

# Off-Flavor Training

## Part I - Fermentation Faults

**Introduction:** This is the first part of a series of “mini-classes” designed to help homebrewers detect and identify the various flavor faults listed on the BJCP Beer Scoresheet. The various faults have been divided into categories based on the *most likely* origin of a particular off-flavor, although they can arise due to other causes.

The off-flavors in this class are most likely to arise during fermentation, as byproducts of yeast metabolism.

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### Acetaldehyde

**Detected In:** Aroma, Flavor.

**Perceived As:** Bready, cidery, fruity, grassy, green apple, “rough.”

**Chemical Origin:** Acetaldehyde is produced as a precursor to ethanol produced during fermentation: Glucose is metabolized into pyruvic acid which is then converted to acetaldehyde and then to ethanol. During fermentation some acetaldehyde escapes from the yeast cell. During the final phases of fermentation, the yeast scavenges free acetaldehyde and finishes converting it.

It is detectable at 10-20 mg/l. At 6-8 g/ml it is perceived as a “fruity” flavor. At higher levels it has a distinctive “green apple” aroma flavor and aroma. The combination of bacterial action and oxidation might reduce it to acetic acid (vinegar) due to the chemical reaction of ethanol and acetaldehyde.

**Increased By:** Yeast strain (highly flocculent strains). Poor yeast health. Underpitching. Fermentation at temperature too cool for yeast. Incomplete/stuck fermentation. Removing yeast from wort prematurely (e.g., fining, filtering, crash cold conditioning). Insufficient conditioning time. Aeration of green beer. Bacterial infection.

**To Avoid or Control:** Proper fermentation temperature. Longer fermentation and/or conditioning times. Proper yeast health/quality. Proper yeast strain. Proper pitching rate (at least 0.5 quarts per 5 gal. for ale, more for lager and high gravity beers). “Diacetyl rest” at ~50 ° F for 1-3 days at end of lagering period. Proper sanitation (to avoid bacterial infection).

**When Are Acetaldehyde Notes Appropriate?:** For most styles of beer, detectable level of acetaldehyde is a fault. The exception is that Light American Lager and Standard American Lager may have very low levels of acetaldehyde.

### Alcohol (Ethanol)

**Detected In:** Appearance, Aroma, Flavor, Mouthfeel.

**Perceived As:** High alcohol beer might have distinct alcoholic “legs” which become visible when the beer is swirled in the glass and then allowed to settle.

Ethanol “smooth” or vinous in smell and flavor and as smooth or warming in mouthfeel.

**Chemical Origin:** Yeast produces ethanol (along with carbon dioxide) as a major product of anaerobic respiration during fermentation. Acetate and various fusel (“higher”) alcohols are produced as minor respiratory byproducts during the metabolism of amino acids. Ethanol, acetate and fusel alcohols can all react chemically with oxoacids to produce esters. Ethanol is detectable at 1.5-2% ABV.

**Increased By:** Yeast strain (beyond about 9% alcohol). High-gravity/highly-fermentable wort. Proper fermentation temperature for yeast strain. Higher fermentation temperatures.

Longer fermentation times (if “feeding” a high-alcohol fermentation).

**Decreased By:** Improper choice of yeast strain. Poor yeast health/quality. Low fermentation temperatures. Prematurely removing yeast from fermenting wort (e.g., filtering or fining).

**To Avoid or Control:** Proper wort gravity. Proper level of fermentable sugars in wort. Proper yeast selection. Proper yeast health. Proper fermentation temperature for yeast strain.

**When Are Alcoholic Notes Appropriate?:** Low to medium-high levels of ethanol aroma, flavor and mouthfeel are desirable in any strong beer, specifically Bocks, Scotch Ale (Wee Heavy), Baltic Porter, Foreign Extra Stout, American Stout, Russian Imperial Stout, Weizenbock, Saison, Bière de Garde, Strong Belgian Ales and Strong Ales.

Very low ethanol notes are acceptable in Vienna Lager, Munich Dunkel, Cream Ale, American Wheat/Rye Beer, English Pale Ale, Irish Red Ale, American Pale Ale, American Amber Ale, American Brown Ale, Robust Porter, English IPA, American IPA and Belgian Pale Ale.

Detectable levels of alcohol are a fault in low-alcohol beers, specifically English Ordinary Bitter, Mild and Berlinerweisse.

