low tannin spectrum of the rotary filter wort.

Worts of the novel and conventional brewhouse have different mineral spectra. The novel wort differs in calcium, potassium, sodium, iron, zinc, manganese and copper content. Magnesium and aluminum contents did not differ in the coolant wort. Since there are clear differences in zinc and potassium uptake, these minerals and their influence on yeast metabolism should be considered in more detail. The trace element zinc is essential for yeast metabolism. It is involved as a cofactor of many enzymes and catalytic

reactions as well as in several biological functions of the yeast cell [20, 21]. For example, zinc is important for the function of alcohol dehydrogenase and promotes the absorption of carbohydrates [22, 23]. In addition, zinc promotes the multiplication rate of yeast [24]. The zinc present in most worts is a deficiency for the yeast [25]. Recommended is at least 0.10–0.15 mg/l zinc in pitching wort [18]. The dissolution of zinc in the beer-making process depends on several factors: the malt, the mashing process, the pour, the brewing water, mash filtration and hot trub removal [26, 25, 13]. Potassium is absorbed in the mineral metabolism of yeast. Potassium is important for cell growth, enzyme activity, protein synthesis, the balancing of charges in the yeast cell as well as the maintenance of the permeability of the membrane and the intracellular pH value. Yeasts maintain a low sodium/potassium ratio by efficient and selective uptake of potassium and a release of excess sodium. Active transport is necessary for this [27]. In addition, there is a close correlation of potassium intake and carbohydrate metabolism [28]. The more sugar is absorbed during fermentation, the more potassium is absorbed. However, as fermentation time increases, potassium is also excreted again. It is also reported that under optimal physiological conditions for the yeast, for example at high temperatures, potassium uptake increases [29]. In addition to the high zinc and potassium degradation, it is striking that, compared to the conventional brewhouse, the newly produced wort allows a high uptake of maltose and maltotriose, a higher degradation of free amino nitrogen and total soluble nitrogen. Consequently, the yeast in the fermentation exhibits increased cell proliferation and the beer a higher final degree of fermentation. With increased yeast growth, further carbohydrate uptake is also required for energy generation. Consequently, the yeast requires more sugar. However, since the simple sugars are consumed first during fermentation, the sugars that require active mass transfer must now be taken up. Zinc and potassium support glycolysis and active mass transport. As a consequence of the activity, the degradation of minerals is evident. Newly produced seasonings therefore provide, in addition to the long-chain fatty acids required for yeast growth, a mineral composition that enables higher fermentation. Since very vital yeasts are required for high fermentation and potassium is also related to intracellular pH, measurement of ICP of yeast cells should be investigated for further research.

Fermentation proceeded well with all the worts produced. It can be noted that the worts of the novel brewhouse always achieve two days faster fermentation compared to the conventionally produced wort. In addition, a high degree of final fermentation is achieved in the novel worts. In the fermentation of the novel worts, a high

proliferation of yeast cells and, consequently, an increased amount of yeast sediment after fermentation is observed. It can be seen that due to the wort turbidity and the accompanying increased concentration of fatty acids, zinc and potassium, newly produced worts allow a higher fermentation intensity than conventionally produced worts. This can be seen in the breakdown of sugars, nitrogen sources, fatty acids, and zinc and potassium. This speaks for an improved supply of yeast during fermentation by the newly produced wort.

Overall, the method of production using the novel brewhouse permits beers that are durable in terms of taste and physic-chemical properties and also exhibit a good taste impression over a long period of time. Generally, it has to be noted that the beers produced by both brewhouses have similar taste impressions.

The described turbidity of the beer influences the foam stability of the beer. This is particularly noticeable in the top-fermented beer. The conventional top-fermented beer exhibits slightly higher foam stability than the beer produced by the new method. The bottom-fermented beers exhibit good foam stability. There is no significant difference between the foam stabilities of the bottom-fermented beers.

It can be clearly seen that the wort and beers from the different brewhouses differ with the same quantities of water, malt and hops

