Feilner, R. and Oehmichen, T.

Flash Pasteurisation of Filtrated- and Wheat Beer with one Heat Holding Tube

A process comparison with shortened heat-holding

Flash pasteurisation of beer is an important instrument for reliable extension of shelf life. In conjunction with a suitable hygienic filler, flash pasteurisation constitutes a product-friendly alternative to tunnel or chamber pasteurisers. The haze- and taste-stabilising effect of a flash pasteuriser, on wheat beer, for example, is also gaining steadily in perceived importance. Established figures for pasteurisation units (PUs) specify the dimensions of the heat-holding sections (30 seconds) and the heat-holding temperatures (64–72 °C). The question here arises of whether these traditional parameters – using the analytical and technological options now available – actually constitute the optimum. The following article shows results of a comparison 30 seconds heat holding tube and a shorter one with 6 seconds. Within the context the influence to heat-, oxygen- and aging indicators will be discussed which allows a detailed comparison between the processes and the beer quality.

Descriptors: flash pasteurizer, colloidal stability, haze stability, flavour stability, beer quality, heat-holding time

1 Introduction

The flash pasteuriser focuses essentially on killing off beverage-specific micro-organisms. In the case of hazy beers, it is also tasked with stabilising the haze by means of selective protein denaturation, which for filtered beers has to be prevented. In all cases, it is essential to minimise the influence of pasteurization on organoleptics and ageing stability.

Thus, in almost 100 % of cases involving wheat beer stabilisation, the beer is being over-pasteurised, since the 30-second heat-holding time customary in the sector for shelf-life extension in conjunction with a minimum temperature of 78–80 °C required for denaturation are significantly excessive.

This paper describes a heat-holding process that enables haze-stabilised, microbiologically stable wheat beers and at the same time also filtered beers to be produced in better quality using a system with reduced exposure to heat.

Indices

PU	Pasteurisation units	–
t	Time	min
T	Actual temperature	°C
T_{ref}	Reference temperature	°C
z	z-value	°C
D	D-value	min
T_0	Start temperature	°C
v	Speed	m/s
s	Distance	m
$\dot{V}$	Volume	m³/s
A	Area	m²

Authors

Dr. Roland Feilner, Dr. Thomas Oehmichen, Krones AG, Neutraubling, Germany; corresponding author: roland.feilner@krones.com

The crucial constituent of this process is a dramatic shortening of the heat-holding section and a concomitant increase in the pasteurisation temperature. It is crucial, particularly for the filtered beers, to fix a maximum temperature that, in contrast to a desired haze in the unfiltered beers, does not cause any change in the clear-filtered beers.

As is already becoming evident, it does not suffice to limit the planning of the flash pasteurisers to just a single goal. Different requirements and highly disparate beer types, plus variable outputs, are to be produced, if at all possible, using only a single system with unaltered hardware.

The PU value has become established in the beverage industry as the control parameter for guaranteeing microbiological safety, and constitutes a measure for the accumulated lethal values.

Using a control system known as "sliding PU control", the "temperature *T*" variable can be employed to implement a variable volume flow requiring limitation with a constant heat-holding section. In other words, if the amount of product being requested by a machine downstream of the flash pasteuriser falls, the buffer volume can be increased by reducing the volume flow in the flash pasteuriser by up to 50 %. Given a constant heat-holding section, in accordance with equations 4 and 5, the temperature must be reduced in order to maintain constant PU values and to avoid excessive thermal stress on the product.

PU calculation is based on D-values (*decimal reduction value, defined by the time required to reduce the number of micro-organisms to a tenth – log = 1*) and z-values (*the temperature required to* *reduce the D-value to a tenth – log = 10*) that are specific to the micro-organisms and media involved.

Equation 1 shows one of the possibilities to calculate the PU's. This formula is mostly used in practical.

$$PU_{beer} = t \times 1.393^{T-60\,°C} \qquad \textbf{Eq. 1}$$

$$t = \frac{s*A}{\dot{V}} \qquad \textbf{Eq. 2}$$

It must be noted in this context that the z-value when calculating PUs is regarded as constant (z = 7 min) – which because of the dependence on external factors (including alcohol content and surrounding medium) does not correspond to reality and may lead to substantial divergences (Table 1).

Table 1 Comparison of mathematical PU values with variable z-values (T_{ref} = 60°C)

z-value [min]	PE [–] using equation 3	PE [–] using equation 1
5	125.6	26.7
6	50	26.7
7	25.9	26.7
8	15.8	26.7
9	10.8	26.7

The precise differential calculation of the PU values while factoring in the z-values is described by Equation 3 [8].

$$PE = \int_{t_0}^{t_1} 10^{\frac{T-T_{ref}}{z}}\, dt \qquad \textbf{Eq. 3}$$

1.1 Challenges when using a sliding PU control: log rates v. pasteurisation units

From the temperature-and time-dependent physical laws involved, it swiftly becomes clear that limits have to be imposed on a sliding PU control system.

In purely mathematical terms, sufficiently high PU values can be achieved using Equation 1 with any desired extension of the heat-holding time. Ergo, the volume flow is reduced while maintaining a constant length of the heat-holding, and the dwell time is extended, which then is adjusted for constant PU values with a lower temperature.

