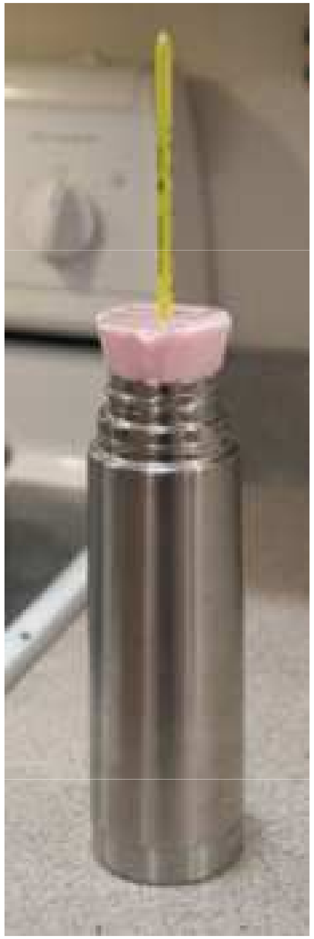
A Closer Look At Efficiency

or

How to make efficiency predictable

Why yet another discussion about efficiency?



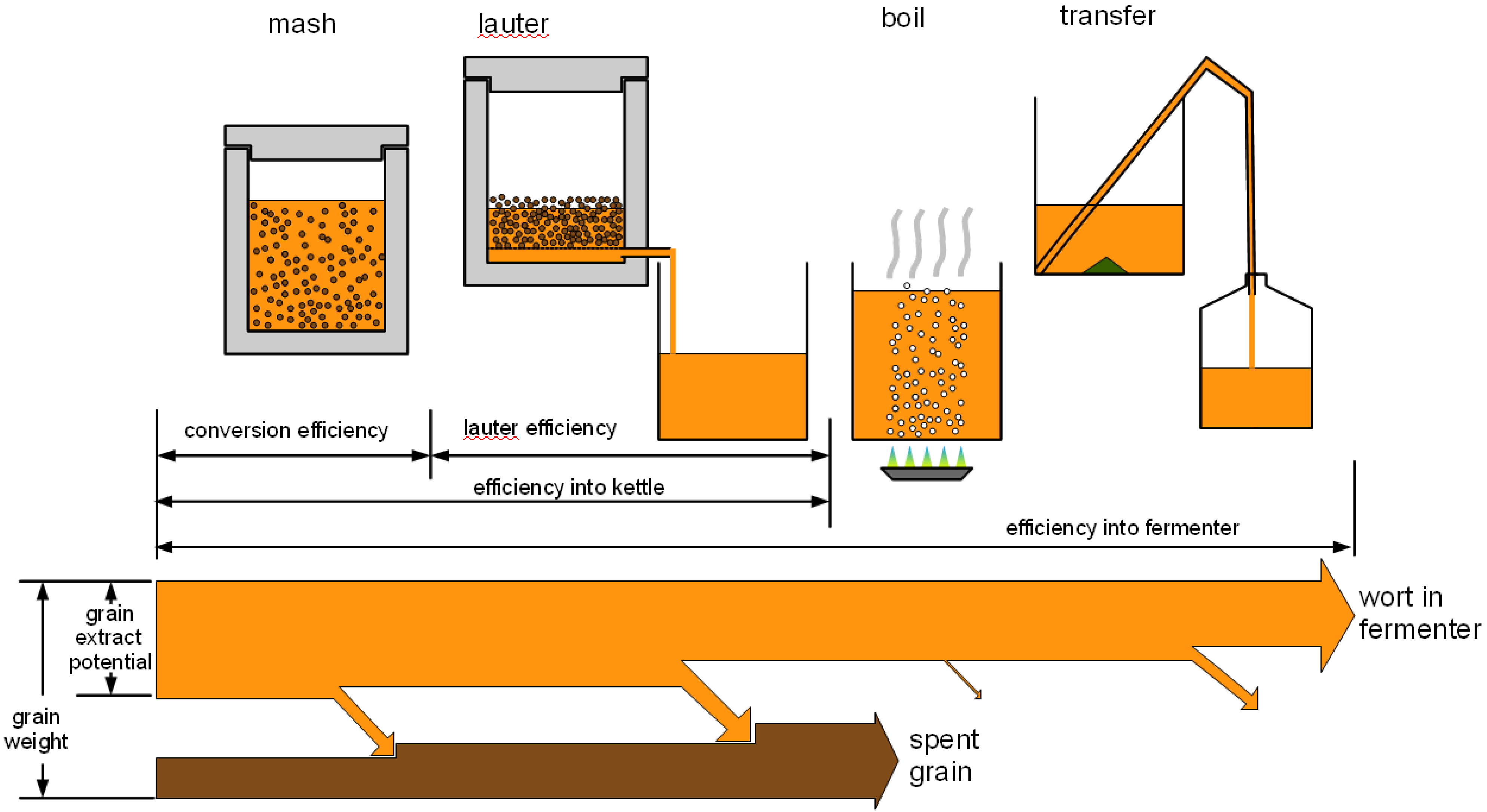
- many brewers wonder about changing efficiency
- micro mashing experiments provided detailed insights into mash conversion
- batch sparging analysis provided insight into lauter losses
- low efficiency can be a sign suboptimal mashing conditions
- very high efficiency may not be the best for your beer

It is not so much about the actual number
It is about being able to count on it

Where can efficiency be assessed?

- after mashing -> conversion efficiency
  - how well the mash converted the available starches
- between mashing and before boiling -> lauter efficiency
  - how well lautering transferred the converted starches (sugars) into the kettle
- before or after boiling -> efficiency into kettle
  - we care about this when we discuss efficiency in all grain brewing
- fermenter -> efficiency into fermenter
  - includes losses during wort transfer (e.g. trub losses)
  - may depend on more than just mashing and lautering
  - many be needed for recipe design

efficiency losses between grain and fermenter



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efficiency into kettle

- covers mashing and lautering
- official efficiency formula:

extract weight in wort

wort weight

extract percentage

$$\mathit{efficiency\ into\ kettle}=\frac{V_{kettle}\cdot sg_{kettle}\cdot E_{kettle}}{m_{grist}\cdot e_{grist}\cdot\frac{1}{100}}$$

extract available in grist

- Extract percentage is given in Plato
- Wort volume needs to be temperature corrected:
  - * 0.96 for 100 C / 212 F
  - * 0.97 for 80 C / 176 F
  - no correction for room temperature wort

working with gravity units

- **extract in kettle** can also be expressed as the product of kettle volume and gravity points
- **extract available in grist** can be expressed as product of grist weight and extract potential
- **extract potential** is given as PPG (**p**oints per **p**ound per **g**allon)

$$efficiency\ into\ kettle = 100 \cdot \frac{V_{kettle} \cdot GP_{kettle}}{m_{grist} \cdot PPG_{grist}}$$

extract weight in wort

extract available in grist

- PPG values for malts and adjuncts can be determined from their extract potential *e* given in %

$$PPG = 0.46 \cdot e$$

- despite simplifications made for this formula it only shows a small (<1%) error over the gravity range used in brewing

