Hop Science and Pseudoscience

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Ale Asylum
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Overview

- General strategy
- Maintaining consistency
- Hopping methods
  - First wort hopping
  - Flameout hopping
- Understanding IBUs
  - Definition and significance
- Estimating IBUs
  - Tinseth as a starting point
  - Pellet utilization
  - Whirlpool utilization
  - Saturation
  - Dry hop utilization (seriously?)
  - Brewing equipment adjustments
- Challenging conventional wisdom: cohumulone and gypsum
- Compensating for post-boil volume additions

General Strategy

- Commit to adding whatever late kettle/dry hops will provide your desired flavor and aroma.
- Pick a target IBU value (you'll need it to account for saturation).
- Calculate IBU contributions of late/dry hops.
- If needed, increase target IBU to a higher value than the combined contribution of your late/dry hops.
- Calculate full-boil hop addition needed to achieve target IBU.
  - This addition should be large enough to not disappear if the alpha acids of your late kettle hops increase.

Maintaining Consistency

- Suppose you once brewed a great IPA with the following hopping schedule:
  - 1.2 oz Magnum, 14% alpha acids, boiled for 60 min
  - 4.8 oz Centennial, 8.5% alpha acids, flameout addition
  - 2.7 oz Centennial, 8.5% alpha acids, dry hop addition
- You want to repeat the recipe, but your Centennials now have 10% alpha acids.
- Keep weights of flameout and dry hop additions the same so levels of oils and polyphenols don't drop.
  - Oil content affected by harvest time, not alpha acids[1].
- Maintain consistent overall IBUs by adjusting the full boil addition.

First Wort Hopping

- Adding hops to kettle shortly after beginning lauter.
- Theory is that extra contact time oxidizes hop oils, which become less volatile during the boil.
- My experience is that it adds a subtle layer of noble hop flavor.
  - Great for beers where you want to taste hop nuance, such as Pilsner and Belgian Blond.
  - At best, it gets lost in heavily-hopped beers like IPA. At worst, it muddies the bright intensity of an otherwise great hop bill.
- Interestingly, German brewers often do the opposite and pre-boil wort before adding hops[2].
  - Allows malt polyphenols to form complexes with proteins before hop polyphenols can interfere.

Flameout Additions

- Adding hops at flameout and letting your wort sit in the kettle for 30 minutes before chilling is a great way to boost hop flavor.
- You may think this would cause DMS issues, but 30 minutes of whirlpool + settling is common at commercial breweries that use pellet hops.
  - Commercial knockouts to fermentation tanks often take another 45 minutes while wort in kettle/whirlpool stays hot until it reaches the heat exchanger.
  - Percent volume evaporated is much higher in typical homebrew kettles than typical commercial kettles, which further reduces DMS.
- Still try to cool your wort quickly after the hot rest.

What is an IBU?

- Developed in the late 1960s to quantify bitterness[3].
- Defined by its measurement procedure[4]:
  - Mix beer with hydrochloric acid and iso-octane.
  - Shake and centrifuge to separate iso-octane extraction.
  - Using a spectrophotometer, measure absorbance of iso-octane extraction at wavelength of 275 nm and multiply by 50.
- An IBU consists of everything in beer that can be extracted by iso-octane and absorb 275-nm light[5].
  - This includes isomerized alpha acids.
  - It also includes alpha acids, oxidized alpha and beta acids, and polyphenols.
- 1 IBU does not equal 1 mg/L of isomerized alpha acid.
  - Utilization is usually expressed as a percentage of available alpha acids, but the unit should really be 100 x IBU / (mg/L alpha acid added to wort).

Significance of IBUs

- Case study of IPA across 35 Rock Bottom breweries[6]:
  - Lab-measured IBUs had a moderate correlation with perceived bitterness.
  - Lab-measured IBUs had no correlation with perceived hop flavor or aroma.
  - Perceived hop flavor had a strong correlation with perceived bitterness.
  - Perceived hop aroma had a moderate correlation with perceived bitterness.
- IBUs are a poor indicator of overall hoppiness.
- IBUs are still useful to maintain an important aspect of consistency.

Estimating IBUs

- At a 2009 session of Sierra Nevada Beer Camp, participants were able to test their homebrew in the brewery's lab and compare the results with popular calculations[7].

Beer	**Measured**	**Rager**	**Garetz**	**Tinseth**
Best Bitter	21.1	26.2	16.5	22.3
Barleywine	65.6	98.7	61.5	64.9
Double IPA	61.9	122.5	85.5	88.1

- Overall, Tinseth's method[8] was the best match.
- Tinseth calculations are also the most common in brewing software.
- To estimate IBUs, start with Tinseth calculations and adjust for known deficiencies in the method.

