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Use of pressurized shockwaves generated by cavitation as a non-shear method for increased extraction of alpha acids and oils from hops

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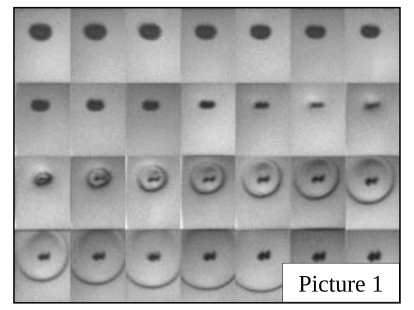
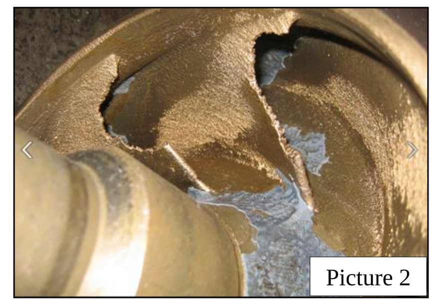
Cavitation

Introduction

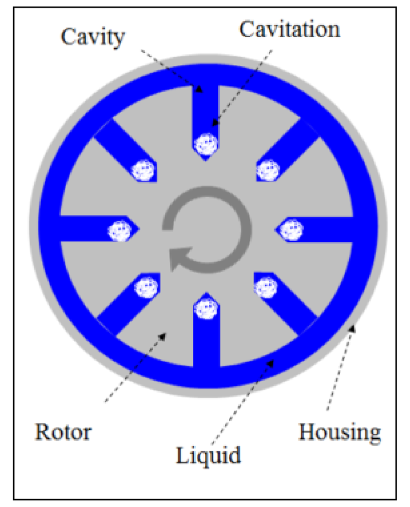
Everyone is familiar with the sound of banging water pipes. Laymen call it "water hammer;" scientists call it "cavitation." Cavitation is the sudden formation and collapse of low pressure vapor cavities (picture 1) in a fluid by means of mechanical forcers. Uncontrolled cavitation can lead to damage of adjacent components or surfaces (picture 2).


Picture 1


Picture 2

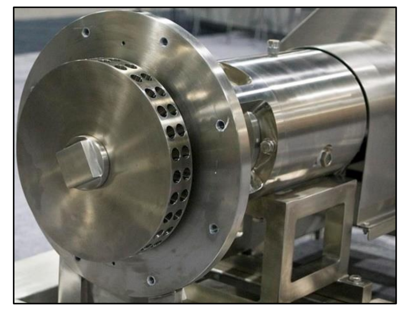
As a liquid products, in this case wort or beer, passes through the system it is subjected to "Controlled Cavitation." Microscopic cavitation bubbles are produced and as they implode, energy is given off into the liquid in the form of intense shockwaves. This energy is harnessed for extraction of Alpha Acids and Oils from Hops.

The heart of the technology is a specialized rotor with cavities that spins. 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.



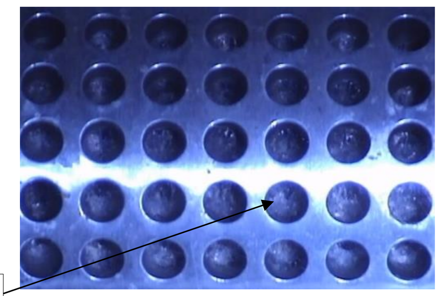
Cavitation technology is used in a wide range of processes including:

- Process intensification
- Pasteurization
- Homogenization
- Esterification
- Starch extraction
- Scale-free Heating