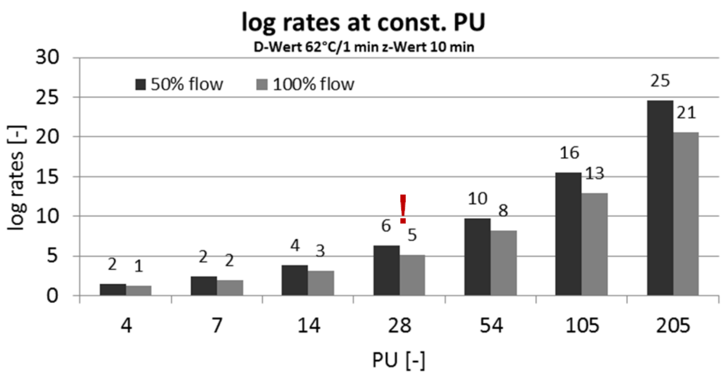

Fig. 1 Temperature and reduction differences with sliding PU control featuring 30 sec. heat-holding at z =10 min

If this temperature now falls below the lethal temperature for a critical germ, the killing rate will be inadequate. It is also interesting to note that, primarily due to z-values set as constant in calculating the PUs, at constant PUs the log rates will differ as the output is adjusted. If we take log 6, as established in practice, as the target value for dimensioning the equipment [1], it is apparent that with a constant PU of 28 (full/half output), these values are not reached at full output! The further the z-value here lies above the reference variable for PU calculation of 7 °C, the greater the differences also become.

1.2 Fluid dynamics and thermodynamics

Uniform flow conditions at the heat-holding section in terms of velocity distribution, and thus a maximum uniform thermal dwell time distribution and thermal stress, are conditional upon fully turbulent flows (plug profile). Due to the direct proportionality to the velocity, the Reynolds number is halved when the output is halved within the framework of a sliding PU control.

In the case of low-viscosity media like beer, of course, a fully turbulent flow is still extant – the more highly viscous the product (already as from 3–5 mPas) and the more generously dimensioned in diameter the heat-holding sections is, however, the more this influence also gains increasingly in importance.

It is a far more serious consideration, however, that in the case of wheat beers in particular, cell aggregates, cell clumps and envelopes around these agglomerations cause a delay before the lethal core temperature is reached. Besides the killing kinetics of an individual germ, a time-delaying heat transport has to be added to this D-value. The velocity of heat transport depends, according to the familiar laws of thermodynamics, primarily on the temperature difference, the diameters of the cell agglomerations, and the thermal resistances through the cell membranes.

If now a sliding temperature control reduces the temperature, the heat transfer output and the reduction rates will decrease further.

In the case of wheat beer, this challenge involves furthermore the task of haze stabilisation. This, too, requires a corresponding amount of activation energy to enable the protein structure to be unfolded and the desired coarsening of the particles to be achieved. In trials with different PUs – set to a constant temperature (80 °C) and variable time – no significant change was observed in the particle size distribution [6]. Different PUs – set with rising temperatures at a constant time – showed a significant coarsening of the particles [5, 6].

If a sliding PU control is now deployed, the falling temperature will (through the output adjustment) result in a different or even inadequate or non-existent haze intensification. PU-based control with a cut-off temperature of 60 °C is thus totally unsuitable for controlling a wheat beer stabilisation process.

Schwarz [15] describes a direct causal connection between turbulence (due to pumps, shear forces, etc.) and the success of haze stabilisation. This additional benefit is accordingly possible only with a flash pasteuriser and not with a tunnel pasteuriser, whose utility is limited to the microbiology.

If now, as is in most cases is the customary practice, filtered beer with a focus on microbiology and at the same time wheat beers with an additional focus on haze stabilisation and inactivation of foam-inhibiting and ageing-conducive enzymes are to be produced using one heat-holding section of the flash pasteuriser (30 seconds), the thermal stress on the wheat beers is higher than it ought to be.

In practice, a value of at least 80 °C has established itself as necessary to achieve reliable haze. Given constant heat-holding, this results in PU values that are higher many times over than would be required by microbiology and enzyme activation (Table 2 – 220 PE [9]).

To prevent the temperature from falling below 80 °C, in this case the sliding PU control is often dispended with, but not the output adjustment feature (buffer time), which leads to a doubling of the thermal stress at half output.

If the heat-holding time is reduced to 6 seconds, the requisite temperature for denaturation is reached without stressing the beer with higher PUs, which is necessary for inactivating enzymes and beer-spoilage organisms. Even when the output is halved, the temperature does not fall below the critical level of 80 °C, which means a sliding PU control should be possible again. It remains to be examined how far the temperature differential of around 2 °K between full and half output influences the haze.

Table 2 comparison between the time/temperature combination of a 30 and a 6 sec. heat holding

	Time	Temperature	Beer PU
	[sec]	[°C]	[PU]
100 % Flow	30	80.0	378
50 % Flow	60	80.0	757
100 % Flow	6	83.2	220
50 % Flow	12	81.1	220

1.3 Product-friendliness

The effects of different time-temperature combinations on the beer quality in flash pasteurisation have already been examined by *Wackerbauer* [13]. In contrast to the received wisdom that higher flash pasteurisation temperatures mean more severe damage to the product, flash pasteurisation at 60 °C led to a more marked ageing taste, higher aldehyde contents, and less taste stability than at higher temperatures.

In this context, the heat-holding time manifestly played a crucial role. While in the case of 15 PU a temperature of 72 °C has proved to be ideal, with 80 PU and 500 PU the best product-friendliness was achieved at 84 °C. The pasteurisation unit is thus unsuitable as a measure for product damage due to thermal stress [13], and the sliding control, too, due to the above-mentioned aspects in accordance with the known equation 1, with the temperature reference of 60 °C and with a currently established fixed heat-holding section of 30 seconds, is not ideal either.

The approach adopted in this paper is to find an optimal heat-holding process for the requirements presented here.

The reaction kinetics of the micro-organisms, taking due account of the z-values with absolutely compared identical killing rates, enable the time to be reduced and, conversely, the temperature to be increased. According to Wackerbauer, there appears to be a beneficial effect on the product's quality in comparison to higher temperatures.

Too short a time, however, would exacerbate the endangerment due to cell aggregates and envelopes, because the influence exerted by the increased difficulty of heat conduction with a concomitantly longer time required, may be greater than the beneficial effect of a larger temperature differential. In the case of filtered beers (which must not be subjected to protein denaturation), an excessively high temperature entails a risk of irreversible pasteuriser haze [10]. This means a corresponding minimum time is required, and thus a complete omission of heat-holding or a relocation to a heat exchanger [14], as proposed by *Kalinowski*, for example, is not possible.

