

# Tracking IBU Through the Brewing Process: The Quest for Consistency

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## ABSTRACT

International Bitterness Units (IBUs) were measured with a spectrophotometer throughout the brewing process for a wide variety of beer styles. Most of the data were collected at our 50 BBL Scripps Ranch facility, although some data were also gathered from our 5 BBL R&D brewery and 150 BBL production facility. It was determined that mash hops add a small amount of IBUs to wort with an average utilization of 9.1%. As expected, 60 min hop additions added substantially more IBUs; the average hop utilization was 44.0%. Whirlpool hops also con-

tributed high IBUs with an average utilization of 29.9%. In addition, hot-side wet hopping had 8.0% utilization. A large amount of IBUs are lost during the first 2 days of fermentation. Losses were also observed during filtration. It was discovered that high amounts of dry hopping resulted in an increase of IBUs. However, the average overall IBU loss in the cellar was 33.7%.

Keywords: Utilization, Hop rate, IBU, Iso- $\alpha$ -acid, Spectrophotometer, Isomerization

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## Introduction

The quest for understanding IBU creation and loss started a few years ago while in a meeting with our quality team. We were going over the critical beer specs of our core brands. One of the beers was out of spec for IBU. An analyst turned to me and asked how the IBUs could be out of spec. I did not have good answer for him. Had a brewer missed a hot-side hop addition? If so, which one? Or were there issues afterward during fermentation, dry hopping, or filtration? From schooling and brewing experience, I had a firm grasp of brewhouse IBU calculations; however, I had no concrete proof about how many IBUs were gained from each hot-side hop addition. Further, we did not have much data to show how IBUs are lost through fermentation, conditioning, and filtration. Troubleshooting can be difficult without a benchmark. In addition, working by trial and error is not an option when trying to achieve consistency or scaling up recipes. Over the course of 2 years, we collected as much data as possible to better quantify these variables.

It is important to state that measuring IBU with a spectrophotometer using ASBC Wort-23 and Beer-23A has limitations. It is a fast and relatively economical tool, although it produces a result that only reveals part of the picture. There are many compounds in hops that can contribute bitterness to beer, including  $\alpha$ -acid, iso- $\alpha$ -acid, humulinones, hulupones, and polyphenols. This method will measure iso- $\alpha$ -acid and any other bitter substance that is soluble in isooctane and absorbs at 275 nm. Unfortunately, this excludes polyphenolic substances such as xanthohumol, which have been shown to contribute some bitterness to beer (12). Furthermore, at Ballast Point, we have noticed that compounds from miscellaneous ingredients can register IBUs on our spectrometer (bitter orange peel, cinnamon, and other spices).

HPLC is more sophisticated and can measure each of these bittering compounds individually. This is why, metaphorically, I typically compare a spectrophotometer to an X-ray (rough picture) and HPLC to a CAT scan (more detailed). There are many studies that have used HPLC to track individual substances through the brewing process to measure utilization (4–9,11), assess the bitterness intensity of certain compounds (1,3), or show how dry hopping can alter bitterness (10,12).

Lastly, sensory analysis is the most important step in determining the overall impression of a beer's bitterness. With all of that said, a spectrophotometer is still a useful tool to help verify brewhouse performance and batch-to-batch consistency.

## Materials and Methods

### Scripps Brewery

Most of the data were collected at our Scripps Ranch production facility. It has a three-vessel, 50 BBL single-infusion brewhouse with external calandria. Volume and flow were measured by four Endress Hauser Promag H flow meters: one for measuring water into the mash tun, another measuring wort from mash tun to kettle, a third measuring wort from the kettle to whirlpool, and the last measuring wort from whirlpool to the fermenter. We brewed into 50, 100, and 200 BBL fermenters. Antifoam was dosed into the fermenter during knockout. Filtration was performed by a GEA SC35 centrifuge and a polishing filter with 60×60 XE90 filter sheets.

T90 hops were used for hot- and cold-side additions. Mash hops are added midway through dough-in. Typical mash rest temperature is 150°F, with a maximum temperature of roughly 165°F at the end of lautering. The 60 min hops are added through the manway at the top of the kettle once the wort is at a rolling boil and 212°F. At the end of boil, wort is pumped to the whirlpool at a high velocity to create strong circulation. Once all the wort is in the whirlpool, hops are added through the top manway and allowed to settle for 20 min. Knockout typically takes 45–60 min depending on batch size, so the total steep time is 65–80

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min. Dry hopping techniques vary for each brand, and we use a variety of yeast strains depending on the beer style.

### Little Italy Brewery

Our Little Italy R&D brewery has a two-vessel 5 BBL brew-house with a mash/lauter tun and a direct-fire kettle. Volume was measured via sight glass. Fermenters are all 5 BBL. Antifoam was dosed into the fermenter during knockout. Most beers are unfiltered; otherwise, filtration was performed with a 40×40 sheet filter with XE90 pads.

T90 hops were used for hot- and cold-side additions. The 60 min hops are added through the manway at the top of the kettle once the wort is at a rolling boil and 212°F. A whirlpool is created within the kettle at the end of boil. Once the pump is turned off, hops are added and allowed to settle into a trub pile for 15 min. Knockout typically takes 20–25 min, so the total steep time on hops is 35–40 min.