What affects efficiency into kettle?

$$efficiency\ into\ kettle = conversion\ efficiency \cdot lauter\ efficiency$$

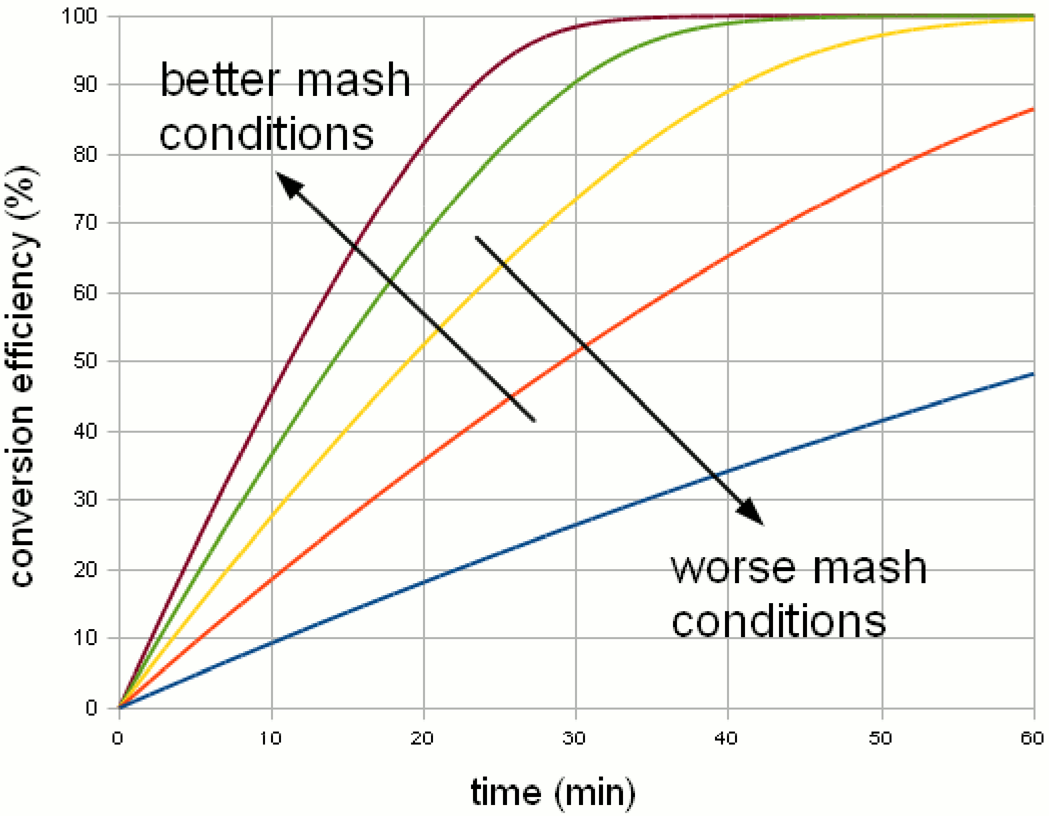
- to keep kettle efficiency predictable conversion and lauter efficiency need to be predictable
- conversion is affected by conditions during mashing -> mainly a biochemical process
- lauter efficiency is affected by lauter tun design and lauter procedure -> physical process

conversion efficiency

- new concept for home brewing
- measures the percentage of starch made soluble during mashing
  -> conversion
- not all mashes convert equally well
- many efficiency problems are the result of poor mash conversion
  -> low conversion efficiency
- negative iodine test does not necessarily mean complete conversion
  -> unconverted starches can be “hiding” in grits
- conversion efficiency is affected by mash parameters

The concept of “good enough”

- base malts have more than enough enzymes to convert all of the malt's starches
- mash parameters don't have to be at their best -> they only have to be “good enough”
- parameters affect each other -> one parameter being more optimal can compensate for another being suboptimal
- once a mash parameter is not “good enough” anymore conversion efficiency changes as that parameter changes



Mash Parameters

- **Temperature:** The hotter the better for efficiency (until 75-80 C / 167–176 F). **But** temperature is needed to control fermentability. The lower the temp the longer it takes for full mash conversion
- **Time:** the longer the better. **But** there will be a time when conversion efficiency doesn't change or changes only little. Extended mashing extracts more tannins and mash may spoil.
- **pH:** alpha amylase optimum is at pH 5.6 – 5.8 **But:** other benefits shift the optimal mash pH towards 5.4 – 5.6 (room temperature sample)
- **milling:** the finer the faster and more complete the conversion. **But:** mash tun design and lauter practice set a limit to how fine one can go. The absence of channeling may allow finer grists for batch sparging than for fly sparging. Malt conditioning can mitigate run-off problems.
- **mash thickness:** thinner mashes convert faster and more easily. Thick mashes impede starch gelatinization and inhibit alpha amylase activity. Even 6 l/kg (3 qt/lb) is not too thin.

Mash Parameters cont.

- **mash schedule:** the more intense the better the conversion. Single infusion -> least intense. Decoction mashing -> most intense. **But:** you should not have to resort to triple decoction mashing to fix low conversion efficiencies.
- **“Mash out”**: raises temp to supercharge alpha amylase. Can convert more starches (i.e. raise conversion efficiency) if conversion was not complete before this point
- **Diastatic power:** The darker the malt the lower its enzymatic strength (generally). Only a problem in Munich malt or adjunct mashes. Some light malt helps as “enzymatic boost” in dark malt mashes.

