

# A Homebrewer's Guide to Beer Flavor Descriptors

Compiled by the editorial staff of **zymurgy** magazine to help guide and assist brewers in identifying some of the more common desirable and undesirable characteristics found in beer.

- 34 **Acetaldehyde**, by George J. Fix, Ph.D.
- 34 **Alcoholic**, by Terence Foster, Ph.D.
- 35 **Astringent**, by Greg Noonan
- 36 **Carbonation**, by Grosvenor Merle-Smith
- 37 **Cooked Vegetable**, By Kathryn Word
- 38 **Diacetyl**, by Norman Soine
- 39 **Dimethyl Sulfide (DMS)**, by Norman Soine
- 40 **Fruity-Estery**, by David Logsdon
- 41 **Grassy**, by George J. Fix, Ph.D.
- 41 **Husky-Grainy**, by Greg Noonan
- 42 **Light-struck (Skunky)**, by Fred Eckhardt
- 43 **Metallic**, by Rao Palamand
- 45 **Moldy**, by Greg Noonan
- 45 **Nutty**, by Fred Eckhardt
- 46 **Oxidation**, by Dave Schroedl
- 46 **Phenols**, by George J. Fix, Ph.D.
- 48 **Salty**, by Fred Eckhardt
- 48 **Solventlike**, by Terence Foster, Ph.D.
- 49 **Sour-Acidic**, by David Logsdon
- 50 **Sulfury-Yeasty**, by Earl Van Engel
- 52 **Sweet**, by Fred Eckhardt

ALL ILLUSTRATIONS IN THIS SECTION BY MARK HESS

# Acetaldehyde

By George J. Fix

Acetaldehyde is a constituent characteristic of young beer. It has a flavor that recalls freshly cut green apples. It is also a potential oxidation product, where it will have an acetic-cider tone. It can be perceived in both taste and smell, and there should be no discrepancy between the two.

Acetaldehyde is a natural fermentation product and a precursor to ethanol via the anaerobic cycle:

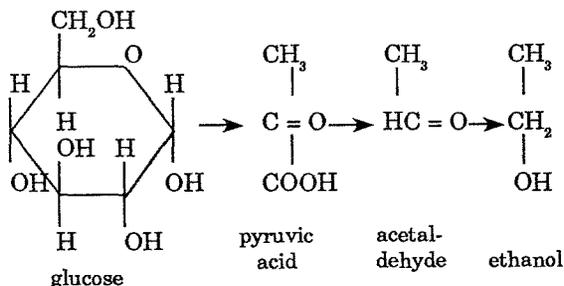
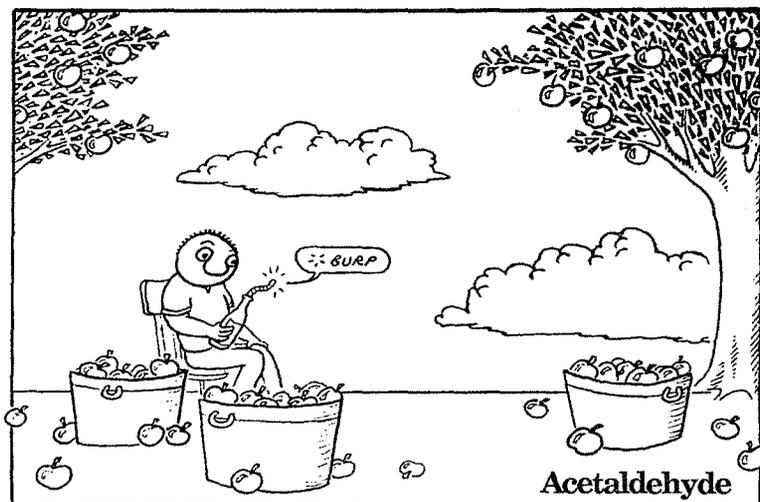


Figure 1

Thus in a normal fermentation the acetaldehyde level will rise, typically well above its flavor



threshold of 10 ppm, and then decrease as it is converted to ethanol. Observe that this transformation is one of reduction in the sense that the alcohol gains two H<sup>+</sup> atoms as the aldehyde is reduced.

