Crisp Malt Webinar Series: Wort Boiling
09/04/20

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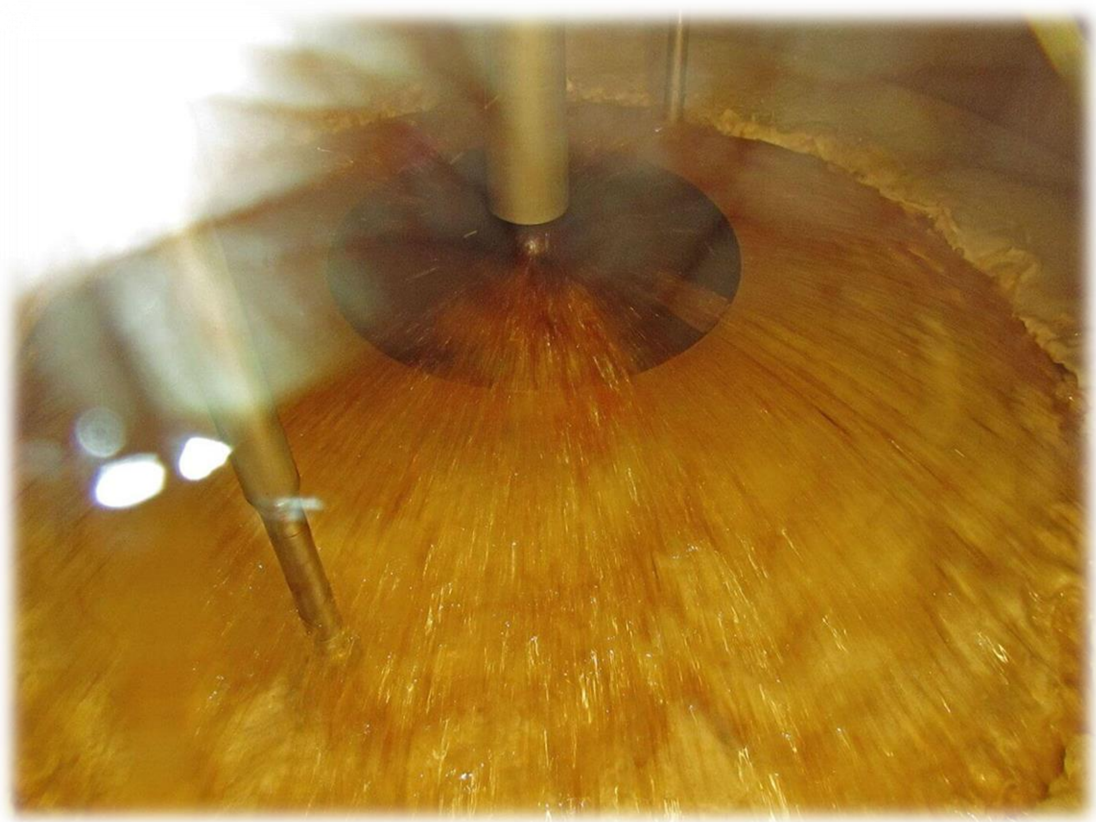
https://crispmalt.com/news/4-crisp-webinar-boiling/

Wort Boiling

- Materials & Methods
- Main Objectives
- Process Overview
- Enzyme Deactivation
- Sterilisation
- Evaporation
- Trub formation and pH reduction
- Hops and bitterness
- Removal of volatiles
- Colour and flavour development



Wort Boiling - Materials

- Early kettles were made from cast iron and heated over open fires. As scale increased, they became covered and had chimneys added.
- By the 20th century nearly all were made from copper
  - Easily worked
  - High thermal conductivity
  - Can catalyse oxidative reactions
  - Remove sulphur substances from the wort

- Modern kettles are made from stainless steel but are still often called coppers
  - Cheaper
  - Better resistance to chemicals
  - Less easily worked so simple shapes
  - Its stronger so can be made thinner making the lower thermal conductivity less important

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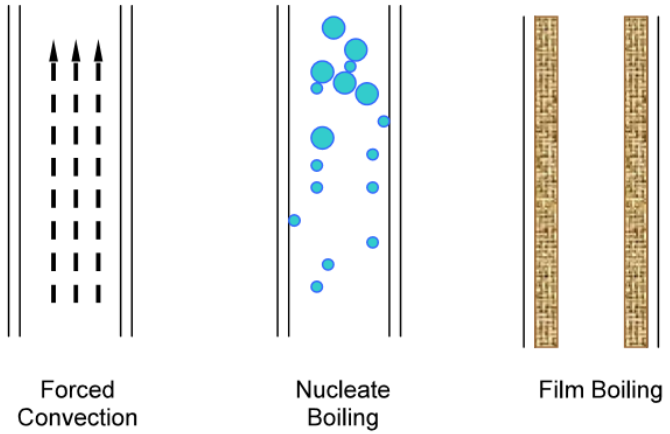
Wort Boiling – Modes of Heat Transfer

