H. Scheuren, F.-J. Methner, K. Sommer and M. Dillenburger

Optimisation of Wort Boiling by Process Reformulation and Design

The current article introduces two possible optimisation tools for wort boiling. The first improvement tool refers to a reformulation of the different boiling phases. By a clever variation of the ratio between pump around velocity (turn rate) and evaporation velocity (evaporation rate) the advantages of a flash evaporation are combined with those of a kettle boil which leads to an optimised calandria boil (internal/external boiler). A second optimisation tool even intensifies this combination with a mechanical improvement. Thus, an energy reduction in wort boiling can be achieved which has so far not been possible to that extent.

Descriptors: boiling, optimisation, DMS, DMSP, wort, evaporation

1 Introduction

The reduction of dimethyl sulphide (DMS) during wort boiling is calculable for both evaporation principles flash evaporation and kettle boil [1, 2, 3, 4]. The decrease consists of formation and evaporation of DMS. One of the major questions is whether a flash evaporation is better, equal or worse in terms of the reduction of DMS compared to a kettle boil [5].

If in a first approach formation and evaporation of DMS are considered separately for both boiling principles the calculation leads to the assessment that every system is better than the other in one of the regarded unit operations: Kettle boil is superior to flash evaporation in terms of the evaporation while flash evaporation effects a better DMS formation compared to the kettle boil [5].

If in a second approach formation and evaporation of DMS are considered and calculated as simultaneous processes for both formation and evaporation it has to be stated that a possible superiority depends on the according process conditions. For equal and continuous evaporation the flash evaporation converges towards the characteristics of a kettle boil with a higher pump around velocity. Both systems are then rather equivalent. For breweries using forced flow boilers with low turn rates an optimisation strategy is to increase the wort volume flow while keeping the other parameters constant. The needed over all evaporation will decrease [5].

Subject to this article is a third approach. Via reformulation of the entire wort boiling process the principle of the flash evaporation is modified so that it is superior to a kettle boil. In favour of this, two boiling phases have to be established:

Phase 1 enhances the advantage of flash evaporation which is an improved DMS conversion due to higher temperatures. This is done by reducing the pump around velocity of wort through the boiler at a constant evaporation rate. The wort pumped through the boiler and treated at higher temperatures shows a strongly reduced content of DMS precursor (DMSP) when leaving the boiler and entering the kettle.

Phase 2 is meant to even up the flash evaporation's disadvantage which is the worse DMS evaporation. For this purpose the temperature difference of the flash evaporation (difference of wort temperature within boiler and within kettle) of the superheated wort has to be reduced. The reduction is realised by increasing the pump around velocity of wort through the boiler while evaporation rate is kept constant.

Both phases have to be established for every boiler operating the principle of a flash evaporation with forced flow. Furthermore, the processes‘ reformulation needs no constructive modification of the existing brewing equipment.

However, in order to enable a further improved brewing process a constructive adaption can be retrofit. The constructive modification reduces the superheating of wort in the boiler provoking the subsequent flash evaporation on the wort's way back to the kettle. The most easy solution for calandria is a certain "cooling" of superheated wort by mixing it with wort which has not been superheated prior to the reflux into the kettle. Contrary to existing procedures this has to happen immediately after the calandria by adding wort from the kettle to the superheated, not yet relieved wort.

Addition of wort has to be realized in a complementary mixing space between boiler and wort kettle in order to enable a sufficient mixing necessary to reach the desired effect: Depending on the existing wort temperature the relief of the performed flash evaporation is reduced while keeping the overall evaporation constant (instead

Authors

Dr.-Ing. Hans Scheuren, Ingenieurbüro Dr.-Ing. Hans Scheuren, Bad Kreuznach, Germany; Prof. Dr.-Ing. Frank-Jürgen Methner, Lehrstuhl Brauwesen, TUB, Berlin, Germany; Prof. Dr.-Ing. Karl Sommer, Lehrstuhl VDS, TUM, Freising, Germany; Dipl.-Ing. Michael Dillenburger, Dillenburger & Hertel GmbH, Haxthausen, Germany; corresponding author: H.Scheuren@Dr-Scheuren.de

of having a relief of flash evaporation from 104 to 100 °C only from 102 to 100 °C for example).

The process has to be kept constant via measuring the temperatures of wort in kettle and boiler and adjusting the pump around velocity accordingly (alternatively adjusting the evaporation rate). Constructively this is done by inserting the mixing space between boiler exit and wort kettle entrance. This particular mixing space is provided with "cooling" wort from wort kettle via a corresponding feeding pipe.