### Miramar Brewery

Data at the Miramar campus were collected on a five-vessel 150 BBL system with a mash mixer, lauter tun, wort receiver, kettle (with external calandria), and whirlpool. Volume and flow between each vessel were measured by Endress Hauser Promag H flow meters and Pyromation pressure sensors. All beer for this experiment was brewed into 200 and 450 BBL fermenters. Filtration was performed with a GEA GSI200 and a polishing filter with 100×100 XE90 filter sheets. Antifoam was dosed into the fermenter during knockout.

T90 hops were used for hot- and cold-side additions. Hot-side additions are similar to our Scripps Ranch facility, although hops are allowed to settle in the whirlpool for 30 versus 20 min. Knockouts also range from 45 to 60 min, so the total steep time is 75–90 min.

### Calculations

To calculate hot-side hop utilization, we need to first calculate the dosage of  $\alpha$ -acid, or  $IBU_{max}$ . This assumes that IBU is only represented as iso- $\alpha$ -acid, which was addressed in the introduction. The equation is as follows:

$$IBU_{max} = \frac{(W)(AA)(3,865.4)}{V}$$

where  $IBU_{max}$  is the dosage of  $\alpha$ -acid in ppm or mg/L,  $W$  is the weight of hops in pounds,  $AA$  is the  $\alpha$ -acid percentage of the hop weight,  $V$  is the volume of wort in barrels, and 3,865.4 is the conversion factor from lb/BBL to mg/L.

Then utilization can be calculated by dividing the measured bitterness (IBU) by the  $\alpha$ -acid dosage ( $IBU_{max}$ ).

$$U = \frac{IBU}{IBU_{max}} \times 100$$

Example: 10.0 lbs of Chinook at 12.0%  $\alpha$ -acid was added at the beginning of the boil. Postboil volume was 50.0 BBL, when a sample was taken for IBU analysis. The measured IBUs were 34.1.

$$\begin{aligned} IBU_{max} &= \frac{(W)(AA)(3,865.4)}{V} \\ &= \frac{(10.0)(12.0\%)(3,865.4)}{50.0} \\ &= 92.8 \end{aligned}$$

$$U = \frac{34.1}{92.8} \times 100 = 36.7\%$$

### Analysis

Hot wort samples were quickly cooled and centrifuged to prevent any further isomerization. All samples were analyzed for IBUs with an Eppendorf BioSpectrometer using ASBC Wort-23 and ASBC Beer-23A.

### Results

Hot-side hop utilization can be affected by several factors (2). Some have a larger impact than others. Most of the focus of this paper will be on the first four in the list below.

- Time: longer residence time in hot wort equates to higher utilization.
- Wort gravity: utilization decreases with increasing wort strength.
- Hop rate: using more hops per barrel will decrease efficiency.
- Wort IBU: as you approach a saturation point in bitterness, utilization will drop.
- Type of hop product: extracts will have better utilization than pellets and whole cone hops.
- Temperature: higher temperatures facilitate isomerization.
- pH: isomerization increases at higher pH.
- Freshness of hops: as hops age, their bittering potential changes.
- Hop variety: the composition of various bittering compounds differs in each variety.
- Type of kettle: calandrias tend to get higher utilization than direct fire.
- Presence of calcium or magnesium: enhances trub formation, which can lower utilization.

### Mash Hops

This had always been a heated debate at the brewery—do mash hops add bitterness to beer? We have done this experiment a few times and gotten the same results: mash hops contribute to total IBU but at a low utilization. In this particular experiment, we single mash-hopped IPA #1 with Palisade (7.5%  $\alpha$ -acid) and IPA #2 with Calypso (14.1%  $\alpha$ -acid). They were each hopped at two levels: 0.25 and 0.50 lb/BBL. Beyond mash hops, the recipe remained the same. Samples were taken once the kettle was full prior to boil.

The results in Table 1 show that the IBUs not only increased with higher hop amounts, they also rose with increasing  $\alpha$ -acid percentage. The average utilization was 9.1%. It is interesting to see that utilization dropped with increasing hop rate. Also, the knockout IBUs were generally the same for IPA #1 and IPA #2, even though IBUs varied significantly prior to boil. Perhaps a threshold for IBU was being approached. Or possibly the iso- $\alpha$ -acids had experienced some thermal degradation (8).

### 60 min Hops

Twelve samples were taken at Scripps Ranch from a wide range of beer styles. The data from a few are highlighted in Table 2, where they are ordered by decreasing hop utilization. The average utilization for all 12 brews was 44.0% with a standard deviation of 15.0%. Scatter plots in Figure 1 show a strong correlation of both hop rate and wort gravity with hop utilization. As hop rate and gravity increase, utilization steadily declines. The trend was not as strong with wort pH; granted, pH values

ranged from 5.05 to 5.35. If there were a wider range of pH, we might see a correlation. However, this would need to be done on a laboratory scale and not in a production facility.

