

The function of wort boiling

The purpose of wort boiling is to stabilise the wort by:

- Killing spoilage micro-organisms.
- Reducing the amount of coagulable nitrogen thus promoting colloidal stability.
- Extracting the desirable principles of hops to give beer its characteristic aroma and flavour.
- Reducing undesirable volatile compounds through evaporation.

Clarified wort is usually collected directly in the wort kettle or run to a wort receiving vessel (often called a pre-run or underback) before being transferred to the wort kettle.

The wort kettle is fitted with heating, either using direct fuel combustion or indirectly, using steam. The wort in the kettle is first heated from wort separation run off temperature, which is between 65°C and 78°C, to boiling (usually just above 100°C, at atmospheric pressure because of the dissolved solids).

The kettle contents are then boiled for between 30 and 120 minutes. Wort boiling has a high energy demand and accounts for as much as 40% of the energy consumption of a brewery.

Most of the energy required to heat worts to boiling point is recovered during wort cooling through the use of heat exchangers, heating up the incoming brewing water (liquor) in preparation for the next brew. This gives a heat recovery efficiency of up to 99%.

The additional energy required to evaporate the water vapour during the boil is generally lost up the chimney. It is by reducing this energy loss that real savings can be achieved. A variety of schemes are available to recover part of the energy from evaporation.

The most effective ways to reduce energy consumption are by reducing % evaporation rates. The average % evaporation rates have fallen over the last 30 years from around 12 – 20% to between 4 – 8%.

In order to appreciate the consequence of reducing evaporation rates it is necessary to

Technical Summary 2

The second in this new series of technical summaries for the Institute & Guild's AME candidates.
By Tim O'Rourke.

understand the principle changes which occurring in the wort during boiling.

Sterilisation of the Wort

Brewing raw materials such as malt, hops and occasionally brewing water itself are infected by micro-organisms, and these have to be killed during the brewing process to prevent wort and beer spoilage.

After boiling the wort is largely free from microbial contamination. Some micro-organisms, primarily *Bacillus sp.* and other thermophilic bacteria are able to form spores which can withstand heat treatment, including boiling, and if present in the raw materials or the brewing water may persist into the finished beer.

However beer does not support the subsequent growth of these organisms.

Halting Enzyme Action

Enzymes rely on their three dimensional structure for their activity. Above certain temperatures, (usually in the range of 50-75°C) the tertiary structure of the enzyme becomes denatured, and they lose their activity. By the time the wort has reached boiling point there is usually no residual enzyme activity.

The continued action of enzymes after the normal mashing programme will alter the fermentability of the wort, and hence in a programmed mash there is a final mash temperature rise to between 76° and 79°C, which is sufficient to halt the malt enzyme activity.

Concentration of Wort

During wort boiling water is driven off as steam, thus concentrating the wort. The amount of water removed during the boil is directly proportional to the rate of evaporation (and hence the amount of energy supplied) once boiling has been achieved. The efficiency will be affected by the design of the kettle, particularly the surface area.

Traditionally, high gravity beers, such as strong lagers and barley wines had a long boil time, the major purpose being the evaporation of water to concentrate the wort. There are however other ways of achieving high gravity worts without excessive wort boiling:

- *Parti-gyles* - collecting different copper gravities.
- *Sugar adjuncts* – direct addition of extract to the copper.
- *Weak wort recycling* – recovering the weak worts from the lauter tun to be re-used for mashing.
- *Dewatering grains* – where the extract left in the grains is recovered and reprocessed for mashing, sparging or to be added to the kettle.
- *High extract wort separation techniques* – such as the Mash Filter achieve high gravity worts and high extract efficiencies.

These techniques enable the production of high gravity worts, while still maintaining brewhouse yield without the use of unnecessary heat for wort concentration.

Isomerisation of Bitter Substances

During boiling the insoluble alpha acid extracted from hops are converted to a more soluble iso-alpha acid. This reaction is accelerated by temperature.

Isomerisation is a relatively rapid reaction with production of over 90% of the wort bitterness occurring within the first 30 minutes of boil. Maximum isomerisation usually occurs within 60 to 70 minutes of

boiling and accounts for around 60% of the total alpha acid present. Iso alpha acid continues to be lost during the fermentation and maturation process and is lost in any foam produced so that the final conversion value of alpha acid into iso-alpha acid in the beer is around 40% (see Figure 1).