- Forced Convection
  - Wort is pumped at high velocity with turbulent flow picking heat
  - Good for heat transfer but has high sheer
- Nucleate Boiling
  - Bubbles form and create turbulence
  - The bubbles move away from the wall taking heat with them allowing fresh liquid to be heated
  - Ideal for wort heating
- Film Boiling
  - Should be avoided
  - Occurs when there are high temperature differences
  - The bubbles cling to the wall and join up to form a vapour film
  - The film acts as an insulator increasing the wall temperature



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Wort Boiling – Fouling

- Fouling of the heating surface reduces heat transfer
- The following reduce fouling:
  - Soft water – hard water will form scale on heating surfaces
  - Whole hops rather than pellets or extracts
  - Lower differential heating temperatures
  - Avoid excessive energy input
  - Avoid grain carryover from the tun
  - Low wort gravity's
  - Regular cleaning
    - NAOH between 2% and 4% (on stainless steel)
    - NAOH additives boost detergency by adding a source of oxygen

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Wort Boiling – Different Heating Methods

	Electricity	Direct Heating	Steam	Hot Oil Generator (HOG)
Brewery Size	Up to 15 brl (24hl)	10 to 50 brl (16hl - 82hl)	20 brl up (33hl)	20 brl up (33hl)
Methods of heat transfer	Element in kettle	Hot flue gasses through jacket or coil	Through jacket, internal or external calandria	Jacket, coil, internal or external calandria
Capital Cost	Low	Medium	High	Medium - High
Efficiency	Low	High	High	High
Differential Temperature	High	High	Low	Low
Colour Pick up	Higher	Higher	Lower	Lower
Speed of heating	Slow	High	Medium	Medium
Use in other parts of the brewery?	No	No	Yes in all parts	Yes (but not steam sterilisation)

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Wort Boiling – Electric Elements

- Electric Elements
  - Up to 4 brl needs an electricity supply of 20kw @ 240v
  - Between 4 and 15 brl needs between 28kw @415v to 60kw @415v
  - High differential temperatures give higher colour pick up
  - Spreading out the elements disrupts convection currents and can cause local over heating.
  - Power controllers can reduce the differential temperatures
  - Remember to switch them off

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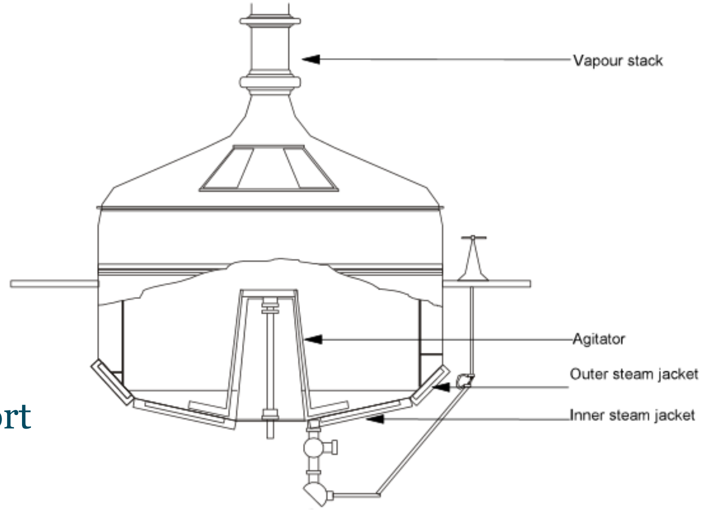
Wort Boiling – Coils & Jackets

- Internal Coils
  - Steam or Hot flue gasses are fired into a stainless steel coil wound around the inside of the kettle
  - Difficult to control applied heat causes wort caramelisation and burning onto the coil
  - Difficult to keep clean
- Jackets
  - Thermally inefficient
  - Difficult to control applied heat causes wort caramelisation and burning
  - Difficult to keep clean
  - Agitator needed for vigour



