

# Brewing Science

Hops

# Introduction

- Hops have been used in brewing beer for many centuries. They provide a bitterness to beer that compliments the sweetness from malt. Hops also impart an aroma and flavor to beer. Moreover, hops act as a preservative for beer.

# The Hop Plant

- The hop plant used in brewing beer is from the species *Humulus lupulus*. Hops are a cone-like flower that contain many lupulin glands. These glands house the resins and essential oils that provide hop bitterness, aroma and flavor.
- Only the female hop plant contains a significant number of the lupulin glands. So, the male hop plant is not used for brewing purposes.

# brewing beer -Hopping

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## *Humulus lupulus*

a tall, non-woody vine that dies back to the ground every winter, perennial, Cannabaceae family, sister genus to hemp

female flowers produce cones that bear lupulin glands which contain many different oils that contribute bitterness, flavor, and aroma to beer, also bacteriostatic, used to balance sweetness of malt

must be boiled vigorously to extract the oils

# brewing beer -Hopping

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# brewing beer -Hopping

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many different varieties, typically grouped by region of origin, American hops most distinct

## - England

- Fuggles
- East Kent Goldings
- Target
- Challenger

## - Germany

- Spalt
- Tettnanger
- Hallertau

## - United States

- Cascade
- Simcoe
- Chinook
- Magnum

## - Czech Republic

- Saaz

# The Hop Plant

## Resins

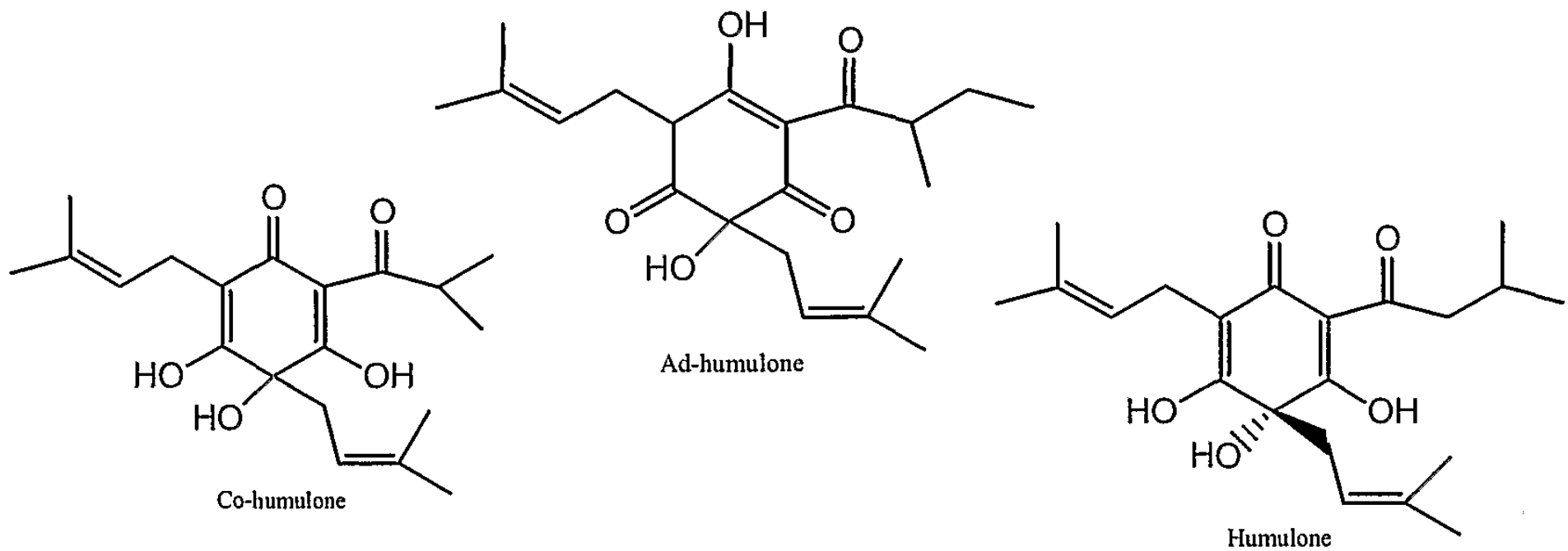
- The hop lupulin has hard and soft resins. The hard resins are not soluble in hexane and are of little value to the brewer
- The soft resins are the ones that are soluble in hexane. These soft resins contain alpha and beta acids.

