MBAA TQ vol. 53, no. 4 • 2016 • pp. 227–230

SUPPLIER PERSPECTIVE

Use of Microscopic Pressurized Shockwaves Generated by Controlled Cavitation as a Nonshear Method of Increased Extraction of Hop α-Acids and Conversion into IBU and Extraction of Hop Oils

Santiago Gomez

Apotek Solutions, Plymouth, MI, U.S.A.

ABSTRACT

Cavitation is the sudden formation of low-pressure vapor cavities by means of mechanical forces; uncontrolled cavitation can lead to damage of adjacent components or surfaces such valves and pump impellers. Cavitation reactors use a specialized drum/rotor that spins at high rates of speed to generate cavitation within the drum cavities, away from metal surfaces, and projecting the energy in the form of shockwaves to the surrounding liquid. In late 2012, I started a series of trials to determine whether controlled cavitation could be a viable option to increase the recovery and conversion of α-acids into their iso form in beer.

Tests have shown recovery and conversion of α-acids of up to 79% and the apparent saturation of wort with iso-α-acids as well as a direct relationship between this saturation point and wort gravity. Tests indicate that losses of International Bitterness Units (IBUs) during fermentation are low to none and that boiling times may not play as big of a role in recovery and conversion of α-acids.

The scope of the project was eventually expanded to determine whether the pressure fluctuations from the cavitation-generated shockwaves could be harnessed for extraction of aromatic oils from hops from cold side additions. Organoleptic test have shown potential savings between 25 and 50%.

Background

I've spent my entire professional career in the egg products processing industry. I've always been a fan of good beer and very interested in the intricacies of the brewing process. While working on an article for the Michigan Beer Guide explaining hops and IBU, I tried to break down the IBU calculation to understand what kind of processes would result in such a mathematical formula. I also wondered what kind of processes could be driving the typical low recovery and conversion from α-acids to IBU.

I researched the subject and met with local industry experts to learn as much as I could about the subject. Initially, I theorized that the recovery limitations could come from chemical or physical limitations taking place during the boil.

I hypothesized that the α-acid addition process would be comparable with that of mayonnaise production: adding a non-water-soluble compound to a water-based solution. Mayonnaise is an oil-in-water emulsion stabilized with emulsifiers from egg yolk. As the oil is vigorously blended, oil droplets are coated with the emulsifying compounds from egg yolk, which prevent them from coalescing and eventually separating. The smaller the oil droplet, the more stable the mayonnaise is. I thought that it would be possible that the isomerized α-acids were playing the role of egg yolk and coating small droplets of α-acids, making them unavailable. The lengthier the boil, the smaller the droplets would be, allowing them to remain in suspension in the wort and, eventually, the finished beer.

If this was indeed the case, a piece of technology we've applied to egg processing for the last 10 years could resolve the low α-acid recovery and conversion problem. The technology works by inducing cavitation and releasing mixing and heating energy in the form of shockwaves.

Everyone is familiar with the sound of banging water pipes. Laymen call it "water hammer"; scientists call it "cavitation." Cavitation is the sudden formation and collapse of low-pressure vapor cavities in a fluid by means of mechanical forces. The collapse of the vapor cavity is shown in Figure 1A, and the formation and expansion of the shockwave are shown in Figure 1B. Uncontrolled cavitation can lead to damage of adjacent components or surfaces (Fig. 2). The heart of the cavitation technology is a specialized rotor with cavities that spins (Fig. 3). The spinning action generates cavitation within the cavities, away from the metal surfaces. The cavitation is controlled; therefore, there is no damage to the equipment.

Email: s.gomez@apoteksolutions.com

http://dx.doi.org/10.1094/TQ-53-4-1012-01

Cavitation technology is used in a wide range of processes, including:

- Process intensification
- Pasteurization
- Homogenization
- Esterification
- Extraction
- Scale-free heating

and in industries such as:

- Ethanol
- Bio-Diesel, bio-gas
- Waste water
- Petroleum
- Egg products
- Dairy
- Cosmetics
- Metal plating

Cavitation and IBU

Low yield in α-acid extraction and conversion to iso form during beer processing is a poorly understood topic. Standard IBU calculations indicate that increased boil times lead to higher IBU in beer. Traditional IBU calculation formulas have the form IBU = [(weight of hops × α-acid %)/(wort × volume gravity)] × utilization factor, where the utilization factor is driven primarily by boiling time.