### Esters

**Detected In:** Aroma, flavor.

**Perceived As:** Bubblegum, butter, cream, citrusy (lemon, orange), floral (feijoa, flowery, geranium, jasmine, lavender, perfumy, rose, ylang-ylang), herbal (pine, sage), honey, Juicy Fruit™ gum, plant-like (“green,” green banana, new-mown hay, parsnip, waxy), soft fruit (grape, raspberry, strawberry), spicy (cinnamon, wintergreen, liniment), tree fruit (apple, apricot, cherry, peach, pear), tropical fruit (banana, passion fruit, pineapple, coconut, “tutti-frutti”), “sweet” (aroma only) and/or vinous (wine-like, rum, sherry). Solventy or glue-like in very high concentrations.

**Chemical Origin:** Produced by chemical reactions between oxoacids and alcohols or phenols, in a process called esterification. Ester precursors are produced as minor elements of yeast metabolism: Alcohol Acetyl Transferase (AAT) and Acetyl Coenzyme A (aCoA).

Type and character of esters produced depends on the exact chemical reaction. Perception thresholds vary depending on the exact molecule. Esters commonly found in beer include:

\* **Isoamyl Acetate:** Banana, pear, pear drops. Detectable at 1.0-2.0 mg/l. Part of the signature of German wheat beers.

\* **Ethyl Acetate:** Flowery, fruity, Juicy Fruit™. The most common ester in beer, produced by the esterification of ethanol. At high concentrations it can smell like nail polish remover, model paint or model glue. Detectable at 20-40 mg/l.

\* **Ethyl Hexanoate (AKA Ethyl Caproate):** Apple, banana, , brandy, fruity, “green,” pineapple, rum, sherry,

strawberry, “sweet” (aroma), wine-like. Detectable at 0.15-0.25 mg/l.

**Increased by:** Yeast strain. Wild yeast infection. Insufficient or excessive yeast growth. FAN/Amino Acid deficiency. Mineral (Zinc, Calcium, etc.) deficiency. Underpitching yeast. Low dissolved oxygen - low oxygen levels limits rate of yeast reproduction due to limited sterol in cells. Incorrect fermentation temperature for strain, especially high temperature fermentation. Aeration of green beer during growth phase of fermentation. High gravity wort. High ethanol concentration (>9%). Dehydration of yeast. Excessive trub.

**Decreased by:** Overpitching yeast. High dissolved oxygen. Incorrect fermentation temperature for strain (low fermentation temperature). CO<sub>2</sub> buildup in fermenter. Aging - esters are degraded by esterases produced by yeast; they are also volatile and will evaporate or degrade into other compounds over time.

**To Avoid or Control:** Choose appropriate yeast strain. Pitch correct amount of yeast (less for higher fusel levels, which translates into higher esters levels) at 0.5 to 1 quarts of yeast slurry per 5 gallons. Maintain proper fermentation temperature for strain (higher temperature means more fusel alcohols, meaning more esters). Match starter to wort gravity & temperature.

Adequately oxygenate wort after pitching yeast (O<sub>2</sub> is used by yeast to make unsaturated fatty acids, using up aCoA and increasing thickness of cell membranes, thus preventing ester formation). Don't aerate wort once fermentation starts. Proper separation of trub from wort. High-pressure fermentation decreases yeast growth, hence fusel precursors - it is used by some large lager breweries. Aging will decrease or eliminate esters (over the course of 1+ year).

**When Are Esters Appropriate?** Esters are expected low to medium concentrations in American ales and hybrid styles.

They can be present in low to high concentrations in Belgian, English & German Ales. Younger, fresher ales will have higher ester concentrations.

German wheat and rye beers are noted for isoamyl acetate (banana) esters.

Belgian ales often have for bubblegum, tutti-frutti, pineapple & “tropical fruit” notes.

## Phenols

**Detected In:** Appearance, Aroma, Flavor, Mouthfeel.

**Perceived As:** Antiseptic, Band-Aid™, bitter, burnt, Chloraseptic™, medicinal, oaky, peppery, plastic, roasted, scorched, smoky, spicy, tannic, tea-like, vanilla or woody. Some have an astringent, drying, numbing, peppery or puckering mouthfeel. Polyphenols can combine with proteins in beer to form chill (protein) haze.

