Brewhouse Operations II

Influence on yield and quality

main influences of the boiling and wort treatment processes on yield, colloidal stability, microbiological stability, foam and flavor stability

Quality criteria of Wort (Depending on Demanded Beer Type)

Extract (Original extract)	11	-	16	%
Final degree of fermentation	78	-	85	%
Saccharification (iodine value)	<		0,30	ΔE
pH value	5,2	-	5,7	
Colour (light wort)	7	-	20	EBC
Colour (dark wort)	20	-	100 ...	EBC

Quality criteria of Wort

(Depending on Demanded Beer Type)

Bitter substances	15	-	60	BU
Nitrogenuous substances				
Total nitrogen	800	-	1200	ppm
Coagulable nitrogen	15	-	25	ppm
Magnesiumsulphate precipitable nitrogen	200	-	240	ppm
Free amino nitrogen	160	-	220	ppm

Quality criteria of Wort

(Depending on Demanded Beer Type)

Thiobarbiturate index (TBI), rate of thermal impact		
(light wort, beginning of boiling)	< 22	
(light wort, casting)	< 45	
(light wort, after cooling)	< 60	
Tannins	< 50	ppm
DMS + DMS-P	< 100	ppb
Trace elements (Zn)	0,05 - 0,15	ppm

Pitching wort

After cooling: temperature				
Bottom fermentation	6	-	10	°C
Top fermentation	15	-	20	°C
After aeration: Oxygen content	8	-	10	ppm
After pitching: Cell count	15	-	20	x 10^6/ml

Aims of / Processes during Wort Boiling

- Evaporation
- Removal of unwanted volatiles (carbonyls)
- Formation of DMS from DMS-P
- Sterilization of wort
- Destruction / inactivation of enzymes
- Break formation (proteine coagulation)
- Transformation & solution of hop components
- Isomerization of α-acids
- Formation of reductones (SH-; NH-groups)
- Lowering of wort pH
- Colour increase ➔ Maillard reaction
- Proteine – polyphenol condensation reactions
- Changes in content of tannins

Evaporation

➔ Evaporation of water ➔ increase of extract content

- Concentration of wort
- Total evaporation = evaporated water during boiling
- Assumed amount ➔ kettle full wort

➔ Evaporation ➔ costs of energy

➔ Boil no longer than necessary

➔ Not evaporate more water than necessary

➔ Energy recovery

Influence of Evaporation on Wort Parameters

evaporation [%]	12	10	8
boiling time [min]	90	90	90
steam-pressure [bar]	3,5	2,7	2,3
pH	5,49	5,50	5,52
colour [EBC]	10,0	9,7	9,5
TBSF [mg/L]	20,3	19,8	19,0
tot. N [mg/100mL; 12%]	105,2	106,0	106,3
coag. N [mg/100mL; 12%]	1,7	1,9	2,2
BU [EBC]	42	41	39
α-acids [mg/L]	12	12	14
Iso-α-acids [mg/L]	32	30	27
tot. DMS [ppb]	76	81	82
DMS-P [ppb]	58	60	58
free DMS [ppb]	18	21	24
beer colour [EBC]	7,0	6,8	6,8
Foam (R&C)	127	129	130