The aim must accordingly be to find an optimal heat-holding process that permits microbiologically stable beers to be produced for both types of beer, in which a corresponding denaturation temperature is exceeded with the wheat beers, and not reached with the filtered beers .

Due to the maxim of "as much as necessary, as little as possible", the thermal stress has to be minimised, so as to have a beneficial effect on ageing stability as well.

2 Materials and methods

The beer type involved was produced with a shortened heat-holding time (6 seconds) in comparison to a long heat-holding time (30 seconds) (Parameters in table 4).

As the reference germ for theoretical calculation and specification of a heat-holding time of six seconds, *Lactobacillus brevis* was used for the filtered beers and a slime-forming Lactobacillus frigidus for the wheat beers. Fixing the PU values and log rates was modelled on the recommendations of *Back* [2] (40–45 PU – filtered beers), *Schneeberger* [8] (220 PU – wheat beer) and *Daumen* [1] (a minimum of log 6).

The upper temperature for preventing a pasteuriser haze for filtered beers was determined using preliminary trials on a laboratory scale. Due to the multiplicity of parameters involved (polyphenols, oxygen, heavy metals, etc.) that influence the effect of a pasteuriser haze, defining a critical temperature is possible only with reservations. Besides the technological limitations, the CO_2 saturation pressure restricts the maximum temperature for stabilising the unfiltered beers.

In the **preliminary trials**, three filtered beers (types: Light , Dark and Pilsner of the brand Weltenburger Klosterbier) were heated up in a water bath, in each case with a temperature differential of

Fig. 2 Plate heat exchanger with a short heat-holding time of 6 seconds

maximally 5 °C to the desired final temperatures of 75 °C, 80 °C and 85 °C respectively, and held at this temperature for one minute.

The sample concerned was then cooled down in ice water to under 5 °C. Schwarz [15] describes in his dissertation how the influence of shear forces and turbulences makes a crucial contribution towards coarsening the proteins, and thus to rendering haze visible. For this reason, the samples were also mechanically stressed using a laboratory disperser, and compared with a non-dispersed sample. The comparison was performed using a photometer with an absorption of 760 nm.

In order to reduce the taste impairment caused by yeast in wheat beer and to achieve haze predominantly by coarsening the protein structure, in the **practical trials** the number of yeast cells was standardised upstream of the flash pasteuriser by a separator to around 1 million CFUs/ml.

The Pilsner was pretreated by means of diatomite, protein stabilisation and a sterile filter.

Downstream of the flash pasteuriser, identically produced quantities of both beer types were conveyed to a buffer tank pressurised with CO_2, and immediately filed in 30-litre kegs. An oxygen measurement sensor before entering the buffertank shows constant low values of all the tested beers.

Table 3 Experimental parameters and their mathematical killing kinetics

Beer type	Time [s]	Temperature [°C]	PU [–]	Log [–]	Indicator substances
Wheat beer	30	80	378 (overpasteurisation)	24	*Lact. frigidus* $D_{53°}$ 1.188 min, z=15.395 °C [11], Esterase [9]
	6	83.2 [13]	220 [9]	7.7 [1]	
Pils	30	73.6	45 [3,4]	37	*Lact. brevis* $D_{60°}$ 2 min, z=7°C 12]
	6	78.4	45 [3,4]	36	

Table 4 Analytical methods

Analysis	Analytical Method
Ageing indicators:	MEBAK Wort, Beer and Beer-based Beverages, method 2.23
2-3 Methyl Butanal	
2-Furfural	
2-Acetylfuran	
Benzaldehyd	
5-Methylfurfural	
2-Propionfuran	
2-Phenyl Ethanal	
Bernsteinsäure Diethylester	
Phenylessigsäure Etylester	
y-Nonalacton	
oxygen indicators:	MEBAK Wort, Beer and Beer-based Beverages, method 2.23
2-3 Methyl Butanal	
2-Furfural	
Benzaldehyd	
2-Phenyl Ethanal	
heat indicators:	MEBAK Wort, Beer and Beer-based Beverages, method 2.23
2-Furfural	
y-Nonalacton	
BAX/ESR measurement	MEBAK Wort, Beer and Beer-based Beverages, method 2.15.3
Colour (photometric)	MEBAK Wort, Beer and Beer-based Beverages, method 2.12.2
Foam	MEBAK - Nibem WBBM 2.18.2
Particle distribution	Laser spectrometer, dynamic light scattering BLQ Weihenstephan
Oxygen	Centec inline sensor pasteurizer
Absorption	Photometric with 760 nm

The subsequent analytics were carried out as a comparison under identical conditions, and the concentrations of indicators presented were scaled to the same original-gravity concentrations.

3 Results and discussion

3.1 Dwell time simulations

Mathematical simulations of dwell time distribution show, for these in each case fully turbulent flow profiles, a much more homogeneous distribution than with short heat-holding sections. Due to the shorter length that the flow traverses, with fewer deflections, the time difference between the slowest and fastest particles at the end of heat-holding is very much smaller.

Thus, with the short section, fewer fluid particles are subjected to an excessively long heat-holding time, which should contribute towards a reduction of the total thermal stress involved.