# Alpha Acids

- Most of the bitterness from hops comes from the alpha acids
- The alpha acids consist of humulone, cohumulone, and adhumulone
- Cohumulone is more soluble and produces a harsher bitterness than humulone or adhumulone



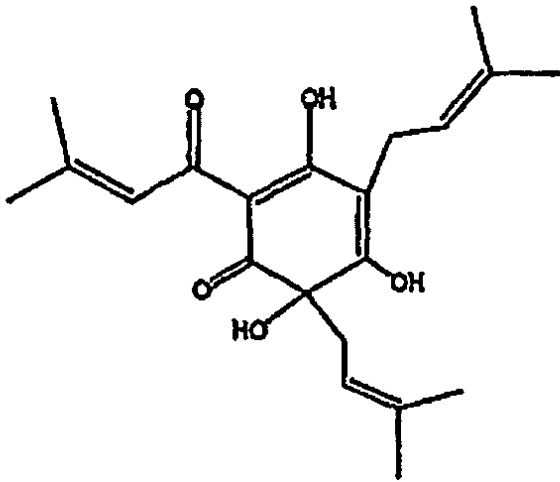
# humulone, cohumulone, and adhumulone



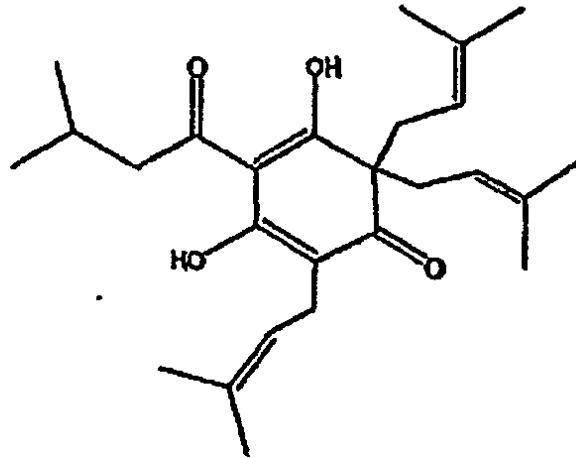
# Beta Acids

- Beta acids are not as soluble as alpha acids and contribute very little bitterness to beer
- The beta acids consist of lupulone, co-lupulone, and adlupulone
- When beta acids are oxidized (during wort boiling or storage) some bitter compounds form.

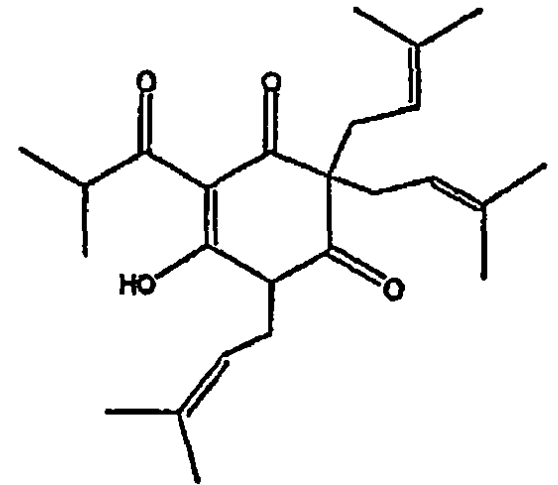
# lupulone, co-lupulone, and adlupulone



Humulone



Lupulone



Colupulone

# Essential Oils

- The essential oils are responsible for the hop aroma and flavor in beer.
- There are hundreds of compounds associated with the essential oils but current research has isolated around a few dozen that have a major impact on flavor and aroma.
- The essential oils are very volatile and typically do not survive long boils.

# Essential Oils

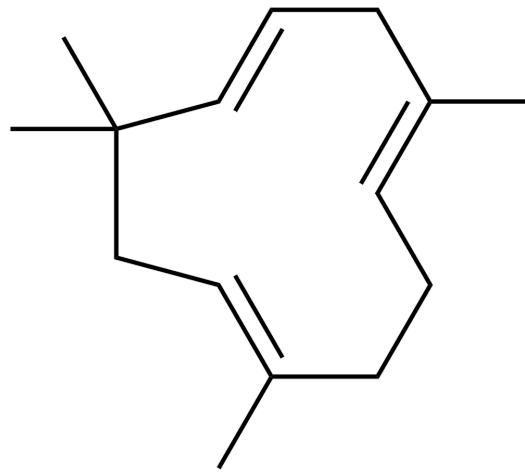
The essential oils consist of

- Hydrocarbons
- Oxygen-Bearing components
- Sulfur components

# Hydrocarbons

The hydrocarbons represent about 75% of the essential oils. The four main hydrocarbons are:

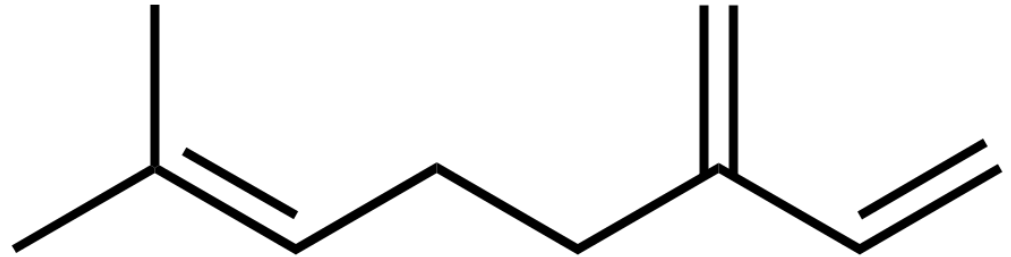
- Humulene
- Myrcene
- Farnesene
- Caryophyllene



## Humulene

- Has a very refined flavor, often described as elegant.
- Unlikely to appear in beer unless the hops are added at the end of the boil or dry hopped
- Degrades into oxygen products that survive in finished beer that contribute to flavor and aroma

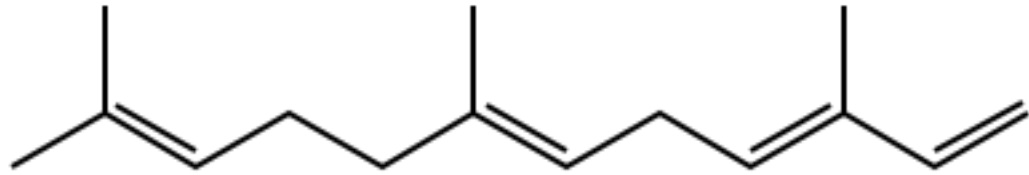
## Myrcene



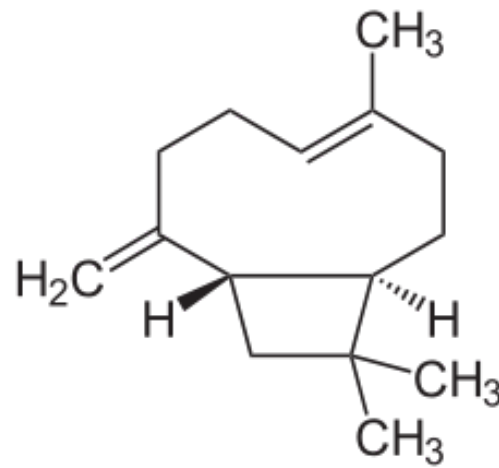
- Has a greater flavor intensity than humulene, and often described as pungent
- Unlikely to appear in beer unless the hops are added at the end of the boil or dry hopped
- Typically is between 20% to 65% of total hop oil, depending on hop variety
- Related oxidation compounds produce floral aromas and flavors



## Farnesene



- Usually less than one percent of total hop oil, but can be as high as twenty percent
- High farnesene hops, like Saaz, can lose farnesene oil during hop pelletization. This reduction may explain some of the difference in hop aroma for pellets versus whole hops

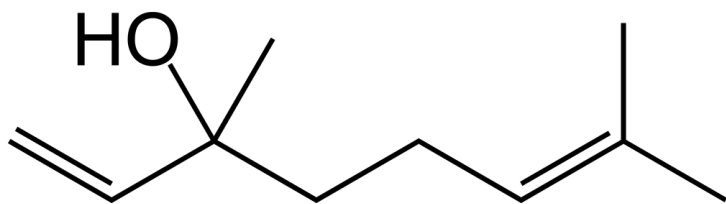


## Caryophyllene

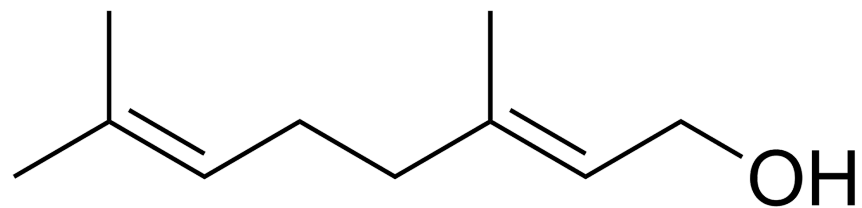
- Typically between 5% and 15% of total hop oil
- Generally speaking, caryophyllene amounts tend to be higher in aroma hops and lower in hops used for bitterness.
- Related oxidation compound, caryophyllene epoxide, can produce a herbal/spicy character

