The process of wort boiling

The reasons for wort boiling were covered in Technical Summary No 2 published in the February edition of *The Brewer International*. This feature covers the methods used to achieve wort boiling.

Technical Summary 6

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The sixth in this series of technical summaries for the Institute & Guild's AME candidates.

Wort boiling has the highest energy requirement of any of the brewing processes. It can account for as much as 60% of the total steam demand of the brewery (depending on the type of packaging operations). It is therefore hardly surprising that a great deal of effort has gone in to reducing energy consumption and recovering energy from boiling.

Wort Boiling Plant Fig. 1

Traditional direct fired kettles Fig 1

Traditionally, wort was boiled in direct-fired kettles, often made of copper, since this metal has particularly good heat transfer properties.

Because the heat source was localised at the bottom of the kettle, it restricts the volume of wort which could be boiled at any one time to a maximum of 200 barrels (330 hectolitres) which probably explains why traditional breweries with larger brew-lengths used number of separate smaller size kettles.

The principal disadvantage of traditional direct peat or coal fired kettles are that they are relatively inefficient in heat transfer and tend to be labour-intensive. The heating surface of the copper becomes very hot and tends to promote caramelisation and burning of the wort, requiring frequent cleaning usually every 2 to 5 brews to ensure effective heat transfer is maintained. High evaporation rates were required to produce sufficient vigour or turbulence in the boil and typical boils would take over 90 minutes with an evaporation rate over 10% per hour.

Kettles with Internal Heating Systems Fig. 2

The advent of steam coils and internal heating systems allowed the production of larger kettles, as it enabled the designers to provide a larger heating area and, because it was surrounded by the wort, the heat transfer was more efficient.

In many designs the heaters were upright and located in the centre of the kettle to give a turbulent boil. Some of the kettles also include base steam coils for preheating the incoming wort, and to avoid the creation of dead spots within the kettles.

The disadvantage of internally heated kettles is that the heaters tend to be difficult to clean with conventional CIP, and were often manufactured from copper, which is dissolved by caustic cleaning.

The internal coils in particular are prone to corrosion, which can result in steam leaks in to the boiling wort which are difficult to detect and repair. Because wort circulation relies on thermal currents within the kettle the turbulence over the heating surfaces is sometimes limited, resulting in wort caramelisation, which requires more frequent cleaning to ensure effective heat transfer is maintained.

Kettles with external heating jackets Fig. 3

To overcome the difficulties with cleaning internal heaters, kettles with external heating jackets were designed. One of the most prolific designs was the Steinecker Asymmetric Kettle. They are generally made of stainless steel and achieve a rolling boil through the location of the heating jackets on one surface.

They suffer from similar problems to the direct fired kettles in achieving effective heat transfer, with the higher volume kettles being rather long and thin. They require mechanical paddles to achieve the necessary agitation for a satisfactory boil. This design overcomes the cleaning problems of the kettles with internal heaters, and has a lower tendency to foul, but it still requires cleaning every 6 to 12 brews to ensure effective heat transfer is maintained.

These kettles are also prone to fob formation during boiling and often use a cold air draught over the wort surface and an extractor fan to keep fob under control.

Kettles with External Wort Boilers Fig. 4

A more modern design uses an external heater (external wort boiler) which takes the wort out of the kettle and passes it through a shell and tube or plate heat exchanger for heating.

These wort boilers achieve high heat transfer through two phase flow and nucleate boiling, and operate at low steam pressure (at 3.0 to 3.5 bar) to heat the boiler.

In these kettles vigour can be introduced mechanically, by wort circulation, and the classical 10% evaporation/hour with a 90-minute boil, can be reduced to 5% to 6% evaporation/hour with a 60-minute boil without loss of wort/beer quality. This represents a considerable saving in energy.

These kettles have other advantages over internal heaters since pre-heating can start once 15% of the total kettle contents have been collected, allowing the kettle to boil immediately it is full, thus improving vessel utilization.

Since low pressure steam is used, the rate of fouling is decreased, allowing more brews to be processed between cleans. Typical installations can process 16 brews between cleans and this number can increase up to 32 brews. This decreases brew house downtime thus improving throughput.

There are some hybrid kettles which use an internal heater but also recirculate the wort through an external pumped loop to improve mixing and increase the vigour of the boil.

One of the negative aspects of external wort boiling involves having to pump the wort, where shear forces may damage the floc formation (trub or hot break particles). In appropriately designed installations this problem can be resolved by using the natural circulation of the thermosyphon effect. The boiler has to be primed during the pre-boil stage using a small circulation pump.