We wanted to further investigate the connection of hop rate with utilization. We brewed four Blonde Ales, all with the same recipe except for the 60 min hop addition. The target knockout IBU was 40. We used hops with a range of  $\alpha$ -acid content: Polaris (17.6%  $\alpha$ -acid), Northern Brewer (10.7%  $\alpha$ -acid), Palisade (7.5%  $\alpha$ -acid), and Tettnang (1.9%  $\alpha$ -acid). The results are displayed in Figure 2 and Table 3. There was a decline in utilization with increasing hop rate. At 45.3% utilization, the Polaris brew exceeded the target with 42.6 IBU, whereas the Tettnang had 30.6% utilization and was significantly below the target with 28.0 IBU.

We also wanted to see how utilization increased with time during the boil. For two of the brews, Scottish Ale and Imperial Red, we collected samples every 5 min for the first 30 min of the boil, and then one more sample was taken at flame-out. In these two brews, no other hot-side hops were added after the 60 min addition. Utilization during the boil was estimated assuming that the volume decreased linearly from the beginning of the boil to the end. The results in Figure 3 show that IBUs skyrocketed in the first 10 min and then plateaued toward the middle and end of the boil. It is interesting to see that the IBUs only rose from 20.9 to 23.5 during the final 50 min of the boil for the Scottish Ale, a 12.4% increase. The Imperial Red went from 66.5 to 85.3, which was a 28.3% increase; however, the overall utilization was still dreadful. This can be attributed to the high gravity and large hop charge in the Imperial Red.

The 60 min data collected from Miramar and Little Italy matched our findings at Scripps Ranch (Table 2).

### Whirlpool Hops

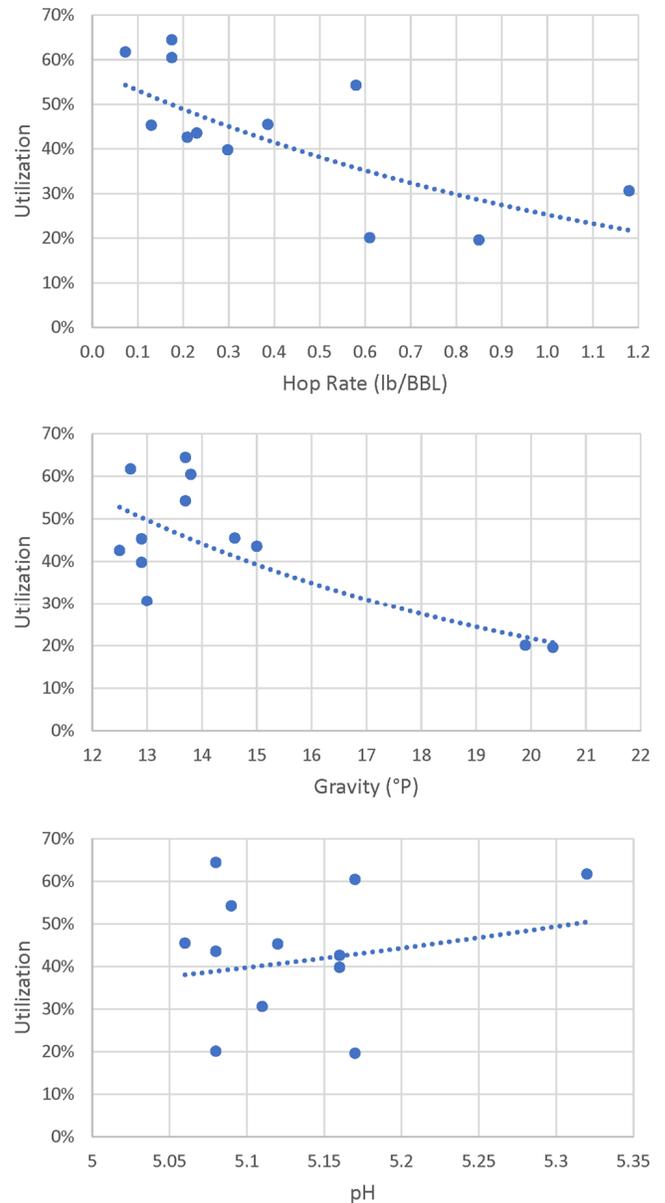
We analyzed 19 different brews for whirlpool utilization at the Scripps Ranch facility. A sample was collected right before the addition of whirlpool hops. Another sample was taken at the beginning of knockout. The average whirlpool utilization was 29.9% with a standard deviation of 12.2%. The scatter plots from Figure 4 show that hop rate and wort

**Table 1.** Data from mash hop additions at the Scripps Ranch location

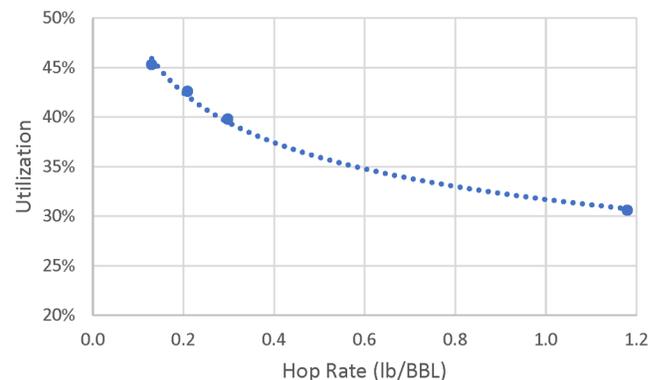
Beer	Hop	Hop rate (lbs/BBL)	Preboil IBU	Mash hop utilization	Knockout IBU
IPA #1.1	Palisade	0.25	8.4	11.3%	106.7
IPA #1.2	Palisade	0.50	11.6	7.8%	109.1
IPA #2.1	Calypso	0.25	13.0	9.0%	103.6
IPA #2.2	Calypso	0.50	23.5	8.2%	109.4

