Reducing energy use in wort boiling

In a nutshell

Summary				
Best practice is to reduce the energy use during wort boiling by: • implementing wort preheating with heat recovered from the wort vapour condensing thanks to the use of an energy storage system, • reducing evaporation rates during boiling (e.g. by two-phase boiling systems, dynamic low-pressure boiling) provided that the beer taste allows adopting this solution.				
Target activities				
All food and beverage manufacturing	Processing of coffee	Manufacturing of olive oil	Manufacture of soft drinks	Manufacture of beer
Production of meat products	Manufacture of fruit juice	Cheese making	Manufacture of bread, biscuits and cakes	Manufacture of wine
Applicability				
This best practice is broadly applicable to all manufacturers of beer. The adoption of wort preheating is applicable to new breweries, provided that there are no space restrictions for installing the equipment needed. In the case of existing plants an economic study should be carried out in order to assess the opportunity to change the wort boiling installation. The reduction of evaporation rates is not suitable for all types of beer since it influences the beer's organoleptic characteristics. When implemented, it needs to be considered within the overall brewing process and applied to the extent that is suitable to the specific product.				
Environmental performance indicators				
• Evaporation rate (%) during wort boiling • Overall energy use in the production process per hectolitre of beer produced (MJ/hl) • Energy use in wort preheating per hectolitre of beer produced (MJ/hl) • Number of brews between two cleans of the kettle				
Benchmarks of excellence				

- A wort preheating system with recovered heat from wort vapour condensing is installed.
- Evaporation rate during wort boiling is less than 4%

Description

The brewing process is energy-intensive, especially in the brewhouse where mashing and wort boiling are the main heat-consuming processes (Table 1). Breweries with conventional systems for process heat have consumption figures between 36 kWh/hl and 40 kWh/hl while it is reported that the Best Available Technique (BAT) provides a minimum benchmark of 24 kWh/hl (Scheller et al., 2008).

Table 1: Energy demand in brewhouse at 7.5% of total evaporation (Scheller et al., 2008)

	Energy use (kWh/hl)	Energy use in brewhouse (%)
Mashing 52/78°C	2.21	19.8
Heating 78/99°C	3.38	30.2
Boiling	5.03	45
CIP	0.28	2.5
Hot service water	2.28	2.5

During the mashing process the malted barley is mashed with hot water for a period to allow the enzymes to break down starch and proteins. Once the wort is separated from the brewers grain by filtration, it is boiled for 1 - 1.5 hours in the wort kettle with hops or hop extracts. The rate of wort evaporation during boiling is 5 - 8 % of the casting volume per hour (EC, 2006).

The boiling stage has particular importance for the beer quality because in this operation the wort is sterilised, the malt enzymes are inactivated, the hops are added to the wort and the undesirable aromas and flavouring compounds are evaporated.

Traditional wort boiling requires high total evaporation (8-12%) to produce enough turbulence in the boil for a homogeneous wort heat transfer and guarantee the stripping of undesirable volatile substances. Two compatible strategies are described: a) recovering heat from boiling vapour condensate and b) reducing total evaporation in boiling. Both techniques can be implemented at the same installation.

<u>Wort pre-heating with heat recovered from the wort vapour condensing</u>

The heat recovery can result in the production of hot water for cleaning operations, flushing brew kettles etc. (EC, 2006).

However, in recent years some brewing plants have been implementing “energy storage systems” for recovering vapour condensate, which is integrated in the heat supply system to preheat the wort before boiling. The wort can be heated from

72°C to approximately 90°C by means of the heat recovered from the vapour condensate (Buttrick 2006; Krones 2013a, 2013b; GEA 2013).

The system consists of several parts: the vapour condenser, "energy storage tank", wort pre-run tank and wort heater. The "energy storage tank" stores water with an internal temperature gradient, colder at the bottom and hotter at the top. The cold water from the bottom part (~77°C) is used to condense the vapour in the vapour condenser. This water heats up to approximately 97°C and is returned to the storage tank from where is used to pre-heat the wort stored in the pre-run tank from 72°C to approximately 90°C. Water is then re-circulated again to the vapour condenser. Alongside this, vapour condensates produced in the vapour condenser are stored in another tank to be used in ohter processes such as cleaning operations.

Table 2 shows the energy savings achieved during wort boiling implementing energy storage systems. The total energy and time needed for the first stage (heating the wort to boiling temperature) is reduced by 70%. The reduction in heating time results in an increase in the number of brews per day.