To help keep the number of variables to a minimum, initial tests were done preparing hop teas, and two identical samples of water with hop cones were prepared with a target of 70 IBU; one of the samples was treated with cavitation for 30 min and boiled for 60 min, while the control sample was only boiled for 60 min. Although there was a clear visible difference between the samples (Fig. 4), the IBU results (spectrophotometric test) from the lab came back with very similar values. The samples were then diluted, reboiled, and tested,

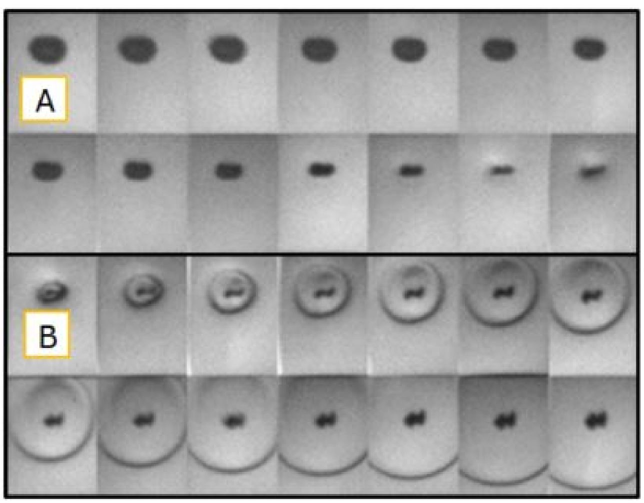

Figure 1. A, Collapse of the vapor cavity and **B,** formation and expansion of the shockwave.

Figure 2. Uncontrolled cavitation can lead to damage of adjacent components or surfaces.

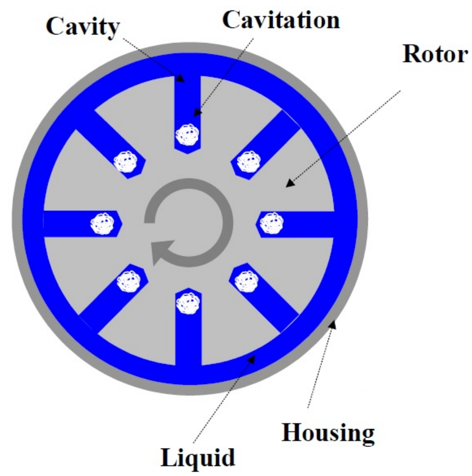

Figure 3. Specialized spinning rotor with cavities.

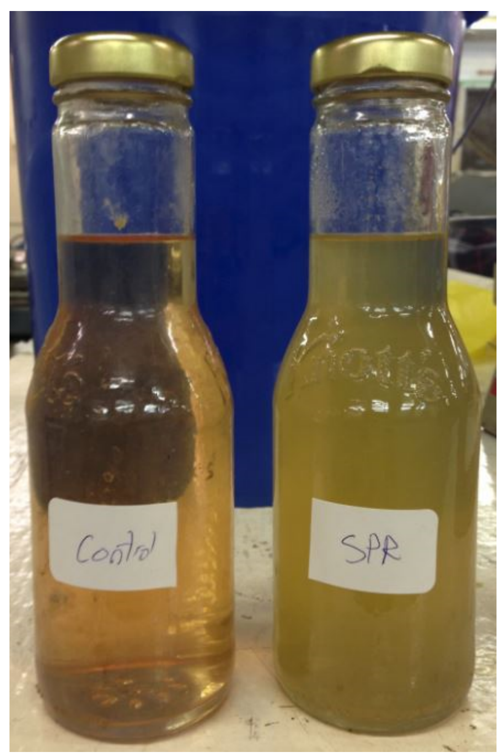

Figure 4. Samples of water with hop cones treated with cavitation (right) and the control (left).

with results showing approximately 22% higher IBU in the cavitation-treated sampled compared with the control.

These early results led me to further develop two hypotheses: 1) the hop teas were chemically saturated, and 2) the use of cavitation did increase the recovery and conversion of α-acids, but the conversion was limited because the test water had reached saturation.

Impact of Cavitation on Beer

The first test was done on an American brown ale, as opposed to an IPA, with the intention to prevent the test from being influenced by the theoretical saturation point. The test was devised to determine whether the intense pressure fluctuations from cavitation would have an impact on beer characteristics and whether we could improve α-acid recovery and conversion.

Using the brewing system at Witch's Hat Brewing Co. in South Lyon, MI, a 125 gallon batch of brown ale was split preboil. In total, 118 gallons were processed using the standard method, with 7 gallons separated for treatment with cavitation.

The 7 gallon batch was hopped and processed for 30 min with cavitation, subjecting the wort and hop mix to controlled cavitation. The high pressure at the crest of the shockwaves pushes the wort deep into the hop particles and, as the pressure recedes, the α-acids are extracted.