The reverse reaction can also take place, one

where ethanol is oxidized to acetaldehyde. Usually acetic acid also is formed via:

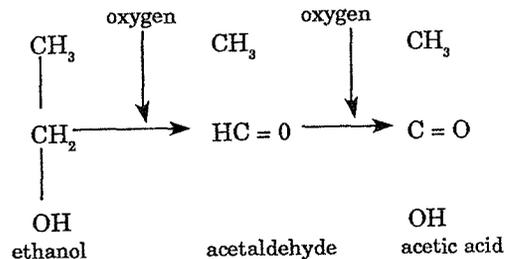


Figure 2

This is where acetic-cider tones can arise. This adverse reaction is stimulated by the presence of oxygen, and also various bacteria can promote it.

Acetaldehyde produced via that anaerobic cycle tends to impart fresh fruity flavors. A good example is Budweiser, in which acetaldehyde levels generally fall in the range 6 to 8 ppm. This is in contrast to most U.S. commercial beers, where the levels are typically below 5 ppm, and hence ones where acetaldehyde is an insignificant tertiary beer constituent.

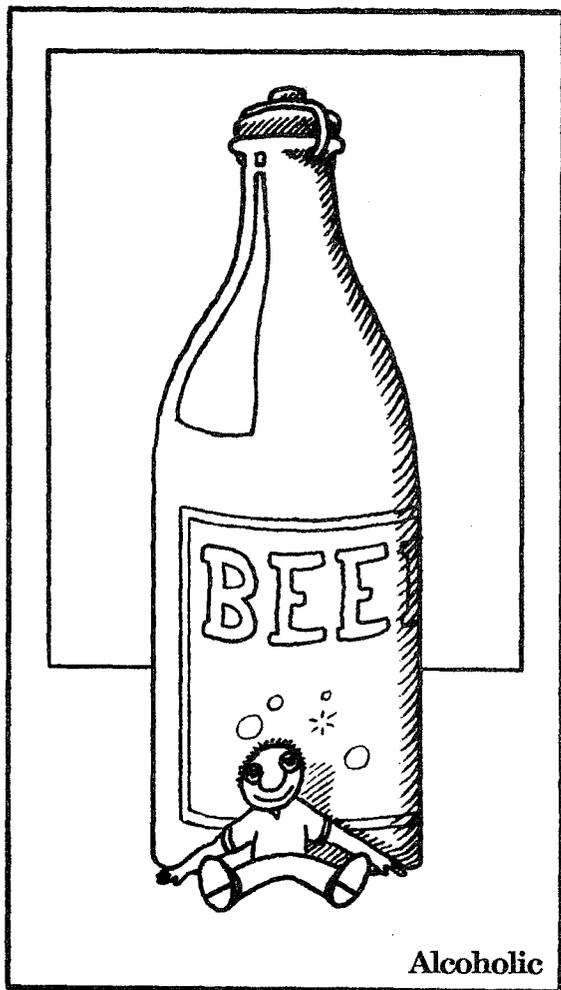
Apparently in Budweiser the acetaldehyde and various esters synergistically produce the snappy, fruity flavor tones characteristic of this beer. Acetaldehyde produced by bacteria or oxidation, on the other hand, tends to be less pleasant.

In the absence of bacterial infection and inappropriate oxygen uptake, acetaldehyde forms what is often called a "spill-over" product. That is, its level depends more on fermentation conditions than on the type of yeast used. For example, Budweiser is kraeusened after the primary fermentation and is given only a brief cold storage. Thus more acetaldehyde tends to "spill over" into the final product than normal. Extensively aged beers, for example Salvator and EKV-28, typically have acetaldehyde levels that rarely exceed 2 ppm. The long, cold storage allows for a more or less complete reduction of acetaldehyde to ethanol, and is the best way to reduce its level, if this is desired.

## Alcoholic

By Terence Foster, PhD

This is a hot, slightly spicy flavor, detected in the nose as a pleasingly fragrant, vinous aroma, and in the mouth mainly by a pleasant warmth on the middle of the tongue. In high-alcohol beers,



the vinous character may be very pronounced, and the warm taste may linger on the tongue and in the back of the throat.

Ethanol, of course, is an important source of alcoholic flavor, but higher alcohols, such as propanol, butanol, isoamyl alcohol, etc., may be even more important. Although present in much smaller amounts than ethanol, they are more aromatic and more strongly flavored than ethanol, and make a big contribution to the vinous character of strong beers.

All of these compounds are produced in the fermentation of wort sugars by yeast. Ethanol, of course, along with carbon dioxide, is the main product of fermentation. The higher alcohols, collectively called fusel oils, are really byproducts, although they are produced by reaction pathways similar to those responsible for ethanol production. Increased levels of fusel oils are obtained when fermentation temperatures are high, when yeast growth is excessive, when high levels of amino acids are present in the wort, or when ethanol levels are high.