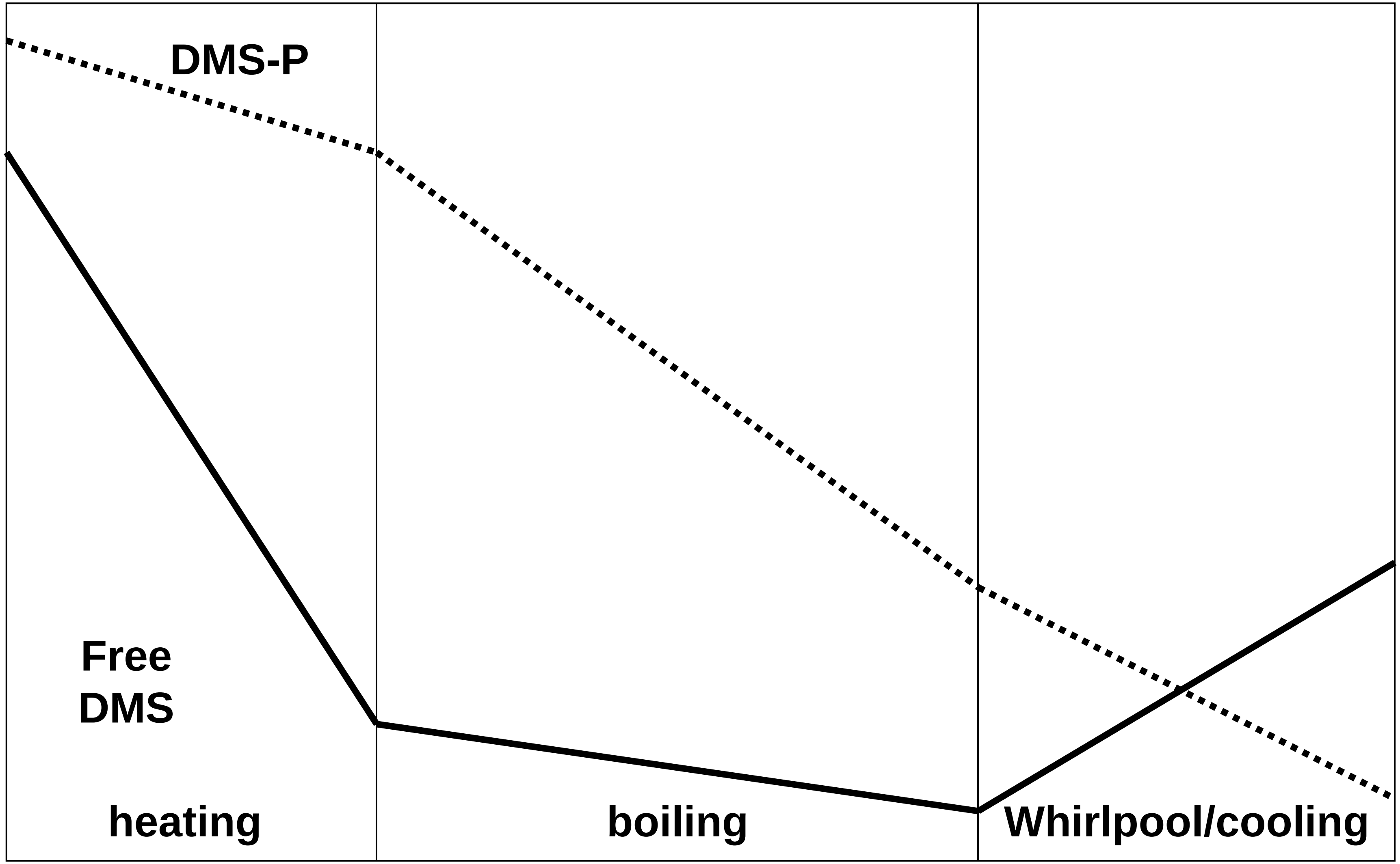
EBC Monograph, 1986

Removal of Unwanted Volatiles

- Evaporation of carbonyls coming from Maillard reaction during kilning and boiling

- DMS (Dimethylsulphide) ➔ indicator substance for the evaporation of undesired aroma compounds ➔ significant component of flavour
- ➔ Very low taste threshold (50 -60 ppb)
- Evaporated during kilning and wort boiling
- Wort contains a high amount of DMS-precursors (mainly s-methylmethionin)
- Free DMS (dimethylsulphide) is formed at high temperatures (> 80 °C)
- DMS obtains from a not heat resistant precursor
- Precursor is produced during malting (germination)
- Amount is reduced by kilning

Formation of DMS from DMS-P



Influences on DMS content

- Malt
- Mashing methods
- Wort boiling
  - Wort movement
  - Temperature
  - Time
  - pH
  - Pressure
- Trub separation
- Wort cooling

Sterilization

- Microorganisms brought into the wort by mashing are destroyed by heat
- Temperatures above 63°C stop microbial growth
- Temperatures above 70°C kill most microorganisms

  but ➔ - some microorganisms produce heat-resistant spores that survive temperatures up to 100 °C

  - microbial growth depends also on pH, sugar concentration, salt concentration, hops dosage …, time

Inactivation of Enzymes

- All enzymes are destroyed by boiling
- After boiling there is no possibility for further changes in wort components based on enzymatic activity