**Table 2.** Data from 60 min kettle hop additions at the Scripps Ranch, Miramar, and Little Italy locations

Beer	Hop rate (lbs/BBL)	Knockout gravity	Knockout IBU	Utilization
Scripps Ranch				
Scottish Ale	0.2	13.8	22.4	60.5%
Stout	0.6	13.7	41.5	54.3%
Porter	0.4	14.6	46.5	45.5%
IPA #3	0.2	15.0	61.1	43.6%
Imperial Red	0.6	19.9	85.3	20.1%
Miramar				
Porter	0.2	14.2	47.7	46.5%
Lager	0.1	12.3	14.9	45.7%
Little Italy				
Imperial Stout	0.7	27.4	79.6	17.1%



**Figure 1.** Scatter plots of 60 min hop utilization versus hop rate, gravity, and pH at the Scripps Ranch location.



**Figure 2.** Hop utilization versus hop rate for beers brewed at Scripps Ranch location. The recipes were the same except for the 60 min hop addition.

gravity both have a large impact on utilization, although the correlation of gravity and utilization was weaker at lower gravities. This is consistent with a previous study that showed no correlation with original gravities between 10.5 and 13.5°P (5). The level of wort IBUs before the hops were added also affected utilization. We have noticed this through the years: there seems to be a saturation point for bitterness, which has a negative effect on hop utilization. Trub carried over from the kettle can also have an impact, especially if there is a large hop charge during the boil. Lastly, the data did not show pH to be a significant factor in utilization within the samples we collected.

Figure 5 shows the results of one brew in which several samples were taken intermittently after hops were added to the whirlpool and throughout knockout. Most IBUs were gained within the first 10 min after hops were added. There was a slight increase of about 3 IBUs (3.8% increase) during the whirlpool stand and throughout knockout. Utilization only increased 2.0% throughout the 70 min whirlpool timeframe.

The data from Miramar and Little Italy generally aligned with the results from Scripps; utilization ranged from 14.5%

for heavily hopped wort to 44.4% for lighter amounts of hops (Table 4).

**Wet Hops**

At Scripps Ranch, we filled the 50 BBL mash tun with 400 lbs of Cascade wet hops. All the wort in the kettle was pumped into the mash tun immediately after the boil. We steeped the hops for 20 min and then pumped the wort to the whirlpool for knockout, which took 30 min, so the total steep time was 50 min. After being harvested, hops lose about 75% of their water weight during kilning. Consequently, our utilization calculations assumed that the hops had about ¼ of their typical α-acid content by weight because they were freshly picked and not kilned. It was interesting to see that the IBUs increased by 32, which equated to 8.0% utilization (Table 5).