The wort was then boiled for 60 min. The 114 gallon control batch was hopped and boiled for 90 min and then cooled down after the boil using a plate heat exchanger. The 7 gallon batch on the pilot line was cooled using a stainless steel immersion coil cooling heat exchanger.

Both batches of beer were fermented in parallel and tested by the brewery staff while samples were sent to Brewing and Distilling Analytical Services (BDAS) for IBU analysis (spectrophotometric). The brewing staff reported that both beers displayed a similar bitterness level but that the sample treated with cavitation produced a "silkier" bitterness that lingered longer.

Thinking that we had reached the saturation point for the particular beer, a second test was conducted; however, the hops on the cavitation-treated sample were reduced by 30%. The test conditions were kept the same as the previous test, and samples of the finished beer were sent to BDAS for IBU determination and an independent triangular taste test. The IBU level of the control batch was measured at 37.1, while the test batch measured 36.8. The triangular test indicated that the panelists were unable to differentiate between the two beers. This meant that, even though the particular brown ale at 37 had lower IBU than an IPA, it seemed we were still operating at saturation. It also meant that treatment with cavitation did not have a detrimental impact on the characteristics of the beer.

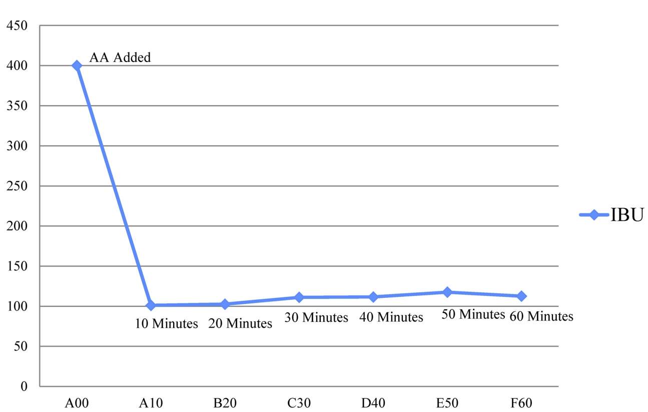

Figure 5. IBU levels at different boiling times. Imperial IPA wort original gravity 1.073.

Impact of Boiling Time

To determine the impact of boiling times on α-acid recovery and conversion, I devised a test to determine IBU levels in wort at different boiling times. For this test the following materials were used:

- Muntons amber malt extract
- Hop Union Amarillo hop pellets with 8.8% α-acids
- Six 12 oz glass bottles
- One 1.5 gallon cooking pot
- One electrical heating plate

A test sample of 1.5 U.S. gallons of Imperial IPA was prepared with Muntons amber malt extract and tap water to a gravity of 1.074. The wort was set on the electric plate and allowed to reach boil. Once boiling, 1 ounce of Hop Union Amarillo hop pellets was added, which represented α-acids at an estimated 410 ppm. Six samples were pulled into 12 oz glass bottles at 10 min intervals and placed in ice water.

The IBU levels at different boiling times (Fig. 5; Table 1) made me question the validity of the standard IBU formula and the impact of boiling times.

IBU Losses During Fermentation

After hearing about the possibility of yeast having a potential impact on IBU levels in beer by adsorbing or absorbing α-acids, I devised a test to determine IBU levels in an American IPA during fermentation.

Samples were pulled at different stages of fermentation of an American IPA from Witch's Hat Brewing Co. from the racking arm (top) and the bottom outlet of the fermenter. If yeast was the cause of the loss, the IBU would be found either in the beer or as part of the sediment:

- Wort: Chilled wort, pre-fermentation
- Day 3: Three days after pitching yeast
- Week 2: End of primary fermentation
- Final: Finished carbonated beer

The IBU values of wort/beer as well as trub in the fermenter for the test IPA are shown in Figure 6. In theory, the IBU level of the wort/beer combined with the IBU level of the sediment should amount to α-acids added but this is not the case. This could mean that the α-acids are being lost before the wort reaches the fermenter.

IBU Testing on American IPA

When combining the IBU results from the different trials, I noticed a relationship between wort gravity and IBU content. The results pointed to a chemical saturation of wort based on

Table 1. Different samples and boiling times

Sample	Boil time
A10	10 min
B20	20 min
C30	30 min
D40	40 min
D50	50 min
D60	60 min

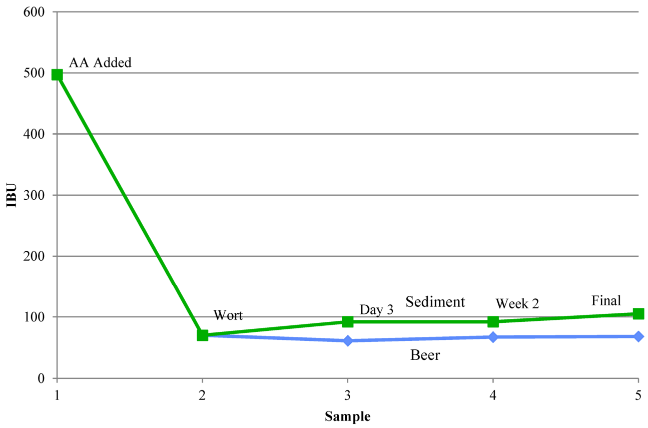

Figure 6. IBU values of wort/beer as well as trub in the fermenter for the test American IPA.