Mash Gravity Test

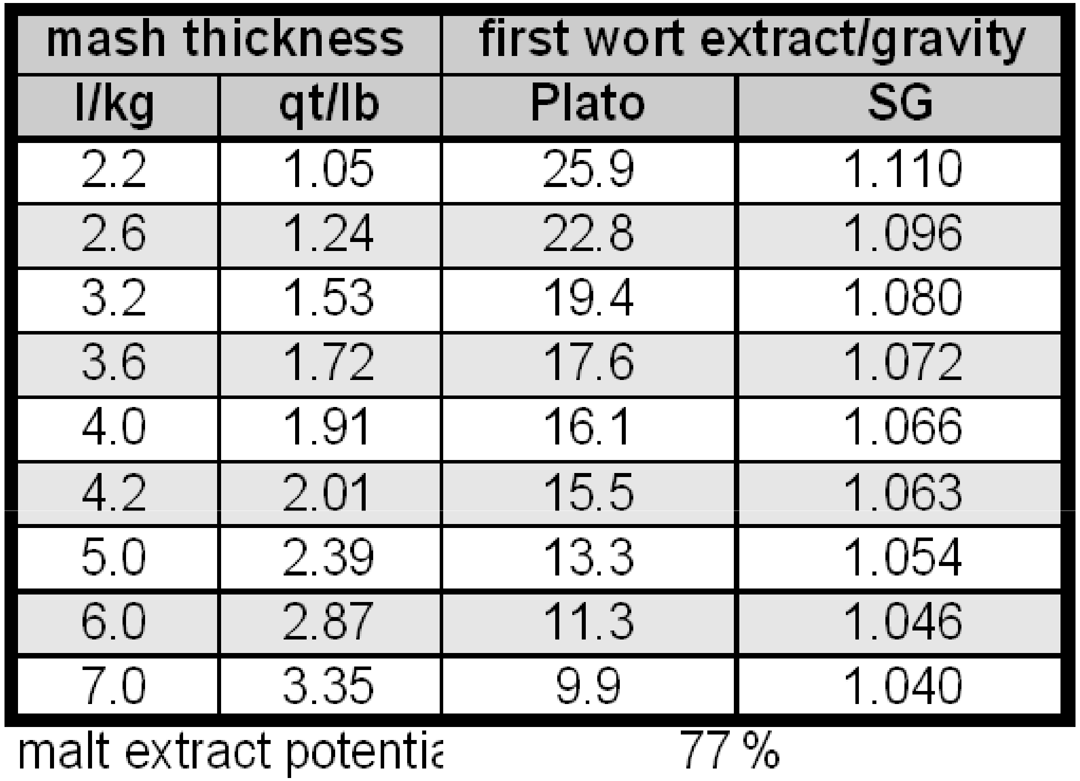
- Kudos to NB-forum for name
- actual wort volume in mash is difficult to measure due to wort displacement by grain and volume increase through dissolved extract
- Definition of the wort strength in Plato:

$$Plato=\frac{m_{extract}}{(m_{extract}+m_{water})}\cdot 100$$

- extract weight is known: extract potential of grist
- water weight is known: water added to mash
- 100% conversion mash gravity can be calculated in Plato and converted to specific gravity

Calculating conversion efficiency I

- 100% conversion mash gravity calculated based on mash thickness and grist extract potential



mash thickness		first wort extract/gravity	
l/kg	qt/lb	Plato	SG
2.2	1.05	25.9	1.110
2.6	1.24	22.8	1.096
3.2	1.53	19.4	1.080
3.6	1.72	17.6	1.072
4.0	1.91	16.1	1.066
4.2	2.01	15.5	1.063
5.0	2.39	13.3	1.054
6.0	2.87	11.3	1.046
7.0	3.35	9.9	1.040

malt extract potentia 77 %

calculating conversion efficiency II

- conversion efficiency is actual mash gravity vs. full conversion mash gravity

$$conversion\,efficiency = \frac{actual\ mash\ strength}{full\ conversion\ mash\ strength} \cdot 100$$

- 95-100% is excellent
- <85% may indicate poor mashing conditions
- can also be assessed throughout mashing to monitor conversion progress -> yet another use for a refractometer

Lauter efficiency

- efficiency of transferring sugars dissolved during mashing into boil kettle
- depends on lauter tun design and lauter process
- Three main approaches exist in home brewing:
  - fly or continuous sparging
  - batch sparging
  - no-sparge
- Efficiency lost during lautering can improve beer quality
- lauter efficiency can be assessed by testing residual sugar in spent grain

Fly or Continuous Sparging

- the more evenly the grain bed is rinsed the more efficient the lauter process will be
- even rinsing depends on
  - **manifold design**: collection points need to be evenly distributed on bottom of lauter tun. False bottoms are best.
  - **grain bed porosity**: porous grain bed -> less wort flow restriction -> less “channeling”
  - **run-off speed**: fast run-off encourages channeling.
  - **wort viscosity**: low wort viscosity leads to less restricted wort flow -> less “channeling”

No Sparge

- All sparge water is added to the mash before the wort is run-off into the kettle
- Lauter efficiency depends only on the amount of wort held back in spent grain and dead spaces

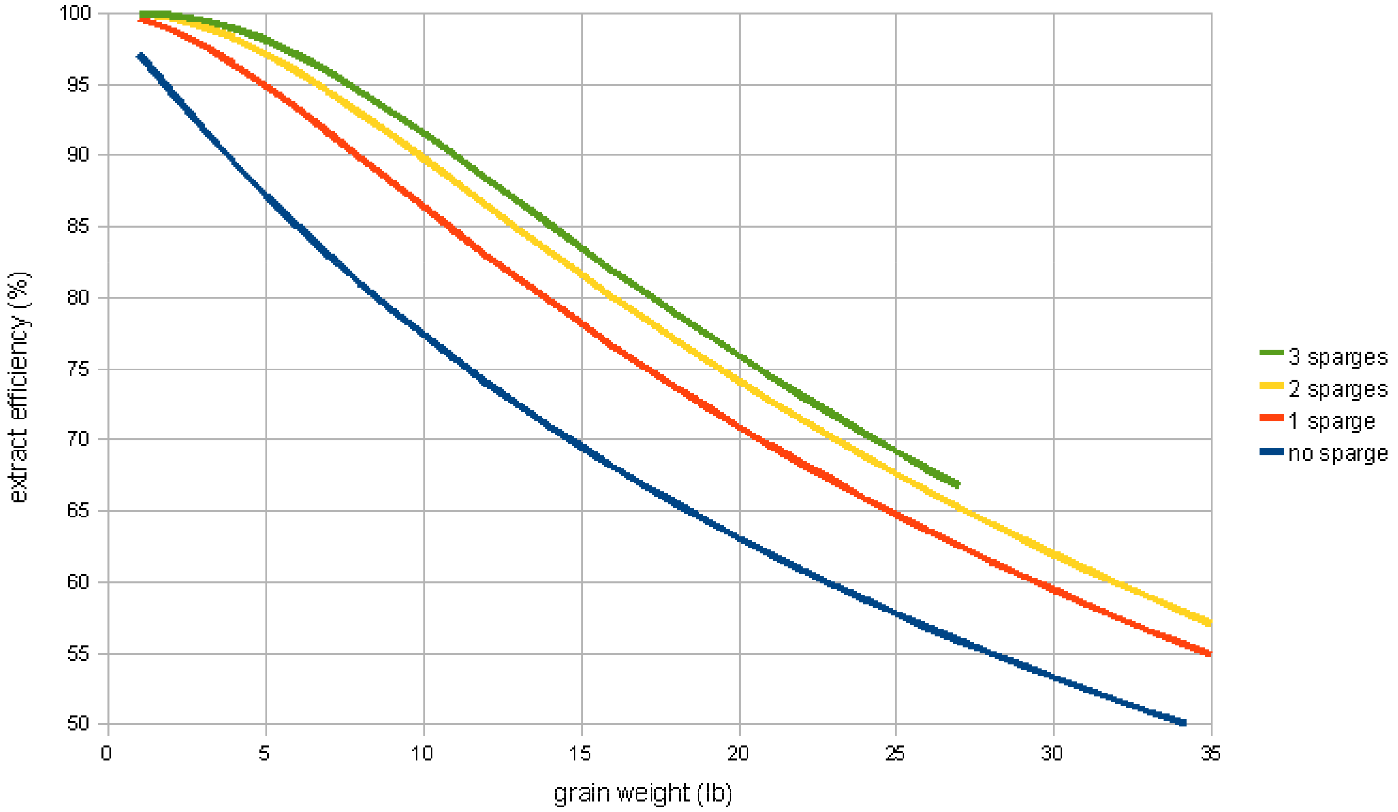
$$\mathit{lauter\ efficiency} = \left(1 - \frac{\mathit{volume\ held\ back}}{\mathit{total\ wort\ volume}}\right) \cdot 100$$