Break Formation

- Mainly coagulated protein ➔ formation of disulfide-linkages
- Bitter substances adsorbing at the surface (e.g.. Ionic bonds)
- Heavy metals stay mainly in the trub
- Free fatty acids stay in in the trub, ➔more short chained fatty acids remain in wort (source: hops)
- Infusion-mashing procedure show higher values in coag. N ➔increased adsorption ➔ clearer and plainer worts
- The longer boiling time and the higher temperatures in boiling ➔ increased break formation

Coagulation of Proteins

- Extensive precipitation of proteins is essential for beer stability
- 15 – 25 ppm coagulable nitrogen should remain in the wort
  - Head retention
  - Palate fullness

Influences on Break Formation

- Boiling time
- Boiling intensity
- Pre-boiling
- Hop dosage
- pH
- Boiling under pressure
- Extract content of the wort
- Aeration
- Mashing methods

Transformation & Solution of Hop Components

- Solubility of not isomerised α–acids increases with ph
- Isomerisation increases with temperature and duration of boiling➔ *Sommer*- Formula
- Better isomerisation by higher pH-values
- Decreased break formation increases yield of bitter substances
- Increased boiling time ➔ increased foam stability
  ➔ increased colloidal stability
  ➔ increased values of tanning agents
- Increased hop dosage ➔ decreased pH
  ➔ Decreased total –N
  ➔ Decreased colloidal stability
  ➔ Increased foam stability
  ➔ Increased values of tanning agents
  ➔ Decreased hop yield

Influence on Isomerization and Bitter Substance Yield

- Addition of bitter substances
- Boiling time of hops
- Formation of break during hop boiling
- Wort temperature
- pH of the wort
- pH of the beer
- Quantity of fermented extract
- Quantity of yeast produced
- Filtration

Changes in Wort / Influence of Boiling Time
(hop dosage 80 mg /L α-acid)

boiling time [min]	0	30	60	90	120	WP
pH	5,62	5,59	5,55	5,51	5,48	5,42
colour [EBC]	5,7	6,5	7,2	8,0	9,0	10,5
colour [EBC] calc. on 12 %	6,4	7,1	7,7	8,2	9,0	10,5
TBSF [mg/L]	8,2	10,2	12,7	15,8	19,2	21,7
tot. N [mg/100mL; 12%]	112,0	110,7	109,1	107,9	106,8	105,3
koag. N [mg/100mL; 12%]	5,9	4,5	3,4	2,7	2,2	2,0
BU [EBC]	0	23	29	33	36	38
α-acids [mg/L]	0	16	16	10	5	4
Iso-α-acids [mg/L]	0	14	20	26	33	38
tot. DMS [ppb]	340	266	268	94	76	70
DMSP [ppb]	230	220	140	82	66	23
free DMS [ppb]	110	46	28	12	10	47