Once boiling is achieved the circulation pump can be by-passed and the wort will circulate due to the energy and change of state resulting from the density change between incoming wort to the boiler at 98°C and the outlet wort and vapour from the boiler at around 105°C.

Overpressure Wort Boiling

Both the internal and external boilers can be operated with an increased over pressure during the boil usually up to 1 bar.

This elevates the boiling temperature to

Figure 1: Direct fired copper

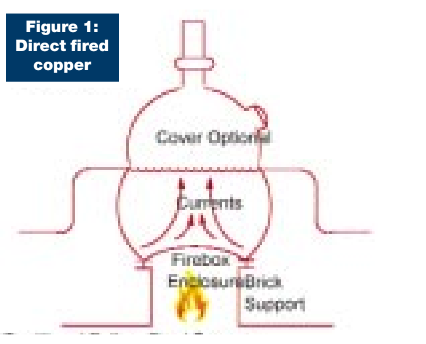


Figure 2: Steam heated kettle

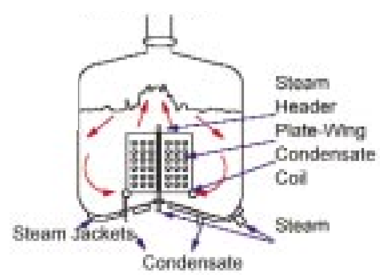


TABLE 1: COMBINED WORT BOILING & STRIPPING – TYPICAL OPERATING CONDITIONS

Wort boiling	Time (mins)	Flow rate (hl/h)	Steam Pressure (bar)	Evaporation rate (%)
Heating up	40	650	1.5	1
Boiling	40	500	1.1	2
Whirlpool rest	15	-	-	-
Stripping	50	120	1.2	1

around 106° to 110°C, which has the effect of accelerating the various wort reactions, and allows the boiling time to be reduced. At the end of boil the excess pressure is released allowing the escape of the volatile compounds.

Over pressure kettles are often operated with some form of vapour recovery energy systems. The advantage claimed from this system is that it allows a shorter boiling time and lower evaporation rates than might be considered necessary in a conventional boiling system.

Combined wort boiling and stripping (Merlin) Fig.5

Merlin is a more recent development which uses a form of external wort boiling to boil the wort and then to strip out the volatiles after the whirlpool stand.

Wort is pumped from the collection vessel across a conical heating surface, which is fed with live steam at 0.6 to 1.5 bar, thus giving a steam temperatures of the order of 110°C. The boiler is supplied with a large heating surface area – about 7.5 sq.m per 100 hl of wort.

The heater operates by providing a large heating surface covered by a thin film of wort allowing gentle boiling and rapid elimination of aroma compounds. The system is able to produce good quality worts with 4% evaporation in 40 minutes.

To strip any addition unwanted aroma compounds formed during the whirlpool stand the clarified wort from the whirlpool is passed over the heating cone on the way to wort cooling. This provides approximately an additional 1% evaporation. *See Table 1.*

Continuous high temperature boiling Fig. 6

An efficient way of reducing energy demands is to use continuous wort boiling, where the energy used for boiling is used for heating up the incoming wort in a multistage process. The process operates as follows:

- The wort from the lauter tun, feeds into a holding vessel where hop additions can be made.
- The wort runs through a specially developed three stage, reverse flow heat exchanger and is heated to approximately 135°C
- The temperature is held for approximately 1.5 to 2.0 minutes in holding tubes.
- The wort is held constant at 135°C by regulating the flow rate at the inlet to the first of two adjoining separators.
- As the wort flows into the separator, the pressure is lowered to a set level. This enables the wort to boil and evaporate.
- The latent heat (enthalpy) in the vapour is given up in the separators and is reused in heat exchangers I and II. Only heat exchanger III is heated with fresh steam (or hot water).
- The wort from separator II runs through a booster pump to one of three whirlpool-casting vessels. The effective volume of the whirlpools should be approximately equivalent to the capacity of one hour throughput from the boiler.
- Each pair of whirlpool vessels are filled alternately. As one is emptied and cleaned the other is available to receive the wort.

The higher boiling temperature of 135°C accelerates the chemical processes of:

- Isomerisation of the hop alpha acids
- Coagulation of the high molecular weight nitrogen compounds which are temperature dependent and are completed in 1.5 to 2 minutes.

An effective evaporation of around 7% is required to remove the undesired aroma components. Continuous wort boiling allows the steam demand of the brewhouse to be maintained at a constant level, thus avoiding the peaks resulting from batch heating or boiling of the wort.

Heat recovery is very efficient, requiring only prime energy input to compensate for the difference between the wort inlet and outlet temperatures and minor heat losses from the heat exchangers.