# Oxygen Bearing Components

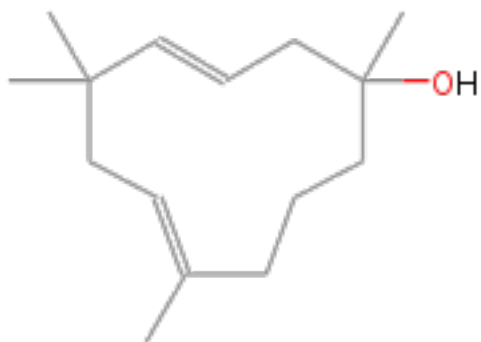
- Oxygen bearing compounds in hops account for about 25% of the total essential oils
- Compounds produced from oxidation or degradation of myrcene tend to have floral aromas and flavor. Examples include the alcohols linalool and geraniol
- Oxidation or degradation of humulene leads to herbal or spicy notes. Examples include humulene epoxides, diepoxides, and humulol



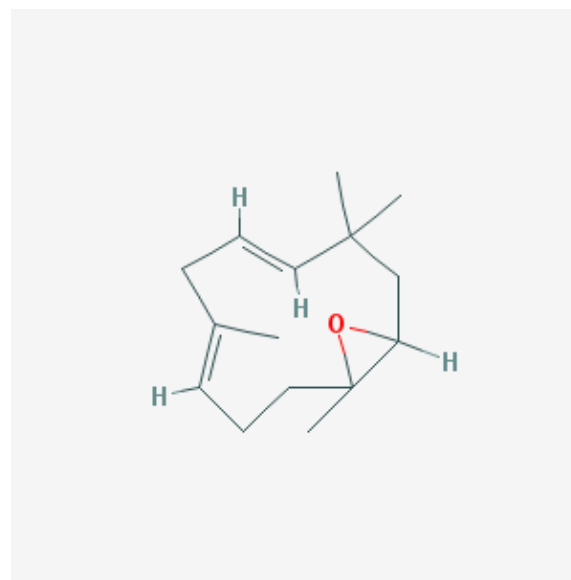
Linalool



Geraniol



Humulol



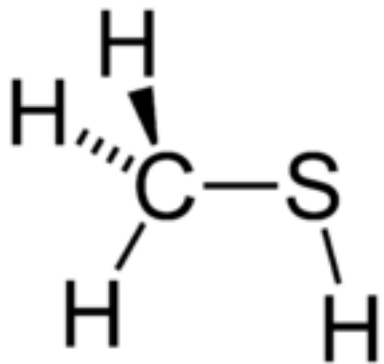
Humulene epoxide

# Sulfur Compounds

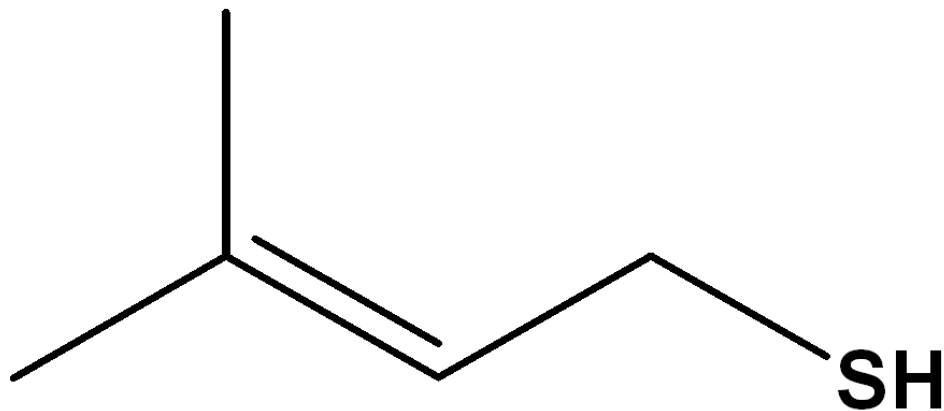
- Malts and fermentation are responsible for some sulfur flavors in brew; however, sulfur compounds can also be introduced through hops