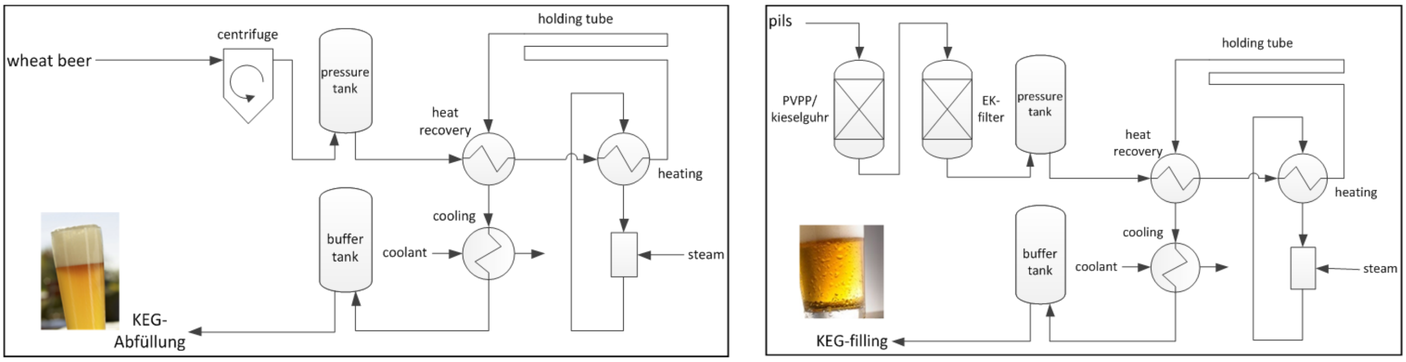

Fig. 3 **Experimental set-up for wheat beer (left) and pilsner (right)**

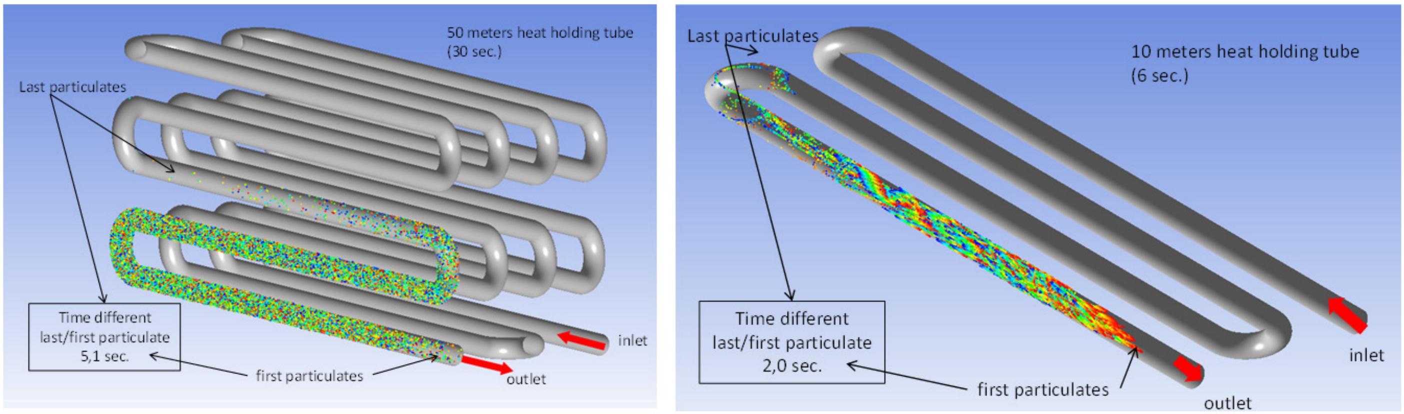

Fig. 4 **50 metres = 30 seconds; 10 metres = 6 seconds at 30 m³/h, DN 80; = 1.66 m/s; Reynold ~ 300,000, dparticles = 10 µm; number of particles 65,000**

Also, with the short heat-holding section, almost no under-pasteurization of particles occurs. Fewer than 1 % of the particles entering leave the section before expiry of the 6-second heat-holding time. In the case of long heat-holding, by contrast, around 20 % of the particles entering leave before expiry of the 30-second heatholding time, and may thus not receive sufficient thermal treatment.

3.2 Preliminary trials for determining the critical temperature with filtered beers

Among the three types examined, no significant difference in the absorption was found for the Dark and Pilsner types. Only with the Light type (Brand "Hell") as from 80 °C (1 minute heat-holding!) with the dispersed sample, and at 85 °C with both samples, was observed a minimal difference from the reference (not visually perceptible).

Another measurement after 7 days at 5 °C revealed no further change in the absorption.

A crucial influence on the creation of haze (reversible/non-reversible) or an negative influence to the chemical/physical stability of the beers is exerted not only by the beer matrix and its stabilisation during filtration, but also by the temperature differential used for heat-up. Parallel trials with a heating plate (delta T > 50 °C) produced flocculent hazes as from 80 °C with one minute heat-holding.

Thereupon, for the major trials and the dimensioning of the heat-holding section, a maximum temperature of significantly below 80 °C is specified with a maximum logarithmic temperature differential of 10 °C – in this case to 78.5 °C at 6 sec.

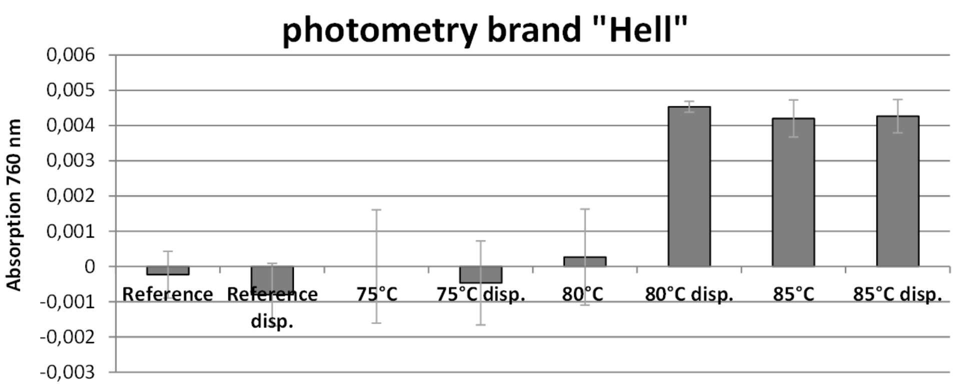

Fig. 5 **Absorption at 760 nm, type Light, in dependence on the heat-up temperature**