However, continuous wort boiling is difficult to manage with a number of different wort streams, and a number of brewers still reservations over quality.

Figure 3: Jacketed Asymmetric Kettle

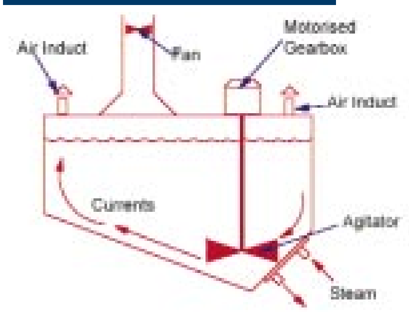
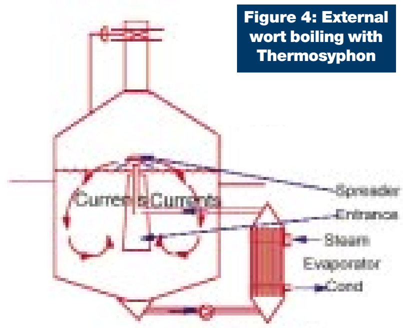


Figure 4: External wort boiling with Thermosyphon



Wort stripping

One of the principle functions of wort boiling is to remove unwanted volatiles such as hop oils and DMS (dimethyl sulphide) which come from the raw materials. Stripping of volatiles can often be the rate determining step for wort boiling and any reduction in boiling time or evaporation rate will have an adverse effect on the level of volatiles remaining in the beer.

Similarly some volatiles, DMS in particular, continue to be formed in the hot wort after boiling is completed and the levels build up in the wort prior to cooling.

The removal of unwanted volatiles after boiling can be split into two stages:

- The first stage takes place in a conventional wort kettle, where the wort is boiled or heated to boiling point and the volatiles are removed with the water vapour evaporated,
- The second stage occurs after wort clarification and before wort cooling, when the volatiles are stripped from the wort in a stripping column. The wort leaving the stripping column has the same or even a lower level of undesired wort aroma compounds compared to a conventionally boiled wort.

Wort stripping should take place after (hot) wort clarification (e.g. whirlpool) and wort cooling. In the normal process wort volatiles continue to be formed after the end of wort boiling during the hot wort stand (clarification and cooling). However, in the absence of evaporation, they are no longer eliminated. Wort stripping is an effective method of removing some of these volatile substances.

The Merlin wort boiling system offers a way of stripping the volatiles after the whirlpool stand.

Factors affecting boiling efficiency

Wort boiling relies on the efficient transfer of energy from the heating source in to the wort. The efficiency is influenced by a variety of design characteristics such as:

- heating area
- material of construction
- steam pressure (which directly relates to temperature).

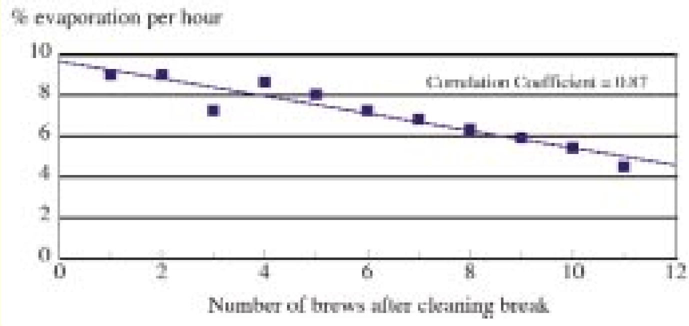
Traditional kettles were made from copper (hence their name) and copper has a much better heat conductivity than stainless steel (the current preferred material of construction) *see Table 2.*

However as each brew is boiled small deposits of caramelised wort along with precipitated mineral from the hardness in the water are deposited on the heating surface building up a fouling layer, which acts as a barrier to heat transfer. This fouling layer has a much greater effect on heat transfer than any material of construction and is the principal resistance to heat flow. The formation of fouling on the wort side of the heater results in a steady fall off in heat transfer with each brew which can be followed by a decrease in evaporation. *See Figure 7.*

TABLE 2: THERMAL CONDUCTIVITY k FOR DIFFERENT MATERIALS OF CONSTRUCTION (W/m°C)

	20°C	100°C	200°C	300°C
Copper (pure)	396	379	374	369
Ferritic Stainless Steel	25	25.5	-	27.5
Austenitic Stainless Steel	16.3	17	17	19

FIGURE 7: FALL OFF IN EVAPORATION WITH SUCCESSIVE BREWS BETWEEN A CLEAN



% evaporation from a standard boil for each brew as measured from the weight of steam supplied. Source: O'Rourke – The Brewer *1984.*

The key factor in reducing fouling include:

- Soft water (ie; low hardness/ carbonates)
- Whole hops (rather than pellets or extract)
- Lower wort original gravity
- Low differential heating temperature (hence moderate heat flux)
- Avoiding excessive energy input, especially short term peaks
- Thorough mixing of liquid adjuncts prior to entering the heater
- Turbulent nucleate boiling (rather than film boiling).