Table 2. Three tests using cavitation conducted on American IPAs

Parameters	Test 1	Test 2	Test 3
Wort gravity	1,064	1,055	1,058
Projected saturation	85	67	72
Measured added α-acids (ppm)	45.4	64.7	111.2
Boil time (min)	10	60	60
Measured IBU	36.0	41.0	67.3
α-Acids to IBU (%)	79.3	63.4	60.5

wort gravity. This relationship followed a fairly linear pattern, and a linear regression with the formula $y = ax + b$ was used to predict IBU levels. Although it may appear linear at a specific range, I believe it may not be the case if the range is expanded.

A control batch of Imperial IPA was prepared at River's Edge Brewing Co. in Milford, MI, using the projected IBU saturation and restricting the boiling time to 10 min:

Wort gravity	1,080
Projected saturation	106
Added α-acids (ppm)	98.5
Boil time (min)	10
Measured IBU	32.4
α-Acids to IBU	32.9%

Three additional independent tests using cavitation were conducted on American IPAs to determine the impact of cavitation on α-acid recovery and conversion, with adjusted formulations to account for projected saturation.

For the test, a portion of the wort was circulated from the kettle to a secondary 40 liter tank where hops were dosed as the wort/hop mixture was pumped through the cavitation unit and back to the kettle. Only enough wort was circulated through the unit to allow for the hops to be pumped through the unit without plugging (Table 2).

Cavitation and Hop Oils

The subject of aroma hops from dry hoping has been more subjective, but results point to an average savings in hops of up to 50%, depending on the method used. Tests have been conducted at local Michigan breweries that include Witch's Hat Brewing Co., Griffin Claw Brewing Co., and Ellison Brewing and Spirits, as well as Indeed Brewing in Minnesota.

Two different methods were used:

Method 1. In a process similar to kettle additions, beer from the fermenter was gravity fed to a small 40 liter tank with a CO_2 blanket. Hops were dosed into the blend tank and pumped back through the cavitation unit and back to the fermenter.

- Beers were dry-hopped with 50% less hops than control beers and evaluated by the brewing staff. The staff reported that there was no appreciable difference between control and test beers.

Method 2. Hops were added directly to the fermenter, and the entire content of the fermenter was allowed to recirculate through the cavitation unit. The system was allowed to work for a sufficient time to complete one complete turn.

- Beers were dry-hopped with 30% less hops than control beers and evaluated by the brewing staff. The staff reported that there was no appreciable difference between control and test beers.

A third method, in-line dry hopping of the beer in route to the clarifier, has yet to be tested.

Our research is ongoing, and we're looking for methodology to objectively measure hop oil (lipids) content in beer; however, methods used in food processing do not have the required detection level. We are experimenting with different methods for concentrating the beer that would allow us to test the beer before and after dry hopping to measure and compare oil extraction levels.

In principle, oil and water do not mix, but the ethanol content in beer can act as a solvent to help retain hop oils in suspension. There is limited information on the efficiency of ethanol as a solvent for hop oils, but it is generally accepted that 100 g of ethanol can dissolve 10 g of vegetable oil. A quick calculation shows that the alcohol content of most American IPAs, DIPAs, and Session IPAs is sufficient to dissolve the oils from 30+ lbs of hops per barrel of beer. Cavitation technology exposes the hop oils from hops to the ethanol present in the beer, increasing not only extraction efficiency but also retention time.

Conclusions

- Each type of wort has a predetermined IBU saturation level dictated primarily by wort gravity and very likely by liquor chemistry as well.
- At the time of hop additions, α-acids are encapsulated as the wort surrounding the hops gets oversaturated, repelling α-acids, which are then attracted by plant material, protein break, or kettle walls and settle at the bottom of the kettle or whirlpool.
- The shockwaves from cavitation break apart the encapsulated α-acids, making them available for increased recovery and conversion, allowing for recovery and conversion levels up to 79%.
- As the IBU level of the wort approaches saturation with each addition, recovery from late additions suffers, which has been previously interpreted as an effect of boil time.
- The utilization factor is a function of the IBU saturation for each particular type of wort.