Pellet Utilization

- Tinseth calculations are based on whole hops.
- Pellet hops result in higher utilization, but little work has been published to quantify the differences.
- My assumptions:
  - When added at flameout, pellet hops increase utilization by 25% (upper increase from Mitch Steele's IPA book[9]).
  - When boiled for 90 minutes, pellet hops increase utilization by 10% (T-90 pellet = 90% of whole hop material).
  - Pellet calculations should never cause utilization to decrease when boil time is increased.
- Resulting equations:
  - $M_{pellet} = 1.25 – (0.0000375 \times \text{Boil Minutes})^{(1/3)}$
  - Pellet Hop Utilization = M_{pellet} x Whole Hop Utilization

Whirlpool Utilization

- Tinseth calculations give zero IBUs for flameout additions. This is not true when a hot post-boil rest is used.
  - Example: Firestone Walker's whirlpool additions can reach 22% utilization[10].
- For 5-gallon batches with pellet hops, I assume a baseline whirlpool utilization of 10%.
  - Chose utilization value to match BYO recipe assumptions.
- Baseline = conditions that give known (or "known") results. In this presentation:
  - Baseline post-boil gravity = 1.048.
  - Baseline whirlpool + settling time = 30 min.
- For whole hops, baseline whirlpool utilization = 10 / 1.25 = 8%.

Effective Boil Time

- To incorporate whirlpool utilization into Tinseth calculations, convert your whole hop whirlpool utilization to an effective boil time.
- Tinseth utilization at baseline gravity: U_T = 107.2 x (1 – e^(-0.04 x Boil Minutes)) / 4.15
- Rearrange: Boil Minutes = -Ln(1 – 4.15 x U_T / 107.2) / 0.04
- To solve for effective boil time of baseline flameout addition, replace U_T with baseline whirlpool utilization for whole hops:
  - EBT_{BLW} = -Ln(1 - 4.15 x 8 / 107.2) / 0.04 = 9.3 min

Using Effective Boil Time

- If you're not brewing a hoppy beer, there's no need to whirlpool/rest for 30 minutes.
- To adjust for actual whirlpool/rest time:
  - $EBT_W = EBT_{BLW}$ x actual whirlpool time / baseline whirlpool time
- If you want to whirlpool/rest for 10 minutes to settle trub:
  - $EBT_W = 9.3 \times 10 / 30 = 3.1$ min
- For each hop addition, EBT = boil time + EBT_W
- Replace boil times with EBTs in your utilization calculations (except in pellet multipliers).

IBU Saturation

- At high IBU levels, continuing to add more hops will result in progressively smaller IBU gains.
- In 2008, Deschutes brewed a beer with a calculated bitterness of 243 IBUs that only measured 87 IBUs in the brewery's lab[10]. A repeat of the experiment resulted in a lab-measured bitterness of 89 IBUs.
- Mikkeller brews a beer with a calculated bitterness of 1000 IBUs. White Labs measured the beer at 140 IBUs, while the Catholic University of Leuven measured it at 96 IBUs[10].
- At breweries without lab verification, IBU claims above 70 are probably overestimations.

Quantifying IBU Saturation: Attempted Method #1

- Above 65 IBUs:
  - Likely IBU = 15.6 x ln(Tinseth IBU)
  - Rearrange: Tinseth IBU = e^(Likely IBU / 15.6)
  - Saturation Multiplier: M_{sat} = Likely IBU / Tinseth IBU
  - Define Target IBU = Likely IBU
  - Combine: M_{sat} = Target IBU / (e^(Target IBU / 15.6))
  - Likely Utilization = M_{sat} x Tinseth Utilization
- Equations match “known” points (Deschutes, Mikkeller, and Beer Camp Barleywine) reasonably well.