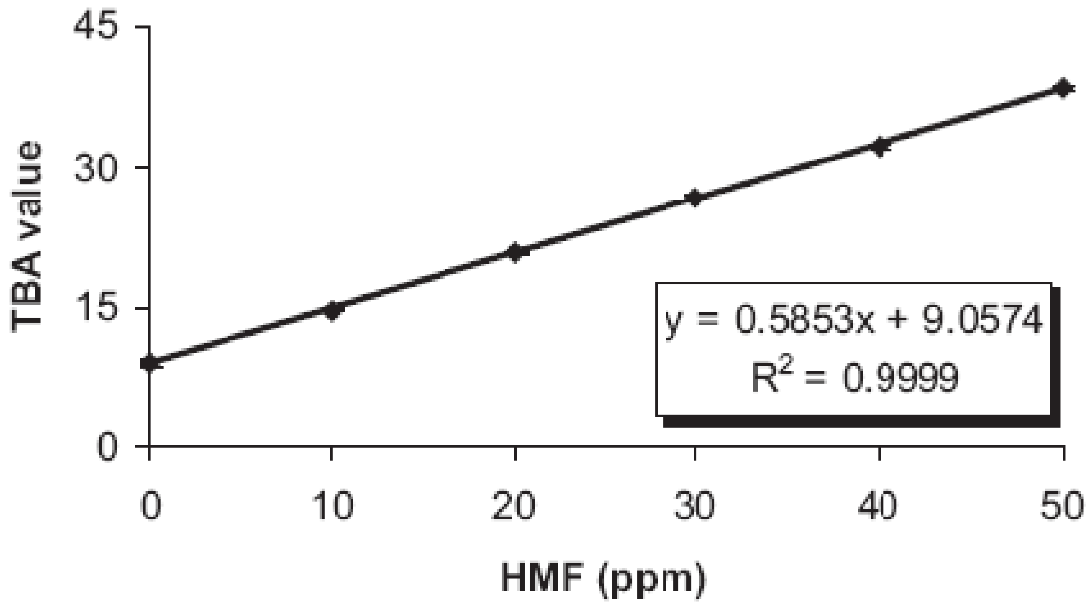
Colour and Aroma Formation

by

- Maillard-reaction
- Caramelisation of sugar
- Oxidation of polyphenols

HMF / TBI / Colour

	HMF	TBI	Colour
	[ppm]		[EBC]
Kettle-full wort	0.5	29.1	8.2
Finished wort	2.7	45.3	11.3
After 50 % was cooled	4.6	54.8	13.6



Technological impacts on thermal stress (colour) during wort boiling

- Boiling time
- Boiling temperature
- Homogeneity in the wort copper
- Heating area surface
- Temperature difference (heating area – wort)
- Residual time of wort above heating area (fouling)

Caramelisation

- Oxidation of sugar
- Non-enzymatic browning reaction
- Oxygen is not involved in caramelisation and the Maillard reaction
    - Does not affect the rate of these reactions..
- Sugars (mono- or disaccharides) react without amines
- Sugars in solution undergo caramelisation when heated at high temperatures (> 100°C) for prolonged periods
- Caramelisation mechanism involve enolisation followed by dehydration and fission
- Sugars reduced to 3- and 4- Desoxyosone ➔ HMF (Hydroxymethylfurfural)
- HMF ➔ specific taste and smell of caramel and yellow to brown colour.
- Also influenced by acids

Wort Boiling Equipment

1. Classical kettles
2. Internal boiler
3. External boiler
4. High temperature wort boiling
5. Thermosyphon
6. Low pressure boiling
7. "Schoko" – The gentle Boiling System
8. Wort stripping
9. Vacuumevaporation
10. "Varioboil"- flash evaporation
11. Wort spray boiling
12. post-evaporation boiling
13. Phase optimized aroma Boiling "Ecotherm"
14. "Stromboli"
15. Thin film evaporation "Merlin"
16. Briggs
17. Wort pre-cooling

Boiling Procedures

	boiling		Post-evaporation before separation of hot trub	Post-evaporation after separation of hot trub
	time [min]	temerature [°C]		
Internal boiler	variable	atmosph.	-	-
External boiler	variable	101-105	-	-
High-temperature boiling	at T_{max}2-3	max. 145	X	-
dynamic low-pressure boiling	40-60	10-103	-	-
Gentle boiling process „Schoko“	60 min holding	97-99	-	X
Wort stripping	app. 40	100	-	X
Vacuum evaporator	40-50	100	-	X
flash evaporator	60	101-103	X	-
Post-evaporation boiling process	>40	atmosph.	-	X
Thin film evaporator	35-40	atmosph.	-	X
wort pre-cooling	variable	variable	-	-
Phase-optimised aroma boiling	70	atmosph.	-	-