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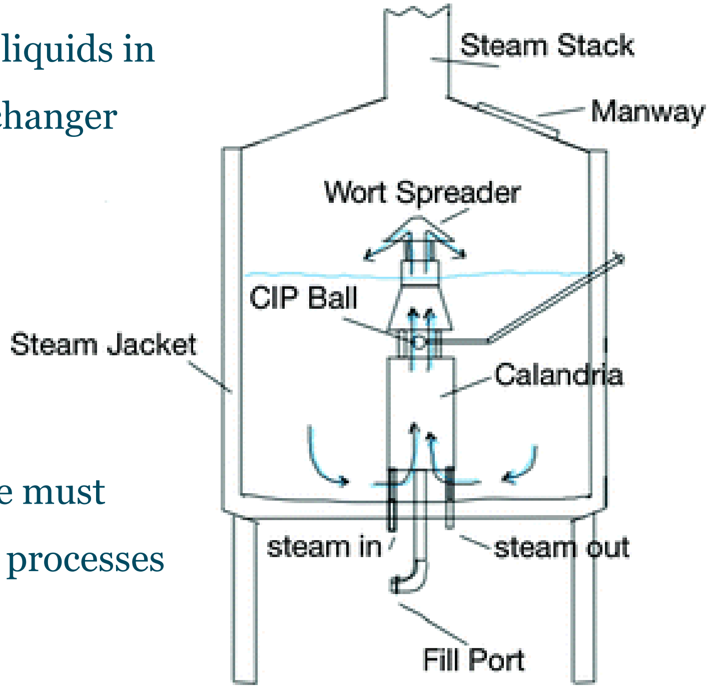
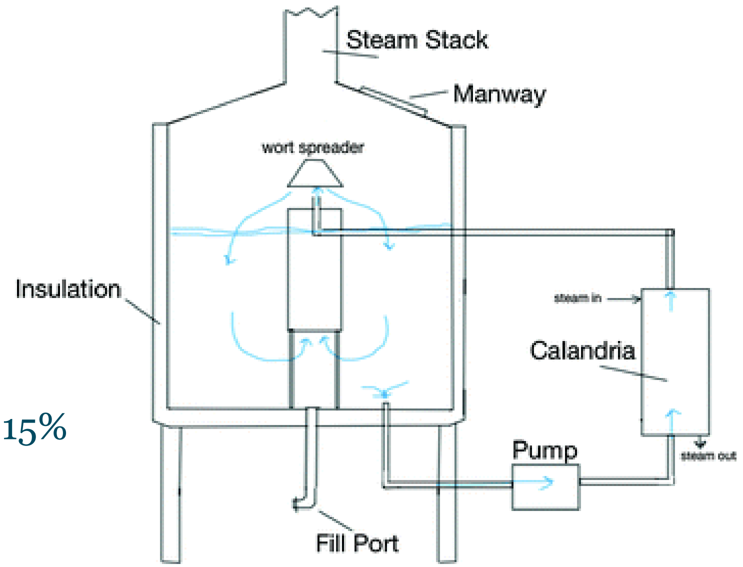
Wort Boiling – Calandrias

- A calandria is a closed vessel penetrated by pipes so the liquids in each don't mix – Its essentially a shell and tube heat exchanger
- Internal Calandria
  - Still common place
  - Thermally efficient
  - Tubes need to be covered before heating – the kettle must almost be full causing a delay in process time. New processes are getting around this.
  - Wort circulation relies on thermal currents within the kettle so turbulence over the heating surface can be low causing caramelisation. Modern example's have pumps fitted.
  - With an enclosed system fobbing can be kept to a minimum



Wort Boiling – Calandrias



- External Calandria
  - Vigour can be introduced mechanically
  - Improvement in hop utilisation
  - Pre-heating can commence once the kettle is around 15% full
  - With an enclosed system fobbing can be kept to a minimum
  - On some systems, the calandria can be cleaned independently of the kettle
  - Longer tubes allow lower pressure steam and reduced caramelisation
  - Its possible to re-introduce wort at a tangent allowing the vessel to become a combined kettle/whirlpool reducing transfer time and may reduce damage to the trub.