3.3 Main trials

3.3.1 Examining the thermal influence

For assessing the difference in terms of energy input and its effect on the beer's quality, radical generation and the BAX value were determined at identical PUs (type Pilsner), not least by means of electron spin resonance measurements. The level of radical generation (T-500 value) and the assessment of the anti-oxidative potential (EAP/

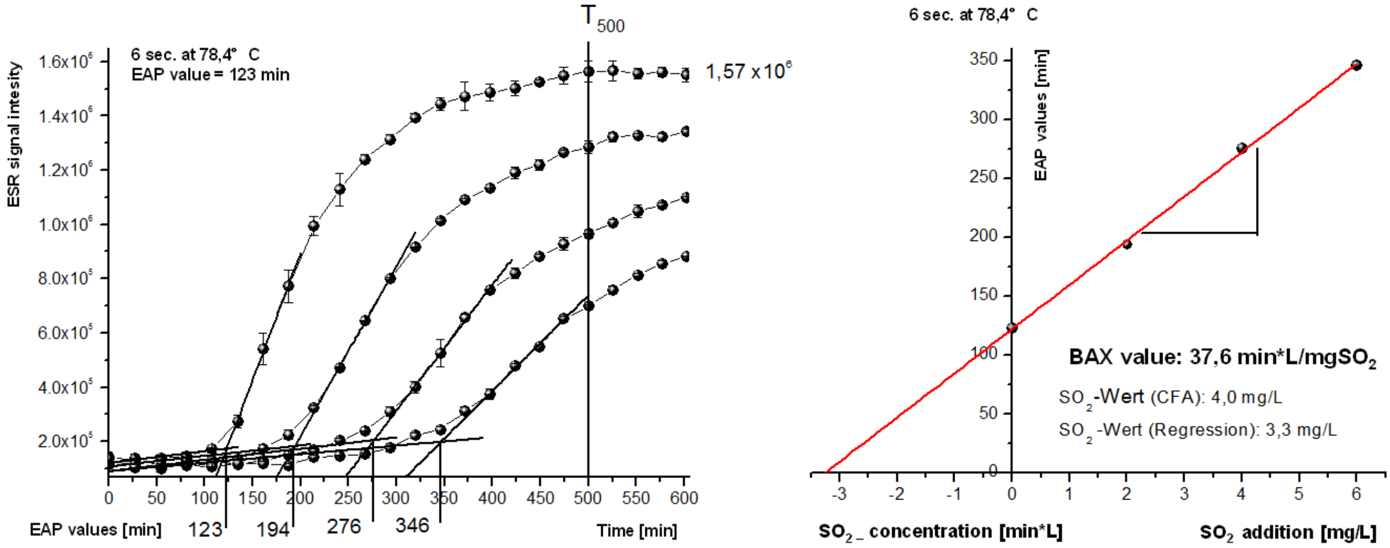

Fig. 6 **Results of the ESR measurements (type Pilsner) for heat-holding 6 sec. at 78,4 °C**

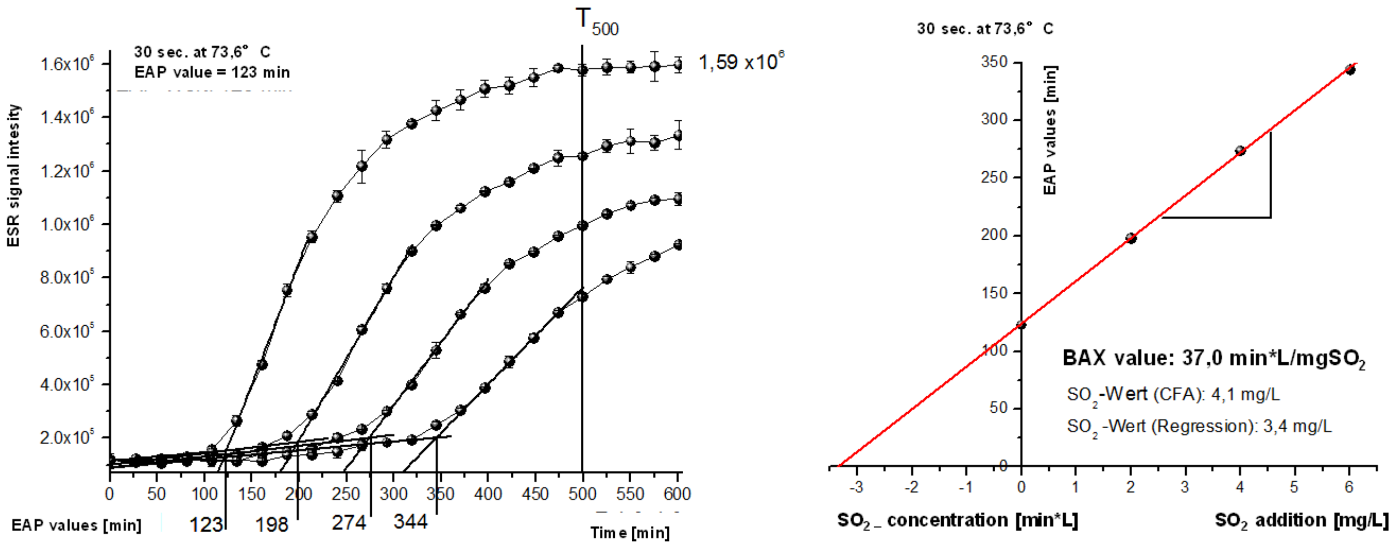

Fig. 7 **Results of the ESR measurements (type Pilsner) for heat-holding 30 sec. at 72 °C**

BAX values) show no significant differences between the two heat-holding processes (BAX: 37.0 v. 36.6 min).