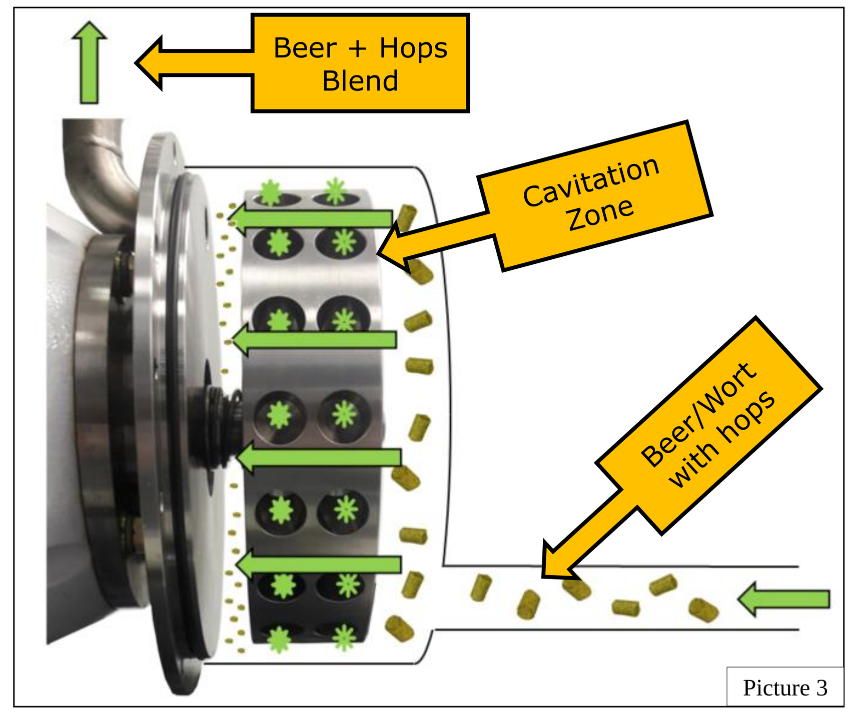
In industries such as:

- Egg Products
- Dairy
- Metal plating
- Ethanol
- Cosmetics
- Dairy
- Bio-Diesel, bio-gas
- Waste Water
- Petroleum


Controlled Cavitation

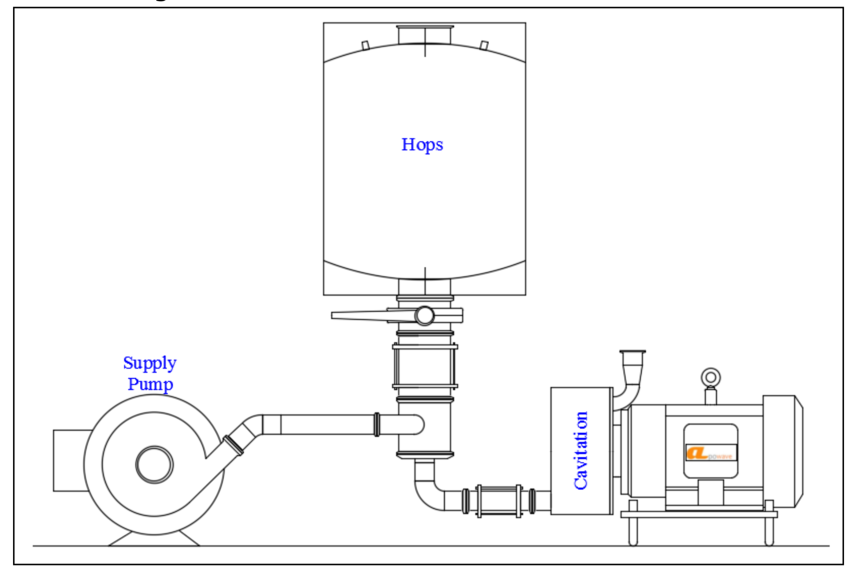
Cavitation and Beer

A blend of wort or beer and hops is pumped through the cavitation zone of the unit. As the hop pellets are exposed to the shockwaves, the high pressure at the crest of the wave forces beer or wort deep into the hop particles. As the shockwave recedes, the hop compounds are extracted into the liquid thousands of times per second (Picture 3).



Picture 3

- For Alpha Acid Extraction and isomerization on kettle additions, a hot wort + hop slurry is pumped through the cavitation system and returned to the kettle.
- For Hop Oil Extraction dry hops, an in-line hop dosing unit, purged with CO2 can be used and the blend returned to the fermenter to fed directly to the centrifuge.



Picture 4: Cavitation unit setup with hop dosing

Cavitation & IBU's

Low yield in alpha acid extraction and conversion to iso form during beer processing is a poorly understood topic. Standard IBU calculations seem to indicate that increased boil times lead to higher IBU's in beer. Traditional IBU (International Bitterness Units) calculation formulas have the form:

$$IBU = \frac{\text{Weight of Hops} \times \text{Alpha Acid \%}}{\text{Wort Volume} \times \text{Gravity}} \times \text{Utilization Factor}$$

With the utilization factor driven primarily by boiling time.