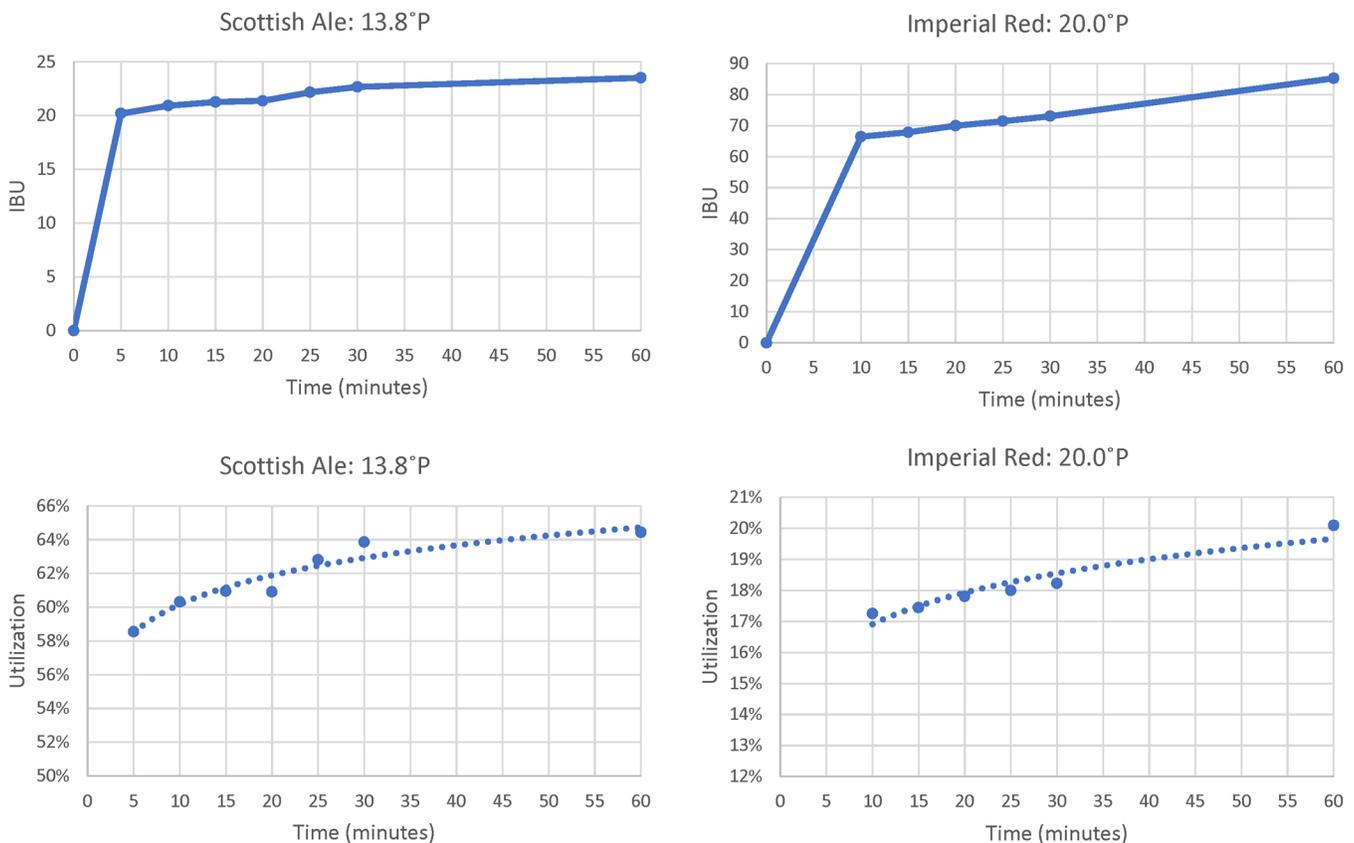
**IBU Loss**

Fourteen beers were tracked for IBU loss during fermentation, conditioning, and filtration. The average loss of IBUs for all 14 beers was 33.7% with a standard deviation of 7.9%. A few

**Table 3.** Hop rate versus utilization for 60 min kettle hop additions at the Scripps Ranch location<sup>a</sup>

Beer	Hop	Hop rate (lbs/BBL)	Knockout gravity	Postboil IBU	Utilization
Blonde #1.4	Polaris (17.6% α-acid)	0.1	12.9	42.6	45.3%
Blonde #1.3	Northern Brewer (10.7% α-acid)	0.2	12.5	39.0	42.6%
Blonde #1.2	Palisade (7.5% α-acid)	0.3	12.9	36.3	39.8%
Blonde #1.1	Tettnang (1.9% α-acid)	1.2	13.0	28.0	30.6%

<sup>a</sup> The recipe remained the same except for the 60 min hop addition.