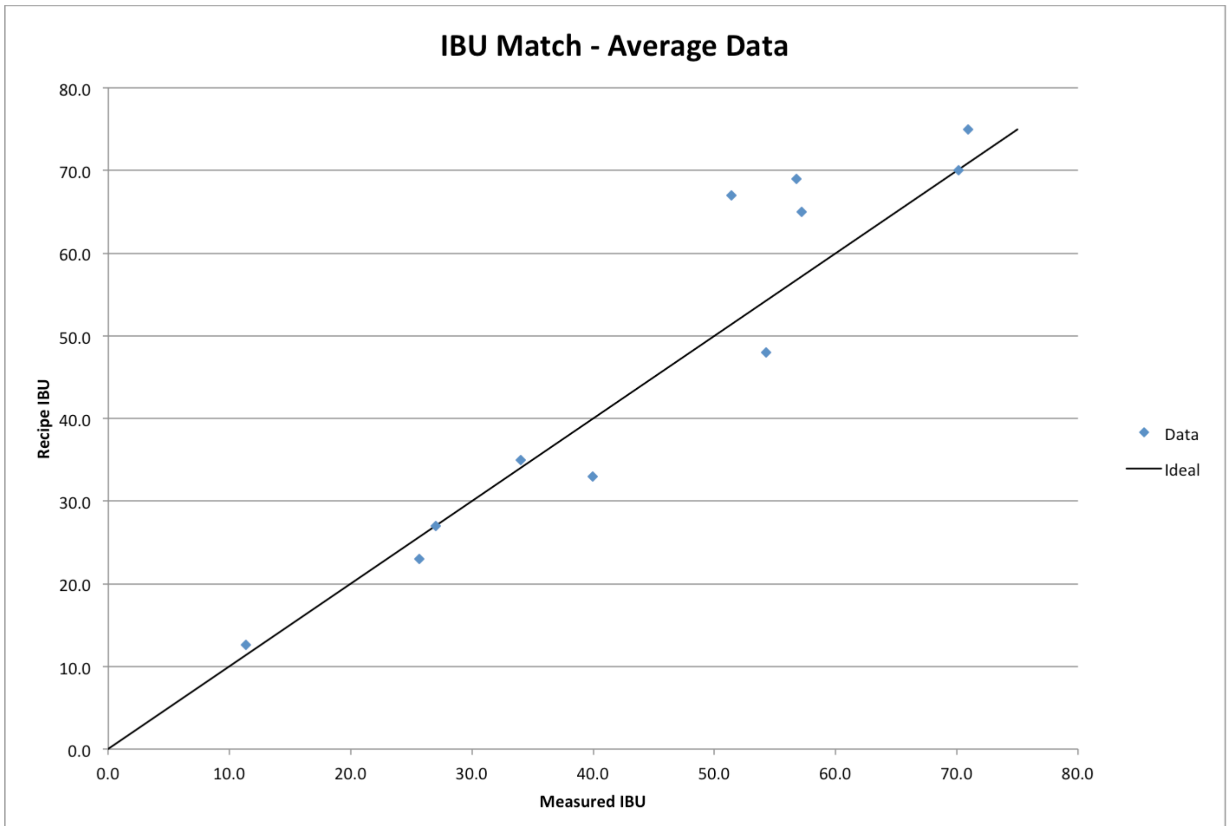
Testing Attempted Method #1 at Ale Asylum

- Tests performed by Midwest Hop and Beer Analysis in Evansville, WI using ASBC methods.
  - Each batch was tested least two times to catch procedural errors.
- Sent average of 4 beers each week for 4 months.
- Tests are ongoing, but results for 66 batches were included in the data presented here.

Testing Attempted Method #1 at Ale Asylum

Recipe	Calculated	Avg Measured
Hopalicious	48.0	54.3
Madtown Nutbrown	23.0	25.6
Bedlam	67.0	51.4
Unshadowed	12.6	11.4
Demento	33.0	39.9
Ambergeddon	65.0	57.2
Ballistic	75.0	71.0
Velveteen	69.0	56.8
Satisfaction Jacksin	70.0	70.2
Kink	27.0	27.0
Pantheon	35.0	34.0

