

# Brewing Calculations



## Craft Brewer Course

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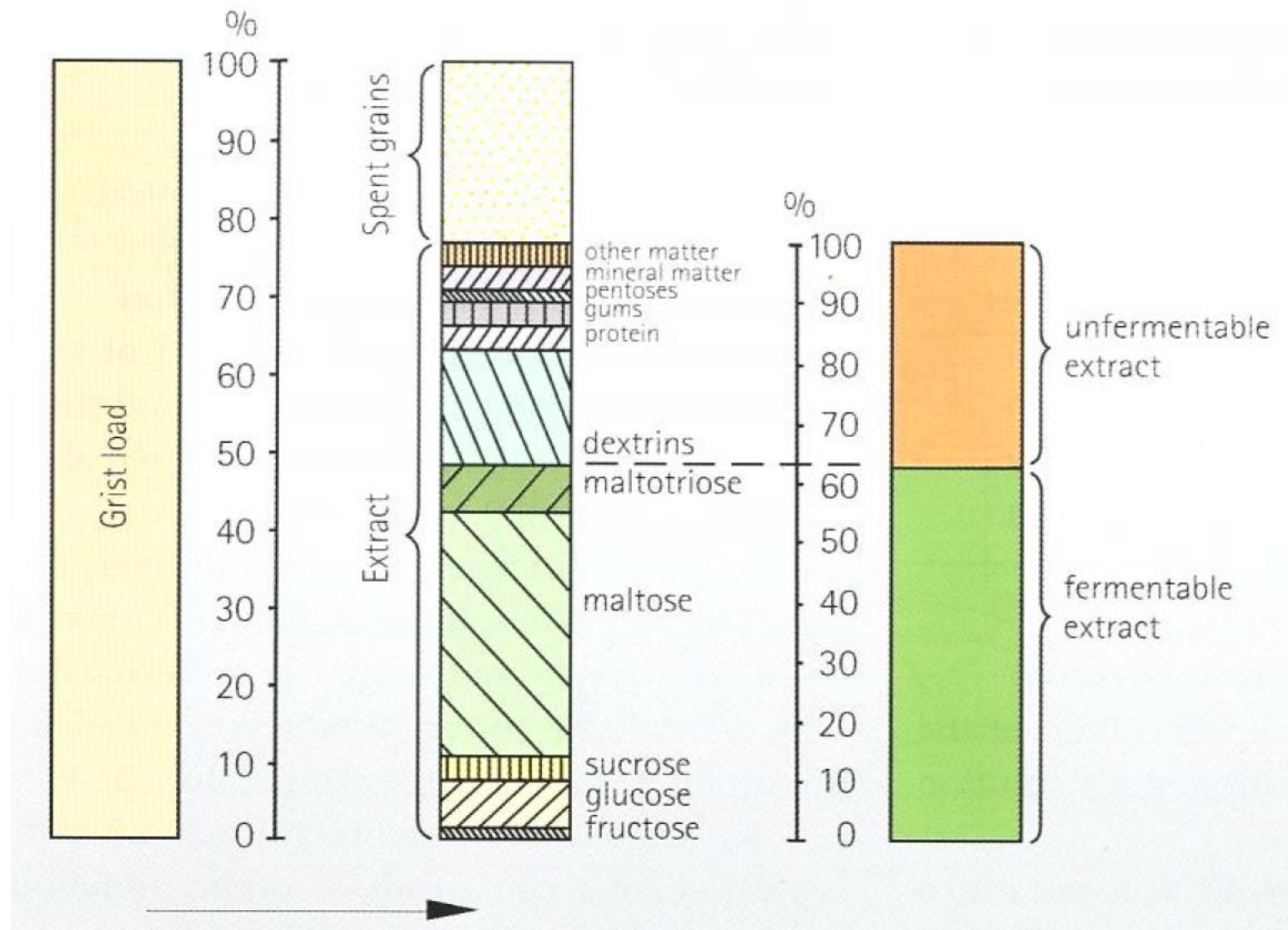


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# Content of Cold Wort



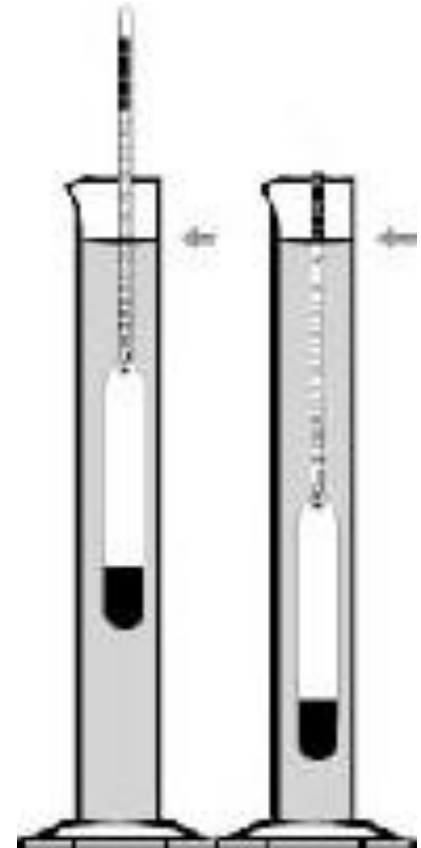
# Wort strength is expressed as

## % Extract by mass

- %Plato = %P = g Extract/100 g wort (2 decimals)
- Real extract, ER%
- Original extract in wort, OE %P