Source:Brauwelt.4-5.93.2003

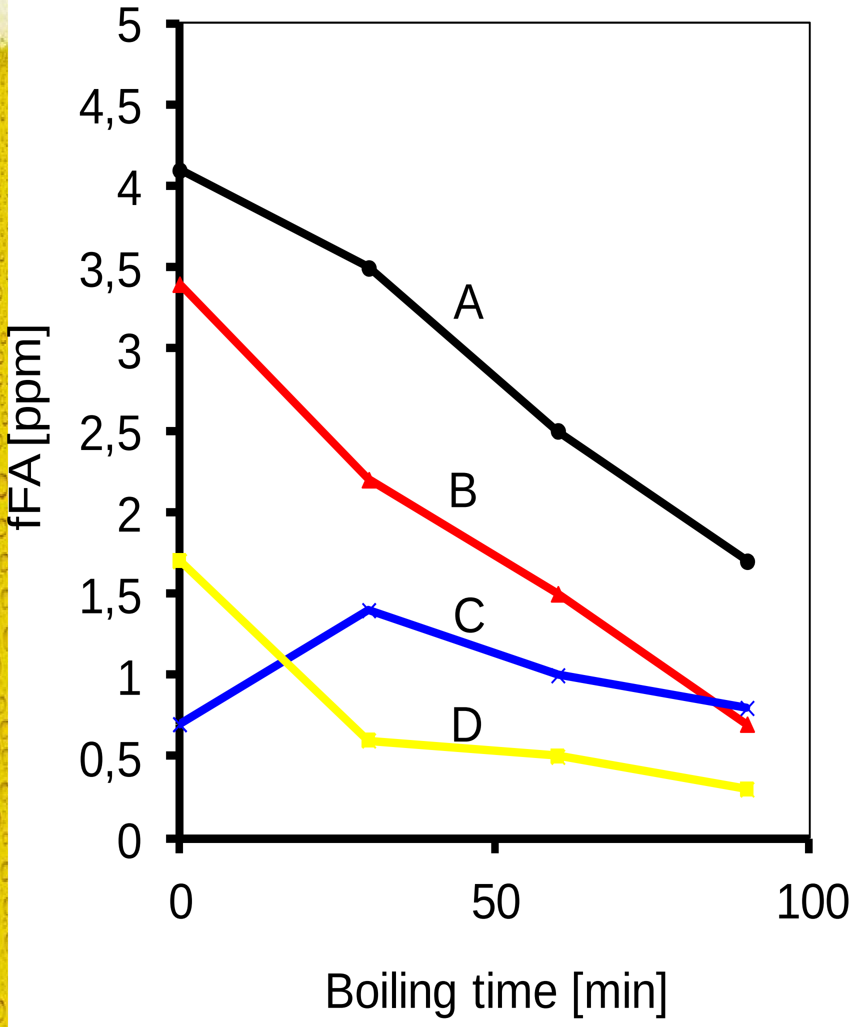
Wort Composition

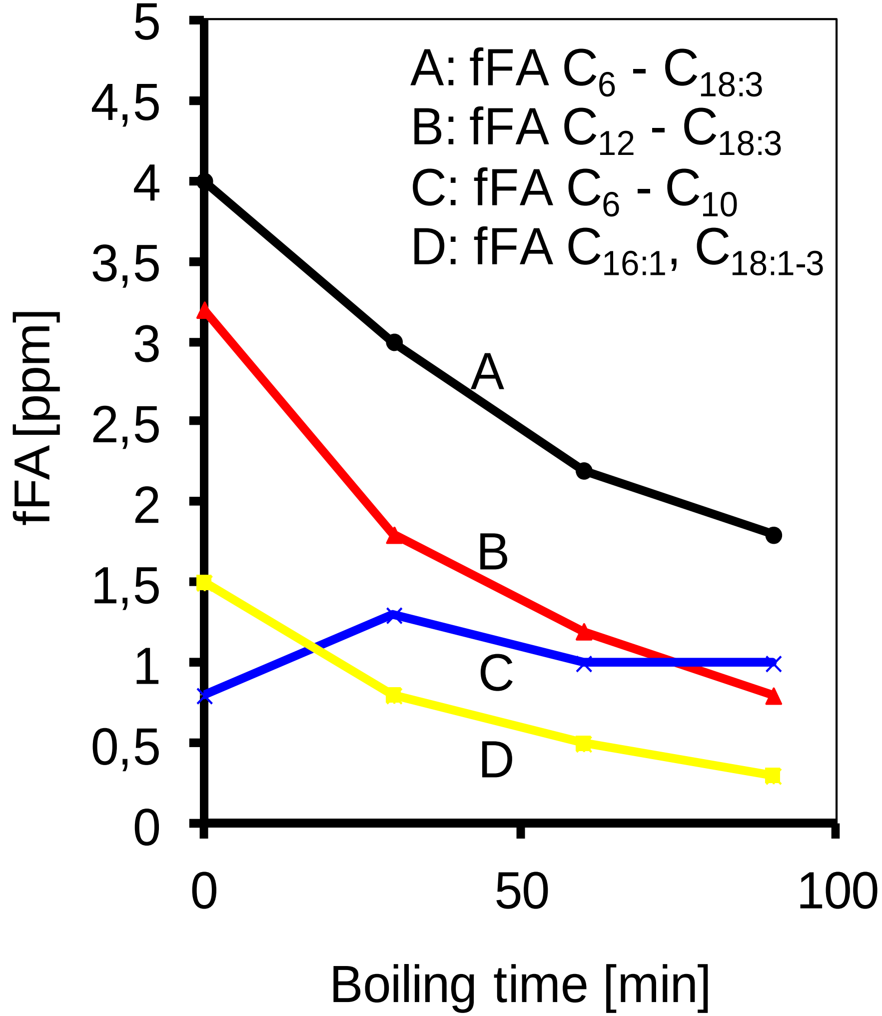
- <u>App. Composition of kettle full wort</u>