**Chemical Origin:** Phenols are a large family of aromatic alcohols consisting of a benzene ring plus a hydroxyl group and side chains. There is genetic variation in the ability to detect certain phenolic compounds and some people are completely insensitive to them. Phenols are produced as minor metabolic products during yeast fermentation, especially by “Phenolic Off-Flavor Producing” (POF+) strains (e.g., Belgian and Hefeweizen strains, wild yeasts). Unlike esters or fusel alcohols, phenols are largely non-volatile and don't get converted into other compounds. This means that once they're in a beer, they tend to remain in it.

Common phenols found in beer are:

\* **Chlorophenols:** Phenols with a chlorine side chain. They have antiseptic, Band-Aid™, Chloraseptic™, medicinal and plastic flavors and aromas. Some have an astringent, drying, numbing or puckering mouthfeel. They are detectable at 1 - 5 ppb in water, 3-40 ppb in beer.

They are formed from chemical reactions between alcohol and chlorine-based sanitizers, chlorine/chloramines in brewing water, or water polluted with chlorine compounds.

\* **Monophenols:** Phenols with a hydrocarbon side chain. They have burnt, scorched or smoky flavors and aromas.

In brewing they occur as minor compounds during pyrolysis (heating material in the absence of oxygen), such as scorching wort/mash or smoking malt. An artificial source of monophenols is smoke flavoring.

\* **Polyphenols (Tannins):** These are phenols composed of two or more benzene rings. They have bitter, oaky or vanilla-like aromas and flavors. Most also have an astringent, drying or puckering mouthfeel. They commonly occur in woody or husky plant materials.

Polyphenols in beer are mainly extracted from grain husks due to improper grain milling, mashing or sparging technique, but they can also be extracted from water left to stand in contact with decaying plant material, or from hops. Herbs, spices and fruits can also impart polyphenols. Finally, beer aged in contact with wood will also pick distinct oaky or woody notes from polyphenols. With time, these compounds will react with alcohol to produce vanillin, imparting the flavor and aroma of vanilla.

Polyphenols can bind with suspended proteins in beer to form protein/chill haze. They can also form oxidized fusel alcohols if oxidized by hot-side aeration.

\* **Complex Aromatic Alcohols:** These are phenols with a multi-carbon and/or ester side chain. They are produced during yeast or bacterial metabolism by the decarboxylation of phenolic acids via enzymes. They are also found naturally in herbs and spices.

They have clove-like, medicinal, plastic, roasted, smoky or spicy notes. Some might have burning, drying, numbing or peppery mouthfeel. Phenolic compounds produced by brewers yeast usually include clove-like, spicy or peppery notes. Wild yeasts or bacteria can produce medicinal, plastic, roasted or smoky notes.

Common complex aromatic alcohols include:

\* **Capsicum:** Found naturally in chili peppers.

\* **4-Vinyl Guaiacol:** The most commonly produced phenolic compound by phenolic off-flavor producing strains of brewers yeast, especially German hefeweizen yeasts. It has a clove-like flavor and aroma. It is detectable at 40 ppb in water, 20 - 100 ppb in beer.

**To Avoid or Control:** Methods of controlling phenols depend on the exact family of compounds:

\* **Chlorophenols:** *To reduce or avoid:* Rinse brewing equipment/storage containers completely. Filter tap water to remove chloramines and chlorine. Let tap water sit overnight to remove chlorine. Add 1 Campden tablet per 20 gallons of water to remove chloramines. Avoid contaminated water (e.g., exposed to industrial pollutants, decaying vegetation, algae or bacterial contaminants).

\* **Monophenols:** *To reduce or avoid:* Reduce or eliminate smoked malt or flavoring. Avoid excess heat during mashing/wort boil. Use a “flame tamer” under direct-fired brewing equipment or used indirectly-heated equipment. Add

malt extract at lower temperatures and make sure it is thoroughly dissolved before bringing the wort kettle to a boil. Stir vigorously after adding extract to wort kettle to avoid scorching. Avoid excessively long boil times. Use proper technique when decoction/step mashing.

\* **Polyphenols:** *To reduce or avoid:* Don't over-crush grain. Avoid excessive sparging (stop runoff before it gets below 0.008 S.G.). Avoid collecting alkaline sparge (pH >5.8) liquor. Don't let mash-out or sparge liquor temperature exceed ~168 °F.