## Specific gravity

- Measured by saccharometer (or refractometer)
- Expressed in g/ml or kg/l
- Measured at 20°C



# The Goldiner, Klemann, Kämpf Table, Sugar table

TABLE A.5  
Specific gravity and extract table

The following table is based on those compiled by Dr Plato for the German Imperial Commission (*Normal-Eichungskommission*) and refers to apparent specific gravities, as determined in the usual manner by weighing in a specific gravity bottle in air or by means of a saccharometer. Cane sugar % wt/vol and % wt/wt represent grams per 100 ml and grams per 100 grams of solution respectively. The percentages by weight in column 6, corresponding with the specific gravities at 60°F given in column 1, were computed by interpolation from Plato's table for true specific gravities at 15°/15°C and 16°/15°C corrected to 60°/60°F and then brought to 60°/60° in air by adding  $(SG - 1) \times 0.00121$ . The cane sugar weight percentages were converted to volume percentages and the solution divisors calculated. The column headed Plato gives the specific gravities in air at 20°/20°C related to the cane sugar weight percentages and, with the latter, corresponds with the Plato Table commonly used in breweries and laboratories where 20°C is the standard temperature. The column headed Balling similarly gives the specific gravities at 17.5°/17.5°C from the Balling Table corresponding with the same sugar percentages. These specific gravities cannot accurately correspond with those at 60°/60°F and 20°/20°C on account of the errors in Balling's Table. The following densities were used in the calculations:

Water at 15°C/4°C      0.999126  
 60°F/4°C              0.999035  
 20°C/4°C              0.998234