- The bigger the beer (i.e. bigger grain bill) the lower the efficiency:
  - 10 Plato OE: ~ 82% (15% boil-off)
  - 16 Plato OE: ~ 71% (15% boil-off)
- Lack of sparging leads to higher quality wort

Batch Sparging

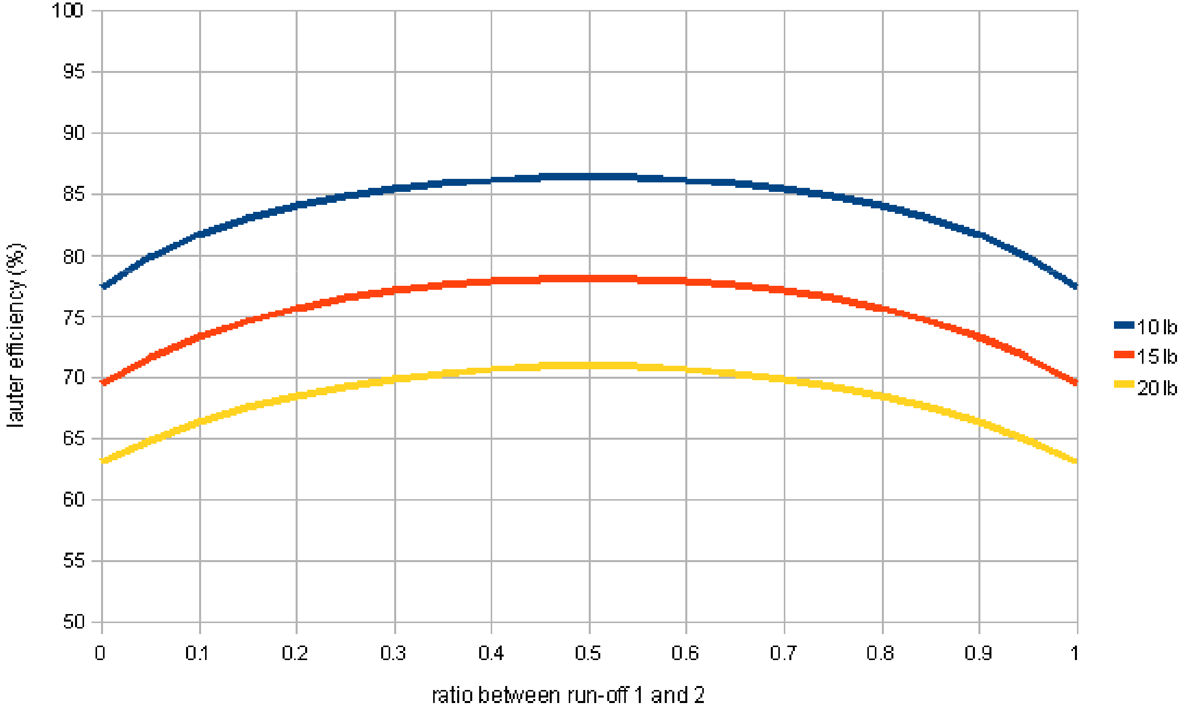
- **Process:**
  - First wort is completely drained -> sparge water is added and thoroughly stirred -> wort is completely drained -> repeated as necessary
- **Efficiency is limited by**
  - wort held back after each sparge (grain bill size)
  - boil-off rate (amount of water available)
- **Efficiency is also affected by**
  - relative volumes of each run-off
  - number of run-offs or sparge batches
- **Efficiency is not affected by**
  - manifold design, if it doesn't change the amount of wort that can be drained
  - run-off speed
  - “channeling”

Batch sparging and grist weight



- equal run-off sizes, constant pre-boil volume of 6.5 gal
- benefit of additional sparges quickly diminishes:
  - no-sparge to 1 sparge -> + ~8% lauter efficiency
  - 1 sparge to 2 sparges -> + 3% lauter efficiency
  - 2 sparges to 3 sparges -> + 1% lauter efficiency

Batch sparging and relative run-off size



- equal sized run-offs are best
- a 30/70 split looses only 1% lauter efficiency compared to 50/50
- Don't get too hung up over equalizing run-offs

Sparging and wort quality

- first wort is highest quality wort
- sparging depletes the mash's buffer capacity -> water pH starts to take over -> pH rises -> tannins become more soluble
- Be careful with high lauter efficiencies (90-95+%). They may reduce wort quality.
- Don't fix poor conversion efficiency with excessive lautering
- 75% efficiency for one brewer may not be the same 75% for another brewer:
  - 95% conversion eff. x 79% lauter eff. = 75% into kettle
  - 79% conversion eff. x 95% lauter eff. = also 75% into kettle
  - former is a realistic no-sparge scenario while the latter could be over sparging

reducing lauter efficiency

- limit the amount of sparge water by using more strike water -> thinner mashes
- German Pilsners have been brewed with thin mashes in order to increase the amount of high quality first wort
- no-sparge. With close to 100% conversion, efficiencies can be in the 70s for average beers
- keep boil-off between 10 and 15% -> limits the amount of sparge water available
- batch spargers may not fully drain the mash before sparge water addition

Predictable efficiency

- conversion, lauter and transfer efficiency need to be predictable
- predictable conversion efficiency:
  - all mash parameters should be “good enough”
  - this means aiming for 95-100% conversion efficiency
  - small changes in temperature (attenuation control), pH and diastatic power have little effect on how much starch is converted
- predictable lauter efficiency:
  - **fly sparging:** avoid channeling by:
    - sparging slow enough
    - good manifold design or false bottom
    - sufficiently porous grain bed

predictable efficiency cont.