# Sulfur Compounds

- Light Struck or Skunky aroma is caused by ultraviolet light reacting with the alpha acid humulone to produce mercaptan. Mercaptan is the same molecule that skunks use to generate their notorious aroma
- Another source of sulfur is from sulfur products used in hop fields to protect the crop from fungus. Most of the sulfur compounds are removed during malting and boiling of the wort, but some sulfur can make it into the finished beer if late hopping or dry hopping is used



Mercaptan



3-methyl-2-butene-1-thiol

# Noble Hops

Noble hops are prized for their aroma and flavor properties. The noble hop varieties are:

- Hallertauer Mittelfrüh
- Tettnang Tettnanger
- Czech Saaz
- Spalt Spalter

Some honorable mentions are Polish Lublin, English Fuggles and East Kent Goldings, and German Spalter Select and Hallertauer Tradition, but unfortunately these varieties are not considered noble hops.



# Noble Hops

## Characteristics

To be considered a Noble Hop the hop variety has to satisfy all of the following conditions:

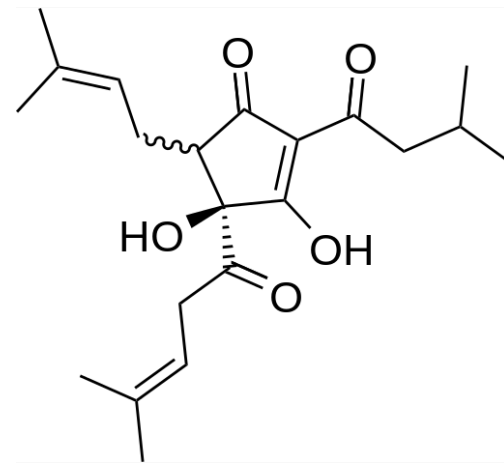
- Low alpha acid percent (below 6%)
- Alpha acid percent close to the beta acid percent
- Low cohumulone alpha acid content
- Low myrcene oil content (typically below 50%)
- High humulene in the hop oil
- Humulene to caryophyllene ratio above 3
- Poor storage attribute

# Aroma and Flavor Hops

- Essential oils that produce aroma and flavor are very volatile and will not survive a long boil. These hops are usually added very late in the boil or after primary fermentation. Adding hops after primary fermentation is called dry hopping.
- Some aroma and flavor hops have similar characteristics. For example, Liberty , Mt. Hood, and Crystal may be substituted for Hallertaur Mittelfrüh. As another example, Willamette is a seedless version of Fuggle.

# Bittering Hops

- Hops used for bittering are normally added to the brew kettle very early in the process because the longer you boil hops (up to a point) the more bitter the beer.
- Some use first wort hopping, which means they add hops to the sweet runnings from lautering. The higher pH is thought to extract some of the finer qualities of the hop flavor. The hops are kept with the wort throughout the boil, and some believe this contributes a more refined bitterness.



## Iso-Alpha Extracts

- Iso-alpha extracts are used to add hop bitterness to beer
- Add this extract just prior to bottling or kegging. If you add them to the boil then you will lose some iso-alpha acid during fermentation
- Use only products calibrated to IBUs
- Avoid products made with toxic solvents
- Only use for at most 50% of bitterness. Use some real hops because they provide a better hot break

# Hop Products

## Hop Oils

- Hop oils are used to add hop aroma and do not affect hop bitterness
- These oils are used in place of dry hopping. The oils should be added at bottling or kegging
- Hop oils are available in single hop variety form or as a blend of hop varieties
- For consistency, buy only calibrated products

# Hop Products

## **Late Hop Essence**

- Late hop essence is designed to simulate late kettle hop additions
- Typically produces a floral or spicy character
- Use only calibrated products

# Alpha Acid Loss

- After harvest, hops begin to lose their alpha acid content. The rate of loss is halved for every 15 °C drop in temperature
- To minimize the amount of alpha acid loss, hops should be stored in a cold, dark place, and in packages that are free of oxygen.
- Some hop varieties store better than others. For example, Cascade hops stored at 20 °C will typically lose 50% of its alpha acids after 6 months storage, while Galena usually will lose only 15% under the same storage conditions