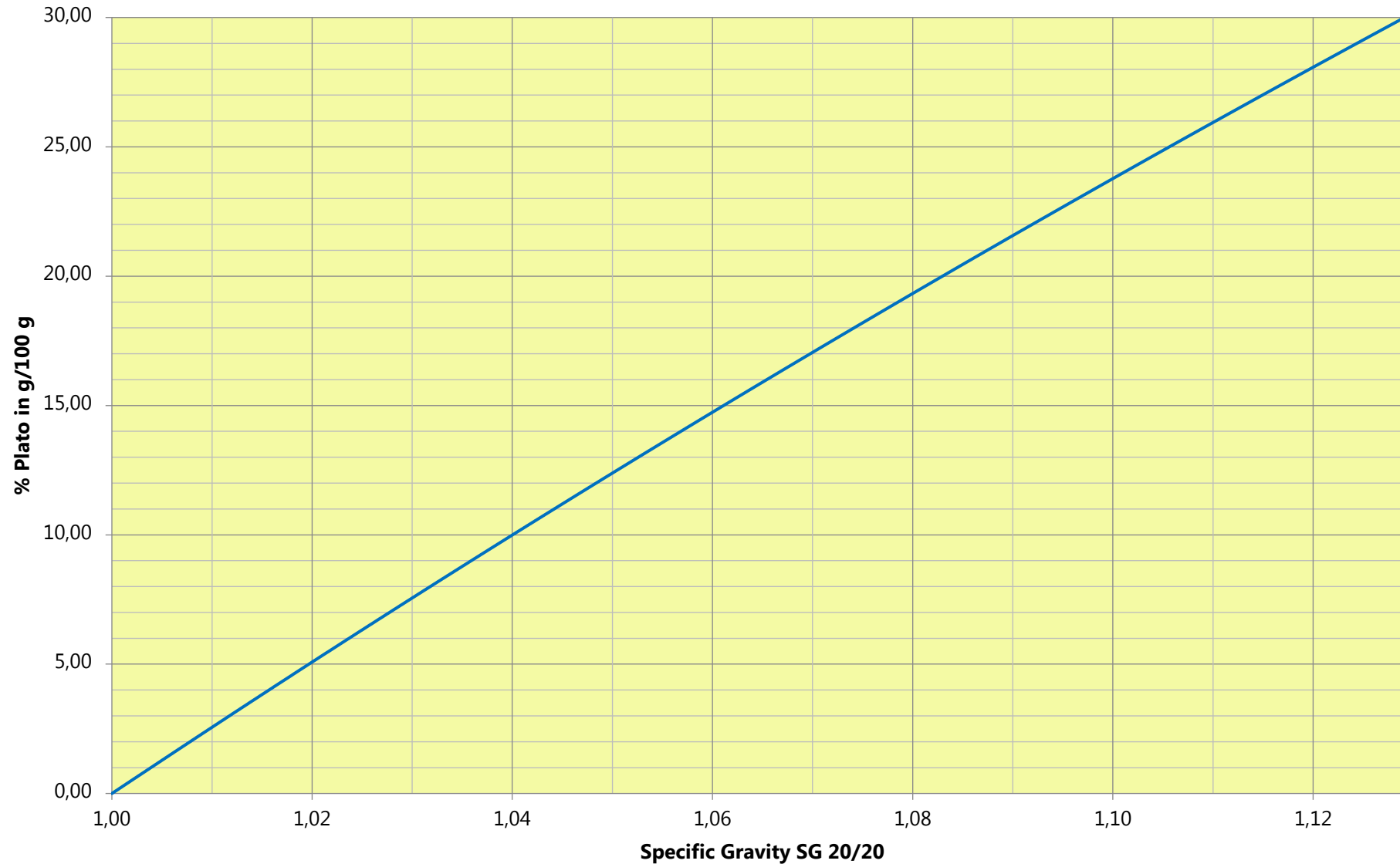
SPECIFIC GRAVITY CONVERSION TABLE  
FOR CANE SUGAR SOLUTIONS

SG 60°F	British units		Solution divisor	Plato		Balling SG 17.5°C	Baumé Modulus 145
	Brewers' pounds	Cane sugar % wt/vol		SG 20°C	Cane sugar % wt/wt Degrees Brix.		
1002.5	0.9	0.643	3.888	1.00250	0.641	1.00256	0.36
1005.0	1.8	1.287	3.885	1.00499	1.281	1.00513	0.72
1007.5	2.7	1.932	3.882	1.00748	1.918	1.00767	1.08
1010.0	3.6	2.578	3.879	1.00998	2.552	1.01021	1.43
1012.5	4.5	3.225	3.876	1.01247	3.185	1.01274	1.78
1015.0	5.4	3.871	3.875	1.01496	3.814	1.01528	2.14
1017.5	6.3	4.517	3.874	1.01745	4.439	1.01776	2.48
1020.0	7.2	5.164	3.873	1.01993	5.063	1.02025	2.83
1022.5	8.1	5.810	3.872	1.02242	5.682	1.02273	3.17
1025.0	9.0	6.458	3.871	1.02490	6.300	1.02523	3.52
1027.5	9.9	7.107	3.869	1.02740	6.917	1.02776	3.86
1030.0	10.8	7.755	3.868	1.02989	7.529	1.03027	4.20
1032.5	11.7	8.405	3.867	1.03238	8.140	1.03277	4.54
1035.0	12.6	9.054	3.866	1.03486	8.748	1.03527	4.88
1037.5	13.5	9.703	3.865	1.03736	9.352	1.03775	5.22
1040.0	14.4	10.354	3.863	1.03985	9.956	1.04024	5.55
1042.5	15.3	11.003	3.862	1.04234	10.554	1.04273	5.88
1045.0	16.2	11.652	3.862	1.04481	11.150	1.04523	6.21
1047.5	17.1	12.303	3.861	1.04731	11.745	1.04773	6.54
1050.0	18.0	12.953	3.860	1.04979	12.336	1.05022	6.87
1052.5	18.9	13.604	3.859	1.05227	12.925	1.05269	7.20
1055.0	19.8	14.255	3.858	1.05476	13.512	1.05515	7.52

SG 60°F	Brewers' pounds	British units		SG 20°C	Cane sugar % wt/wt Degrees Brix.	Plato SG 17.5°C	Balling SG 17.5°C	Baumé Modulus 145
		Cane sugar % wt/vol	Solution divisor					
1057.5	20.7	14.907	3.857	1.05726	14.097	1.05760	7.84	
1060.0	21.6	15.560	3.856	1.05975	14.679	1.06005	8.16	
1062.5	22.5	16.213	3.855	1.06224	15.259	1.06252	8.48	
1065.0	23.4	16.866	3.854	1.06472	15.837	1.06500	8.80	
1067.5	24.3	17.519	3.853	1.06720	16.411	1.06747	9.12	
1070.0	25.2	18.173	3.852	1.06970	16.984	1.06995	9.44	
1072.5	26.1	18.827	3.851	1.07218	17.554	1.07244	9.75	
1075.0	27.0	19.482	3.850	1.07467	18.122	1.07494	10.06	
1077.5	27.9	20.135	3.849	1.07717	18.687	1.07743	10.37	
1080.0	28.8	20.791	3.848	1.07965	19.251	1.07990	10.69	
1082.5	29.7	21.446	3.847	1.08213	19.812	1.08237	11.00	
1085.0	30.6	22.101	3.846	1.08462	20.370	1.08486	11.30	
1087.5	31.5	22.758	3.845	1.08712	20.927	1.08737	11.61	
1090.0	32.4	23.414	3.844	1.08960	21.481	1.08986	11.91	
1092.5	33.3	24.071	3.843	1.09209	22.033	1.09235	12.21	
1095.0	34.2	24.726	3.842	1.09457	22.581	1.09481	12.51	
1097.5	35.1	25.384	3.841	1.09707	23.129	1.09730	12.81	
1100.0	36.0	26.041	3.840	1.09956	23.674	1.09980	13.11	
1102.5	36.9	26.700	3.839	1.10204	24.218	1.10230	13.41	
1105.0	37.8	27.360	3.838	1.10454	24.760	1.10480	13.71	
1107.5	38.7	28.019	3.837	1.10703	25.299	1.10730	14.00	
1110.0	39.6	28.679	3.836	1.10952	25.837	1.10983	14.30	
1112.5	40.5	29.339	3.834	1.11200	26.372	1.11235	14.59	
1115.0	41.4	30.000	3.833	1.11450	26.906	1.11486	14.88	
1117.5	42.3	30.660	3.832	1.11698	27.436	1.11735	15.17	
1120.0	43.2	31.321	3.831	1.11947	27.965	1.11984	15.46	
1122.5	44.1	31.981	3.830	1.12195	28.491	1.12231	15.74	
1125.0	45.0	32.643	3.829	1.12445	29.016	1.12478	16.03	
1127.5	45.9	33.305	3.828	1.12694	29.539	1.12729	16.31	
1130.0	46.8	33.970	3.827	1.12944	30.062	1.12980	16.60	
1132.5	47.7	34.632	3.826	1.13191	30.580	1.13228	16.88	
1135.0	48.6	35.295	3.825	1.13441	31.097	1.13477	17.16	
1137.5	49.5	35.958	3.824	1.13689	31.611	1.13723	17.44	
1140.0	50.4	36.621	3.823	1.13938	32.124	1.13971	17.72	
1142.5	51.3	37.285	3.822	1.14186	32.635	1.14221	18.00	
1145.0	52.2	37.951	3.821	1.14435	33.145	1.14473	18.27	
1147.5	53.1	38.617	3.820	1.14685	33.653	1.14727	18.55	
1150.0	54.0	39.284	3.818	1.14934	34.160	1.14980	18.82	