  - **batch sparging/no-sparge:**
    - the larger the grain bill (large beers) the lower the efficiency
    - grain absorption affects efficiency too, but it rarely changes
- predictable transfer efficiency
  - depends on amount of trub -> hot break and hops
  - brew more than you need and save rest for starters

- Monitor conversion efficiency to take corrective action or prepare for lower than expected efficiency -> mash gravity test
- Understand the losses of your system -> use efficiency spreadsheet on a few batches

References

- L. Narziss, W. Back *Technologie der Würzebereitung, 8*th edition, 2009
- W. Kunze, *Technologie Brauer und Mälzer*. 9th edition, 2007
- R. Daniels, *Designing Great Beers*, 2000
- J. Palmer, *How To Brew*, 3rd edition, 2006

supporting links

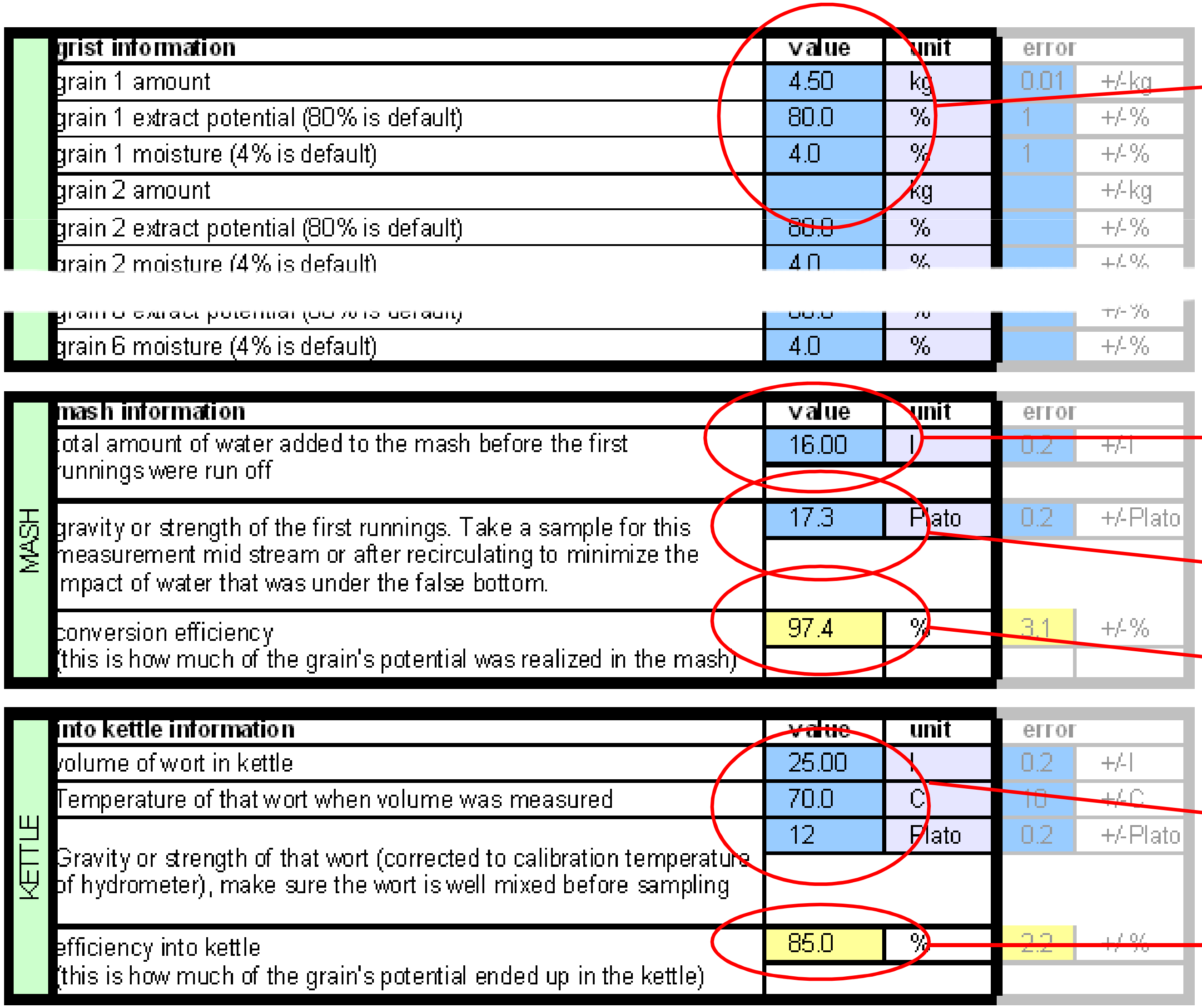
- Understanding efficiency:

http://braukaiser.com/wiki/index.php?title=Understanding_Efficiency

- Science of Mashing: http://braukaiser.com/wiki/index.php?title=The_Science_of_Mashing
- Evaluating malt crush: http://braukaiser.com/wiki/index.php?title=CrushEval
- Malt conditioning: http://braukaiser.com/wiki/index.php?title=Malt_Conditioning
- Mashing parameter experiments: http://braukaiser.com/wiki/index.php/Effects_of_mash_parameters
- Starch Test: http://braukaiser.com/wiki/index.php?title=Starch_Test
- Brew free or Die: http://bfd.org