Testing Attempted Method #1 at Ale Asylum



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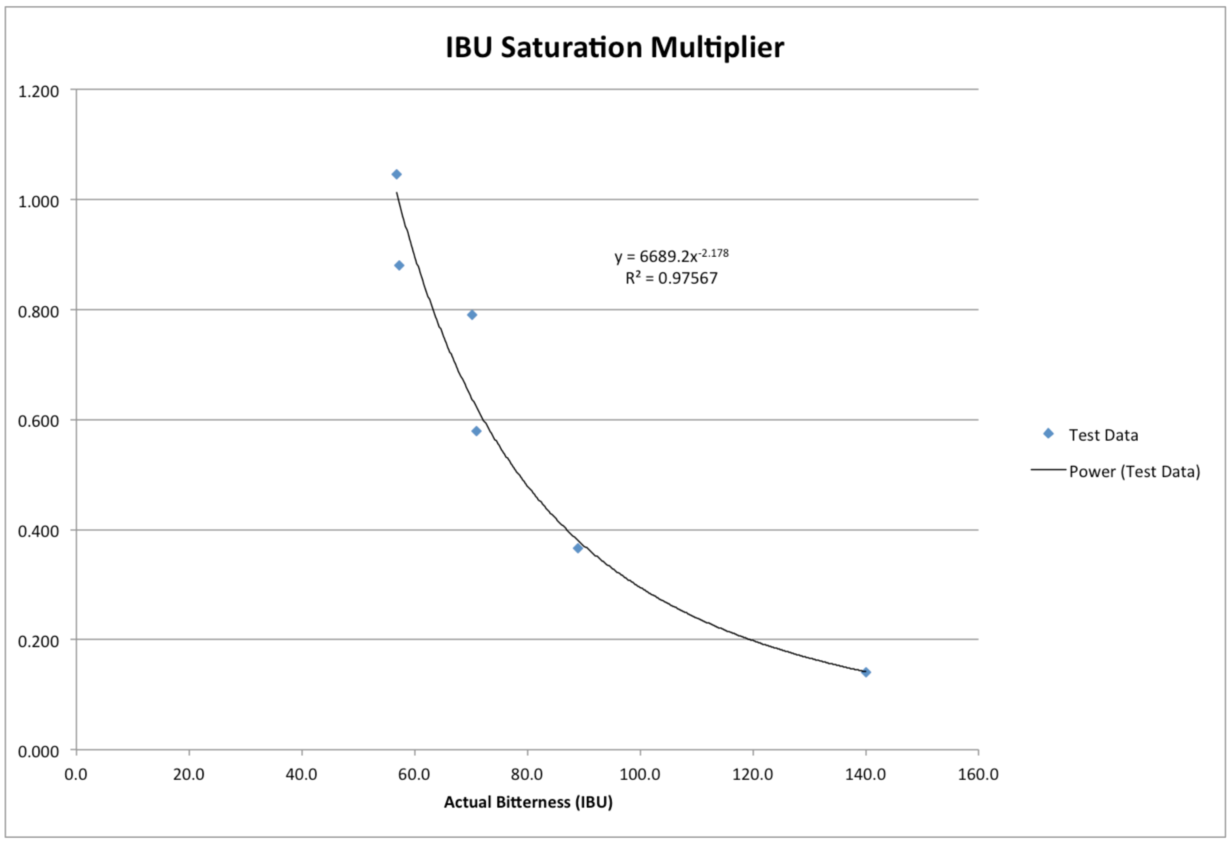
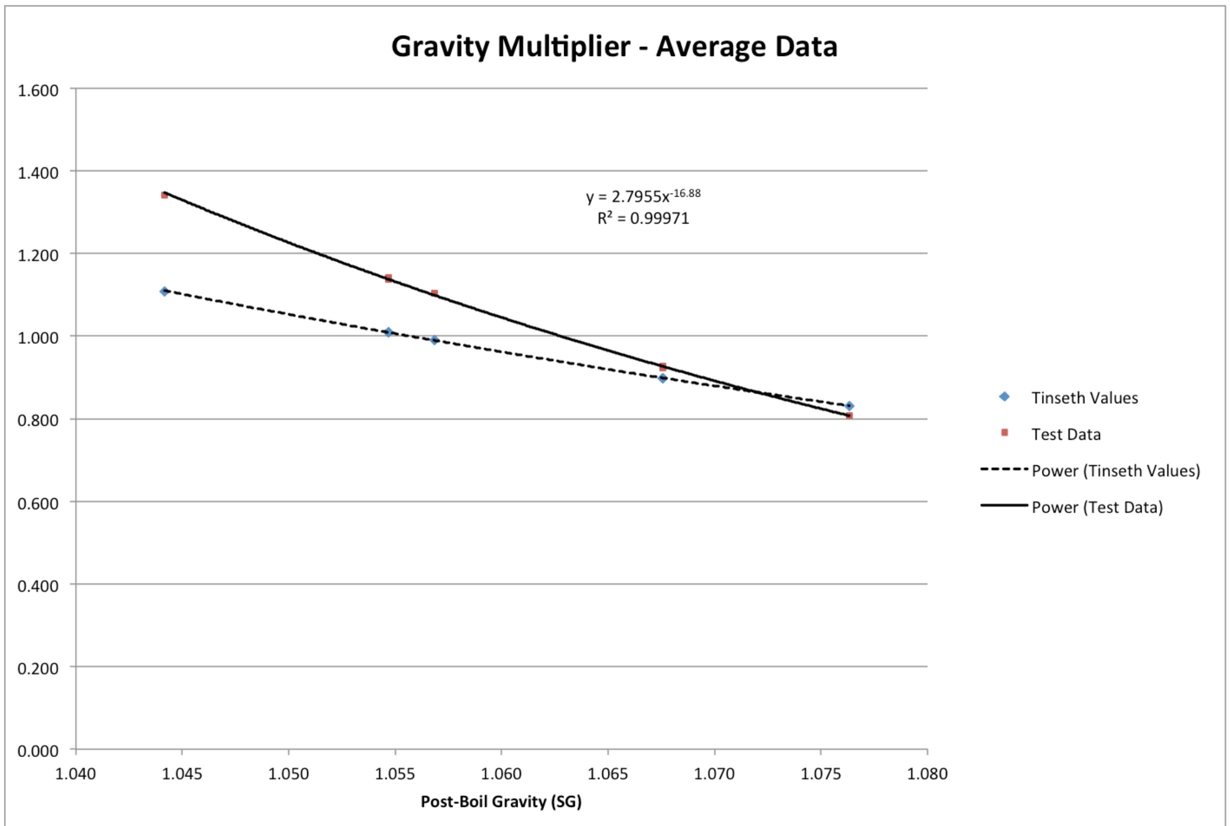