The threshold limit for ethanol is fairly high, at 14 parts per thousand, but this is obviously much lower than the concentration normally pres-

ent in beer. Threshold levels for the higher alcohols are much lower, ranging from 1.5 parts per thousand for isopropanol, down to less than 100 parts per million for isoamyl alcohol. Further, individual higher alcohols may be present below their threshold values, but their collective effects may still be detectable.

Naturally, alcoholic flavors are very desirable in beer! However, the desirable level depends on the particular beer style. Ethanol levels, of say 6 percent, are definitely not suitable in mild ales, for example. Higher alcohols should not normally be detected in light lagers and Pilseners. These fusel oils are generally more desirable in ales than in lagers, although they should be clearly detectable in bock beers, and especially barley wines, which are beers characterized by the vinous complexity conferred by high alcohol contents.

The amount of ethanol, and hence its flavor contribution, is determined by the total amount of fermentable material in the wort. Simply select the original gravity to the proper range for the style of beer you are brewing, and the ethanol level will be correct, providing your yeast is healthy. Finishing gravities should be about one-quarter of the starting gravity; if you cannot get this low, there is something wrong with your yeast, and you should use a fresh sample.

If you get down much lower than one-quarter gravity, you are either using too low a malt-to-sugar ratio, or you have a wild yeast present in your brew. If the former, use less sugar next time. If the latter, throw the beer away, thoroughly sanitize your equipment and use a fresh yeast next time.

## Astringent

By Greg Noonan

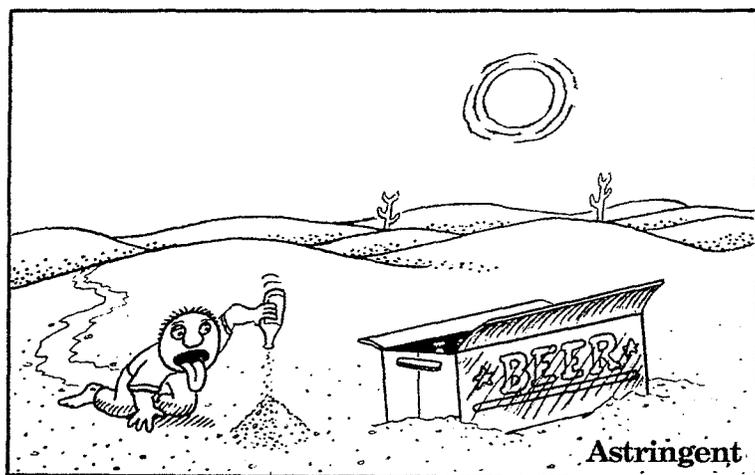
Bitterness is one of the primary flavor characteristics of beer. Astringency, on the other hand, is entirely undesirable in any beer.

Bitterness is perceived by stimulation of specific taste receptors below and on the back of the tongue, and in the aftertaste. Astringency stimulates free nerve endings throughout the oral cavity. It is perceived as mouth feel rather than flavor, and is more closely related to pungent, alkaline, mouth-coating metallic and powdery sensations than it is to bitterness. Astringency is not found in a beer's aroma, but in the drinking and the aftertaste.

Astringency does not mean either sourness or

tartness that is pleasant. It is a mouth-puckering, dry, membrane-contracting sensation. It may be strongly tannic, vinegarish or intensely tart. Un-ripe fruit and chewed grape skins give astringent reactions. The intensely acidic taste can be experienced by any brewer willing to sample the trub scum thrown up by a kraeusen fermentation head.

Bacterial contamination of the fermentation or aging beer can cause astringency, usually with the vinegar flavor indicative of acetic-acid bacte-



rial activity, or a fruity odor. Lactic-acid bacteria that are the cause generally form a detectable rancid-butter diacetyl smell. Contaminant-originated sourness is usually distinguishable by accompanying off-flavors or odors.

More commonly, astringency is a symptom of ill-considered formulation or processing. Worts that lack unfermentable sugars have no balancing maltiness or sweetness to mask astringency. When astringency is from the hops, it is always more noticeable in pale, dry beers than in richer, sweeter types. Excessive hopping will always give polyphenolic-anthocyanogenic astringency in overattenuated brews.