Back-up

Efficiency Analysis Spreadsheet



grist information	value	unit	error	
grain 1 amount	4.50	kg	0.01	+/-kg
grain 1 extract potential (80% is default)	80.0	%	1	+/-%
grain 1 moisture (4% is default)	4.0	%	1	+/-%
grain 2 amount		kg		+/-kg
grain 2 extract potential (80% is default)	80.0	%		+/-%
grain 2 moisture (4% is default)	4.0	%		+/-%
grain 6 extract potential (80% is default)	80.0	%		+/-%
grain 6 moisture (4% is default)	4.0	%		+/-%

mash information	value	unit	error	
total amount of water added to the mash before the first runnings were run off	16.00	l	0.2	+/-l
gravity or strength of the first runnings. Take a sample for this measurement mid stream or after recirculating to minimize the impact of water that was under the false bottom.	17.3	Plato	0.2	+/-Plato
conversion efficiency (this is how much of the grain's potential was realized in the mash)	97.4	%	3.1	+/-%

into kettle information	value	unit	error	
volume of wort in kettle	25.00	l	0.2	+/-l
Temperature of that wort when volume was measured	70.0	C	10	+/-C
Gravity or strength of that wort (corrected to calibration temperature of hydrometer), make sure the wort is well mixed before sampling	12	Plato	0.2	+/-Plato
efficiency into kettle (this is how much of the grain's potential ended up in the kettle)	85.0	%	2.2	+/-%

enter grist information

enter total water in mash: strike water and any infusions

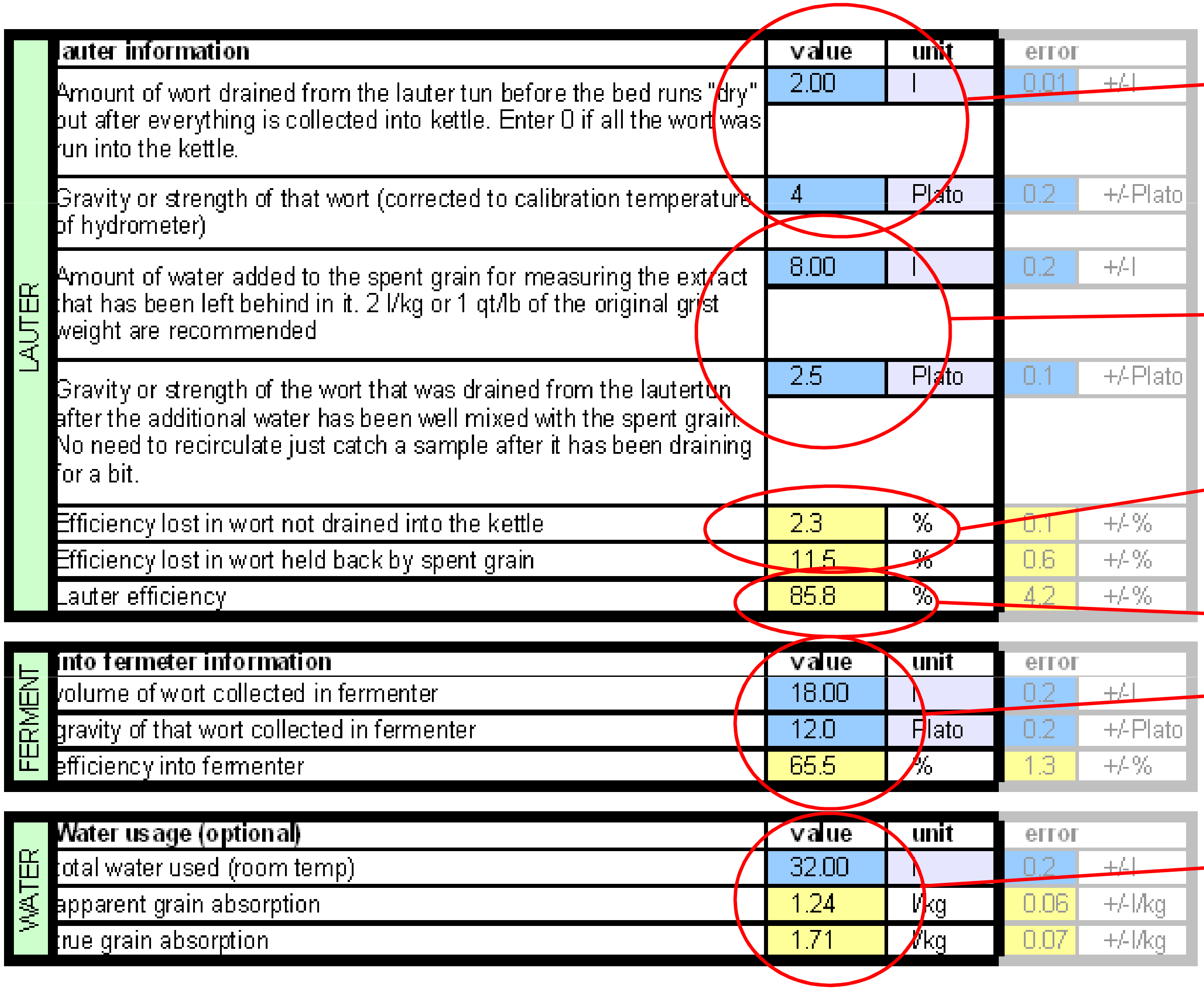
enter first wort gravity

conversion efficiency is calculated

pre boil (or post boil) kettle information

efficiency into kettle. This is what we should compare and discuss

Efficiency Analysis Spreadsheet cont.



	Lauter information	value	unit	error	
LAUTER	Amount of wort drained from the lauter tun before the bed runs "dry" but after everything is collected into kettle. Enter 0 if all the wort was run into the kettle.	2.00	l	0.01	+/-l
	Gravity or strength of that wort (corrected to calibration temperature of hydrometer)	4	Plato	0.2	+/-Plato
	Amount of water added to the spent grain for measuring the extract that has been left behind in it. 2 l/kg or 1 qt/lb of the original grist weight are recommended	8.00	l	0.2	+/-l
	Gravity or strength of the wort that was drained from the lautertun after the additional water has been well mixed with the spent grain. No need to recirculate just catch a sample after it has been draining for a bit.	2.5	Plato	0.1	+/-Plato
	Efficiency lost in wort not drained into the kettle	2.3	%	0.1	+/-%
	Efficiency lost in wort held back by spent grain	11.5	%	0.6	+/-%
	Lauter efficiency	85.8	%	4.2	+/-%

	into fermeter information	value	unit	error	
FERMENT	volume of wort collected in fermenter	18.00	l	0.2	+/-l
	gravity of that wort collected in fermenter	12.0	Plato	0.2	+/-Plato
	efficiency into fermenter	65.5	%	1.3	+/-%

	Water usage (optional)	value	unit	error	
WATER	total water used (room temp)	32.00	l	0.2	+/-l
	apparent grain absorption	1.24	l/kg	0.06	+/-l/kg
	true grain absorption	1.71	l/kg	0.07	+/-l/kg

Info about wort that didn't make it into the kettle but could be drained from the lauter