# Predicting Alpha Acid Loss

- The amount of alpha acid loss due to storage can be estimated by the formula

$$A_t = A_0 * e^{-k*TF*SF*t}$$

Where

$A_t$  = alpha acids after t days

$A_0$  = initial alpha acids

k = exponential decay rate constant

TF = storage temperature factor

SF = storage condition factor



# Example 1

- Estimate the hop alpha acid loss if Fuggle hops are stored at 50 °F for 60 days in a sealed package free of oxygen. The initial alpha acid level is 5.5% and the rate constant is .00239

$$A_{60} = 5.5\% * e^{-.00239 * .630 * .5 * 60}$$
$$= 5.26\%$$

# Measuring Hop Bitterness

- Homebrew Bittering Units (HBUs)

HBUs= Hop Wt. in (ounces)\*Alpha Acid Percent

For example, if you use 2.5 ounces of Cascade Hops with an alpha acid of 6.5% then the HBUs=  $2.5 * 6.5 = 16.25$  homebrew units

# Measuring Hop Bitterness

- International Bittering Units (IBUs)

IBUs = Milligrams of iso-alpha acids in each liter of beer

Professionally, IBUs are measured with a spectrophotometer

# Hop Utilization

- The efficiency of the alpha acid bittering process is called the hop utilization. Basically, the hop utilization is the amount of iso-alpha acids in the finished beer relative to the alpha acids added during the brewing process

$$\text{Alpha Acid Utilization} = \frac{\text{IBUs}}{\text{Alpha Acids Added in mg per liter}}$$

or

$$\text{IBUs} = \text{Alpha Acid Utilization} * \text{Alpha Acids Added(mg/l)}$$

# Hop Utilization Factors

- amount of hops added to the brew kettle
- The length of the boil
- Gravity of the wort during boiling
- Hop rate i.e. alpha acids per liter of wort
- Type of hop, i.e. whole or pellets
- Filtering or using a hop bag
- Boil Temperature (altitude where you brew)

# Estimating IBUs

- Four methods to estimate IBUs
  - Jackie Rager  
*Calculating Hop Bitterness in Beer*, Zymurgy Special 1990  
(vol. 13, no. 4)
  - Mark Garetz  
*Using Hops, The Complete Guide to Hops for the Craft Brewer*, Hop Tech 1994
  - Ray Daniels  
*Designing Great Beers*, Brewers Publications 1996
  - Glen Tinseth  
[www.realbeer.com/hops](http://www.realbeer.com/hops)

# Estimating IBUs

## Rager Formula

- The Rager Formula for estimating IBUs:

$$\text{IBU} = \frac{\%U * W_{\text{oz}} * \%A * 7462}{V_{\text{gal}} * (1 + \text{GA})}$$

Where

$$\text{GA} = (\text{GB} - 1.050) / .2$$

# Rager Formula Variables

GB = Gravity of boiling wort at end of boil

GA = Gravity adjustment

$W_{oz}$  = Hop weight in ounces

$V_{gal}$  = Volume of beer fermented in gallons

%U = Boil utilization percent

%A = Hop alpha acid percent



# Example 2

- Estimate the IBUs if you boil 1.5 ounces of Willamette hops for 45 minutes. The hops have an alpha acid of 6.5% and they are whole hops. Also, the hops are boiled in 3 gallons of wort and you plan to add 2 gallons of water after the boil to make 5 gallons of beer with an OG of 1.040.  
Use the Rager formula:

# Example 2 – Solution

- Determine the gravity of the boiling wort      GB =  
(OG-1)\*(Ferment Vol)/(Boil Vol) + 1

$$= (1.040 - 1) * 5/3 + 1 = 1.066666667$$

- Determine gravity adjustment

$$\begin{aligned} GA &= (GB - 1.050)/.2 \\ &= (1.066666667 - 1.050)/.2 \\ &= .083333333 \end{aligned}$$

# Example 2 – Solution con't

- Determine the IBUs

$$\text{IBUs} = .269 * 1.5 * .065 * 7462$$

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$$5 * (1 + .083333333)$$

$$= 36.13$$

# Hop Variety and Beer Styles

- Some beer styles are strongly identified with particular hop varieties.
- Bohemian Pilseners are typically brewed with Saaz hops because they add a smooth bitterness and flavor profile to the style
- German Pilsners are usually brewed with German hops like Tettnanger, Hallertauer Mittelfrüh

# Hop Variety and Beer Styles

- English Pale ales are often made with East Kent Goldings or Fuggles
- American pale ales are associated with American hops like Cascade