The lower colour values (6.23 ± 0 vs. 6.32 ± 0.02 EBC) and the SO_2 content (4.0 ± 0 vs. 4.1 ± 0 mg/l) of the beer with shorter heat-holding shows a slightly tendency to better values. But the lower values of the heat indicators (Figure 8), there is a clear indication of a lower thermal stress with short heat-holding for the filtered beers with the same PUs.

In the case of the wheat beers, no difference was found between the heat-holding processes in terms of colour intensity (13.5 ± 0 v. 13.5 ± 0.05 EBC).

When examining the heat indicators, a difference was observed (particularly in aged beer), with a concomitant advantage for short heat-holding.

3.3.2 Examining the haze development

In the case of filtered beer (type Pilsner), with the same PUs and the estimated 78.4 °C, no difference was found in the haze values. The retention samples (3 months), showed no changes as well.

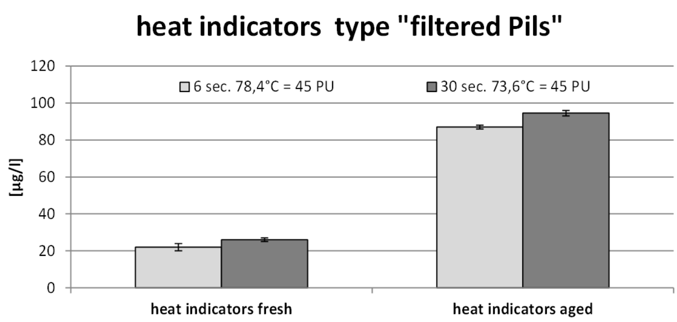

Fig. 8 **Total of the heat indicators (Table 4) in a comparison between long and short heat-holding (type Pilsner)**

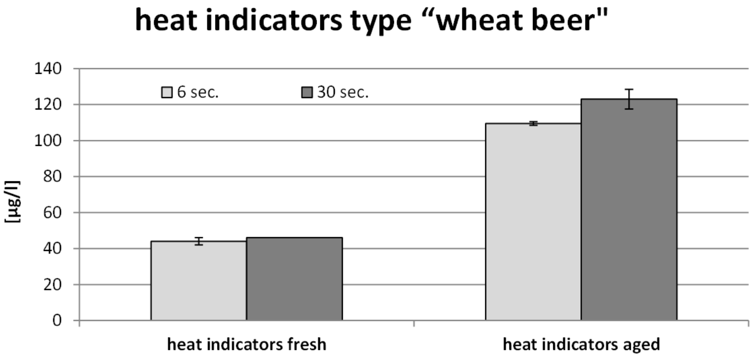

Fig. 9 Total of heat indicators (Table 4) in a comparison between long and short heat-holding (type wheat beer)

The chemical/physical stability of the beers in comparison was then not affected.

Table 5 Haze indicators compared (type Pilsner)

	6 sec. at 78.4°C	30 sec. at 72°C
Haze 90° / 25° [EBC] 0 °C	0.28 / 0.10	0.26 / 0.10
Haze 90° / 25° [EBC] 20 °C	0.21 / 0.06	0.20 / 0.07

With respect to the foam number, no difference was found either between long and short heat-holding (279±4 v. 281±0 seconds). As a result, then, this temperature with 6 seconds heat-holding can be fixed as the topmost limit for filtered beers at present. According to Back, it is with this temperature/time pairing that the range of flash pasteurisation of beer-spoilage organisms in beer with an alcohol content (40 PUs) ends. If non-alcoholic filtered beers are also to be treated, Back recommends PUs up to 70. This would mean a heat-holding time of 10 seconds for heat-holding at a fixed temperature of 78.4 °C.

For assessing the haze, the particle size distribution was analysed for hazy wheat beer.

In comparison to the zero sample, upstream of the flash pasteuriser, the success of the heat-up is manifested in a significant coarsening of the particles. Here, upstream of the flash pasteuriser, only 29 % of the particles were in the range relevant for haze, which is 200–1000 nm [15] (below 200 nm the light diffusion is too low, and above 1000 nm the sedimentation speed is too high). After flash pasteurisation, approx. 55 % of the particles lie in this range, and contribute towards a stable haze independent of the yeast.

No significant difference was found between the two heat-holding processes, however. The crucial factor for denaturation is accordingly (as published by *Engelmann* [6]) a particular temperature's being exceeded (80 °C), whereas the time plays a subordinate role here.

Another crucial factor for output adjustment is the insight that a temperature difference of 3.2 °C does not exert any significant influence. It is accordingly possible, with a shortened heat-holding time at a constant 220 PUs, to adjust the output until a temperature of >80 °C is reached, without having to fear any influence on the haze.

In terms of the foam number, no difference was found between the heat-holding processes, i.e. between long and short heat-holding (253±4 vs. 255±0.5 seconds).

3.3.3 Examining the effects on the beer quality and the aroma

When the filtered Pilsner type was compared with the same PUs, better values were achieved with short heat-holding. Both in the