Spent grain test for extract content

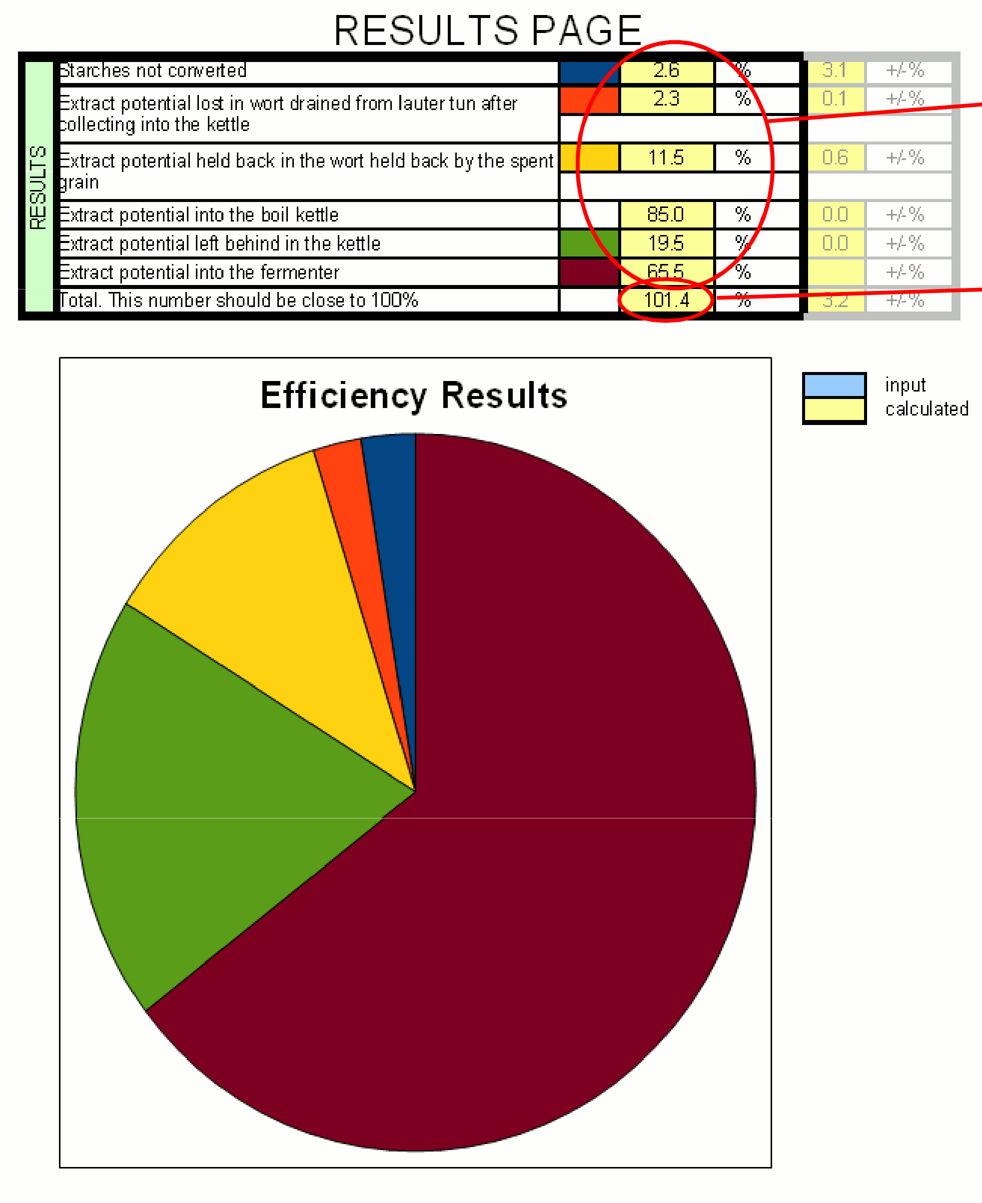
Efficiency losses associated with the two

lauter efficiency

Efficiency into fermenter. Many use this for recipe design

estimation of true and apparent grain absorption. It matters for batch sparging efficiency

Efficiency Analysis Spreadsheet cont.



RESULTS PAGE

RESULTS	Starches not converted	🟦	2.6	%	3.1	+/-%
	Extract potential lost in wort drained from lauter tun after collecting into the kettle	🟧	2.3	%	0.1	+/-%
	Extract potential held back in the wort held back by the spent grain	🟨	11.5	%	0.6	+/-%
	Extract potential into the boil kettle		85.0	%	0.0	+/-%
	Extract potential left behind in the kettle	🟩	19.5	%	0.0	+/-%
	Extract potential into the fermenter	🟥	65.5	%		+/-%
	Total. This number should be close to 100%		101.4	%	3.2	+/-%

