

Effects of homogeneity in wort boiling

Thomas Buehler*(1), Marc Schreder(1), Dietmar Kaltner(2), Willi Mitter(2), (1) Huppmann, Kitzingen, Germany, (2) Hopsteiner, Mainburg, Germany

Abstract

Homogeneity is one of the key aspects with regard to quality and efficiency not only in wort boiling. Evenly distributed reaction rates throughout the content of large volume vessels are a main challenge in all batch processes. Better homogeneity leads to improved product conversion, thus total reaction times, i.e. wort boiling intervals, can be reduced. This results in savings not only in time but also in fuel energy.

The work presented here is based on installations of the Jetstar[®], the new internal boiler system from Huppmann. This boiler design is the first to apply a submerged jet stream to circulate the wort in the kettle.

While the effect of a submerged jet for improved wort homogeneity has been investigated by Delgado et al. in great detail on a pilot scale basis using tracers, temperature measurement and flow simulation modelling, the work presented here investigates technological evidence of the subject improvements.

The paper shows results based on DMS-P degradation that indicate faster reaction rates. DMS-P breakdown has been studied in great detail. The first order reaction is mainly temperature dependent and thus changes in reaction rate can be put down to temperature variation, if all other conditions such as brew length, malt batch or water quality remain constant.

In addition, this paper presents technological and energy aspects associated with improved homogeneity. In cooperation with Hopsteiner the effects of a system upgrade from an existing wort kettle with external calandria to the Jetstar internal boiler system were investigated from a hop utilisation and beer quality point of view.

Key words: wort boiling, homogeneity, hop utilisation, DMS-P degradation, subject flow pattern

Introduction

According to Schwill-Miedaner and Miedaner ^[7], “a basic requirement for constant wort quality is a kettle in which the contents are homogeneously distributed during the boiling process“. To meet this requirement, the equipment manufacturers have continually optimised their boiler systems. With systems relying on natural circulation especially the heating phase from lautering to boiling temperature is critical. Long dwell times associated with increased thermal load in the boiler tubes can occur when the wort is distributed unevenly in the kettle and are thus detrimental for wort quality. In plants with an energy storage system, wort can be pre-heated rapidly and gently to boiling temperature through the use of an external plate heat exchanger, so that the critical phase of heating-up in the internal boiler is completely eliminated.

Other suppliers opted for systems that are pump-assisted in combination with internal or external boilers. While this improved residence time in the boiler tube primarily during heating-up this does not solve the homogeneity problem in the kettle. As Delgado and Baars ^[1-3, 5] have shown, circulation of wort by means of a deflector can generate short-circuit flows which are an obstacle to uniform treatment. To achieve uniform distribution, dead zones and

short-circuit flows must be prevented. It is required that the wort circulates vertically downwards in “piston flow” and is drawn-in as evenly as possible by the boiler (see Figure 2).

Strong, intensive currents are largely prevented by discharging the heated wort below the wort level through a submerged jet orifice. Firstly, because the wort is distributed evenly in circumferential and horizontal direction and secondly, because the steam bubbles in the wort will cause higher energy dissipation and thus lower the speed of the wort current better than a free jet. The new Jetstar boiling system from Huppmann operates according to this principle. Further details regarding the operating principle and the process options have been published by Buehler and Binkert ^[4].

The two phase boiling concept

Thanks to the subjet orifice, it is possible to divide the wort boiling process into two phases:

Phase 1

Thermal conversion (Figure 1): During this phase, wort flows out of the boiler through the subjet orifice below the wort level. The known processes such as hop isomerisation, protein coagulation, degradation of flavour precursors (e.g. DMS precursor), sterilisation, flavour and aroma formation take place. Homogeneous temperature distribution is achieved throughout the entire content of the kettle by gentle circulation. The boiler can be pressurised slightly during this phase as to increase the reaction rates at the higher temperature level.

High circulation rates combined with low interfacial temperatures at the boiler tube conserve foam-positive components. The steam bubbles produced in the boiler tube provide for a high momentum exchange below the wort surface thanks to the two-phase flow at the boiler outlet. The steam bubbles tend to collapse again in the wort, and only very little evaporation occurs. Due to the homogeneous distribution in the kettle, the duration of this thermal conversion can be selected irrespective of the required evaporation. Depending on the content of flavour precursors, thermal conversion generally lasts 50 to 60 minutes. The goal is to reduce the precursors of undesired flavour compounds as far as necessary and to achieve maximum conversion of hop acids.