**Figure 3.** Wort IBU and hop utilization plotted against time during a 60 min boil at the Scripps Ranch location.

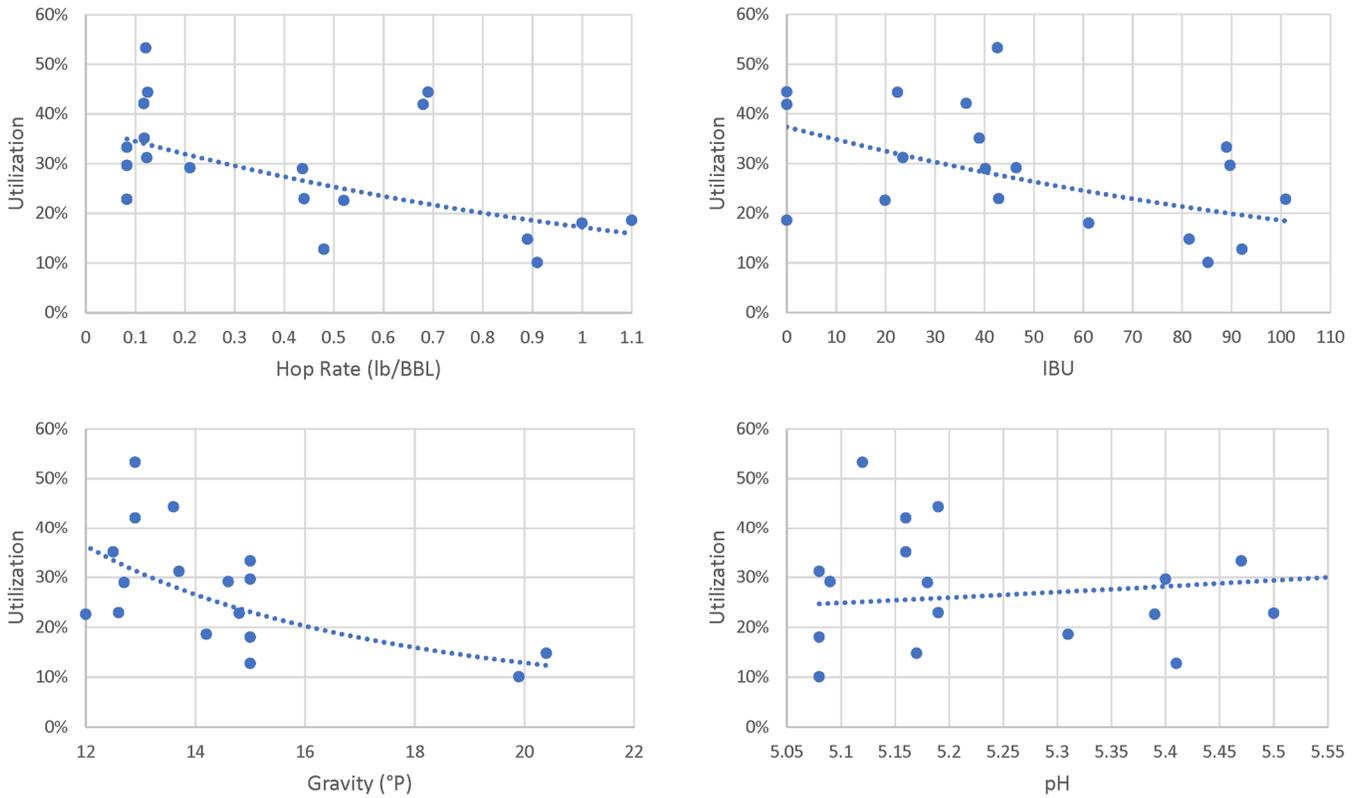


Figure 4. Scatter plots of whirlpool hop utilization versus hop rate, gravity, IBU, and pH at the Scripps Ranch location.

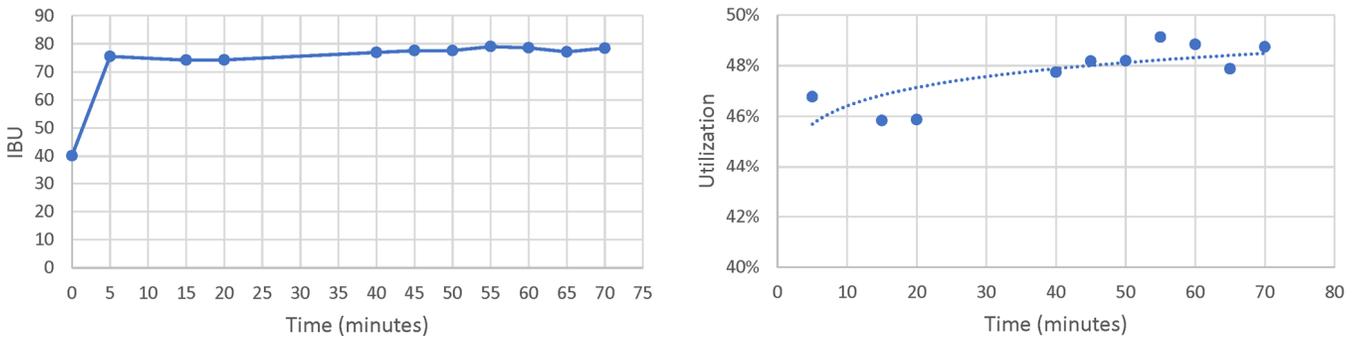


Figure 5. Hop IBU and utilization during whirlpooling and knockout for Amber Ale (12.6°P).

Table 4. Data from whirlpool (WP) hop additions at the Scripps Ranch, Miramar, and Little Italy locations

Beer	Hop rate (lbs/BBL)	Knockout gravity	IBU before WP hop	Knockout IBU	Utilization
Scripps Ranch					
Scottish Ale	0.1	13.6	22.4	32.7	44.4%
IPA #4	0.1	15.0	89.7	102.7	29.6%
Porter	0.2	14.6	46.5	64.2	29.2%
Pale Ale	0.5	12.0	19.9	76.2	22.6%
IPA #5	1.0	15.0	61.1	129.5	18.0%
Imperial Red	0.9	20.4	85.3	114.1	10.1%
Miramar					
Porter	0.2	14.2	47.7	69.8	35.7%
Little Italy					
Hazy IPA #1	0.6	13.0	1.8	78.8	21.9%
Hazy IPA #2	0.6	13.2	2.2	80.6	22.3%
Festbier	0.3	13.6	1.3	51.2	21.7%
IPA	1.1	17.4	1.2	80.5	14.5%