Avoid excessive amounts of hops; to get high IBU levels use a smaller amount of high alpha acid hops rather than a large quantity of low alpha acid hops. Avoid excessively long boil times (>2 hours) when making beer with a large amount of hops.

Don't heat fruit or grains in water above ~168 °F. Limit time that beer spends in contact with dry hops, fruit (especially fruit stems and husks), herbs and spices (time can range from weeks to months depending on the exact material). For wood-aged beers, reduce exposure to wood and/or increase aging time.

\* **Complex Phenolics:** *To increase:* Proper yeast strain (e.g., Belgian or hefeweizen yeast). Yeast mutation. Wild yeast infection, usually by *Saccharomyces Diastaticus* (medicinal, plastic, smoky notes). Underpitching. High temperature fermentation (above ~68 °F).

*To increase 4-vinyl Guaiacol:* Use a Ferulic acid rest during mashing (15 min. at 110 °F, at pH < 5.7). This liberates ferulic acid, the precursor to 4-vinyl guaiacol, which slightly aids in the production of clove flavor. Don't repitch hefeweizen yeast (4-vinyl guaiacol production is highest in the first generation).

*To reduce or avoid:* Proper yeast strain. Reduced fermentation temperature. Good sanitation procedures. Don't repitch yeasts for more than 5-10 generations from the original culture. Don't reculture weak, old or mutated yeast. Reduce or eliminate herb or spice additions.

**When Are Phenolic Notes Appropriate?:** Whether phenolic notes are appropriate in a beer depends on the type of phenol:

\* **Chlorophenols:** Off-flavors and aromas from chlorophenols are always a fault in beer.

\* **Monophenols:** Balanced, very low to high levels of roasted, smoky aromas and flavors from monophenols are appropriate in smoked beer, and are typically imparted by the use of smoked malt. Subtle smoky notes from restrained use of peat smoked malt are acceptable in Scotch Ale. Smoky or burnt notes are a fault in other styles of beer.

\* **Polyphenols:** Balanced low to strong polyphenol (woody, vanilla, oaky) character is expected in wood-aged beers. Subtle peat character is acceptable in Scotch Ale. Harsh or astringent notes are a fault in other styles of beer.

\* **Complex Phenolics:** Low to medium spicy and/or clove-like phenolic notes are expected in German Wheat and Rye beers, French and Belgian Ales and Strong Belgian Ales. Balanced herb and/or spice notes are expected in Spiced or Herbal beers.

## Solventy (Acetate/Fusel Alcohols)

**Detected In:** Appearance, aroma, flavor, mouthfeel.

**Perceived As:** High alcohol beer might have distinct alcoholic "legs" which become visible when the beer is swirled in the glass and then allowed to settle.

Fusel alcohols are described as being "hot," "harsh," solventy or spicy in flavor and aroma, while acetate can smell like nail polish remover, model paint or model airplane glue. Some fusel alcohols might have an initial sweetness, but a harsh aftertaste. They are detected in mouthfeel as burning, harsh, hot or prickly sensations.

**Chemical Origin:** Acetate and various fusel ("higher") alcohols are produced as minor respiratory byproducts during the metabolism of amino acids. Acetate and fusel alcohols can all react chemically with oxoacids to produce esters.

**Increased By:** Wild yeast infection. Underpitching. Mineral deficiency. Poor yeast health. Low dissolved oxygen. High gravity wort. High ethanol concentration (>9%). Incorrect fermentation temperature for strain (too high or low - especially too high). Dehydration of yeast. High levels of amino acids in wort.

**To Avoid or Control:** Proper yeast health. Correct pitching rates for wort gravity and style. Proper sanitation to avoid wild yeast infection. Proper fermentation temperature. CO<sub>2</sub> buildup in fermentor. Avoid over-modification during mashing, to avoid excessive levels of amino acids in wort.

**When Are Solventy Notes Appropriate?:** Detectable levels of higher alcohols are always a fault. They are likely to appear in strong beers, especially beers fermented at high temperatures (e.g., Belgian Strong Ales), but can also appear in poorly-made or inadequately aged Eisbocks.