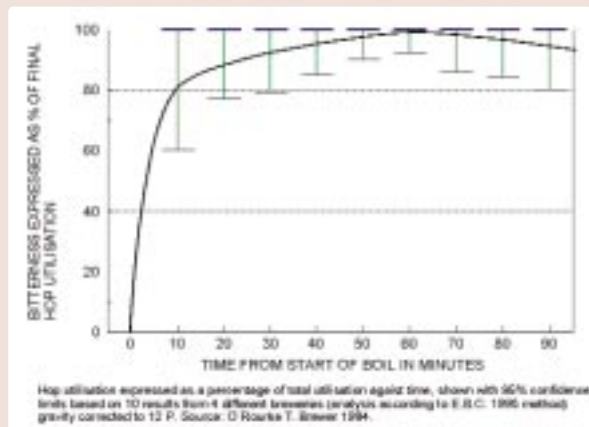


Figure 1

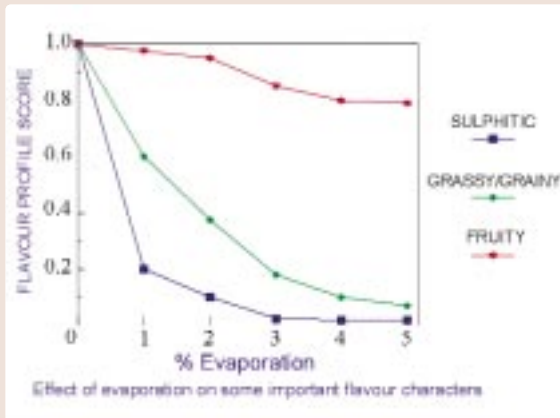


Figure 2

Removal of Volatiles

During the evaporation stage of wort boiling undesirable volatile compounds are driven off with the steam (see Figure 2).

The principal malt derived volatile lost during wort boiling is DMS or dimethyl sulphide which comes from lager malts and gives lagers a taste described as “sweetcorn”. It is produced by thermal decomposition of S-methyl-methionine in a first order reaction, with a half life of around 35 minutes (see Figure 3).

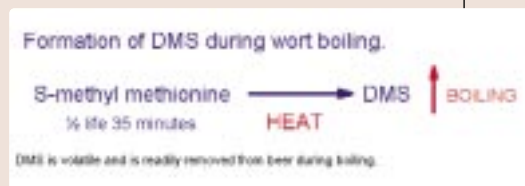


Figure 3

The DMS released during boiling is rapidly lost through evaporation. However, the breakdown of S-methyl methionine continues during the period between the end of boiling and wort cooling.

The DMS released is not lost and persists into the finished beer. It is, therefore, possible to control the level of DMS by varying the duration of boil and whirlpool stage.

Methods of control DMS levels in beer:

- use malt with low S- methyl methionine levels.
- long wort boiling time to decompose precursor and vaporise DMS.
- short whirlpool stand time to reduce decomposition of the precursor.
- rapid wort cooling – reducing the time the wort is held hot.
- use wort stripping after the whirlpool stand to remove DMS.

(Note: not all DMS comes from the malt and small amounts are produced during fermentation and by beer spoilage organisms).

It was found that by reducing the boiling time from 60 minutes to 45 minutes, with the same level of absolute evaporation, the survival of DMS precursor increased by 16% for a standard wort corrected to 1039° original gravity.

Hop volatiles (hop oils) are also lost during wort boiling, and if present in too high a concentration will contribute a bitter,

vegetable grassy flavour to the beer. Most of the hop oil volatiles are lost during a standard 60 to 90 minute boil. Where late hop character is required in beer, a small amount (up to 20% of the total hop charge) of selected aroma hops can be added to the kettle 5 to 15 minutes before the end of the boil.

The principal factors which effect the evaporation of volatiles include:

- Temperature of wort
- Vigour of boil
 - Surface tension
 - Condensation of volatiles in the vapour stack
 - Thickness of diffusion path
 - Duration of boil

The kettle design will have a major influence on the factors listed above and it is found that more late hop

character persists in gently agitated systems such as isometric kettle, than in more vigorous boiling systems with turbulent flow such as kettles fitted with an external wort boilers.

Increase in Colour

The colour of wort increases during the boil. The reactions responsible for colour development fall into three broad categories:

- Maillard reaction between carbonyl and amino compounds (see Figure 4).
- Caramelisation of sugars, which is limited in steam heated coppers.
- Oxidation of polyphenols.

Oxidation during wort boiling increases the colour particularly with oxidation of the polyphenols, which also has the effect of decreasing the reducing power of the wort and beer (see later).

Mash and wort produced with low oxidation produces lower wort and beer with lower colours and improved flavour stability.

Reducing Wort pH

Control of pH throughout the brewing process, from brewing water to final package, is fundamental for product consistency. Wort pH starts to decrease during mashing continues to fall during wort boiling. The principal fall in pH is due to the reaction of Ca₂⁺ compounds with phosphates and polypeptides to form an insoluble compounds releasing H⁺ (hydrogen ions) See Table 1.