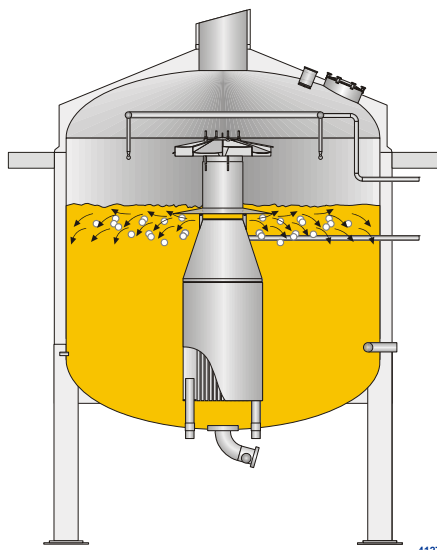


Figure 1: In phase 1, the subjet flow ensures optimum homogeneity in the kettle

Phase 2

For evaporation (Figure 2), the wort is distributed across the two-level wort spreader, as the subjet orifice is closed. The large surface created thereby enables intensive evaporation of volatiles. Depending on the desired final values and the target original gravity, this evaporation phase continues for 10 to 20 minutes. The process can be intensified by

dynamic low-pressure boiling. This leads to faster evaporation of undesirable flavour compounds due to the intense intermittent boiling. As soon as the predetermined pressure is reached a systematic pressure reduction starts under strictly defined conditions. As pressure is reduced, the boiling temperature in the vessel decreases accompanied by a rapid steam bubble formation throughout the entire kettle. This “controlled boiling delay” results in a very large gas/liquid contact surface, thus ensuring optimum stripping of volatile odorous substances.

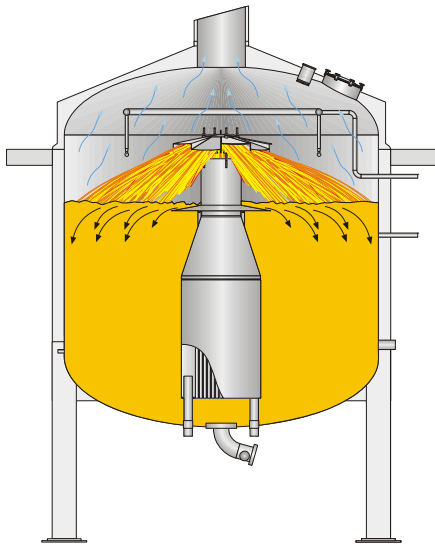


Figure 2: In phase 2, discharging via the two-level wort spreader ensures intensive evaporation.

Experiments: DMS-P breakdown

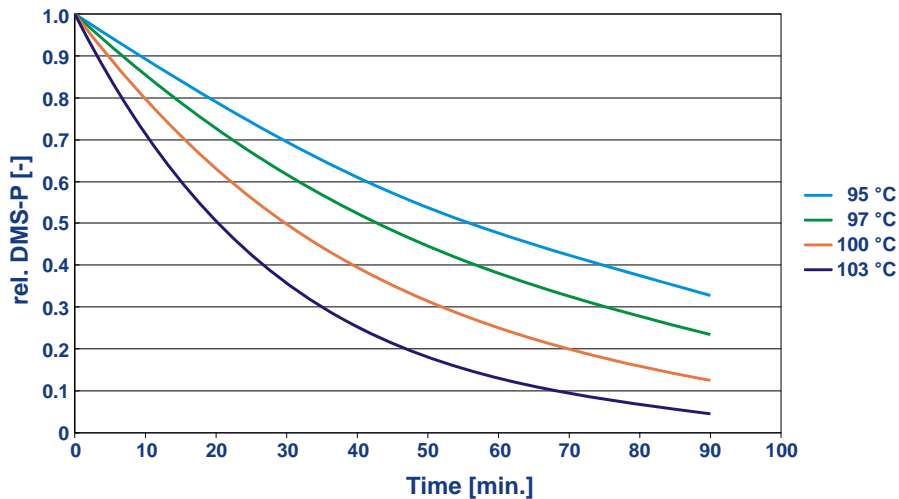
The effect of better homogeneity with subjet boiling was investigated at a large industrial brewery in a conventional wort kettle with a cast wort volume of 710 hl. The DMS precursor was analysed. It is known from literature ^[6] that DMS-P breakdown is in essence a temperature-dependent first order reaction. This is shown in the following equation:

$$c = c_0 e^{-kt} \quad \text{Eq. 1}$$

with

- k: reaction rate
- c: concentration
- c₀: initial concentration
- t: time.