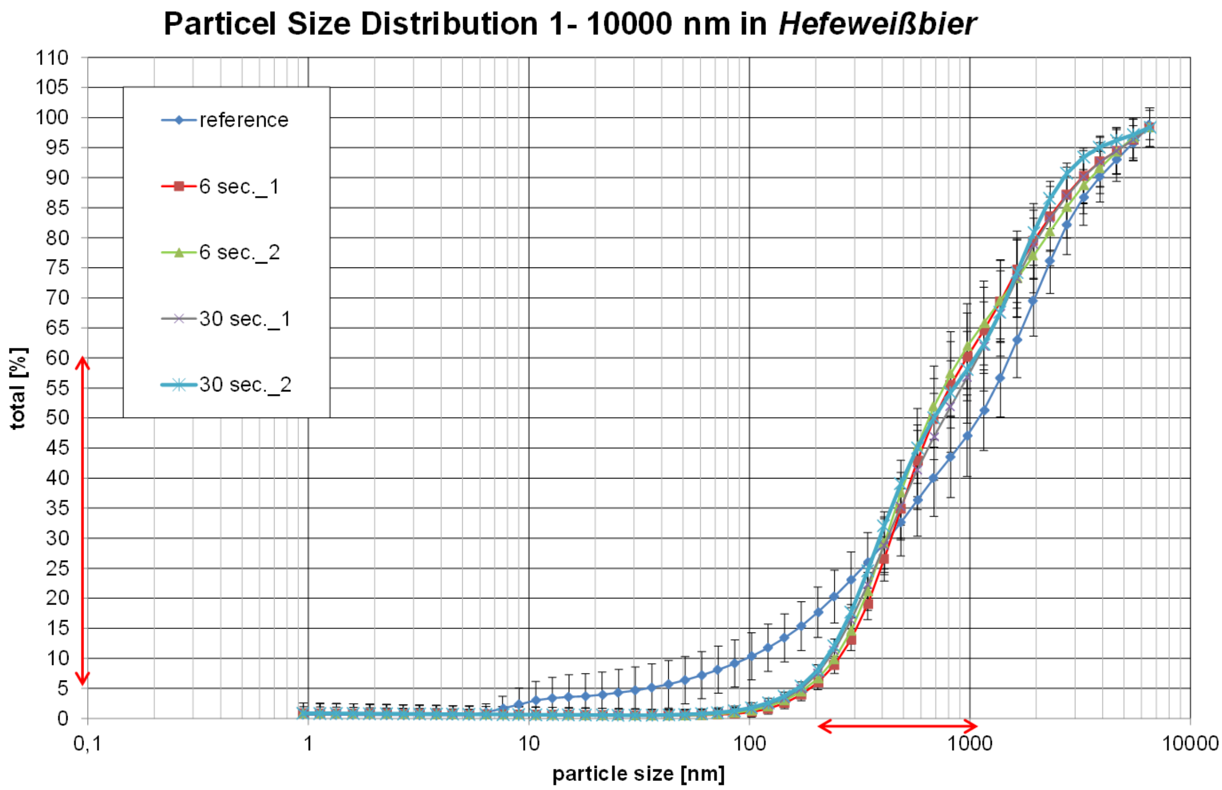

Fig. 10 Particle size distribution

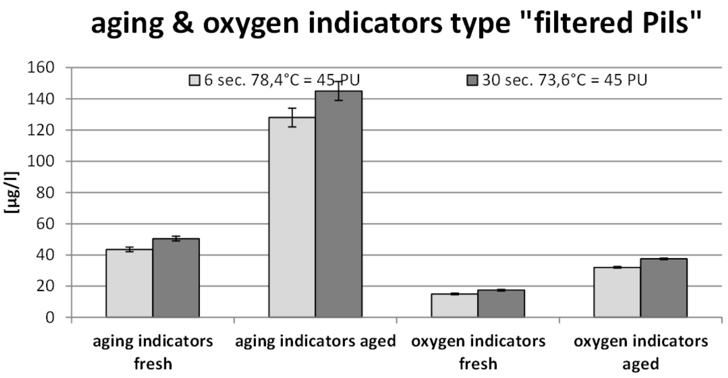

Fig. 11 Total of ageing and oxygen indicators (Table 4) as a comparison between long and short heat-holding (type Pilsner)

fresh and the forcibly aged beers, the beer exhibited lower total values for oxygen and ageing indicators with short heat-holding.

Better values were likewise achieved with short heat-holding in the comparison for the wheat beer type. Both in the fresh and the forcibly-aged beer, the beer showed lower total values for oxygen and ageing indicators with short heat-holding.

A taste test (DLG schemata) shows no significant different.

Table 6 Taste results in comparison

	DLG points fresh beer	DLG points aged beer
Wheat beer 30 sec.	4,4	3,9
Wheat beer 6 sec	4,3	4,1
Filtrated beer 30 sec.	4,4	3,9
Filtrated beer 6 sec.	4,4	3,7

3.3.4 Microbiology

In both processes, both the filtered and the unfiltered beers were equally stable in terms of microbiology (no faults found). The retention samples, too, showed no microbiological or technical haze-related changes.

4 Summary

When the filtered beers are examined individually, shortening the heart-holding time from the traditional 30 seconds to 6 seconds (beers containing alcohol) already produces advantages in terms of beer quality, and in conjunction with unfiltered beers, an analytical measurable reduction in thermal stress. The microbiological safety could be more safety by the 6 sec., because the dwell time distribution is more homogenous.

Shortening the time enables the critical temperature for a desired protein denaturation for haze stabilisation of the unfiltered beers to be achieved using one heat-holding section, without over-pasteurising the beer. Even an output adjustment is possible without letting the temperature fall below the critical value of 80 °C with a target value of a constant 220 PUs.

All beers examined in the comparison showed lower key indicators for oxygen, heat and ageing with short heat-holding. The taste

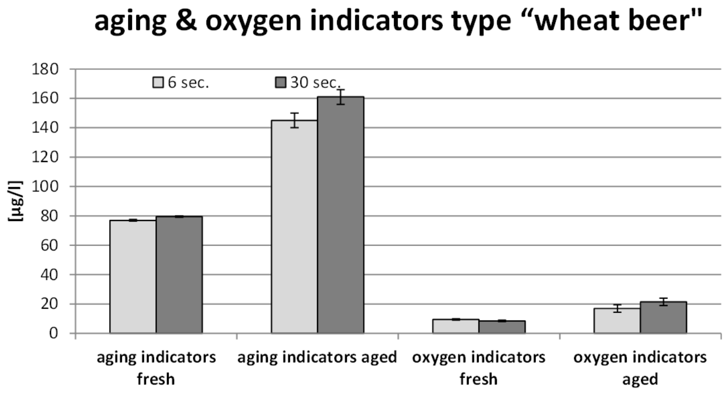

Fig. 12 Total of ageing and oxygen indicators (Table 4) in a comparison between short and long heat-holding (type wheat beer)

results shows no significant different. So we can say that a shorter heat holding have benefits for the beer quality – but especially in the higher microbiological safety, material savings, pressure drops and foot print.