At least half the calcium present in wort is precipitated by the end of wort boiling. Hence sweet wort with a starting concentration of

100 ppm will produce beer with around 40 ppm calcium.

To assist in the fall in pH extra calcium ions in the form of calcium sulphate or calcium chloride are added to the kettle. An alternative method to decrease pH is through the direct addition of acids such as phosphoric or sulphuric acid which drop the wort pH.

In Germany, where the addition of mineral acid is prohibited under the Reinheitsgebot the product of an acidified mash fermentation using lactic acid bacteria is sometimes added to the kettle to assist in dropping the pH and improving beer flavour.

It is important to achieve the required decrease in pH (generally around pH 5.0) as it effects wort and beer character, in particular the fall:

- Improves protein coagulation
- Improves beer flavour in particular VDK (diacetyl) reduction
- Encourages yeast growth
- Inhibits the growth of many other contaminating organisms.
- Lower pH results in poorer hop utilisation.
- Lower pH results in less colour formation

Reducing Wort Nitrogen Levels

During the brewing process it is necessary to decrease the level of high molecular weight nitrogen, which comes from the malt, and if allowed to persist can effect the pH, colloidal stability (chill haze and permanent haze), fining and clarifying properties, fermentation and taste of the beer. Wort boiling is only one, if an important stage, in the reduction of nitrogen, and the effect in reducing the amount of wort nitrogen (measured by the Kjeldahl method) for a standard boil at 100°C are shown below.

% Nitrogen removal after different boiling times for a standard boil

Time of boil (hrs)	% nitrogen removal
0	0
0.5	5.4%
1	6.2%
1.5	7.7%
2	9.9%
3	10.4%

Ref: Hough, Briggs and Stephen “Malting and Brewing Science”

Because of the relatively small overall reduction in total nitrogen during wort boiling it is difficult to obtain consistent results even from the same kettle with the same quality of wort. (for example, over 9 samples from individual brews, a result of 1.9 ± 2.3 mg/100

Maillard Reactions during heating (killing, mashing and wort boiling)

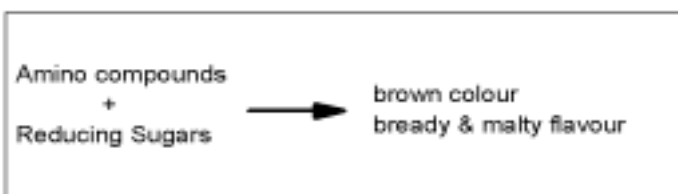


Figure 4

Table 1: Changes in pH which can occur during wort

Before boil	pH of wort	
	After 3 hours	After 6 hours
6.06	5.69	5.46
5.63	5.39	5.22
5.09	4.99	4.96

Ref: Hough, Briggs and Stephen “Malting and Brewing Science”

ml. was obtained at 95% confidence level).

However, using a more specific test (gel electrophoresis) it is possible to separate the nitrogen compounds by their molecular weight, to show that wort boiling is more effective at removing the higher molecular weight fraction, which is also the fraction responsible for colloidal instability in packaged beer (see Table 2)

The process of protein/polypeptide coagulation involves the replacement of intra by inter molecular bonds, thereby increasing the effective molecular weight of each molecule.

Aggregates of different molecular weight molecules are built up during wort boiling as a result of inter-molecular bonding, provided that they are not disrupted by mechanical shear. During the whirlpool phase, with sufficient time and momentum, these aggregates continue to coalesce and sediment out as hot break.

The degree of protein and polypeptide removed depends on the probability of individual molecules colliding and forming stable bonds during the boil, and this is directly proportional to the length and vigour of the boil for a given temperature. Traditional criteria used for evaluating efficient wort boiling are:

- Temperature of boil (usually just above 100°C when boiling under atmospheric pressure).
- Length of boil
- Evaporation % per hour

Traditionally conditions for wort boiling were a 90 minute boil with a minimum of 10% evaporation per hour. However, because of the need to reduce energy costs and to improve

brewhouse efficiencies shorter boiling times with lower evaporation rates are now employed; typical modern kettles operate with a 60 minute boil with between 5% and 9% evaporation.

A criterion not usually measured, but which has been shown to be of critical importance, is the degree of agitation or vigour of the boil. In traditional boiling systems the vigour or boiling intensity has been related to evaporation rate. If some other form of agitation through better design of heat exchange, mechanical rousing or use of pumped or thermosiphoned system is used, then additional agitation independent of the evaporation rate can be achieved.