# The Goldiner, Klemann, Kämpf Table

## Grafic representation – Not a linear relation!



# Approximation formula

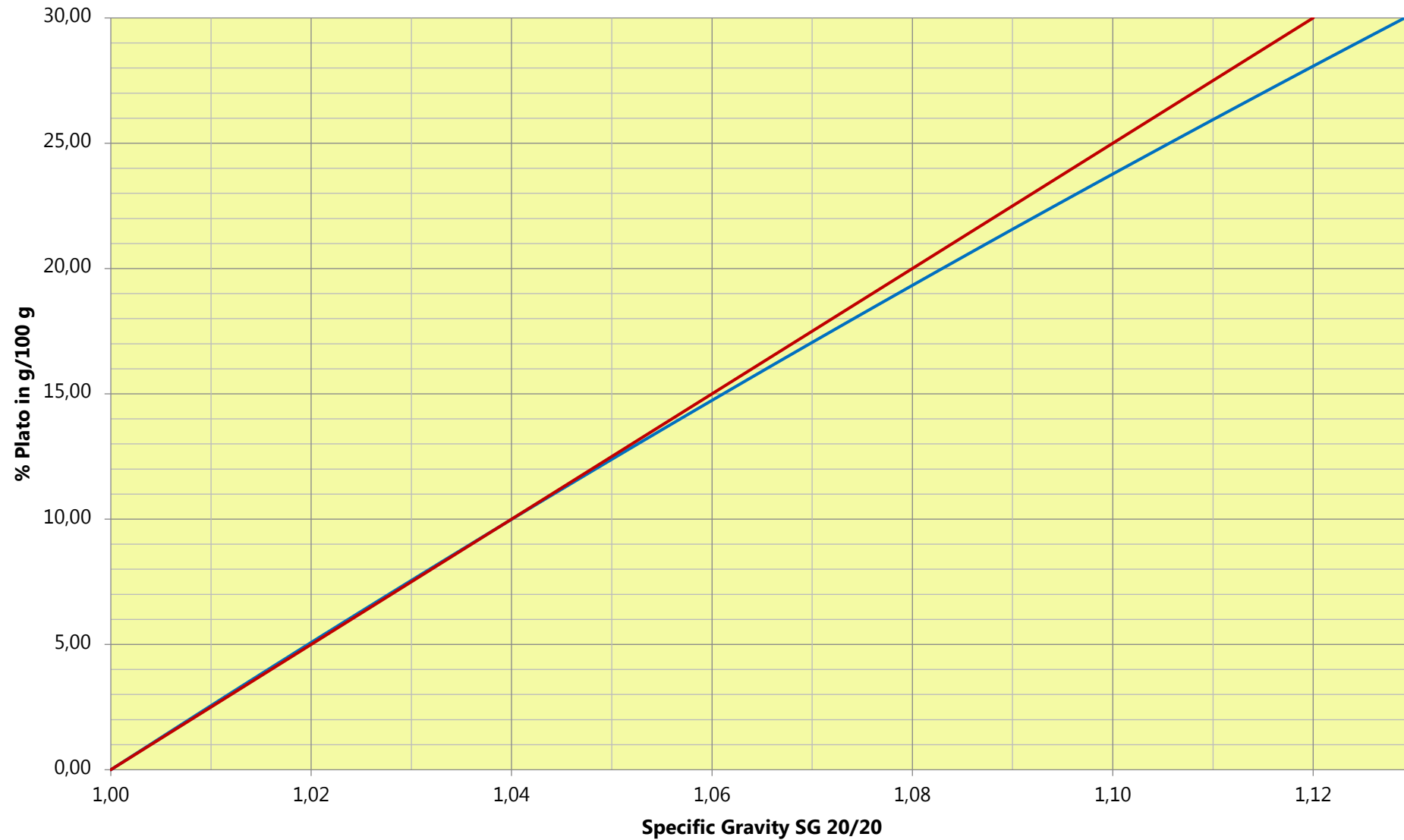
The quick and dirty formula:

$$\mathbf{SG = 1.0000 + 0.004 * \%P}$$

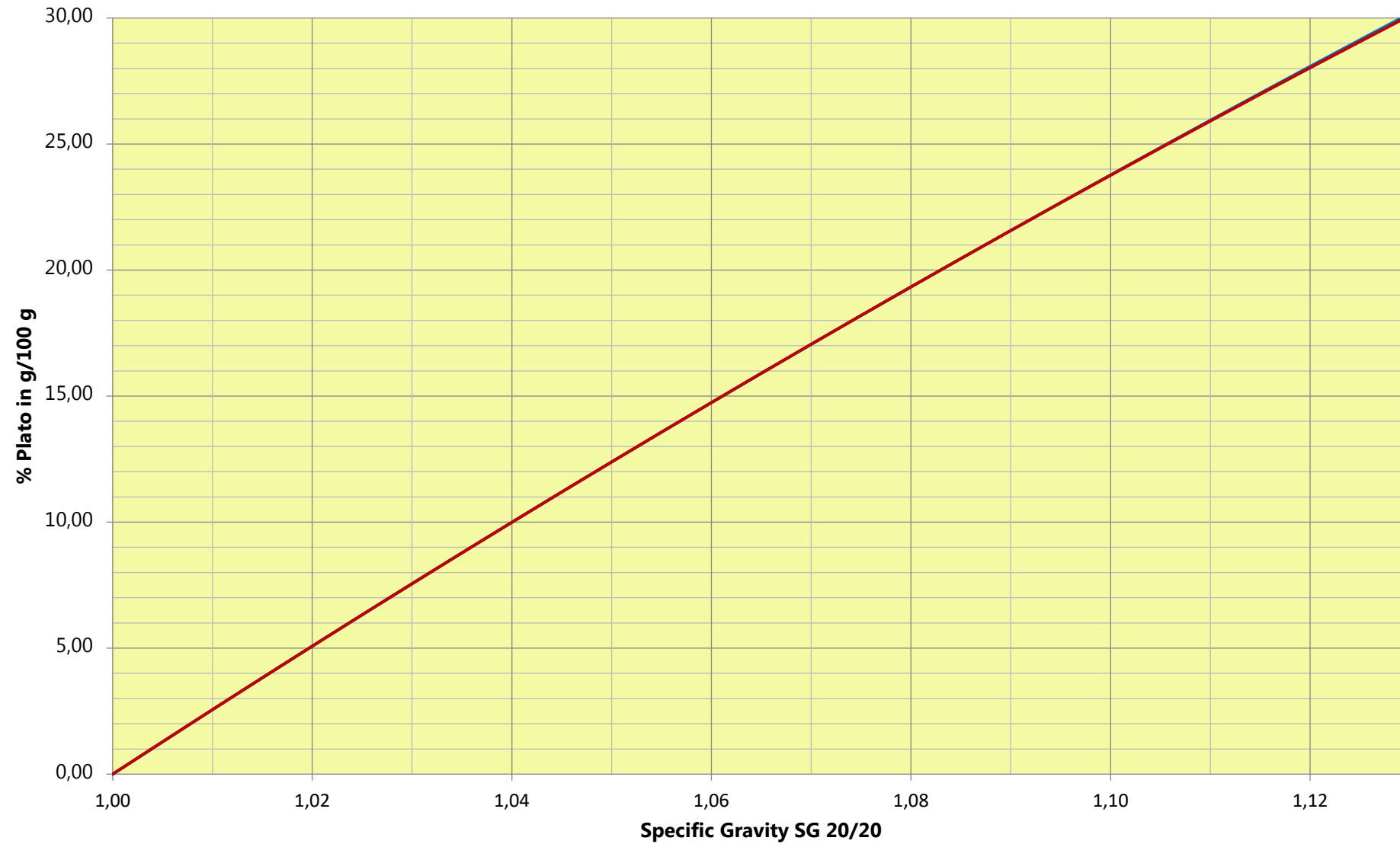
only for 1 decimal or less than 15 %P

More accurate polynomial formulas exist – EBC.