It follows for any kettle processing more than one brew between cleaning, and boiling to a constant time, there will be a difference in evaporation rate between the first and the final brews.

To ensure a constant evaporation is achieved, some systems control wort boiling by the mass of steam delivered. This can be integrated so that it is evenly supplied through the allotted boiling span by means of proportional steam control value, thus ensuring that the evaporation rate is constant regardless of copper volume.

Other systems control evaporation rate by the increase in original gravity or decrease in wort volume, or a combination of both systems.

Reducing the energy consumption during wort boiling

All the sensible heat supplied to heat the incoming wort from lauter transfer (around 78°C) to boiling (at just over 100°C) will be recovered from wort cooling through the heat exchanger or paraflow.

It is generally the energy supplied to evaporate the water (plus volatiles) from the wort which is not so easily recovered. The best way to reduce this energy demand is not to use it in the first place, and there has been a gradual reduction in evaporation rates from 10 to 12% per hour for a 90 minute boil (amounting to a total of 15 to 16% evaporation per hour) to 5 to 6% evaporation for 60 minutes. This has been brought about by designs and process control changes detailed above.

There are a number of ways in which the brewer can recover or re-use the energy used during evaporation.

A number of heat recovery systems produce hot water and the effectiveness of the system depends on the brewery being able efficiently to utilise the low grade hot water recovered.

The typical schemes used recover the latent heat of evaporation from the wort boiling process may be grouped into three types:

1. Recovery of energy for use outside the brewhouse, e.g., either by a simple condenser system exporting hot water or using absorption refrigeration;

2. Recovery of energy for use in the brewhouse, e.g., using hot water from a vapour condenser/energy store system for wort preheating prior to wort kettle;

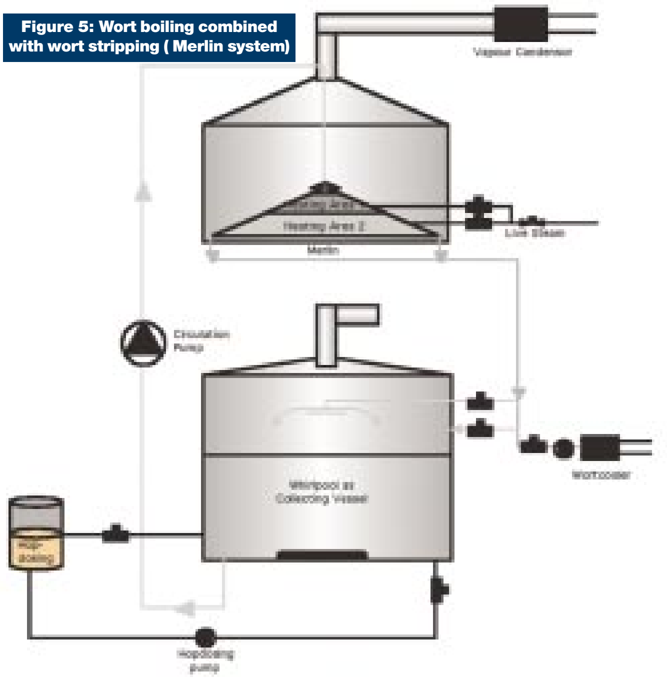
3. Recycling energy within the wort boiling process using either mechanical vapour recompression (MVR) or thermal vapour recompression (TVR).

Summary

Wort boiling has the highest energy demand of all brewing operations, and hence has been subject to considerable research into ways of reducing its energy consumption. The prime energy used to heat the wort to boiling point is recovered through the wort coolers for re-use in brewing.

It is the energy used to evaporate the water which is more difficult to conserve. Over the last three decades evaporation rates have fallen by a factor of three, through better process operations and improved kettle design. The opportunity for further decreases no longer exists and brewers are looking at ways of recovering the energy used in evaporation and either recycling it in the boiling process or using it as a source of energy for other processes in the brewery. ■

Figure 5: Wort boiling combined with wort stripping (Merlin system)



● **Further Reading**

1. Moll "Beers and Coolers"
2. Hough, Briggs and Stephen "Malting and Brewing Science"
3. O`Rourke *The Brewer* 1994
4. Wilkinson R. *Ferment* p 397 Vol 4 No6 Dec 1991
5. European Brewery Convention Manual of Good Practice – Wort Boiling and Clarification.

Figure 6: Continuous wort boiling system.