extract	10,6	%
pH	5,61	
total N	972	mg/l
coag. N	59	mg/l
FAN	180	mg/l
viscosity	1,77	mPas
DMS	246	µg/l
DMS-P	333	µg/l
TBZ	26	

Fatty Acids

Influence of wort boiling on the content of free fatty acids (fFA)





Influences on Hot and Cold Trub Formation

- Formation of trub:
  - Malting process
  - Malt modification
  - Milling
  - Mashing procedure
  - Concentration of wort
  - Quantity and quality of protein in malt / wort
  - Hops
  - Boiling time
  - Wort cooling

BW,1969

Hot trub

- Formed during boiling
  - 50-60% proteins
  - 20-30% organic compounds like polyphenols
  - 15-20% bitter substances
  - Minerals

- Hot trub app. 0,2 - 0,4 % of wort
- Particle sizes app. 30 - 80 µm

BW 118, 1978

Cold Trub

- Formed at T < 70°C but bulk precipitated < 20 °C
- Particle size 0,5 – 1,0 µm
- At 0 °C 150 – 350 mg/l wort
- Contains app.
  - 50% protein
  - 20% carbohydrates
  - 25% polyphenols

BW 118, 1978

Properties of Hot and Cold Break

		Hot break		Cold break	
Particle size	[µm]		30 - 80		0.5 - 1
Contents:	[%]	Protein	50 - 60	Protein	52
		Bitter substances	16 - 20	Polyphenols	25
		Other organic substances (such as polyphenols)	20 - 30	Carbohydrates	21
		Minerals	3 - 30		
Amount	[g/hl]	Extract-free (d. m.)	40 - 80	Extract-free (d. m.)	15 - 30

BW 118, 1978

Amount of Trub in different Worts

		Total trub	Hot break	Cold break
Wort for:		kg/ 100 hl (d. m.) finished wort		
Pale beers	12 %	7.8 - 8.0	6.6 - 6.9	1.1 - 1.5
Pale special beers	13 %	8.6 - 9.5	7.5 - 7.9	1.1 - 1.7
Dark beers	13 %	4.4 - 4.6	3.5 - 3.6	0.9 - 1.0

Reasons of Hot Trub Removal

- Influences the yeast during fermentation → smearing of yeast
- Influence bitterness
- Influences colour → darker colour
- slower pH decrease
- Head retention

Reasons of Cold Trub Removal

- Controversial discussed in the past
- Faster fermentation
- Finer bitterness
- Cleaner yeast for the re-use
- Faster post-fermentation
- Remaining amounts from 0-50 % of cold trub
  - better taste
  - flavour stability
  - foam stability