# The approximation



# EBC polynomium



# Extract and specific gravity

## Overall



	<b>Malt</b>	<b>Cold wort</b>	<b>Final beer</b>
Extract in g/100 g (mass or weight %)	% extract (as is) % extract (DM)	Original extract OE, %P	Apparent extract, EA %P Real extract, ER %P
Specific gravity $SG_{20/20}$ (20°C)	N/A	Original gravity OG, kg/l	Final gravity FG, kg/l

# Question 1

We are brewing a Pale Ale with an original gravity OG = 1.045.

a. What is the Original Extract OE in %P?

The resulting beer has a final gravity (FG) of SG = 1.010.

b. What is the final extract in %P?

# The Extract Balance

Mass balances are widely used in all sorts of food and chemical industries.

In brewing we use a special form of the mass balance:

The extract balance:

$$\text{In-going extract} = \text{Out-going extract}$$

The extract content (kg) in wort at 20 °C is calculated as:

$$\text{kg Extract} = \text{hl wort} * \text{OG of wort} * \text{OE of wort}$$

## Question 2 continued from question 1

The brewsize is 48 hl cold wort.

Calculate kg of extract in the brew.

# Thermal contraction of wort

**1 hl hot wort = 0.96 hl cold wort**

Please note:

Any measurement of a hot volume is uncertain!

## Question 3

### continued from questions 1 – 2

What is the volume of hot wort just before cooling?

## Overall Brewhouse Yield (OBY)

% of extract in raw materials which is recovered in the wort

Cold brewhouse yield is preferred to hot brewhouse yield

$$Y_1 = \frac{\text{kg extract in wort}}{\text{kg extract in raw materials}}$$

Be aware that in Germany also yield based on total material is used:

$$Y_2 = \frac{\text{kg extract in wort}}{\text{kg mass of raw materials}}$$

## Question 4

### continued from question 1 – 3

For the brew we use 800 kg malt with an extract content of 72.7%.

Calculate the two brewhouse yields  $Y_1$  and  $Y_2$ .

# Calculation of amount of malt for a brew

$$M = OE(\%P) * SG * Vol * 0.96 / Y_2$$

where

M = amount of malt (kg)

OE (%P) = original extract in wort (%P)

SG = specific gravity of wort

Vol = brewsize (hl) of hot wort

Y<sub>2</sub> = yield based on total material



## Question 5 – if time allows

Suppose we are adjusting the recipe to make 45 hl cold wort of 12 %P wort. The brewhouse yield  $Y_2$  is 74 %.

How many kg of malt should then be used?

# Calculation of mash thickness

Mash thickness =

**liter mashing-in water / kg brewing materials**

Mash thickness is adjusted in relation to the desired first wort strength (% Plato)

Also called **water-to-grist ratio**

## Question 6

### continued from question 4

At mashing-in we want the mash thickness to be 3.0 litres of water per kg malt.

How many litres of water should we use for mashing in?

## Extract before boiling

To calculate the extract in the wort kettle before boiling:

$$OE_b = OE_a \frac{V_a}{V_b}$$

where

$OE_b$  = extract in wort before boiling

$OE_a$  = extract in wort after boiling

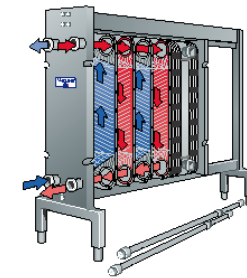
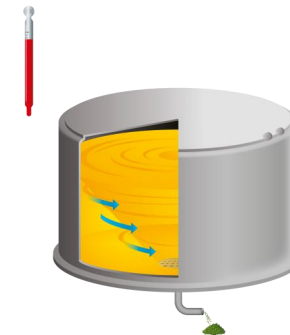
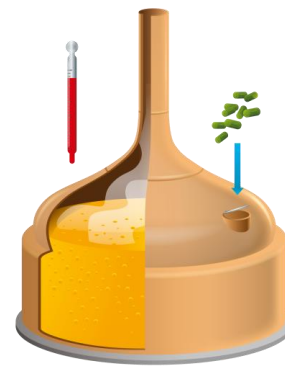
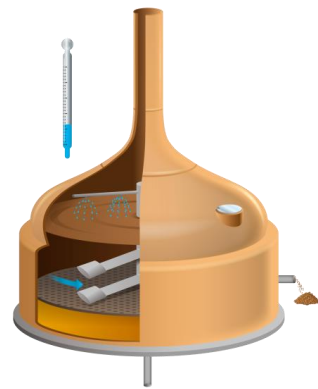
$V_b$  = volume of wort before boiling

$V_a$  = volume of wort after boiling



# Extract and specific gravity

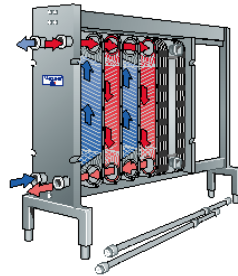
## Brewhouse



	First wort	Hot wort before boiling	Hot wort after boiling	Cold wort
Extract in g/100 g (mass or weight %)	First wort extract %P	Extract in hot wort, %P	Extract in hot wort, %P	Original extract OE, %P
Specific gravity $SG_{20/20}$	First wort gravity kg/l	Gravity of hot wort, kg/l	Gravity of hot wort, kg/l	Original gravity OG, kg/l