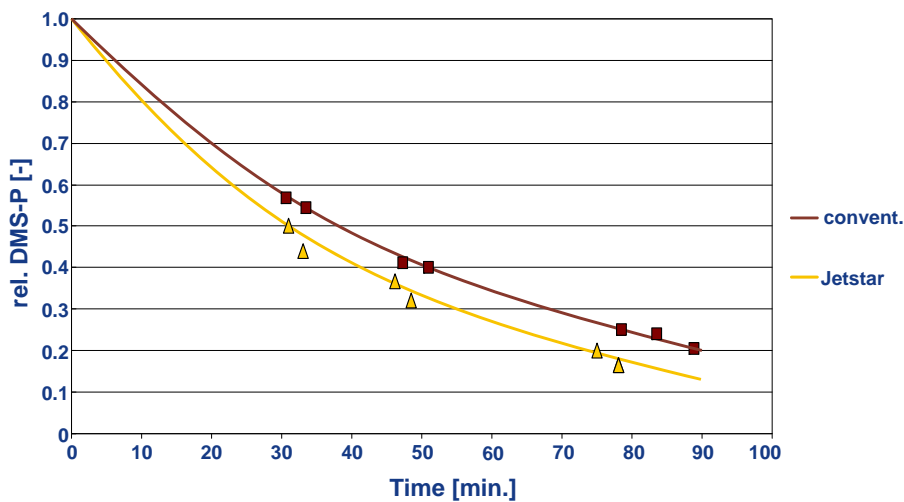
The reaction rate k is mainly affected by temperature. If all other boiling conditions are kept constant, reaction rate will be a function of temperature only. Figure 3 shows breakdown curves at a range of temperatures.



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Figure 3: DMS-P breakdown curves at different temperatures

In the large kettle experiments, wort samples were taken, chilled immediately and later on analysed for DMS-P. This was done for brews with conventional internal boiler and subjet boiling. It can be seen in Figure 4 that in subjet operation breakdown is quicker. The effect relates to a temperature increase of 1.8-2.2 K. The higher temperature can be contributed to the more even temperature distribution with less cold spots in the wort kettle in subjet operation. The general advantage is the higher conversion rate inside the wort kettle which can be used for shorter conversion and reduced evaporation.



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Figure 4: The breakdown of DMS-P in subjet operation indicates higher temperatures

Experiments: Hop alpha acid isomerisation

In a second installation the effect of hop isomerisation during a 'Lager' beer run was investigated. A wort kettle with an external boiler was upgraded to a Jetstar system. The table of analysis values shows the original installation, the upgraded system with the original boiling parameters and the upgraded system with optimised parameters. Total boiling time was set constant to 80 minutes. In the Jetstar operation phase 1 was set to 60 minutes and phase 2 to 20 minutes. In the optimised brew, the total evaporation was reduced to 4.5% from the original value of 7.5%. Boiling was atmospheric for all trials. Reducing total evaporation is a common measure to save energy. However, reduced evaporation can lead

to higher levels of unwanted flavour volatiles, if evaporation efficiency is not adequate. From the standard wort analyses it can be seen that reducing the total evaporation did not affect wort quality in this instance. Samples were taken at mid of cooling and chilled immediately after sampling. Hop analysis was carried out by Hopsteiner. The results from unspecific (EBC 8.8) and specific (EBC 7.8) methods for quantification of bitter substances (Table I) demonstrated a slight increase of the bitterness levels in wort. Due to the cleaner character of the beer and a slightly more pronounced bitterness impression, the brewery decided to reduce the hop dosage in the optimised brew (column 3). This again is an effect of high homogeneity in the kettle.