**Table 5.** Data from wet-hop (WH) brew at the Scripps Ranch location

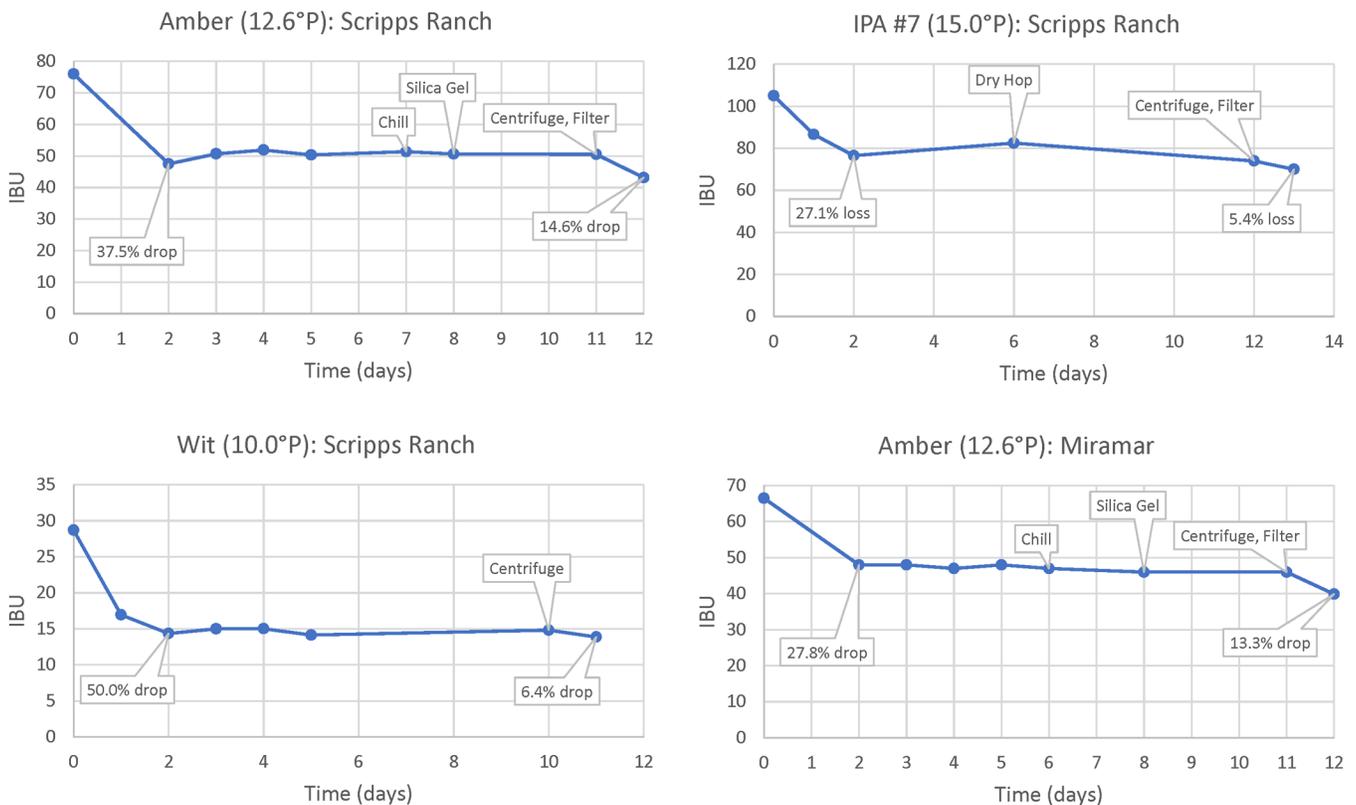
Beer	Hop rate (lbs/BBL)	Knockout gravity	Pre-WH IBU	Knockout IBU	Utilization
IPA #6	7.5	12.3	50.1	82.7	8.0%

**Table 6.** Tracking IBU loss in the cellar at the Scripps Ranch location

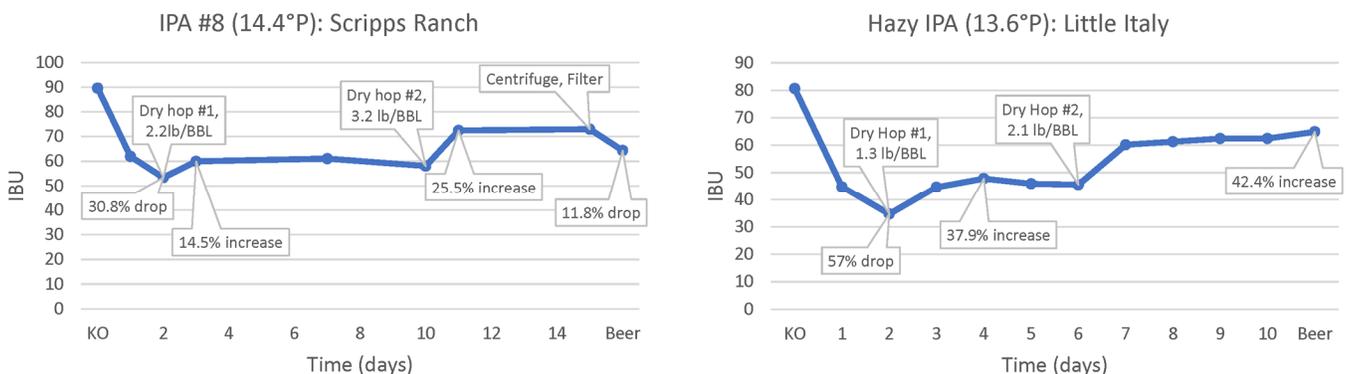
Beer	Knockout gravity	Knockout IBU	Beer IBU	% Loss
IPA #5	15.0	129.5	61.4	52.6%
Pale Ale	12.0	76.2	45.3	40.6%
Imperial Red	19.9	114.1	75.7	36.1%
IPA #4	15.0	102.7	68.6	33.5%
Scottish Ale	13.6	32.7	22.9	30.1%
Porter	14.6	64.2	45.4	29.3%

are listed in Table 6, where the beers are ordered from the highest loss to the lowest.