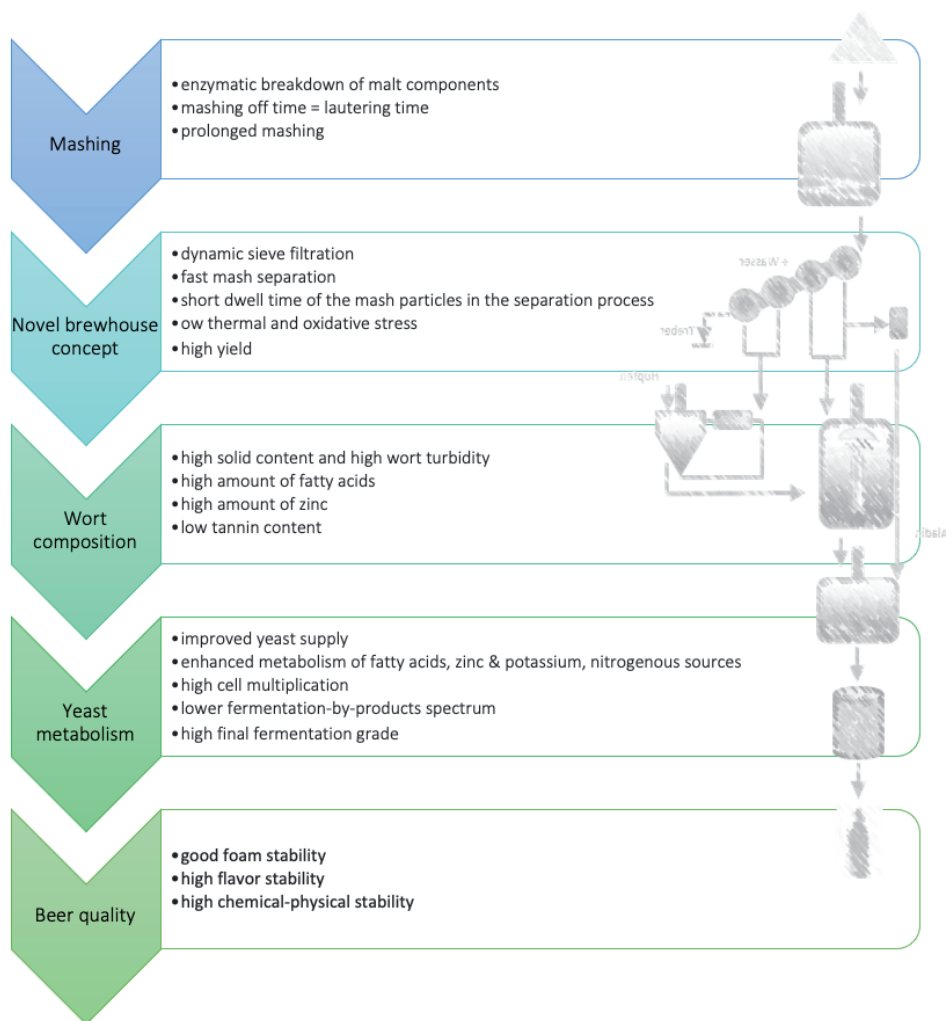


Fig. 7 Effects of the novel brewhouse concept on the beer production process

as well as the same yeast type and yeast addition. The differences are mainly based on the separation technique and the resulting effects on the entire brewing process and yeast metabolism. The interrelated effects of separation technology on the beer production process are summarized in simplified form in figure 7.

4 Conclusion / Summary

In this work, a novel 30-liter scale brewhouse was used to work out differences in wort composition from the conventional brewhouse and to investigate the effects on the beer brewing process. It was shown that the alternative brewhouse technology and resulting process has an impact on the overall brewing and fermentation process as well as the finished beer. Compared to existing conventional brewhouses, the novel brewhouse system exhibits advantageous differences. The new brewhouse technology enables high raw material utilization and the processing of borderline raw material qualities. Nutrient-rich wort is produced for the yeast and high final fermentation levels are achieved during the rapid fermentation process. The beers produced exhibit naturally high chemical-physical stability and flavor stability. The new brewhouse technology represents a suitable alternative to existing brewhouse technology. Especially the flexibility in terms of alternative raw materials which are husk-free or not DIN-conform (Brewhouse plants – Minimum specifications) be further investigated in order to benefit from this technology. Additionally, this work also shows potential approaches to improve lauter tun brewhouses.