# Extract and specific gravity

## Beer processing



	<b>Cold wort</b>	<b>Fermentation</b>	<b>Final beer</b>
Extract in g/100 g (mass or weight %)	Original extract OE, %P	Apparent extract, EA %P Real extract, ER %P	Apparent extract, EA %P Real extract, ER %P
Specific gravity $SG_{20/20}$ (20°C)	Original gravity OG, kg/l	Specific gravity SG, kg/l	Final gravity FG, kg/l

# Estimation of colour

<b>EBC</b>	<b>Description</b>
0-5	Very pale
6+	Pale yellow
8+	Golden
12+	Amber
18+	Deep Amber / light copper
28+	Copper / reddish brown
34+	Deep copper / light brown
36+	Brown
44+	Dark brown
60+	Very dark brown
70+	Black

# Colours in different beer types

Beer style	Colour (EBC)	Visual description
Int. Style Lager	5 - 8	Pale straw yellow
Belgian Witbeer	4 - 8	Pale and opaque
Danish Classic	12	Dark straw yellow
English Pale Ale	10 - 30	Light Amber
German Vienna	24 - 32	Amber / copper
Munich/Dunkel	30 - 40	Copper
English Brown Ale	30 - 50	Brown
English Porter	50 - 80	Brown / Black
Baltic Porter	100	Black

# Total Colour Contribution TCC

Not concise – depends on:

- Hopping rate
- Boling method and time

Example of TCC calculation:

100 kg Pilsner malt colour 5:	500 TCC
<u>20 kg caramel malt colour 20:</u>	<u>400 TCC</u>
120 kg total malt:	900 TCC

Calculated colour:  $900 \text{ TCC} / 120 \text{ kg} = 7.5 \text{ EBC}$

i.e. pale yellow to golden



## Question 8 – if time allows

The recipe for Pale Ale includes the following malts:

- Pilsner malt:            colour 4            620 kg
- Munich malt:            colour 16            80 kg
- Crystal malt:            colour 75            100 kg

Estimate the colour of the beer.

## Calculation of hops dosing - simplified

$$\text{Kg hops per brew} = \frac{\text{Wanted BU} * \text{brewsize in hl}}{\% \text{ Utilisation} * \% \alpha\text{-acid in hops}}$$

Brewsize = brewlength to be hl cold wort

Bitterness units are measured in mg/l

% Utilisation is plant specific and usually around 30%

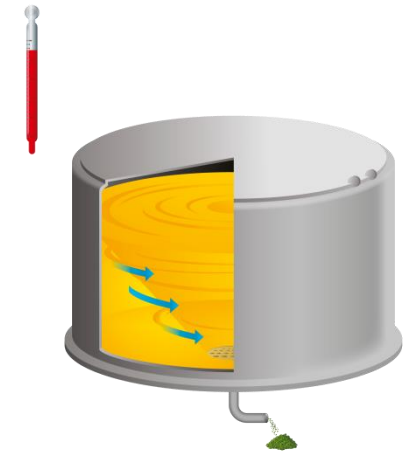
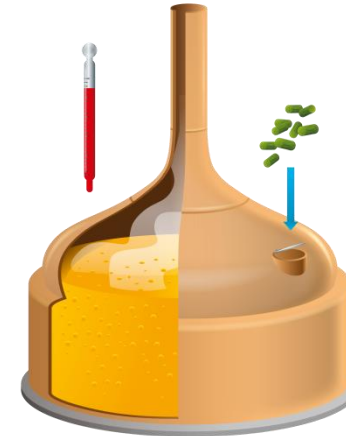
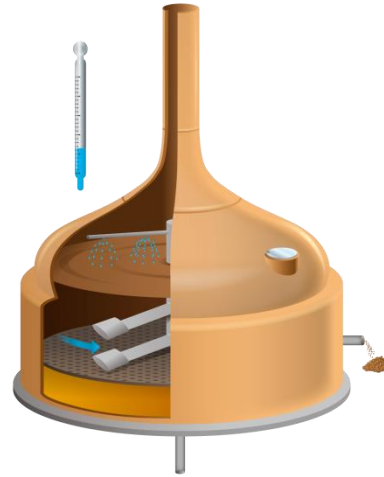
“Glenn’s Hop utilisation number” is a more precise tool available to get more precise utilization degree based also upon % P of wort and boiling time

## Question 9

Pale Ale should have a bitterness of 36 IBU. The brewsize is still 48 hl. The alfa-acid content in the hops is 10.5 % and utilisation is reckoned to be 30%.

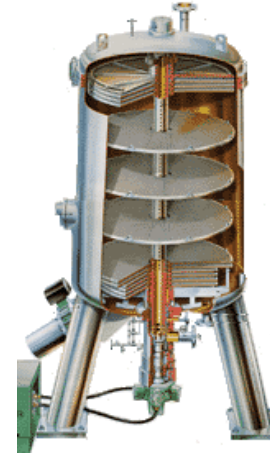
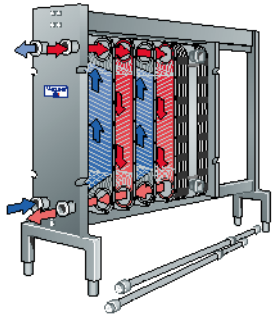
Calculate the amount of hops to be added in kg.