To sum up, the recommendations listed in table 7 can be specified for the temperature/time combination.

It should be emphasised that flash pasteurisation thus has further crucial advantages over a tunnel pasteuriser. As already described by *Schwarz*, the turbulence makes a crucial contribution towards agglomeration and denaturation of the proteins, something that a

Table 7 Recommended dimensioning parameters for beer flash pasteurisers

Beer types	Heat-holding time	Temperatures 100 % output*	Temperatures 50 % output*
Alcoholic, filtered beer	6 seconds	77 °C (28 PU) 78.4 °C (45 PU) Maximum	74.9 °C (28 PU) 76.3 °C (45 PU)
Non-alcoholic filtered beer's & "critical" beers**	10 seconds	78.2 °C (70 PU) Maximum	76.1 °C (70 PU)
Unfiltered beer	6 seconds	83.6 °C (220 PU) 82.1 °C (150 PU)	81.1 °C (220 PU) 80.0 °C (150 PU) Minimum
Non-alcoholic filtered beer or critical beer, in conjunction with alcoholic beer	10 seconds	**Unfiltered beer:** 81.5 °C (220 PU) 80.5 °C (150 PU)	**Unfiltered beer:** 81.1 °C (220 PU) 80 °C*** (150 PU) ***Minimum reached at 90 % of output!
		Filtered alcoholic beer: 75.5 °C (28 PU) 76.9 °C (45 PU) **Filtered non-alcoholic beer:** 78.2 °C (70 PU) Maximum	**Filtered alcoholic beer:** 73.4 °C (28 PU) 74.8 °C (45 PU) **Filtered non-alcoholic beer** : 76.1 °C (70 PU)

* Values calculated using equation 1

** e.g. return beer, Containerbeer

tunnel pasteuriser is unable to do. The results clearly show that a hot/short process is far gentler on the product than a long/warm process. It would be interesting to conduct further studies between the now-shortened heat-holding and a short heat-up and cool-down phase in the flash pasteuriser, and a tunnel pasteuriser with very long dwell times in the temperature sections concerned. The already-significant differences between 30 and 6 seconds at the relevant temperatures should, in comparison to a tunnel pasteuriser, show very significant advantages for the flash pasteuriser in terms of product quality.

Besides the technological advantages, shortening the heat-holding section by an average of around 40 metres (at 30 m^3/h) enables the pressure drop to be reduced, and thus the pump rating, the mixing phases and thus the product losses, the material, the weld seams, and the footprint. The difference between the fastest and slowest particles (dwell time distribution) also decreases when there is a smaller length for the flow to traverse, which leads to more homogeneous heat-up and a further reduction in partial overheating phenomena or microbiologically critical partial under-pasteurisation. This effect, besides the reaction kinetics of the individual indicator substances and their substance conversions, is regarded as a determinant reason why a hot/short process is gentler on the product than a warm/long process.

5 References

1. Oliver-Daumen, B.P: Produktsicherheit bei UltraClean- und kaltaseptischen Abfüllanlagen; dissertation TUM, 2011.
2. Roesicke, J.: Pasteurisiereinheit und Abtötungseffekt; BRAUWELT, **121** (1981), no. 15, p. 522.
3. Back, W.: Farbatlas und Handbuch der Getränkebiologie 2; Hans Carl Getränkefachverlag, Nürnberg, 2000.
4. Back, W.: Farbatlas und Handbuch der Getränkebiologie 1; Hans Carl Getränkefachverlag, Nürnberg, 1994.
5. Feilner, R. and Jacob, F. F.: Improving Resistance to Aging and Increasing Haze Stability in Southern German Wheat Beer Through Process Optimization; BrewingScience **68** (2015), no. 5/6, pp. 58-66.
6. Engelmann, J.; Jacob, F. and Titze, J.: Vergröberung erwünscht; Brauindustrie 2010, no. 8.
7. Oliver-Daumen, B.P and Back, W.: Pasteurisationskriterien unter Berücksichtigung der Hitzeresistenz getränkeschädlicher Mikroorganismen; BRAUWELT 152 (2012), no. 33, pp. 958-963.
8. Schwarzer, K.; Schneider, J.; Müller, U.; Becker, B. and Wilhelm, P.: Lemgoer Datenbank für D-und z-Werte: Anwendung für getränkeschädliche Mikroorganismen; BRAUWELT **150** (2010), no. 18, pp. 540-544.
9. Schneeberger, M.: Verwertung von Prozessbieren in der Brauerei; dissertation, TUM 2006.
10. Narzis, L.: Abriss der Bierbrauerei; 7th revised and updated ed., Wiley-VCH Verlag 2005.
11. Tsang, E. W. T. and Ingledew, W. M.: Studies on the heat resistance of Wild yeasts and Bacteria in Beer; Journal of the American Society of Brewing Chemists (1982), no. 40, pp. 1-8.
12. Zufall, C. and Wackerbauer, K.: The biological impact of flash pasteurisation over a wide temperature interval; Journal of The Institute of Brewing 106 (2000), no. 3, pp. 163-168.
13. Wackerbauer, K. and Zufall, C.: Der Einfluß der Kurzzeiterhitzung auf die Bierqualität; Monatsschrift für Brauwissenschaft **50** (1997), no. 11/12, pp. 196
14. Kalinowski, R.: 30 Sekunden? Auslegung einer KZE für optimale Produktqualität unter Berücksichtigung der Betriebskosten; Brauindustrie 2011, no. 8.
15. Schwarz, C.: Trübungsstabilität von Weizenbier; dissertation, TU München-Weihenstephan, 2012.

Received 18 August 2016, accepted 9 Octo ber 2016