🟦 input
🟨 calculated

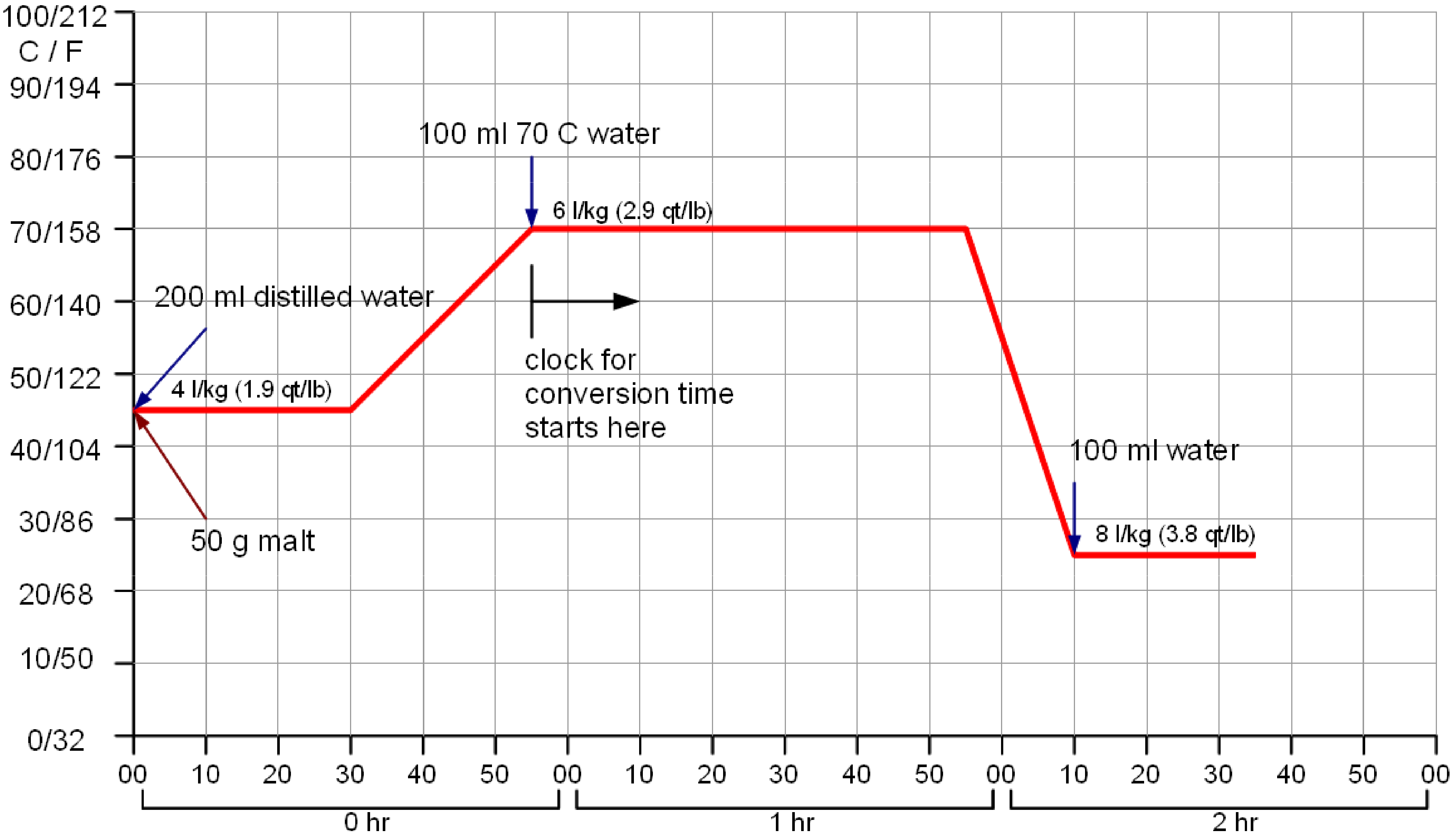
efficiencies from previous sections

total should be close to 100%

Congress mash

- used to determine extract potential and fine grind / coarse grind difference
- 50 g malt sample
- malt milled at 0.2 mm (7.8 mil) and 0.7 mm (27.6 mil) in a disc mill
- mash is done with distilled water -> no water minerals are necessary for mash conversion

congress mash



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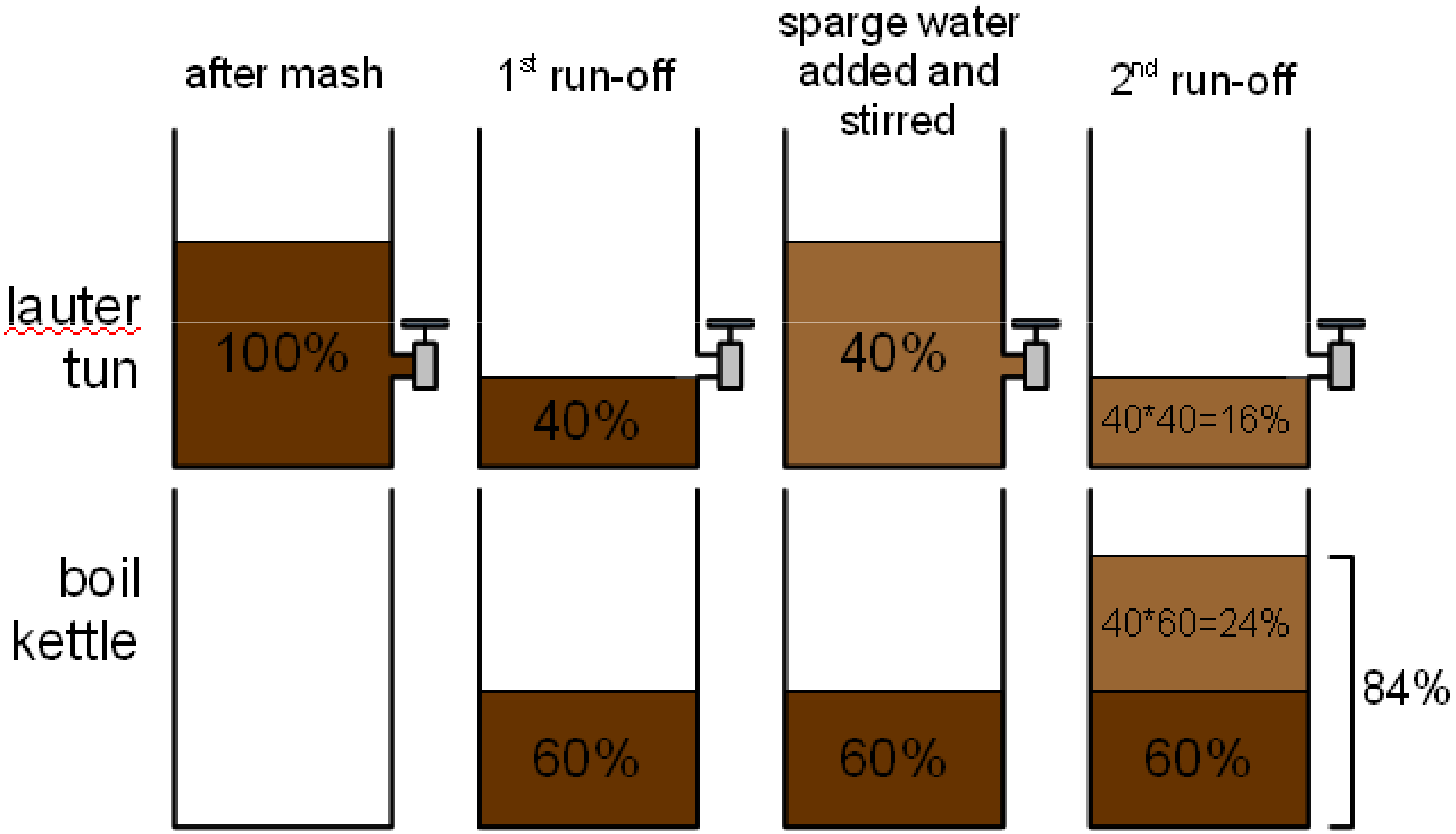
Congress mash cont.

- wort is filtered through filter paper
- specific gravity of congress wort is measured to determine extract content
- mash thickness (8 l/kg) and grain moisture content are used to calculate the dry basis extract content of the grain

$$e=100\cdot\frac{E_{congress}\cdot 8}{(100-MC)-E\cdot(100-MC)}$$

- collected wort volume does not matter -> lautering of congress mash doesn't mater

Batch sparge model



- batch sparing and no-sparging can easily be modeled
- model can be used to predict efficiency or analyze the effect of various parameters