# Calculations in brewhouse



milling, mash-in	mashing	lautering	boiling	whirlpool
recipe	thickness	first wort %P	volumes	volume
kg malt	volume	yield first wort	extract	hop dosing
colour TCC	temperature	load kg malt/m <sup>2</sup>	evaporation	
water	hot water addition	kg spent grains	hop dosing	
	decoction	litres spent grains		
	pH			

# Calculations in beer processing



wort cooling	aeration, pitching	fermentation	filtration	bright beer
volume	aeration rate	RDF	blending	alcohol % w + vol
brewhouse yield	pitching rate	ADF		extract
		temperature of max density		final gravity
		freezing point		Tabarier, Balling, Craft
				Energy, BOD

# The Craft Formula

For craft brewers (measurement of gravity only):

$$A\%vol = \frac{OE\%P - EA\%}{2.048 - 0.0126 * OE\%P}$$

Note:

Not valid, if water or sugar has been added during or after the fermentation.

# Back-up slides

## Units for beer volume

# Definitions

**Mass** = weight of material in kg or ton

**As is** (m) = total weight of material incl. water

**Dry matter** (d.m.) = weight of material remaining after drying for 2 hours at 120°C (EBC Method)

**Moisture** (m) = As is – Dry matter

% = **percentage by weight**

**Extract** = soluble part of malt (EBC Analytical methods)

% Extract, as is = kg Extract in 100 kg material incl. moisture

% Extract, d.m. = kg Extract in 100 kg material excl. moisture

% Moisture = kg water in 100 kg material incl. moisture

# Abbreviations

Abbreviation	Beer	Wort	Unit
HI	Beer volume	Cold wort volume	100 litre
OE%P	Extract in Original Wort	Wort Extract	% Plato, g/100 g
ER%	Reel Extract	Wort Extract	% Plato, g/100 g
EA%	Apparent Extract	Wort Extract	% Plato, g/100 g
RDF%	Real Degree of Fermentation	0	%, g/100 g
ADF%	Apparent Degree of Fermentation	0	%, g/100 g
A%mas	Alcohol content by mass	0	%, g/100 g
A%vol	Alcohol content by volume	0	%, ml/100 ml
SGA	Specific Gravity of distillate	1	
SGE	Specific Gravity of Reminiscence	SG of wort	
SGBeer	Specific Gravity of Beer	SG of wort	
TMXD°	Temperature of Max. Density		°C
FRZP°	Freezing Point of Beer		°C
CALV	Calorific Value of Beer		kcal/100 ml
Energy	Nutritive Value of Beer		kJ/100 ml
BOD5	Biological Oxygen Demand		g/l
kgOE	Kg of Original Extract	Wort Extract	kg

# Units for beer volume – metric (SI)

<b>Unit</b>	<b>Amount in litres</b>
1 cubic metre	1000 litres
1 hektolitre	100 litres
1 dekalitre	10 litres
1 decilitre	0.1 litres
1 centilitre	0.01 litres
1 millilitre	0.001 litres

# Units for beer volume – British

Unit	Amount in British units	Amount in litres
1 butt	108 gallons	490.96 litres
1 hogshead	54 gallons	245.48 litres
1 beer barrel	36 gallons	163.65 litres
1 kilderkin	18 gallons	81.825 litres
1 firkin	9 gallons	40.914 litres
1 beer gallon	4 quarts	4.546 litres
1 quart	2 pints	1.1365 litres
1 pint	20 fl. oz.	0.5682 litres
1 fluid oz.		0.028412 litres

# Units for beer volume – US

Unit	Amount in US units	Amount in litres
1 beer barrel	31 gallons	117.34 litres
1 standard barrel (not for beer)	31.5 gallons	119.24 litres
1 beer gallon	4 quarts	3.7853 litres
1 quart	2 pints	0.9463 litres
1 pint	16 fl. oz.	0.4732 litres
1 fluid oz.		0.02957 litres

# Additional calculations

# Volume of mash and spent grains

## Emperic figures

1 kg of ground malt takes up 0.8 liter space in the mash.

Total mash volume will then be:

Volume of mashing in water +  $0.8 \text{ l/kg} * \text{kg malt}$

1 kg malt produces 1.2 kg spent grains, which takes up 1.8 liter space as spent grains (if 80% water) in the lauter tun





# The Craft Formula for calculation of alcohol content

For craft brewers (measurement of gravity only):

$$A\%vol = \frac{OE\%P - EA\%}{2.048 - 0.0126 * OE\%P}$$

No water or sugar has been added during or after the fermentation!

# Question 11

## continued from question 1

You need to declare the alcohol by volume on the label. From Q1 we have  $OG = 1.045$  and  $FG = 1.010$

Calculate ABV %vol