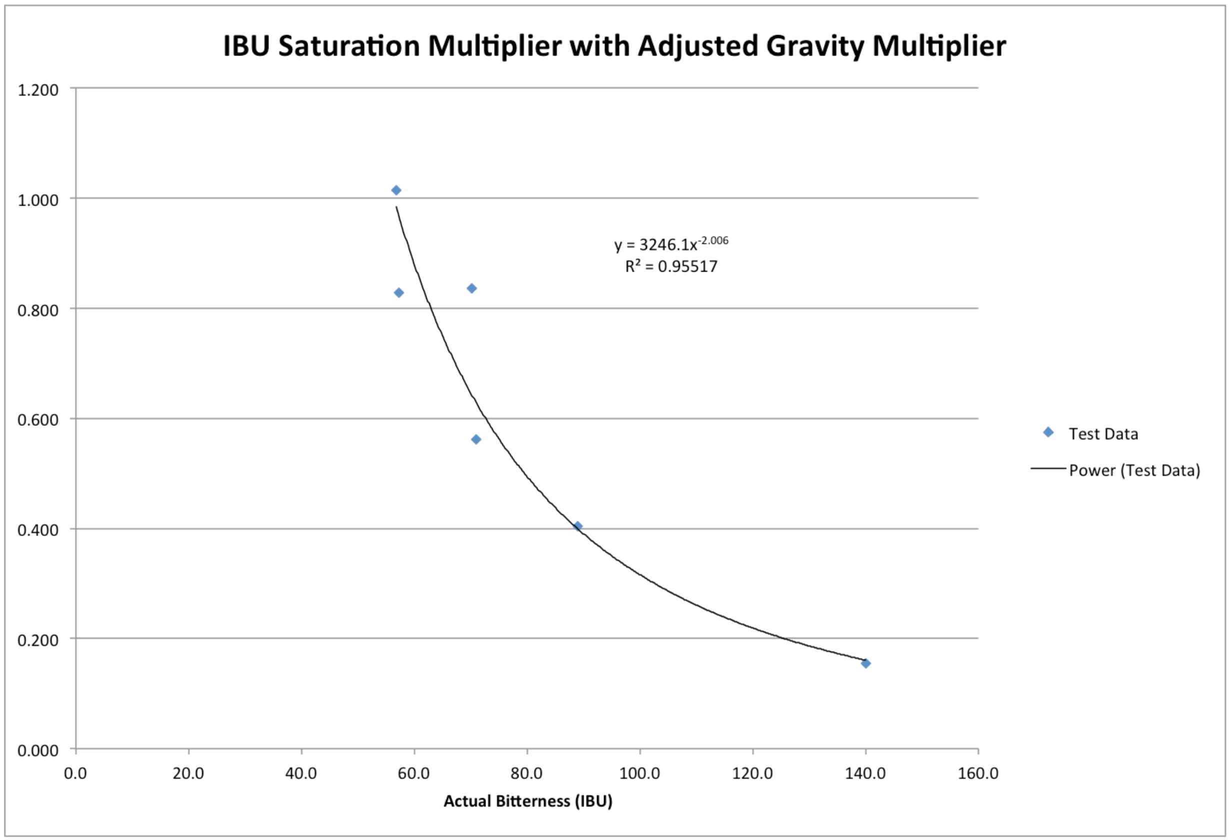
Potential Solutions

- Citra utilization seemed to be far lower than other varieties.
  - Applying a multiplier of 0.68 reduced IBU match discrepancy between Velveteen Habit and Ballistic/Satisfaction Jacksin.
  - Same multiplier eliminated discrepancy between Bedlam and Kink.
- Yeast strains seemed to affect utilization. Multipliers of 0.8 for weizen yeast and 0.9 for Belgian yeast brought Unshadowed and Kink/Bedlam in line with rest of beers.
  - Similar strategy may be useful for cellar processes in general, e.g. fermentation vigor, pH drops, and prolonged aging.
- Tinseth gravity correction need refinement?