The process is divided into to two phases again. The intensified formation is phase 1. Phase 2 is the evaporation where no further "cooling" wort is fed. In order to obtain the same optimal DMS reduction as with a kettle boil and in order to minimise the thermal load the pump around velocity through the boiler has to be increased accordingly. As now all DMSP is cleaved the optimal form of evaporation can take place subsequently.

The process according to the described device includes two positive effects: The evaporation via flash evaporation is on par with the optimum of the kettle boil. Nevertheless there still is the higher temperature in the calandria effecting an improved formation. All together this leads to the most efficient evaporation which so far has not been reached by any of the conventional boiling processes in the brewing industry.

Additionally to the theoretical considerations about the described reformulation as well as the constructive improvement of wort boiling the following paragraphs contribute several calculations. The relevant equations base on the previous articles and are disclosed more detailed in literature [2, 5].

2 Basics and Calculation

The boiling process' reformulation includes a phase 1 during which the improved DMS formation takes place and a phase 2 during which the improved evaporation of the previously formed DMS is carried out.

In terms of a flash evaporation phase 1 and 2 are calculated with the following equation:

$$\frac{dx_i}{dt} = -\frac{\dot{D}}{L_0} \cdot \left(\omega_i \cdot K_i \cdot x_i - x_i - c_{i,0}\right) + n_{i,g} \qquad \text{eq. 1}$$

The process time (dt) dependent change in the concentration (dx_i) of compound (i) which is in this particular case the aroma compound DMS is predictable via the evaporation velocity/evaporation rate ($\dot{D}$), the wort volume (L_0), the correction factor for flash evaporation (ω_i), the fugacity (K_i), the liquid side concentration of precursor ($c_{i,0}$) and the DMS formation given by term ($n_{i,g}(t)$).

In terms of a kettle boil phase 1 and 2 are calculated with the following equation:

$$\frac{dx_i}{dt} = -\frac{\dot{D}}{L_0} \cdot \left(K_i \cdot x_i - x_i - c_{i,0}\right) + \cdot k \cdot c_{i,0} \cdot e^{-k \cdot t} \qquad \textbf{eq. 2}$$

The different terms refer to the description of equation 1. In case of a kettle boil the calculation of formation is simplified so that the formation kinetic is indicated directly. Thus, the term ($n_{i,g}(t)$) as shown in equation 1 can be left out.

The calculation of the constructive improvement is based on a flash evaporation. It consists of putting equation 1 and 2 together. Again, both phases, phase 1 and 2, have to be calculated separately.

Phase 1 is calculated as shown below:

$$\frac{dx_i}{dt} = -\frac{\dot{D}}{L_0} \cdot \left(K_i \cdot x_i - x_i - c_{i,0}\right) + n_{i,g}(t) \qquad \text{eq. 3}$$

A comparison of equation 3 with equation 1 and 2 clearly shows the superiority of the constructive improvement. The different advantages of both the flash evaporation and the kettle boil are brought together. The flash evaporation's advantage is the improved formation ($n_{i,g}(t)$) as temperatures within the boiler are higher compared to the kettle. The kettle boil's advantage is the improved evaporation. Thus, parameter (ω_i) becomes one and is not part of equation 3 anymore.

Phase 2 contributes the reduction of superheating within the boiler. Equation 3 merges into equation 2. This is reasonable as DMSP is nearly entirely converted and a superheating within the boiler is thus not desired at this process step anymore. The reduction of superheating can be realised by reducing the heating rate while increasing the turn rate (for forced flow boilers) at the same time.

In the current article the reformulation and the corresponding constructive development are calculated with the shown equations. The changes in DMS and DMSP content are illustrated in order to highlight attaining a total DMS value of 100 µg/l as per DIN standard 8777. For this purpose equations 1 to 3 regarding the development of free DMS' content have to be added up with the equations regarding DMSP conversion [2, 5].