5 References

- Wasmuht, I.: Relevant process steps influencing wort and beer composition and its quality: A review, *BrewingScience*, **76** (2023), no. 9/10 pp. 113-129, .
- Wasmuht, I.: Systematische Untersuchung von Würzen des „OMNIUM“-Sudhauskonzepts im Vergleich zu konventionellen Läuterbottichwürzen und deren Auswirkungen auf den gesamten Brauprozess, Hochschule Geisenheim University, 2022.
- Schwill-Miedaner, A. and Miedaner, H.: Neues Verfahren der Maischefiltration (Teil 3), *BRAUWELT*, **157** (2017), no. 18-19, pp. 545-548.
- Schwill-Miedaner, A.; Miedaner, H.; Englmann, J.; Preis, F.; Bilge, D.; Pahl, R.; Ruß, W.; Krottenthaler, M.; Bastgen, N.; Becher, T.; Benninghaus, T.; Ziller, K.; Wasmuht, K. and Gehrig, K.: Neues Verfahren der Maischefiltration (Teil 5), *BRAUWELT*, **157** (2017), no. 34, pp. 974-977.
- Fermentis: fermentis fermentation solutions, <https://fermentis.com/en/fermentation-solutions/you-create-beer/safale-k-97/>, [Accessed 22 Januar 2020].
- Fermentis: fermentis fermentation solutions, <https://fermentis.com/en/fermentation-solutions/you-create-beer/saflager-w-3470/>, [Accessed 22 Januar 2020].
- Sandstedt, R.; Kneen, E. and Blish, M.: A standardized wohlgemuth procedure for alpha-amylase activity, *Cereal Chemistry*, **16** (1939), pp. 712-723.
- Schmidt, S.: Untersuchungen zur Validierung einer Hochschulbrauerei, Wiebaden: Hochschule Geisenheim University, 2013.
- Goldnik, D. and Ripperger, S.: Waschen von Suspensionen mittels dynamischer Scheibenfilter, *F&S Filtrieren und Separieren*, **28** (2014), no. 2, pp. 66-75.
- Wilkens, M. and Peuker, U. A.: Grundlagen und aktuelle Entwicklungen der Filterkuchenwaschung, *Chemie Ingenieur Technik*, **84** (2012), no. 11, pp. 1-13.
- Schönbucher, A.: *Thermische Verfahrenstechnik*, Springer-Verlag, 2002.
- Narziss, L.: *Abriss der Bierbrauerei*, Ferdinand Enke Verlag Stuttgart, 1995.
- Kühbeck, F.: *Analytische Erfassung sowie technologische und technische Beeinflussung der Läutertrübung und des Heißtrubgehalts der Würze und deren Auswirkungen auf Gärung und Bierqualität*, TUM, 2007.
- Engstle, J.; Briesen, H. and Först, P.: Mash Separation in the Lauter Tun – a Particle Size Dependent Separation Process, *BrewingScience*, **70** (2017), no. 1/2, pp. 26-30.
- Briggs, D.: A Modification of the Sandstedt, Kneen and Blish Assay of α -Amylase, *Journal of the Institute of Brewing*, **67** (1961), no. 5, pp. 427-431.
- Zarnkow, M.: Einfluss der Lagertemperatur und -zeit auf Würzproben, *BRAUWELT*, **159** (2019), no. 27, p. 775.
- Pahl, R.: *Aktuelle technologische Fragestellungen*, VLB Frühjahrstagung, 2015.
- Back, W.: *Ausgewählte Kapitel der Brauereitechnologie*, Fachverlag Hans Carl GmbH, 2008.
- Schlenker, R.; Thoma, S. and Oechsle, D.: Beer stabilisation with recycled PVPP – state-of-the-art, *BRAUWELT International*, **18** (2000), pp. 212-217.
- Parkin, G.: The bioinorganic chemistry of zinc: synthetic analogues of zinc enzymes that feature tripodal ligands, *Chemical Communications*, **20** (2000), no. 20, pp. 1971-1985.
- Vallee, B. and Auld, D.: Zinc coordination, function, and structure of zinc enzymes and other proteins, *Biochemistry*, **29** (1990), no. 24, pp. 5647-5659.
- Taidi, B.; Hoogenberg, B.; Kennedy, A.I. and Hodgson, J.: Pre-Treatment of Pitching Yeast with Zinc, *Technical Quarterly Master Brewers Association of the Americas*, **37** (2000), no. 4, pp. 431-434.
- Rees, E. and Stewart, G.: Strain Specific Response of Brewer's Yeast Strains to Zinc Concentrations in Conventional and High Gravity Worts, *Journal of the Institute of Brewing*, **104** (1998), no. 4, pp. 221-228.
- Bromberg, S. K.; Bower, A.; Duncombe, G. R.; Fehring, J.; Gerber, L.; Lau V. K. and Tata, M.: Requirements for Zinc, Manganese, Calcium, and Magnesium on Wort, *Journal of the American Society of Brewing Chemists*, **55** (2018), no. (3), pp. 123-128.
- Donhauser, S.; Schauburger, W. and Geiger, E.: Verhalten von Zink während der Würzbereitung, *BRAUWELT*, **123** (1983), no. 14, pp. 516-522.
- Donhauser, S. and Wagner, D.: Möglichkeiten der Beeinflussung des Zinkgehaltes der Würze, *Monatsschrift für Brauwissenschaft*, **39** (1986), no. 6, pp. 223-230.
- Yenush, L.: Potassium and Sodium Transport in Yeast, *Advances in Experimental Medicine and Biology*, **892** (2016), pp. 187-228.
- Pulver, R. and Verzar, F.: Der Zusammenhang von kalium- und Kohlehydratstoffwechsel bei der Hefe, *Helvetica*, **23** (1940), no. 1, pp. 1087-1100.
- Riemay, K. H.: Einfluss von Temperaturänderungen auf die Kaliumaufnahme von *Saccharomyces cerevisiae*, *Zeitschrift für Allgemeine Mikrobiologie*, **10** (1970), no. 1, pp. 63-75.

Received 30 April 2024, accepted 31 May 2024