This result is demonstrated in figure 5, which shows a similar decrease in the high molecular weight nitrogen fraction throughout a boil under atmospheric pressure with different evaporation rates, when the same level of agitation is supplied by an external wort boiler.

These results suggest that, given adequate turbulence during the boil, the actual removal of the high molecular weight nitrogen fraction is a function of time and vigour, and can be relatively independent of evaporation rate for atmospheric boiling.

Vigour is only one feature of importance for coagulation, since protein agglomeration is improved by intense vapour bubble formation. The actual wort surface temperature, and the duration of the intimate contact of the wort with the heating surface, may also be of importance.

Although it is often stated that it is desirable to remove as much protein/polypeptides as possible, nitrogen compounds have an important role in the quality and fermentation performance of a beer and in providing foam

compounds and mouthfeel. Excess protein/polypeptide removal could lead to poorer quality product.

Extraction and precipitation of tannins/ polyphenols

Simple hop tannins and most malt polyphenols are soluble in boiling wort and moderately soluble in cold water. Tannins/polyphenols are readily oxidised and polymerise to give an increase in molecular

weight. Tannin/polyphenols also combine with proteins to form protein/polyphenol complexes:

- Proteins which combine with oxidised polyphenols are insoluble in boiling wort and are therefore precipitated during the boil to form hot break.
- Proteins which combine with unoxidised polyphenols are soluble in boiling wort but precipitate when chilled and can give rise to chill haze and cold break. The polyphenols may subsequently oxidise during beer processing and may produce colloidal instability in packaged beer.

Unprocessed hops contribute around 40% of the total polyphenol content to boiled wort, however most hop polyphenols are removed as hot and cold break. The rest of the polyphenols comes from the dry goods, (particularly the husk), and less polymerized and hence less likely to be removed. Worts devoid of hop tannins give poorer wort clarity and have a lower reducing potential.

Producing Reducing Compounds

Malt and wort contain a number of reducing compounds which if not oxidised during the wort production or processing stages can provide the packaged beer with oxygen scavenging protection which may delay the onset of stale flavours and the rapid production of oxidised chemical hazes.

Many of these compounds come from the raw materials, such as tannins described above, but others such as reductones and melanoids are formed during wort boiling through the condensation between sugar and amino compounds. Darker beers with high addition of unprocessed hops tend to produce the greatest reducing power. Brewing systems with low levels of oxidation tend to preserve the natural reducing compounds in the wort, which can persist into package beer and delay the onset of ageing, improving colloidal and flavour stability.

Summary.

Wort boiling is a poorly understood but crucial stage in the stabilization of wort and the beer derived from it. Changes in the boiling process can effect the stability and quality of beer. ■

Further Reading

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2. Hough, Briggs and Stephen "Malting and Brewing Science".
3. O'Rourke *The Brewer* 1994.
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6. Hudson, J. R. and Rennie, H. *M.B.A.A. Technical Quarterly*, Vol. 9, No. 4.
7. Zanglando, T. *Brewers Digest*, April 1979. Buckee G.K. et al *J.I.B.* Vol 99, 1992. *European Brewery Convention Manual of Good Practice - Wort Boiling and Clarification.*

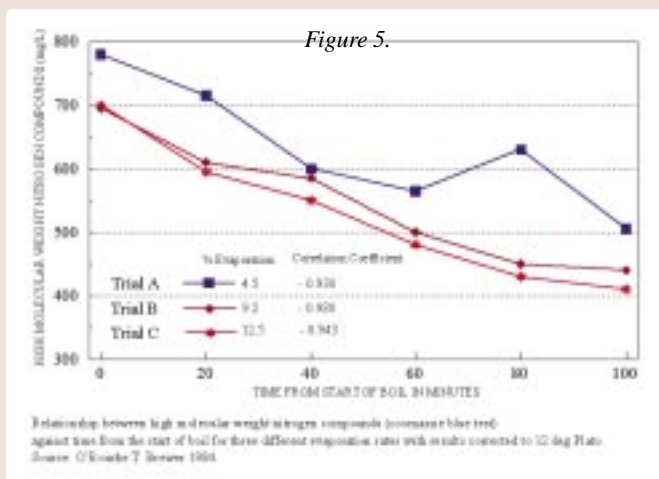


Table 2: Effect of boiling on the molecular weight distribution of wort proteins

Molecular distribution of proteins/polypeptides measured by gel electrophoresis					
	< 5,000	5,000 to 10,000	10,000 to 50,000	50,000 to 100,000	> 100,000
Before boil	0.0336	0.195	0.101	0.0023	0.0029
After boil	0.0175	0.125	0.004	0.001	0.0
% removal	49%	32%	96%	95%	100%

Ref: Hough, Briggs and Stephen "Malting and Brewing Science"