Aged to Perfection
The Maturation of Beer
In a Brewery, Fermentation is Historically a Two Tank Process

• Separate primary and secondary fermentations

• Specialized tank design
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Goals of Maturation

• Flavor Maturation
• Clarification
• Carbonation
• Stabilization
Traditional Maturation

An old brewer’s rule said “1 week of fermentation and one week of lagering for each percent original extract content”

12% Plato - 13 weeks in tank

Technology Malting and Brewing, Kunze
Modern Brewery Maturation

Beer must be fermented and matured in the shortest possible time to make a plant economically viable. Nowadays usually no more than 17 to 20 days can be used for the fermentation, maturation and lagering and there is a trend to even further shortening of the fermentation and maturation time whilst maintaining the same quality.

Technology brewing and malting, Kunze

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Clarification at home

• Yeast Removal
  1. Settling and time
  2. Fining with isinglass or gelatin
  3. Filtration

• Chill haze
  1. Settling and time
  2. Cold filtration
Yeast Removal

- Sedimentation due to Stoke’s Law

\[ V = \frac{2 \left( \rho_p - \rho_f \right) g R^2}{9 \mu} \]

Where \( V \) = the particle’s velocity in m/s  
\( \rho_p \) = is the mass density of the particle in kg/m\(^3\)  
\( \rho_f \) = is the mass density of the fluid in kg/m\(^3\)  
\( g \) = acceleration due to gravity m/s\(^2\)  
\( R \) = radius of the particle in m and,  
\( \mu \) = viscosity of the fluid in kg/m/s

An average sized yeast particle will settle at 0.13m per day

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Yeast Removal

• Fining agents are positively charged collagen protein which attracts negatively charged yeast cells to cause them to agglomerate and then settle more quickly according to Stoke’s Law
  1. Isinglass from swim bladders of fish
  2. Gelatin from bovine sources
Filtration is governed by Darcy’s Law

\[ Q = \frac{K \Delta P \times A}{L \mu} \]

- \( Q \) = Units of volume per time
- \( K \) = the permeability coefficient of the bed
- \( \Delta P \) = the pressure across the filter bed
- \( A \) = the filter surface area
- \( L \) = the depth of the bed
- \( \mu \) = the viscosity of the liquid
Chill Haze

• Protein – Polyphenols in beer combine
• Precipitate at low temperatures
• Re-solubilize on warming
• Polyphenols come from malt husks, high hopping levels, dry hopping (20% of total from hops)
• Protein comes from malt
Carbonation at Home

• Bottle conditioning
• $\text{CO}_2$ top pressure and time
• $\text{CO}_2$ top pressure and shaking
Flavor

Concentration in Beer

Ferm w/growth
Ferm w/no Growth

Organic Acids And Higher Alcohols

Esters

Aldehydes and Vicinal Diketones

Apparent Extract

Yeast in Suspension

Primary Fermentation
Secondary Fermentation

ppm

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Flavor Maturation

12-10. Decrease in Flavor Compounds in Storage
Flavor Maturation
Vicinal DiKetones (VDK’s)

• Vicinal - adjacent
• di - two
• ketone - a double bond oxygen connected to a carbon atom located on the interior of the molecule
Controlling Buttery Flavors: Management of Vicinal diKetones
Bill Pengelly,PH.D, New Brewer Jan/Feb 2001
Controlling Buttery Flavors: Management of Vicinal diKetones

Bill Pengelly, PH.D
New Brewer
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Factors leading to an increase in diacetyl production

- **Yeast strain.** Needless to say different yeast have different characteristics when it comes to their ability to produce diacetyl. Low diacetyl producers are prized.
- **Rate of fermentation.** A fast, healthy fermentation reduces the release of the precursor into the wort.
- **Temperature.** A lager beer fermented at 57°F produced as much as 3 times as much diacetyl compared to a brew at 40°F.
Factors leading to an increase in diacetyl production continued

- **Yeast Growth.** Factors that inhibit yeast growth result in the release of the precursors into the wort.
- **Pitch rate.** A higher pitching rate will lead to an increase in the formation of the precursor due to suppressed growth.
- **Wort Quality.** The wort must contain sufficient amino acids (>150 ppm, ideally >230 ppm) or the yeast will need to manufacture them. The pathway that the yeast uses results in more formation of α acetolactate
Factors increasing the rate and degree of diacetyl removal.

- The presence of sufficient live, active, healthy yeast during ageing. Yeast remove diacetyl much faster than they produce it. Sending the beer into maturation with some fermentable extract and 2-10 million cells/ml should be sufficient to reduce the diacetyl in a timely manner.

- Removal is accelerated at higher temperatures. Some lager brewers raise the temperature of the beer to around 57-61 °F for a day or so after primary fermentation and prior to cold conditioning. This is called a diacetyl rest. Ale brewers should also perform a diacetyl rest by waiting for a couple of days after primary fermentation is over before chilling the beer.
Factors increasing the rate and degree of diacetyl removal continued

- **pH.** At pH’s between 4.2 and 4.4 the conversion of α acetolactate to diacetyl is rapid. This rate decreases as the pH rises.