Table 2: Energy savings using energy storage systems: Evaporation rate of 4% (Krones, 2013b)

	Standard	With Energy storage system
Evaporation [%]	4	4
Temperature at start of heating [°C]	75	92*
Temperature at start of boiling [°C]	99	99
Energy for heating [kJ/hl]	10,176	2,968
Heating time [minutes]	48*	14**
Brews per day	10.8	14.5

* Downstream of lauter wort heater; ** Start of heating at lauter end

Techniques for reducing evaporation rate during wort boiling.

It is reported that each 1 % of evaporation during wort boiling corresponds to a specific energy loss of 0.67 kWh/hl. Therefore it is worth applying practices that reduce the total evaporation because of the high impact on total energy consumption in the boiling process. However, this technique can be adopted provided that the beer taste allows it.

The standard total evaporation for an acceptable wort quality is around 8–12% despite the fact that breweries use different set points regarding time and evaporation rate. The quality of wort is related to the maintenance of homogeneity during wort boiling, low thermal stress on wort particles and enough stripping of unpleasant flavour volatiles. New techniques allow evaporation to be reduced to values below 4% without jeopardising the wort quality.

Different technical approaches have been developed by manufacturers to reduce total evaporation based on either increasing the heat transfer homogeneity (lower temperature differences between the heating medium and the wort by effectively increasing the heating area) or promoting the stripping of volatiles (by promoting the formation of liquid/vapour bubbles).

In particular, the two-phase boiling system achieves reductions in total evaporation to values under 4%. The first phase corresponds to the thermal conversion, in which wort naturally flows through the internal boiler and the boiler is pressurised very slightly to overcome the low pumping height for circulation. Only very little evaporation occurs in this phase and so, its duration can be selected irrespective of the required evaporation. In the second phase, an intensive evaporation of flavours takes place. The two phases (boiling with high homogeneity and stripping) are achieved with the same boiler equipment and in separated kettle and stripping equipment (Buttrick 2006; GEA-Huppmann 2013; Ziemann 2013). A reduction in total evaporation to values under 4% can be also achieved by means of a low rate evaporation boiling stage followed by an additional stripping step. Stripping is caused by flash evaporation due to a drastic drop in pressure in the liquid phase (Krones 2013c; Ziemann 2013).

Dynamic low-pressure boiling

Similar evaporation figures can be achieved using the dynamic low-pressure boiling technique. This technique involves heating wort at a pressure of 150 mbar, equivalent to a boiling temperature of 103°C. When this pressure is reached, it is rapidly reduced to 50mbar and the temperature drops back to 101°C. This takes place several times during each boil and the effect produces a flash evaporation, with the formation of foam and bubbles within the wort kettle, which strips unwanted volatiles and aids coagulation of hot break particles. In order to accommodate the flash evaporation, the kettle volume needs to be 30% greater than for a standard system and the wort is circulated 20–30 times per hour (Buttrick 2006).

The two-phase system and dynamic low-pressure boiling system can be combined in the same equipment. In this case, the second phase is conducted/considered as dynamic low-pressure boiling improving the stripping of undesirable aromas due to an intense formation of steam bubbles in all the wort in the kettle. This combined system allows the removal of undesirable aromas with very low total evaporation rates (3-4%) (GEA 2007).

Environmental benefits

The main environmental benefit achieved with heat recovery and reduction in the wort evaporation systems is the reduction of thermal energy use. As this operation accounts for most of the energy requirement in the brewing processes, their implementation has a significant impact on the total energy consumption in the brewing plant. The installation of a vapour condenser and plate heat exchanger to recover heat from the wort vapour can reduce by 70% the energy needed to preheat the wort from 74 to 95°C during the transfer from the tank to the wort kettle.

The energy saving in wort boiling reaches 0.67 kWh/hl. In particular, the energy saving with dynamic low-pressure boiling at a total evaporation rate of 4.5% is approximately 19% lower compared with atmospheric boiling at 7.5% total evaporation. The equivalent reduction of CO_2 emissions would be 0.43 kg CO_2/hl (Scheller 2008).

Therefore a reduction in the use of fossil fuels is achieved with an additional benefit of reducing the CO_2 emissions. Moreover, the condensation of wort vapour minimises odour emissions.