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Wort Boiling – Different Heat Transfer Surfaces

	Electric Element	Internal Jacket	Internal Coil	Internal Calandria	External Calandria
Brewery Size	Up to 15 brl (24hl)	10 to 50 brl (16hl -82hl)	20 brl up (33hl)	50brl up (82hl)	13 brl up (22hl)
Methods of heat	Electricity	Direct fire, steam or HOG	Direct fire, steam or HOG	Steam or HOG	Steam or HOG
Efficiency	Low	Low	High	High	High
Vigour	Low	Low	Low	Medium	High
Colour Pick up	Higher	Higher	Higher	Medium	Lower
Speed of heating	Slow	Slow	High	Slow (due to volume needed)	High
Cycles before CIP	2-3	2-5	5-8	8 - 10	8-16

Wort Boiling Main Objectives

- Halt enzyme activity
- Sterilise the wort
- Concentrate the wort by evaporation
- Reduce pH precipitate unwanted compounds
- Extract bitter substances and aroma from hops
- Remove unwanted volatile compounds
- Colour and flavour development

Wort Boiling - Overview

- Sweet wort is run-off from the mash or lauter tun and collected in the kettle.
- The kettle slowly heats the sweet wort so the temperature of the wort approaches boiling as run-off completes
- The wort is boiled vigorously for 1 to 2 hours
- Boiling effectiveness is normally measured by calculating the evaporation from the increase in gravity or alternatively the reduction in volume
- Hops are added at the start, middle and end of the boil for bitterness, flavour and aroma respectively
- 39% of the energy usage in a brewery is due to wort boiling, nearly half of this is pre-heating the wort (raising to 100^{o}C)

Wort Boiling - Safety

- Hot wort is very dangerous – its hot and sticky and causes severe burns
- Before sampling or making additions to the kettle:
  - Turn off any heating and agitation
    - Modern systems should have interlocks fitted
  - Add additions slowly – if you have any heat pockets these can be disturbed and cause over foaming
  - Use early hops or antifoam to avoid over foaming
  - Have written SOP's and train staff
  - PPE must fit and not be damaged
- Follow pressure regulations

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Enzyme De-activation and Sterilisation

- Most enzymes should have been denatured during run-off if the sparge temperature is high enough
- Fungal β-glucanase will reduce wort viscosity and amylo-glucosidase (AMG) will create a completely fermentable wort, both are active up to 80-90^{o}C and will survive mashing and sparging. Boiling will deactivate them.
  - If producing a zero attenuation beer such as low carb or Brut IPA, AMG will need to be added to fermentation
- It is a given then, that the sugar spectrum of the wort is fixed once boiling is achieved (unless you add sugar)
- Bacteria, spores, yeast and mycelial fungi will be present in wort until it is boiled

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Evaporation

- Wort held between 98°C and 100°C without boiling or agitation remains turbid
- While we can measure the temperature, measuring and controlling the vigour is difficult so we use the evaporation rate
- Normally 5 to 10% over 1 to 2 hours with a typical boil being 6-8% over 1 hour
- Gravity increases and volume decreases
- Volatiles are driven up the stack and this should have a channel to catch any condensate that try's to run back into the wort
  - Ensure the channel is free from blockages and regularly CIP's
- Wort OG does not affect the evaporation rate

Evaporation Continued

- Either gravity or volume can be used for the calculation, but only volume if sugar has been added to the boil
- The equation using volume is:
  - % evaporation = ((post boil volume/pre boil volume)-1)*100
- The equation using gravity is:
  - % evaporation = ((post boil SG/pre boil SG)-1)*100
- Larger / more complex kettles have a mass flow meter that measure the steam added to the boil
- Remember the boil time plays a part, 8% evaporation in a 1h boil has a different vigour to 8% in a 2 hour boil

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Trub Formation and pH Reduction

- Formation and precipitation of protein/polyphenol complexes during boiling, are essential for beer haze stability, these compounds are collectively known as trub
- Polyphenols from malt and hops are in oxidised form and will complex with protein to form hot break
- Trub also contains insoluble salts, some hop resin material & a significant proportion of Lipids from sweet wort (especially last worts) and hops.
- The trub formation is helped by the vigour of the boil, the rate of energy added to the system and the duration of the process
- The optimum pH for trub formation is 5.2

Trub Formation and pH Reduction Cont

- Wort pH at the start of boil will be 5.8 to 5.9 and this reduces by around 0.2 due to melanoidin formation, hop acids, precipitation of phosphates and polypeptides by calcium and release of H^+ ions
- Acids or salts of calcium can be added to the kettle to reduce pH to the desired level
- Sheer forces can reduce the trub particle sizes resulting in longer boil times and cloudy worts
- The formed tub is separated from the wort by a hop back if using whole hops or a whirlpool if using pellets.
- Polyphenols also complex with other protein degradation products and these will remain in solution until after wort cooling and then precipitate as cold break aided by copper finings (electrostatic attraction)