All else being equal, it appears that beers that rely on whirlpool hops for bitterness tend to lose more IBUs in fermentation. Also, low-flocculant yeast will produce more IBU losses than high-flocculant yeast. In addition, higher gravity beers lose more IBUs than lower gravity beers. IPA #5 and the Pale Ale were both heavily hopped in the whirlpool. In addition, they both had the same low-flocculant yeast strain. Both experienced high losses. We also saw big losses in our Amber (Fig. 6), which has high whirlpool hop amounts. Our Wit has a low-flocculant yeast strain and lost 50% of its bitterness during fermentation (Fig. 6). I should also add that we have measured large losses in IBU from excessive blow-off during high krausen, which can be controlled by antifoam.



**Figure 6.** IBU loss during fermentation and finishing practices at the Scripps Ranch, Miramar, and Little Italy cellars.



**Figure 7.** IBU through fermentation and finishing practices at Scripps Ranch and Little Italy for heavily dry-hopped beers.

We tracked daily IBUs through fermentation and finishing practices at all three locations. The results are shown in Figure 6. The majority of IBUs were lost within the first 2 days of fermentation, during which we saw losses ranging from 27.1 to 57.0%. We saw no major changes in IBU after the first 2–3 days of fermentation, even during light dry hopping (1–2 lbs/BBL) or injecting fining agents. Filtration further stripped beer of bitterness, with losses ranging from 5.4 to 14.6%. Early data suggest that these losses are correlated to yeast strain and dry hop amounts (anything that can affect the filter's performance).

### IBU Increase from Dry Hopping

High dry hop amounts resulted in an IBU increase (Fig. 7). IPA #8 had a 7.7 increase in IBU when it was dry hopped during fermentation and another increase of 14.9 IBU when it was dry hopped at terminal gravity (22.6 total increase in IBU). The Hazy IPA at Little Italy had a 13.2 rise with the first dry hop and a 19.3 increase with the second dry hop (32.5 total increase). This increase in IBU can be attributed to humulinones and  $\alpha$ -acids introduced during dry hopping (1,10).

We continued to study dry hopping's contributions to bitterness at our R&D brewery, where we brewed two Hazy Session IPAs. We did not add any hot-side hops on brew day. Once both beers were at terminal, the temperature was dropped to 50°F and hops were added to the fermenter. Both beers were roused with CO<sub>2</sub> for three subsequent days and then chilled. Hazy Session IPA #1 was dry hopped at 3 lbs/BBL with equal parts Amarillo, Cashmere, and Citra. Hazy Session #2 was dry hopped with 4 lbs/BBL of Centennial. The measured beer IBU for #1 was 26.6, while #2 was 42.9 (Table 7).

## Discussion

After compiling all the data for our Scripps Ranch location, I decided to create a predictive equation for hot-side hop utilization. For 60 min hop additions, the focus was on three variables: wort gravity, hop rate, and time. If there are more hop additions during the boil, use a running total of hops for the hop rate (60 min plus any other addition). This will help account for the total amount of trub from all the hops. The equation is as follows:

$$K = [(0.5e^{-0.7R})(2.0e^{-0.05G})(0.7t^{0.12})]$$

where  $K$  is kettle hop utilization,  $R$  is the hop rate in pounds per barrel,  $G$  is wort gravity in °Plato, and  $t$  is time boiled in minutes.

Whirlpool additions were treated differently. I removed time out of the equation because whirlpool rest times are usually the same (65–80 min total steep time at the Scripps Ranch location) and, most significantly, the majority of the IBUs were gained within 10 min. So the whirlpool equation has three variables (wort gravity, hop rate, and wort IBU prior to the hop addition):

$$WP = [(0.5e^{-0.7R})(4.0e^{-0.1G})(1.1e^{-0.01I})]$$

**Table 7.** Hazy Session IPAs brewed at the Little Italy location, with no hot-side hops

Beer	Original gravity	Dry hop (lbs/BBL)	Beer IBU
Hazy Session #1	10.0	3.0	26.6
Hazy Session #2	10.0	4.0	42.9

where WP is whirlpool hop utilization,  $R$  is the hop rate in pounds per barrel,  $G$  is wort gravity in °Plato, and  $I$  is predicted IBU before whirlpool hop addition.

These equations are not perfect, but I matched the data as much as possible. With these equations, we were usually capable of hitting our knockout and beer targets within 5 IBUs at Scripps Ranch. This included a wide variety of beer styles (core brands, collaborations, R&D scale-ups, etc.).

There are so many variables involved with IBU loss during fermentation and finishing practices. When scaling up a recipe for the first time, I will typically use the average loss of 33.7% to predict a final IBU of the beer. This is usually a good estimate. Afterward, the recipe can be tweaked once the actual loss can be determined.

I want to emphasize that every brewery is unique and that these equations are not universal. We plan to collect more data at Miramar and Little Italy, which will allow us to adapt the model to each location.

## Future Work

Eventually, we would like to track individual bitter substances with HPLC through the brewing process at Ballast Point. I also look forward to seeing more research on the topic. This would allow us to better understand true utilization of iso- $\alpha$ -acid and other compounds from hops. In addition, it would be interesting to see how these individual bitter substances change from the brewhouse through the cellar. From a brewer's standpoint, this information will help with formulating recipes, choosing processing techniques, and achieving better consistency.

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