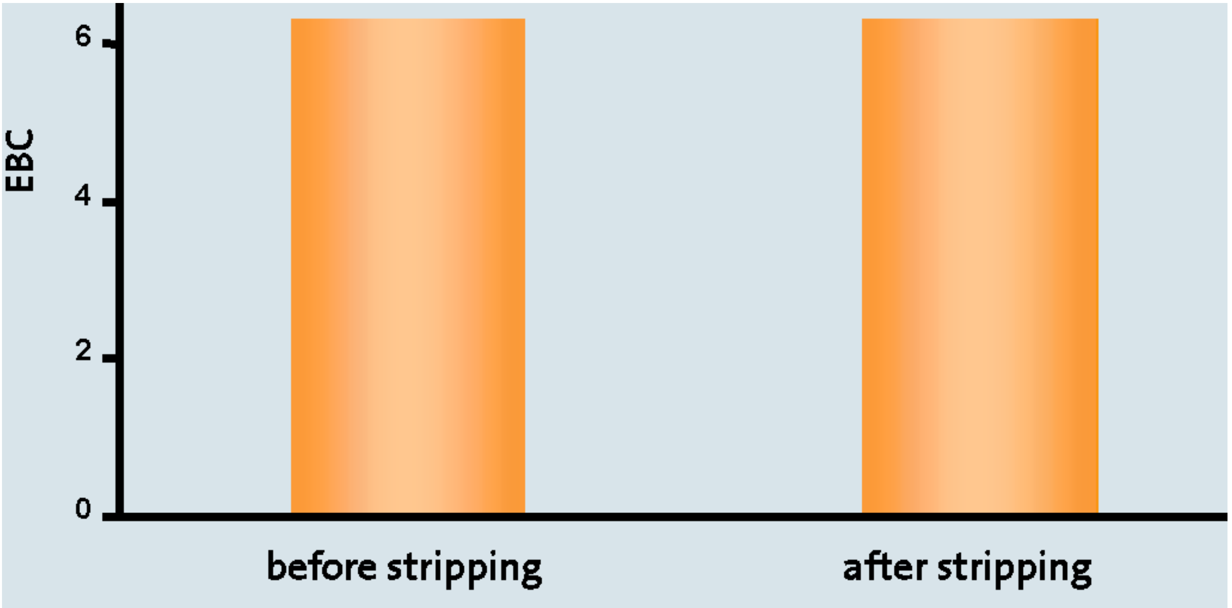
Wort Flavour Profile by wort treatment system *Calypso*

Aroma components	before stripping	after stripping	change
2-Methylbutanal [µg/l]	31	25	↘
3-Methylbutanal [µg/l]	135	113	↘
2-Furfural [µg/l]	1665	1497	↘
Hexanal [µg/l]	10	8	↘
Benzaldehyde [µg/l]	2	2	→
2-Phenylethanol [µg/l]	3	2	→