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Kettle Finings

- The addition of kettle finings improves the coagulation of insoluble proteins from mashing and boiling.
- Negatively charged polymer that interacts with positively charged proteins
- Soluble in hot water producing a highly viscous solution that gels on cooling
- The main factors that affect kettle finings addition are:
  - Dose Rate
  - Time of addition
  - Hot wort clarity
  - Wort pH
  - Malt variety
  - Level of cold break
  - Wort Gravity
  - Wort polyphenol levels
- Check optimisation on new crop year
- Different beer's will have different addition rates
- Don't add if you want hazy beers
- Speak to your supplier for optimisation trials

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Hops and Bitterness

- α-acids readily dissolve in wort
- Iso α-acids take longer to form and are influenced by;
  - boil temperature
  - boil time
  - form of hop used and addition time
  - wort pH
  - even hops added after flame out will isomerise to a degree

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Hop Addition

- Hops added at the start of the boil will add bitterness – all the aroma oils will be evaporated
- When brewing beers where most of the bitterness comes from hate hop addition, still add a small amount of hops to the start of the boil to control foam. Over foaming in the kettle can cause beer head retention issues.
- Hops added at the end of the boil will still contribute to bitterness with utilisations being between 5-20%
- It is becoming common place to cool wort to 80^{o}C before adding late hops. This reduces the utilisation and increases the aroma

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Removal of Volatiles

- The main volatile written about in the literature is Di-Methyl Sulphide (DMS) which tastes and smells like sweetcorn and undesirable at high levels in lagers
- DMS is formed from S-Methyl Methionine (SMM) which is found in all malts but lightly kilned malts have higher levels. Can be on C of A as SMM or DMSp and normal levels are below 5mg/l
- Grassy & grainy aromas from mashing are reduced with just 2% evaporation
- Hop aroma compounds from the bittering hops are lost in the first 20 minutes of the boil
- Some hop oils that lead to unpleasant vegetal and grassy aromas can take up to an hour to be driven off
  - Mixing hops in hot water can add them back!
- Volatile carbonyls are also lost helping prevent formation of staling compounds

Removal of Volatiles - DMS

- Flavour threshold is 40-60ppb
- Can be acceptable in lagers up to 100ppb before becoming undesirable
- DMS is formed by the thermal decomposition of SMM during kilning and boiling
- Will be rapidly driven off by evaporation
- SMM will continue to breakdown during whirlpool stands and wort cooling
- DMS formed will stay in the beer

TO REDUCE DMS	TO INCREASE DMS
Boil for a minimum of 60 min	Reduced boil time – 45 min
Limit WP stand time – 15 min max	Increased WP stand time – 45 min
Rapid wort cooling	Higher levels of SMM in malt

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Colour and Flavour Formation

- During boiling the colour will increase by 2-4 EBC – the darker the wort the greater the colour pick up.
- Colour is formed in direct fired and electrically heated kettles by caramelisation – due to higher differential temperatures across the heating surface
- Colour is also be formed through Maillard reactions between carbonyl and amino compounds
- Increased malt FAN levels will form higher colours during the boil
- Wort also darkens as polyphenols oxidise and this can be minimised by avoiding oxygen in the system
- Some of the products of these Maillard reactions add to flavour too, bringing roasted (furan), sulphurous (thiophene) and other complex aromas
- Brewing a light beer after a dark beer can lead to higher colours.

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Troubleshooting

Function	Effect	Causing
Poor Boil (low evaporation/vigour)	Insufficient trub formation	Increased protein and polyphenol levels in beers causing haze issues Erratic fermentation from nucleation effect, over nutrition and possible yeast health issues Poor head retention from lipid carry over into beer
	Failure to remove volatiles	Grassy, vegetable and DMS flavours in beers
	Failure to reduce volume	Possible low OG, reduced colour and dilution of bitterness, flavour and aroma from hops
Over Boiling	Remove foam positive proteins	Affect head retention
	Reduce trub particle size	Haze issues, fermentation issues & head retention issues
Fining rate	Over finings	Remove foam positive proteins
	Malt variety	Different malt variety's may need different kettle finings rates
Malt Quality	Milling	Incorrect milling regime can cause filtration issues resulting in cloudy worts and increased trub Damage to husks can increase polyphenols
	Protein levels	High protein levels can increase trub formation and pass through to final beer causing haze issues
	Proanthocyanidins	Can be extracted from last worts and increase astringency and polyphenol levels
pH	Low pH	Ineffective fining
Breakdown	Pump failure Waiting for FV etc	Hold the wort between 75^{o}C & 80^{o}C to protect from micro infection and colour pick up.
Trace metals	Zinc	Yeast needs zinc to produce alcohol, it may need adding to the kettle
	Copper	Adding sacrificial copper catalyse oxidative reactions and remove sulphur substances

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Thank You

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