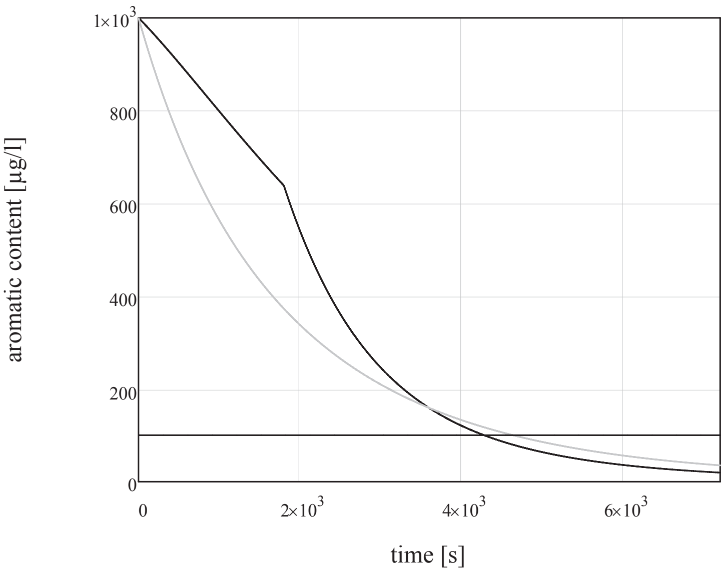

Fig. 1 Evaporation with kettle boil (grey curve) and optimised flash evaporation (black curve); (process' conditions view table 1)

Table 1 Process' conditions figure 1 and 3

DMS [µg]	500
DMSP [µg]	500
Evaporation Rate [GV/h]	0.06
Turn Rate 1 [Turn Overs/h]	2
Turn Rate 2 [Turn Overs/h]	20

Reformulation of wort boiling is calculated based on the values from table 1 and drawn in figure 1. Table 1 gives two different pump around velocities which refer to phases 1 and 2. Inverting the pump around velocities as shown in table 2 will lead to a different result. This is shown in figure 2. For the calculation of the constructive improvement conditions as shown in table 1 are used. The corresponding result is displayed in figure 3.

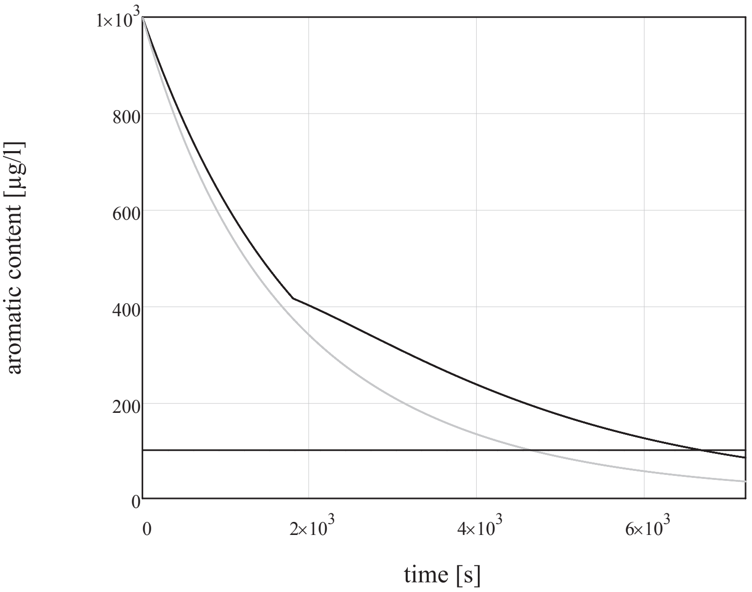

Fig. 2 Evaporation with kettle boil (grey curve) and not-optimised flash evaporation (black curve); (process' conditions view table 2)

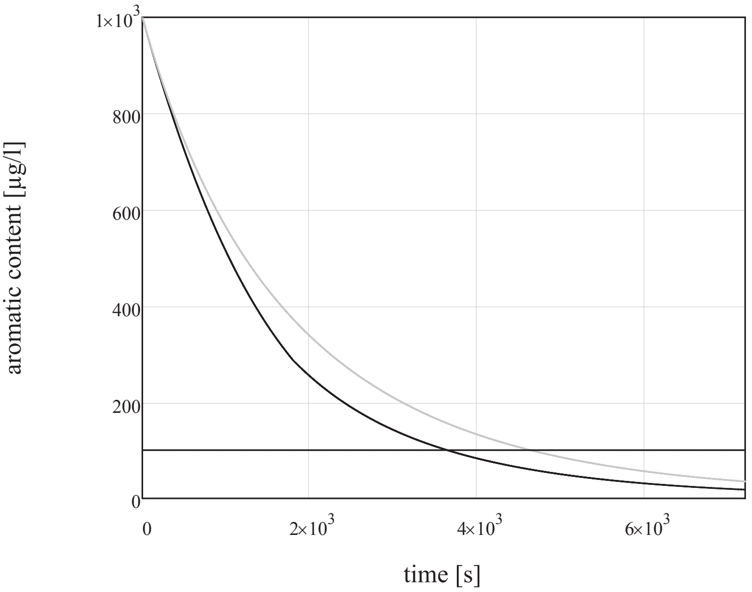

Fig. 3 Evaporation with kettle boil (grey curve) and new flash evaporation (black curve); (process' conditions view table 1)