May Be Onto Something



Nope. Made Calculation of IBU Saturation Worse



Issues with Method #1

- Assumed saturation point of 65 IBUs too high for Amber and Velveteen (actual IBUs in upper 50s).
- Assumed saturation point worked well for higher-IBU beers like Ballistic and Satisfaction Jacksin.
- Simply lowering the saturation point would trade one problem for another.
- Different equation types (e.g. power instead of natural log) did not improve data match.
- Changing gravity multiplier would worsen data match for Satisfaction Jacksin.

Quantifying IBU Saturation: Method Improvements

- Start with premise that Tinseth gravity multiplier is reasonable (could always change later).
- Quantify observation that as original gravity increases, saturation seems to begin at higher IBU values.
- Tweak utilization assumptions towards whirlpool:
  - Full-boil 35% -> 33.2%
  - Whirlpool 20% -> 23.7%
- Added the following formulas to my calculations:
  - Saturation start point: $IBU_{sat} = 2 \times OG + 25$
  - Natural log multiplier: $M_{ln} = 0.371 \times OG + 8.162$

Estimating IBU Saturation

- Above IBU_{SAT} for a given beer:
  - Likely IBU = M_{ln} x ln(Tinseth IBU)
  - Rearrange: Tinseth IBU = e^(Likely IBU / M_{ln})
  - Saturation Multiplier: M_{sat} = Likely IBU / Tinseth IBU
  - Define Target IBU = Likely IBU
  - Combine: M_{sat} = Target IBU / (e^(Target IBU / M_{ln}))
  - Likely Utilization = M_{sat} x Tinseth Utilization
- Equations still match “known” points (Deschutes, Mikkeller, and Beer Camp Barleywine) reasonably well.

Example IBU Saturation

- Original gravity = 16 Plato
- Target IBU = 80
- Tinseth Full-Boil Utilization = 25%
- IBU_{sat} = 2 x 16 + 25 = 57 IBU
- M_{log} = 0.371 x 16 + 8.162 = 14.098
- M_{sat} = 80 / (e^(80 / 14.098)) = 0.275
- Likely Full-Boil Utilization = 0.275 x 25 = 6.9%
- That’s a huge drop in utilization!

Strange Data Point

- Batch of Bedlam tested by at John I. Haas:
  - Isomerized alpha acids via HPLC = 23.2 ppm
  - Alpha acids via HPLC = 20.0 ppm
  - IBU via spectrophotometer = 50.5
- Poor isomerization + some alpha acids probably came from low-temperature (207 °F) “boil” with external calandria (see images on following slide).
- Alpha acids contribute to IBU measurements, but not to sensory bitterness.
- Haas lab gave beer a sensory bitterness of 30-35 IBUs.

Isomerization Curves[1]