- **Krausening.** The addition of actively growing yeast along with the fresh wort encourages a rapid removal of diacetyl in the finished beer. Of course, the increase in the levels of the potential haze forming agents doesn’t actually result in much of a time saving.

- **Increasing the surface area for yeast sedimentation.** This will allow the use of a flocculant strain and still shorten the maturation time. (i.e. Beechwood chips, horizontal maturation tanks, shallow coned unitanks etc)
Factors leading to an increase in diacetyl in beer.

- Poor wort aeration. Yeast use oxygen absorbed at the start of fermentation to desaturate fatty acids which, in turn, increases the fluidity of membranes produced in subsequent generations. Cells with less fluid (or rigid) membranes late in the fermentation or in maturation are less able to reabsorb diacetyl.
Factors leading to an increase in diacetyl in beer.

- Too short a maturation period. Removal of diacetyl by yeast takes time. The large lager brewers of the world use the final disappearance of diacetyl below its flavor threshold as their criteria for determining how long the maturation period should last. Care must be taken to ensure a complete conversion of the precursor to diacetyl since $\alpha$ acetolactate can oxidize to diacetyl at any time, and if this happens once the yeast has been removed then there is no other mechanism available by which diacetyl can be removed.
Factors leading to an increase in diacetyl in beer.

- Flocculant yeast. If your yeast is very flocculant then it will tend to remove itself from the wort/beer before it has the chance to reabsorb the diacetyl. Some English and Canadian ale brewers use flocculant yeast that require a recirculation pump to keep them in contact with the wort until diacetyl can be absorbed. A system that also allows oxygen contact such as a Yorkshire square or even just an open fermenter can cause an increase in diacetyl in beer.
Factors leading to an increase in diacetyl in beer.

• Mutated yeast. One of the most common yeast mutations is one that causes the yeast to lose the ability to reduce diacetyl. On an agar plate these cells produce small colonies leading to them being named “petite mutants” (petite is French for small)
Factors leading to an increase in diacetyl in beer.

- Crash chilling too early. Some brewers ferment in the primary fermenter until the terminal gravity is reached, then crash chill the fermenter to around freezing point to “drop out” the yeast. Unfortunately if the yeast is dormant, and stuck in the fermenter cone then it isn’t up in the beer where it can be removing the diacetyl.
Factors leading to an increase in diacetyl in beer.

- Uptake of oxygen late in fermentation. Yeast will begin releasing more $\alpha$ acetolactate if oxygen is introduced late in the fermentation. This eventually leads to an increase in diacetyl, so care must be taken to avoid oxygen pickup during beer transfers.
Factors leading to an increase in diacetyl in beer.

- **Bacterial contamination.** Lactic acid bacteria are capable of producing diacetyl by a similar pathway to that used by yeast. However, they are unable to reduce it again. This was once known as “sarcina sickness” after the original name for gram positive brewery bacteria. A clean brewery and a yeast carrying a low contamination load will ensure that bacterial sources of diacetyl will be minimal. If your processes are geared toward minimizing diacetyl and it suddenly shows up then this is the first place to look for the source.
Exotic Methods.

• **Enzymic approach.** An enzyme $\alpha$ acetolactate decarboxylase can be added to young beer to remove the precursor by converting it directly to acetoin.
Exotic Methods

- Immobilized yeast. Centrifuged, warm conditioned, beer is passed through a chamber containing immobilized yeast cells. Diacetyl is removed in a matter of hours.
Exotic Methods

- Genetically engineered yeast. A yeast has been developed that has the ability to decarboxylate $\alpha$ acetolactate internally. This results in a strain that doesn’t produce a great deal of diacetyl. Researchers in Japan see this as the key to controlling diacetyl in the future.
12-11. Production and Reduction of Diacetyl in Fermenting and Storage
Acetaldehyde

Pyruvate $\xrightarrow{H^-} CO_2$ $\xrightarrow{NADH + H^+} CH_3 - CH_2 - OH$

Acetaldehyde

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Overproduction

• High metabolism and low growth
  – high pitching rates
  – poor wort aeration
  – pressure early in fermentation

• Higher fermentation temperature
Removal

- Viable healthy yeast present during maturation
- Warmer maturation
- Good early wort aeration
Sulfur H$_2$S

- Produced during yeast growth cycle from sulfur containing amino acids and sulfate ions in solution
- Scrubbed from the beer by evolution of CO$_2$ bubbles during maturation and carbonation
DMS

- Produced from a precursor, present in barley, during malting, kilning, mash boiling and wort boiling.
- Oxidized during kilning to DMSO
- Reduced by yeast to DMS (lager yeast tend to produce more)
- Scrubbed from the beer with evolution of CO$_2$ bubbles during carbonation.
Thank you

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