3 Results and Discussion

Figure 1 illustrates the time dependent total content of DMS for flash evaporation and kettle boil. The black curve represents flash evaporation while the grey curve represents kettle boil. Figure 1 makes clear that flash evaporation is superior to a kettle boil for a process according to parameters from table 1. This is due to the two determined phases:

- At beginning of process in phase 1 an enhanced formation within the calandria is performed as temperature is strongly increased via a reduced pump around velocity of wort through the boiler (here exaggerated for visualisation purposes). At the end of phase 1 (here after 30 min) nearly all DMSP has been converted into DMS in the calandria. For a kettle boil this is not the case. Even if more DMS has been evaporated there is still DMSP as temperature is too low to achieve a sufficient conversion.
- As in phase 2 the increased pump around velocity (turn rate) sets in (here exaggerated for visualisation purposes) the evaporation within the calandria is improved. Even if free DMS' content at beginning of the current phase is higher for the flash evaporation only few DMS is formed. This is, why DMS content decreases more strongly with a flash evaporation as with a kettle boil. The latter is influenced by the formation in terms of its evaporation success. As a result, the flash evaporation is superior to a kettle boil in terms of the DMS reduction (reduction means simultaneous formation and evaporation) for the first time.

For figure 2 the particular case of inverting both phases' pump around velocity is calculated: (see table 2). Clearly visible is that kettle boil (grey curve) is superior to flash evaporation (black curve) for these conditions. In phase 1 both processes are nearly equal in terms of the DMS reduction due to the high pump around velocity. In phase 2 the influence of a worsened evaporation in the calandria predominates the advantage of a better formation.

Table 2 Process' conditions figure 2

DMS [µg]	500
DMSP [µg]	500
Evaporation Rate [GV/h]	0.06
Turn Rate 1 [Turn Overs/h]	20
Turn Rate 2 [Turn Overs/h]	2

Thus, it has to be stated that flash evaporation and kettle boil always have to be compared under the corresponding process conditions. Stating that internal or external boilers are generally worse compared to a kettle boil in terms of DMSP and DMS reduction is not valid. Kettle boil performs the optimal evaporation while flash evaporation performs the best formation. In order to achieve a process optimisation for internal of external boilers the phases of formation and evaporation have to be combined. The process as described in this article is superior to state of the art processes of separated hot holding and evaporation as it runs both phases optimised in terms of time and energy.

Figure 3 shows the constructive improvement as black curve compared to a kettle boil as grey curve. The calculation result is obvious: The reformulated process enables a better DMS reduction than the kettle boil does. DMS threshold of 100 µg/l in total is achieved earlier (about 20 % earlier). Accordingly, less energy has to be applied for constant or even reduced evaporation rates compared to the kettle boil.

4 Summary and Perspectives

The procedural considerations of wort preparation include calculations of both DMS formation and evaporation. The current article shows methods which enable optimisation of existing equipment only via reformulation of process guidance without the need of constructive modifications. An improved process has been introduced and the impact of a modification in pump around velocity has been illustrated, in particular.

Pushing these considerations further, leads to a procedural combination of both the advantages of flash evaporation and kettle boil which results in a process efficiency that so far was not achievable. Additional effects as for example improved hop isomerisation are yet not regarded. Furthermore an overall energy balance has to take peripheral consumers into account.

5 Literature

1. Feilner, R.: Forciertes Austreiben von unerwünschten Aromastoffen aus der Bierwürze, dissertation, TU Berlin; 2013.
2. Hertel, M.: Das Ausdampfverhalten von Aromastoffen während der Würzekochung, dissertation, TU München, 2007.
3. Scheuren, H.: Modellierung gekoppelter Austreibungs- und Nachbildungsprozesse aromatischer Komponenten in der Lebensmittelindustrie am Beispiel der Würzebereitung. dissertation, TU München, 2011.
4. Scheuren, H., Heinemann, S., Hertel, M., Dauth, H. and Sommer, K.: Vorhersage und experimentelle Bestätigung des Ausdampfverhaltens gängiger Würzekochsysteme, BRAUWELT, **14** (2008), pp. 380-384.
5. Scheuren, H., Methner, F.-J.; Sommer, K. and Dillenburger, M.: Thermodynamic validation of wort boiling systems, BrewingScience, **67** (2014), pp. 96-100.

Received 15 August 2014, accepted 17 Oktober 2014