Kottmann, 2006

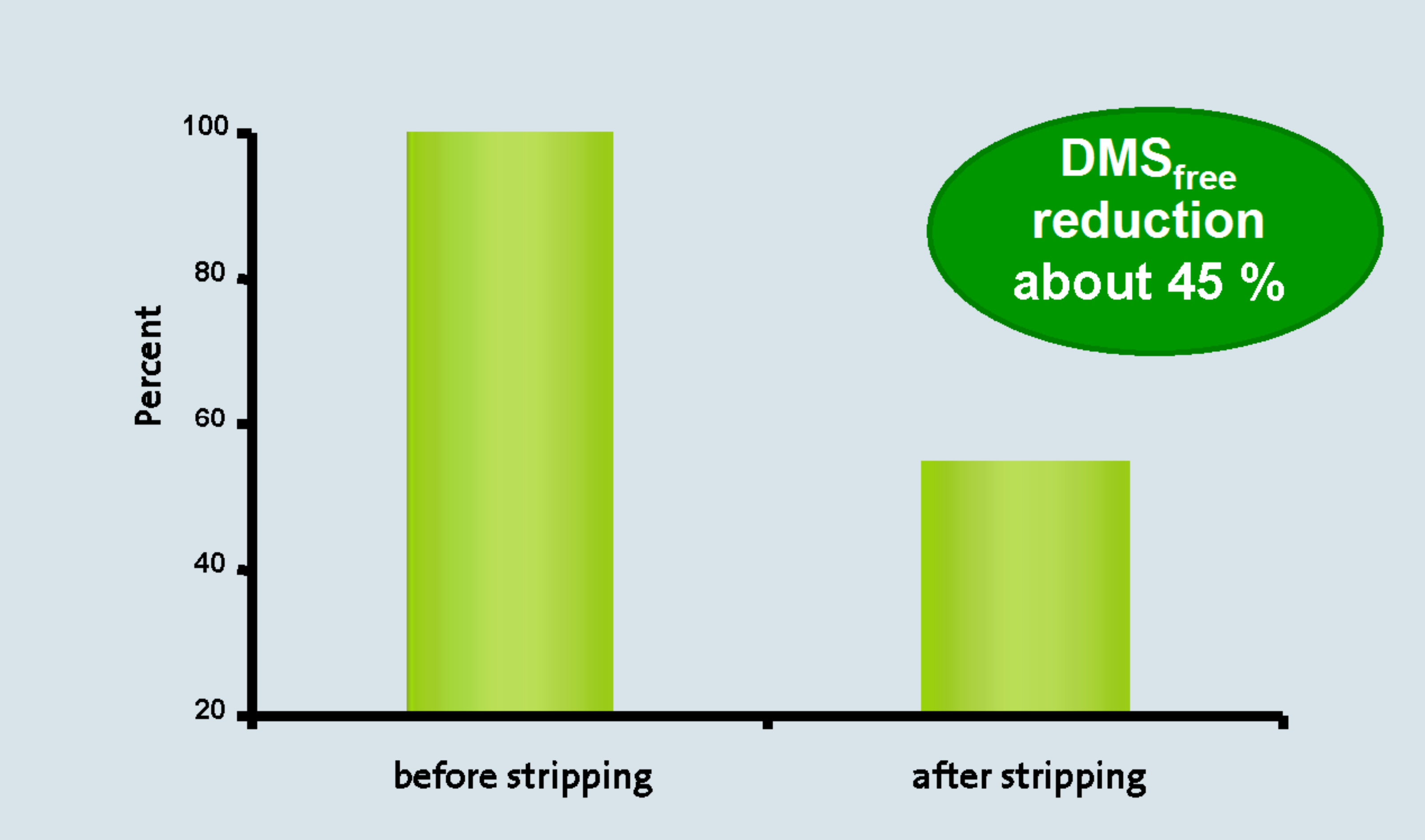
Hop Yield and Colour

	before stripping	after stripping	change
Bitter units [BU]	49,4	49,5	→
Iso-α-acids [µg/l]	33,8	33,4	→
α-acids [µg/l]	21,9	19,5	→



Kottmann, 2006

DMS_{free}



Kottmann, 2006

Hot Trub Removal Systems

	Cool ship	Sedimentation	Whirlpool	Separator
Operation mode	Batch	batch	batch	continuous
Dependence	High	medium	medium - high	high
Required space	High	high	high	low
Waste water	High	high	high	low
Losses	High	high	medium - high	low
Energy cons.	Low	low	low	high

Influence of Malt Modification on Cold Trub Composition

Modification of malt	Poor	Good	Very good
Total cold break [mg/L]	309	272	220
Protein [%]	53.6	50.6	52.7
Carbohydrates [%]	33.4	21.2	21.0
Polyphenols [%]	11.4	25.4	25.0

BW 3, 1978

Cold Trub Removal Systems

	Separation	Filtration	Sedimentation	Flotation
Operation mode	continuous	nearly continuous	batch	batch
Seperation rate	60 % max	over 80 %	50 % max	60 % max
Required space	Low	medium	high	high
Losses	Low	low	high	High
Waste	No	yes	no	no
Waste water	Low	high	high	high
Energy cons.	High	medium	low	low
Energy for sterilisation	Low	high	-	-

Wort Aeration

- Stainless steel and ceramic candles in the cold wort line ➔ micro bubbles
- In line static mixers ➔ turbulent flow
- Venturi systems ➔ pressure increase to force gas into solution
- 6 - 8 ppm dissolved oxygen for normal wort
- > 16 ppm dissolved oxygen for high gravity brews
- Wort flow velocity 1.0 - 2.5 m/s

Wort Aeration

Excess aeration ➔

- Increase in fatty acids
- Increase in sterols
- Less formation of esters
- Less formation of acetaldehyde
- Foaming problems
- Oxidative stress on wort and yeast

Wort Aeration

- Oxygen → necessary for the biosynthesis of essential membrane lipids
- An adequate cellular oxygen supply is critical for yeast growth, fermentation performance and beer flavour
- Problems in aeration:
  - oxidation of wort constituents with undesirable colour and flavour changes,
  - low solubility of oxygen in high gravity worts,
  - poor oxygen transfer due to foam formation,
  - risk of over-aeration resulting in excessive yeast growth,
  - risk of under-aeration resulting in a poor attenuation,
  - foam formation during the filling of the fermenting vessels.

Possibilities for Oxygen Uptake in the Brewhouse

Aeration takes place via

- Milled malt in dry milling systems
- Water in pre-mashing systems
- Leaking pumps
- Too high rotation velocity of the stirrer