An additional positive environmental effect of the reduction in the evaporation rate is the reduction of the cleaning of the kettle. During each brew a fouling layer is created in the wort side of the kettle which acts as a barrier to heat transfer. This layer has to be eliminated by means of periodic cleaning after a number of brews. The reduction in the evaporation rate reduces the formation of fouling so that less water, energy and cleaning products are required for cleaning. Typical installations require a cleaning operation after processing 16 brews. The number of brews between cleans can increase up to 32 in the case of kettles with external wort boilers where low pressure steam is used (O'Rourke, 2002).

The energy store (wort pre-heating) results in 68-80% energy savings by using recovered boil energy. It is reported that a minimum evaporation level of 3.6% is necessary to recover enough heat for wort pre-heating. Where evaporation exceeds this figure, excess recovered energy may be used for CIP or water heating (Hancock, 2014).

In particular, the following energy reduction levels can be compared for the use if wort preheating (Hancock, 2014):

a) with no wort preheating: heating 1000 hl wort from 75°C to 100°C requires 10000 MJ

b) with wort preheating: heating 1000 hl wort from 92°C to 100°C requires 3200 MJ

Therefore, the achieved savings are 6800 MJ[1] or 68%.

According to Hancock, (2014) it is reported that a 1% reduction in evaporation results in energy savings of 2 to 4% of brewhouse energy consumption as well as emission reduction.

[1] For steam: 6800 kJ/ 2133 kJ/kg = 3,188 kg/brew

Side effects

The reduction of total evaporation in wort boiling reduces the energy recovery for wort pre-heating. This lower energy recovery could be compensated with another low temperature heat source, such as solar thermal heat.

A reduction of the boiling time can entails extra wort recirculation requirements to increase the homogeneity of boiling. The additional power consumption of extra pumping should be considered. However, in appropriately designed installations, this problem can be minimised by using the natural circulation of the thermo-syphon 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 circulated due to the density change between the wort entering the boiler at 98°C and the wort and vapour exiting from the boiler at around 105°C (O'Rourke, 2002).

Applicability

This best practice is broadly applicable to all manufacturers of beer. Energy storage systems are applicable for any brewing plant, provided that there are no space restrictions for installing the tanks (storage, wort pre-run) and the condenser.

Energy-saving methods based on the reduction of evaporation rate are applicable for any new brewing plant. Different technological alternatives exist for different plant sizes.

For existing plants, an economic study should be compiled in order to assess the opportunity to change the wort boiling installation and the most suitable alternatives. Additionally, the reduction of evaporation rates is not suitable for all types of beer since it influences the beer's organoleptic characteristics (Hancock, 2014). When implemented, it needs to be considered within the overall brewing process and applied to the extent that is suitable to the specific product.

Economics

The energy storage system involves the installation of a condenser, a hot water storage tank and heat exchanger for taking the wort from approximately 75°C after the wort separator to 95°C. Large energy savings are possible, especially if the energy recovered from the vapour condenser is used for preheating wort going to the copper vessel.

Data from Mahou-San Miguel in Alovera show an investment of around EUR 1,800,000 with a yearly saving in energy of EUR 825000.

Driving forces for implementation

Brewing is an energy-intensive activity, so brewers are very interested in finding innovative solutions to reduce energy consumption. Wort heating and boiling is one of the most relevant stages in energy consumption, so the improvement of energy efficiency is a challenge for brewing companies. Economic savings are the main driving force to install the systems proposed.

Another driving force is the reduction of direct CO_2 emissions (fuel combustion for thermal energy) and therefore the reduction of carbon footprint linked to produced beer.

Reference organisations

Table 2: Reference organisations for the implementation of wort pre-heating and reduction of evaporation

Company	Country	Technique
Heineken Madrid plant	Spain	Wort vapour recovery system Reduction of the evaporation rate with two-phase wort boiling from 6.2 % to 4.5 %. This technique has reduced the thermal energy rate to 1.5 MJ/hl beer. (Heineken 2013)
Heineken Seville plant	Spain	Wort vapour recovery system Two-phase wort boiling Dynamic low-pressure boiling (testing) (Heineken 2013)
Heineken Vialonga plant	Portugal	Reduction of the evaporation rate from 4 % to 2.5 % (Heineken sustainability report 2012)
Heineken The Wijlre plant	The Netherlands	Achieved an evaporation rate of 2.5 %, down from 4.5 %. (Heineken sustainability report 2012)
Mahou-San Miguel Alovera plant	Spain	Wort vapour recovery system. Total consumption of thermal energy was reduced by 25 %, (Mahou-San Miguel 2013 pers. comm)

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