I initially developed a theory that the reason for low alpha acid to IBU conversion rate pointed to either a chemical (saturation) or physical (dispersion) limiting factor, or a combination of both.
To determine the effect of boiling time in alpha acid utilization we developed a test to determine the impact of boiling time on IBU's. A 5-gallon batch of wort with a starting gravity of 1073 was set to boil and enough hops were added to achieve a potential 400 IBU level. Samples were pulled from the kettle every 10 minutes and chilled. Chart 1 shows the IBU levels of wort at different boil times and indicates that there was very little gain after 10 minutes.

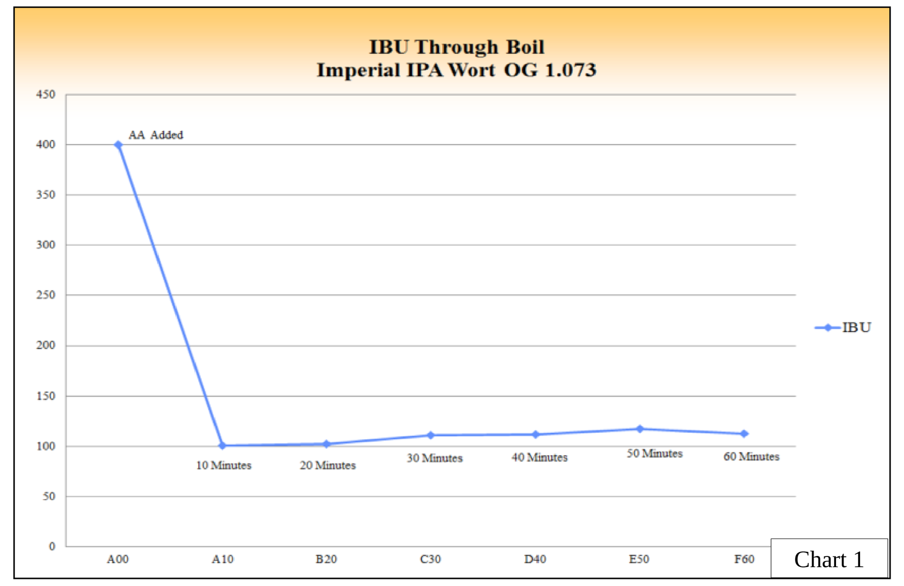


Chart 1

To determine if yeast may be absorbing or adsorbing isomerized alpha acids we setup a test to quantify IBU loss by pulling samples of wort/beer during fermentation.
Chart 2 shows the IBU values of wort/beer as well as trub in the fermenter for an American IPA. In theory, the IBU level of the wort/beer combined with the IBU level of the sediment should amount to alpha acids added, but this is not the case. The alpha acids are being lost before the wort reaches the fermenter.
When combining the IBU results from the different trials we noticed a relationship between wort gravity and IBU content. The results pointed to a chemical saturation of wort based on wort gravity and liquor chemistry.
The relationship between wort gravity followed a fairly linear pattern and a linear regression with the formula $y = ax + b$ was used to predict IBU levels.

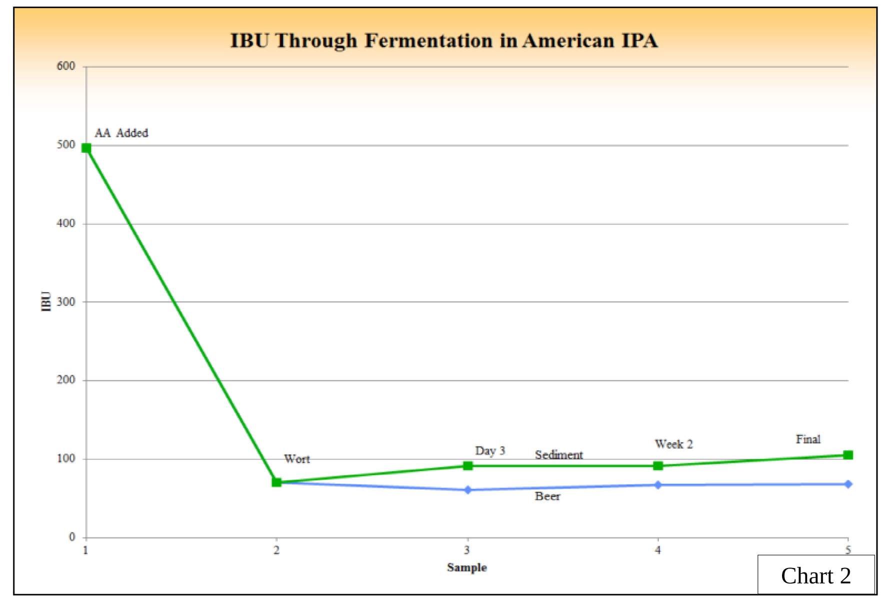


Chart 2

Cavitation trials

A control batch of Imperial IPA was prepared using the projected IBU saturation and restricting the boiling time to 10 minutes:

Wort Gravity	1080
Projected Saturation	106
Added Alpha Acids (ppm)	98.5
Boil time (min)	10
Measured IBU's	32.4
Alpha Acids to IBU	32.9%

Three tests were conducted on American IPA's to determine the impact of cavitation on alpha acid recovery and conversion:

	Test #1	Test #2	Test #3
Wort Gravity	1064	1055	1058
Projected Saturation	85	67	72
Measured Alpha Acids (ppm)	45.4	64.7	111.2
Boil time (min)	10	60	60
Measured IBU's	36.0	41.0	67.3
Alpha Acids to IBU	**79.3%**	**63.4%**	**60.5%**

Conclusions

1. Each type of wort has a pre-determined **IBU saturation** level dictated by gravity and liquor chemistry.
2. At time of hop additions AA are **encapsulated** as the wort surrounding the hops get oversaturated, repelling AA which are then attracted by plant material or protein break and settle at the bottom of the kettle/whirlpool.
3. The shockwaves from cavitation break apart the **encapsulated AA**, making it available for increased recovery and conversion.
4. As the IBU level of the wort approaches saturation, recovery from late additions suffer, which can be misunderstood as an effect of boil time.
5. The **Utilization Factor** is a function of IBU saturation as opposed to boil time.

Cavitation & Hop Oils

The subject of aroma hops from dry hoping has been more subjective but results point to an average savings in hops of 50%. Tests have been conducted at local Michigan breweries that include Witch's Hat Brewing Co., Griffin Claw Brewing Co. and Ellison Brewing and Spirits.
Beers were dry hopped with 50% less hops and processed with cavitation evaluated by the brewing staff showed no appreciable difference between control and test beers.

Hop Dosing

As beer is circulated from the fermenter to the cavitation unit and back to the fermenter, hops are dosed and exposed to the shockwaves. The pressure fluctuations from the shockwaves expose hop oils to the beer allowing for instant and efficient extraction. The prototype hop dosing unit on Picture 4 and 5 allows the in-line dosing of hops into a stream of beer under an environment purged with CO2. The technology allows for in-line dry hoping in route to the centrifuge.

Hop Oil Retention

Our on going research is looking for methodology to objectively measure hop oil (lipids) content in beer, as methods used in food processing do not have the needed detection level.
In principle Oil and Water do not mix, but the ethanol content in beer can act as a solvent and help retain hop oils in suspension. There's not a lot of information on the efficiency of ethanol as a solvent for hop oils, but is generally accepted that 100g of ethanol can dissolve 10g of vegetable oil. A quick calculation shows that the alcohol content of most American IPA's, DIPA's and Session IPA's is sufficient to dissolve the oils from 50+ lbs of hops per barrel of beer.

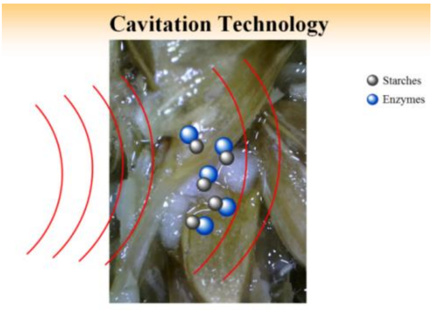

Picture 5

Cavitation technology exposes the hop oils from hops to the ethanol present in the beer increasing not only extraction efficiency, but retention time, keeping the hop aromatics in the beer longer.

Research is ongoing and we are evaluating the option of freeze drying the beer samples to increase concentration to help determine lipid content before and after dry hoping.

Other Applications

- Extraction of flavor and aroma compounds from spices.
- Increased extraction and saccharification efficiency during mashing.
- Accelerated aging of beer and spirits



Acknowledgements

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Apotek Solutions