## Vicinal Diketones (VKD) AKA Diacetyl

**Detected In:** Aroma, flavor, mouthfeel.

**Perceived As:** Butter, butterscotch, honey, toffee, vanilla. Oily or slick mouthfeel. Can give illusion of fuller body.

**Chemical Origin:** Vicinal diketones (VKD) consist of diacetyl & pentanedione. Since they are virtually indistinguishable by typical chemical tests, they are grouped together. Both are natural byproduct of fermentation. The highest concentrations are found in the initial stages of fermentation, during the reabsorbed by yeast in final phases of fermentation and are metabolized to relatively flavorless substances.

\* **Diacetyl:** Produced during fermentation as a byproduct of valine synthesis when yeast produces  $\alpha$ -acetolactate, which escapes the cell and is spontaneously decarboxylated into diacetyl. The yeast then absorbs the diacetyl, and reduces the ketone groups to form acetoin and 2,3-butanediol.

Diacetyl is typically detectable at 0.5 to 0.15 mg/l, although the ability to taste diacetyl is genetic. Some people can taste diacetyl down to 0.2 mg/l, while others are insensitive to it! It is described as tasting like artificial butter, butter, butterscotch, toffee or vanilla.

\* **Pentanedione:** 2,3- pentanedione is produced during fermentation as a byproduct of isoleucine synthesis when yeast produces  $\alpha$ -ketobutyrate, which escapes the cell and is spontaneously decarboxylated into 2,3- pentanedione. The yeast then absorbs the 2,3- pentanedione and reduces the ketone groups to form relatively flavorless compounds.

Compared to diacetyl, pentanedione is much less important, since the perception threshold is 10 times higher than that of diacetyl and most yeast strains produce far less

pentanedione than diacetyl. It is detectable at 0.90 mg/l. It is detectable in aroma and flavor as honey or honey-like perfume.

**Increased By:** Yeast strain selection - some produce more VKDs, especially those which flocculate well and those which produce respiratory-deficient mutants. Wild yeast infection (bacterial contamination can produce high levels of 2,3-pentanedione). Insufficient or excessive yeast growth. Yeast mutation. Reusing yeast collected too early in previous fermentation cycle.

Poor yeast health (e.g., Mineral deficiency, overpitching, low dissolved oxygen, high gravity wort, >9% ethanol concentration, delayed yeast collection, insufficient cooling of fermentor cone, incomplete mixing in fermentor, excessively high or low pH). FAN/Amino Acid deficiency, especially insufficient levels of valine in wort (needed for diacetyl reduction). Underpitching yeast. Aeration of green beer after yeast growth phase. Slow/weak fermentation. Incomplete mixing in fermentor.

Dehydration of yeast. Incorrect fermentation temperature for strain, especially low temperature fermentation. Swings in fermentation temperature. Insufficient fermentation time. Prematurely removing yeast from the wort (e.g., filtering, fining, reducing fermentation temperature).

*Pediococcus Damnosus* infection produces large amounts of diacetyl, which isn't reduced with time. *Lactobacillus* infection during storage.

**Decreased By:** CO<sub>2</sub> buildup in fermentor. Keep adjuncts low (<40%) or add yeast nutrient. Use good quality malt extract (with good nitrogen and amino acid composition). Aerate wort well after pitching yeast. Use yeast starter (at least 0.5 quart per 5 gallons for ale, more for lager and high gravity beers).

Use a "diacetyl rest" at ~50 ° F for 1-3 days at end of lagering period. Use optimum fermentation temperature for yeast strain (not too cold). Use good quality moderately flocculating yeast, which is not susceptible to mutation or contaminated by wild yeast. Allow fermentation/diacetyl reduction to finish before racking off, lowering temperature or adding finings. Sufficiently age beer on yeast (rouse yeast if necessary, while avoiding aeration). Minimize aeration during transfer. Use good sanitization practices to avoid bacterial infection.

**When Are VKDs Appropriate?:** Low levels of diacetyl are acceptable in Bohemian Pilsner, English Pale Ales, Scottish Ales, English Brown Ales, Brown Porters, Robust Porters, Sweet Stouts, Oatmeal Stouts, Foreign/Extra Stouts, English IPA and Strong Ales. They are a fault in other styles of beer, especially most lagers.

Low (sub-threshold) levels of diacetyl can give the illusion of richness or body in any beer style, although this is undesirable in thin-bodied beers.

## Inspirational Reading

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