Table I: Wort analysis

Trial brew	Special before upgrade	Special first brew	Special optimised
Total evaporation [%]	7.4	7.5	4.5
Extract [°Plato]	13.09	13.35	13.22
pH-value	5.54	5.68	5.61
Colour [EBC]	11	10.8	10.9
TBI [-]	38.4	42.8	40.6
DMS [µg/l]	89	70	79.5
DMS-P [µg/l]	64	28	46
Total soluble nitrogen [mg/l]	1190	1288	1239
Coagulable Nitrogen [mg/l]	29	23	26

Table 2: Hop analysis and hop utilisation

Hop dosing	Special before upgrade	Special first brew	Special optimised
Total alpha acids [g]	1565	1775	1670
Cast out volume hot [hl]	212	222	272.5
Alpha acid dosing [g/hl CW]	7.38	8.00	6.13
Bitterness in wort			
BU [EBC]	35.0	38.0	30.5
Iso-alpha acid [mg/l]	25.4	29.1	22.0
Alpha acid [mg/l]	10.9	14.4	14.3
Hop yield in wort			
BU in cast wort (%)	47.4	47.5	49.8
Iso-alpha acid (%)	34.4	36.3	35.8
Iso-alpha + alpha (%)	49.2	54.3	59.2

A sensory evaluation by the beer tasting panel of Hopsteiner was made of the Jetstar beers from the optimised brew with a special focus on hop bitterness and the quality of hop flavour. The taste scores indicate that the beer has a clear and very pleasant bitterness taste impression. The smell of hops is weak and pleasant with typical hoppy aroma notes.

Smell	Taste	Diagrams of bitterness	Perception of bitterness	Ranking			
These impressions are exclusively for the smell of the hops							
				0 1 2 3 4 5 6 7 8 9 10			
Smell	Intensity	<input type="checkbox"/>	very weak <input type="radio"/> <input type="radio"/>	weak <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/>	noticeable <input type="radio"/> <input type="radio"/>	clearly <input type="radio"/> <input type="radio"/>	intensiv <input type="radio"/> <input type="radio"/>
	Quality	<input type="radio"/>	unpleasantly <input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	neutral <input type="radio"/> <input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/> <input type="radio"/>
If you can't smell anything, then it is necessary to click on the "0"!							
				0 1 2 3 4 5 6 7 8 9 10			
Smell	fruity	<input type="radio"/>	very weak <input checked="" type="radio"/>	weak <input type="radio"/>	noticeable <input type="radio"/>	clearly <input type="radio"/>	intensiv <input type="radio"/>
	flowery	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	citrusy	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	fresh grassy	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	hops-spicy	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	others, not typical for hops	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 5: Flavour analysis of the optimised brew with reduced evaporation

Smell	Taste	Diagrams of bitterness	Perception of bitterness	Ranking			
These impressions are exclusively for the taste of the hops							
				0 1 2 3 4 5 6 7 8 9 10			
Taste	Intensity	<input type="checkbox"/>	very weak <input type="radio"/> <input type="radio"/>	weak <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/>	noticeable <input type="radio"/> <input type="radio"/>	clearly <input type="radio"/> <input type="radio"/>	intensiv <input type="radio"/> <input type="radio"/>
	Quality	<input type="radio"/>	unpleasant <input type="radio"/> <input type="radio"/>	<input type="radio"/> <input type="radio"/>	neutral <input type="radio"/> <input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/> <input type="radio"/>
If you can't taste anything, then it is necessary to click on the "0"!							
				0 1 2 3 4 5 6 7 8 9 10			
Taste	fruity	<input type="radio"/>	very weak <input checked="" type="radio"/>	weak <input type="radio"/>	noticeable <input type="radio"/>	clearly <input type="radio"/>	intensiv <input type="radio"/>
	flowery	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	citrusy	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	fresh grassy	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	hops-spicy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
	others, not typical for hops	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 6: Flavour analysis of the optimised brew with reduced evaporation

Conclusion

As an overall result it can be noted that the installation of the Jetstar resulted in slightly better hop utilisation. In addition, the cleaner character of the beer caused the bitterness to be more apparent. To allow for these effects, alpha acid dosing was reduced.

With DMS-P-breakdown, the reaction rate illustrates the effect of the Jetstar on wort homogeneity in the wort kettle. The higher reaction rates could be realised with the same or even lower energy input only by introducing a subject flow. The possibilities to adapt and

adjust the process phases provide more flexibility. Better homogeneity made it possible to reduce total evaporation without compromising on beer flavour quality.

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