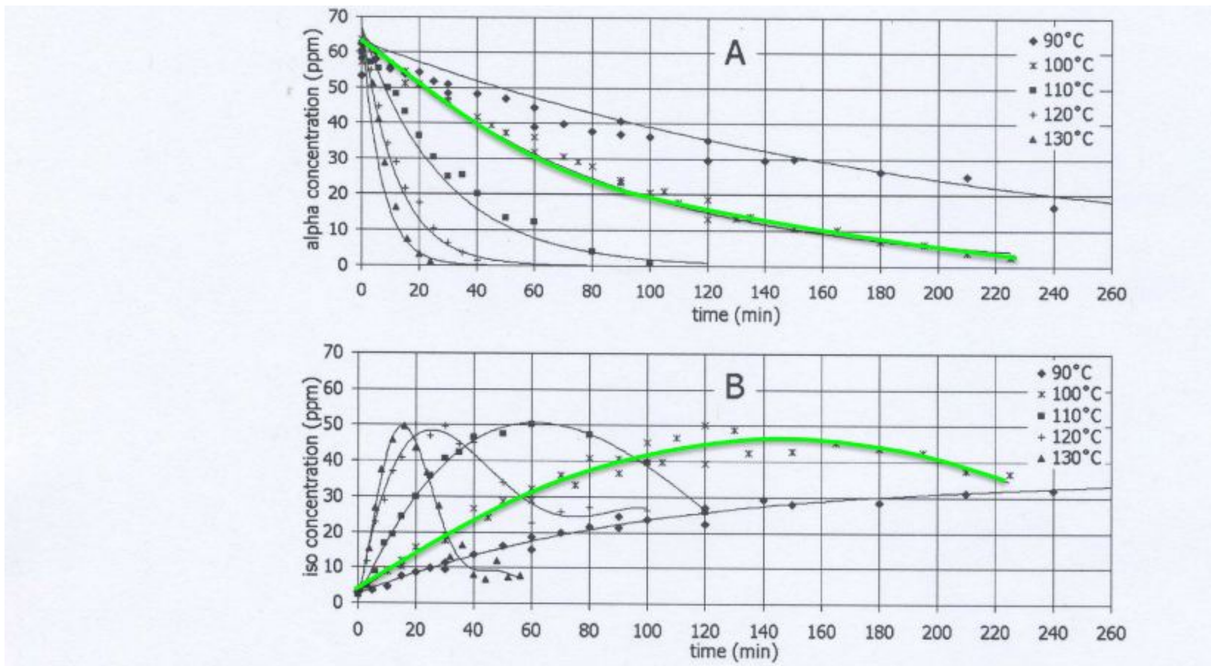


Figure 4. Alpha acid (**A**) and iso-alpha acid concentrations (**B**) versus heating time in a pH 5.2 acetate buffer.

Original image from Isomerization and Degradation Kinetics of Hop Acids in Model Wort-Boiling System, M. Malowicki, T. Shellhammer, J. Agri. Food. Chem. 2005, 53, 4434-4439.

Dry Hop Utilization?

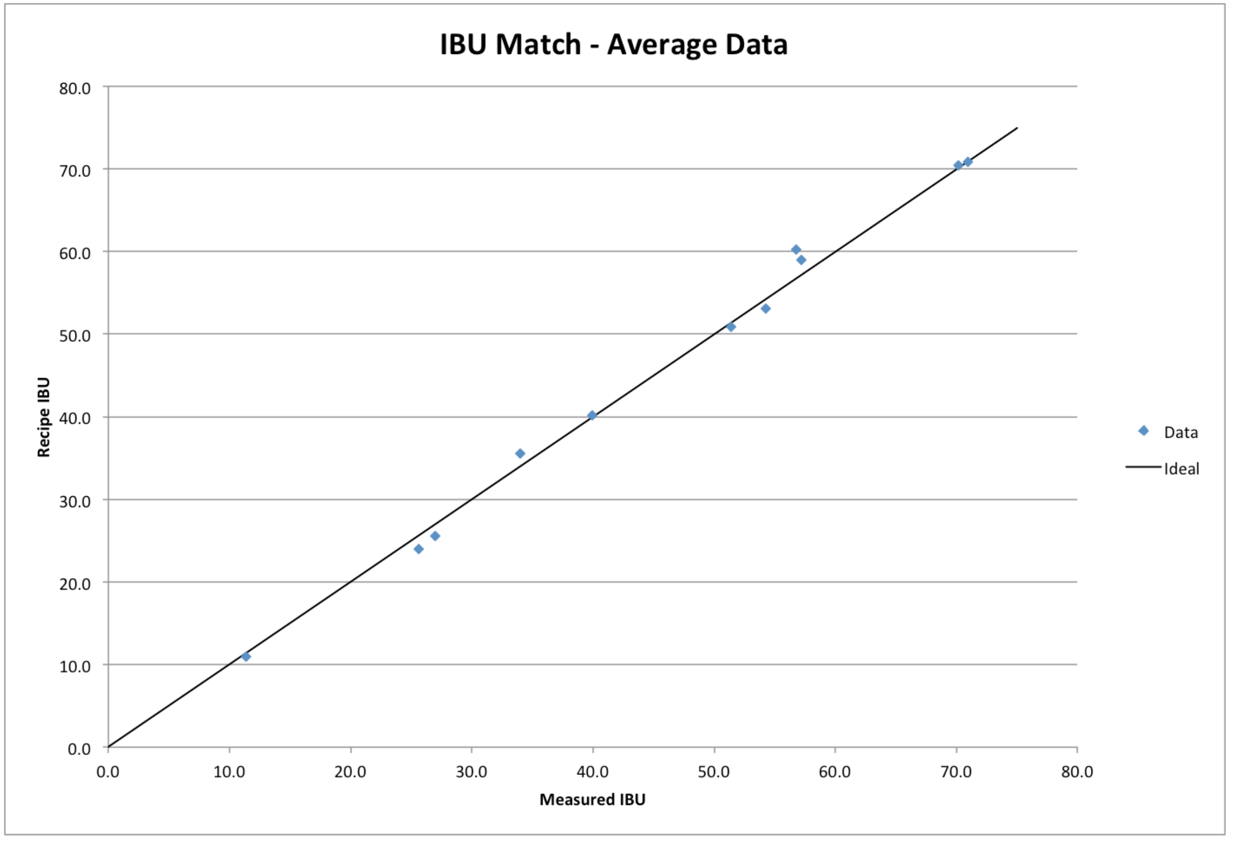
- German dry hopping experiment[11]:

Dry Hop Variety	None	Mand Bav	Hull Melon	Hal Blanc	Polaris
Dry Hopping Rate (lb/bbl)	N/A	0.19	0.27	0.24	0.10
Alpha Acids in Hops (% wt)	N/A	8.7	7.0	9.8	19.5
Alpha Acids in Beer (mg/L)	2.8	5.8	5.7	6.4	6.6
Polyphenols in Beer (mg/L)	201	221	219	227	215
Bitterness of Beer (IBU)	26	27	29	28	27

Dry Hop Utilization

- IBU increases in dry hopping experiment were small, but proportional to amounts of dry hops added.
  - Not proportional to amounts of alpha acids added.
- Already know that alpha acids and polyphenols contribute to IBU measurements.
  - Dry hopping clearly adds both to finished beer.
- Attributing small amount of IBUs to dry hopping improves match between calculations and Ale Asylum data.
- My calculations assume dry hop utilization = 0.2 IBU / (lb/bbl dry hops) / Beer ABV
  - Still subject to multipliers for hop variety and saturation, but not yeast variety.

Testing Improved Method at Ale Asylum



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Brewing Equipment Adjustments

- Equipment multiplier M_{eq} = Your full-boil utilization / Tinseth full-boil utilization for same conditions (gravity, pellets, etc).
- Apply brewhouse and saturation multipliers to Tinseth baseline whirlpool utilization -> adjusted effective boil time.
- Apply adjusted effective boil time to Tinseth full-boil utilization -> M_{eq} changes.
- Requires iteration to converge on a solution.
- Probably not worth pursuing unless you have utilization data for your equipment.

Cohumulone May be Fine

- Belief that cohumulone leads to harsh bitterness can be traced to poor conclusions in a 1972 study about bitterness[12].
- Studies conducted in 1993 and 1997 could not quantify any link between iso-cohumulone and poor sensory scores[13].
- Recent research from Oregon State University suggests that iso-cohumulone does not result in harsh bitterness[13], but studies are ongoing.
- Takeaway: trust your own taste more than a cohumulone analysis.

Gypsum May be Overrated

- Oversight in Rock Bottom study resulted in several batches where water chemistry was the only difference[6].
- Analysis found a moderate, statistically significant negative correlation between sulfate levels and perceived hop flavor.
- Matches my personal experience of gypsum simply giving beer a sulfur dioxide character.

Post-Boil Volume Additions

- Use the mixing formula to compensate for post-boil additions such as yeast starters or priming solutions:
  - Target Post-Boil Gravity = (Total Volume x Target OG – Addition Volume x Addition Gravity) / Kettle Wort Volume in Fermentation Tank
  - Adjusted IBU = (Total Volume x Target IBU – Addition Volume x Addition IBU) / Kettle Wort Volume in Fermentation Tank
  - Total Volume = Kettle Wort Volume in Fermentation Tank + Addition Volume
- Use Target Post-Boil Gravity instead of Target OG in kettle utilization calculations.
- Use Adjusted IBU instead of Target IBU to calculate kettle hop additions
  - Target IBU is still the goal for finished beer.

Example Post-Boil Addition

- Target 5.5 gallons in FV with OG of 1.060 and 60 IBU.
- Replace 0.5 gallons with the same volume of yeast starter with an OG of 1.040.
- Target Post-Boil Gravity = (5.5 x 1.060 – 0.5 x 1.040) / 5 = 1.062
- Adjusted IBU = (5.5 x 60 – 0.5 x 0) / 5 = 66 IBU

Additional Resources

- RePublic Brewpub file cabinet at http://sites.google.com/site/republicbrewpub
  - Recipe_Gallons spreadsheet includes these hop calculations.
  - Presentations on a handful of topics, including this one.
- Articles for Madison Beer Review at http://www.madisonbeerreview.com/search/label/five%20gallons
  - Disclaimer: some of the content is outdated, but the general concepts are still useful.

Sources

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- 13: Thomas Shellhammer, "Hop Components and Their Impact on the Bitterness Quality of Beer". Hop Flavor and Aroma: Proceedings of the 1st International Brewers Symposium. Master Brewers Association of the Americas, 2009.