Poor separation of the trub from any fermenting beer should be suspect whenever astringency is encountered. The brown scum thrown up during vigorous fermentation is largely composed of intensely bitter phenolic hop and malt-husk residues. These may be reabsorbed by the fermenting beer if they are not in some manner separated from it. Separation may be done by simply letting it stick to the top of an oversized fermenter, or by removing it by skimming, or "blowing off."

Dry, husky bitterness in grain-brewed beers is usually the result of overzealous crushing. Torn,

shredded husks cause melanoidin and phenolic astringency. Less readily pinpointed astringency may be caused by alkaline mash or sparge water, or very excessive sparging. Again, very dry, lingering astringency on the roof of the mouth and in the throat suggests this source.

Where astringency is encountered, review the beer's flavor profile and its brewing. If it seems to originate by a faulty process, use accompanying clues to determine its origin.

## Carbonation

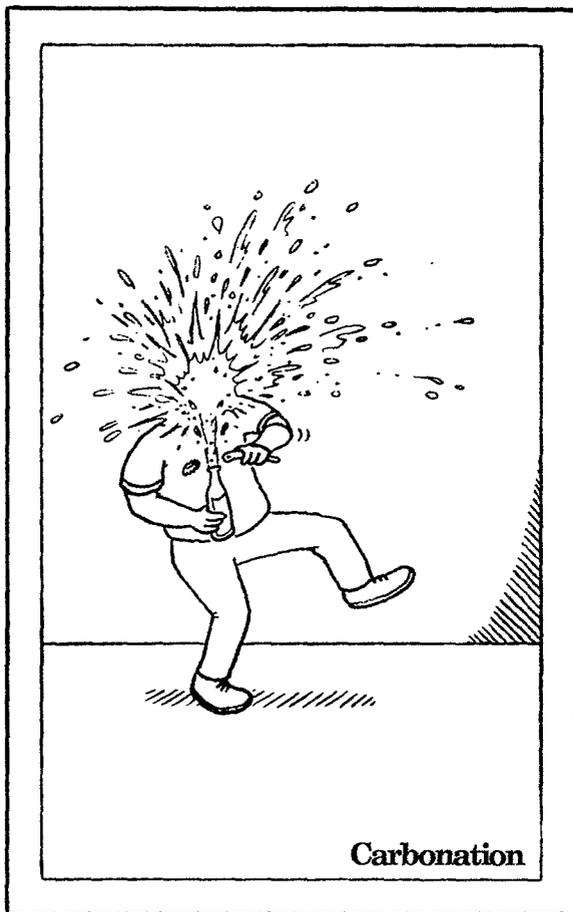
By Grosvenor Merle-Smith

Carbonation is literally the breath of life, for a flat beer is a dead beer. Visually our drink becomes more exciting with bubbles trailing up through the beer to the surface, forming a luscious creamy head. Raising the glass, we find that this release of carbon dioxide carries with it a barrage of volatile aromatics. Even before tasting we are given an exciting preview of what is to come. Now in the mouth, bubbles titillate the palate, enhancing the flavor sensation and making the experience more refreshing.

Beer is somewhat carbonated after a normal non-pressurized fermentation. As homebrewers usually we wait, allowing the beer to go flat, insuring a consistent point at which we can add a certain amount of ingredients to result in carbonation. Before kegging or bottling, the brew is primed with more fermentable sugars creating a carbonation pressure in the final product of approximately 2 1/2 atmospheres.

In serving, we would like the beer, once the initial excess pressure is released, to lose the CO<sub>2</sub> at a slow rate, creating a sparkle in the body while maintaining an appropriate head. There are a number of factors involved in accomplishing this. First, let's make the assumption that the beer has been primed with the correct amount of sugars to give the desired carbonation initially. Obviously, too little will result in a flat product, while too much results in overcarbonation.

When a beer is tapped or opened, the ambient pressure is lowered and the CO<sub>2</sub> starts to come out of solution. Bubbles form and rise to the surface, where they float and create a head. Smaller bubbles initially coming out of solution tend to



bleed off the CO<sub>2</sub> more slowly and produce a finer, more lasting head.

High-molecular-weight proteins are predominately responsible for this effect. The fundamental source of these large proteins is malt; therefore, this is one reason recipes with a higher percentage of malt will tend to have smoother, creamier heads.

Another source is isohumulones, the bitter, water-soluble isomerized alpha acids created by boiling hops. Isohumulones create a strong clinging or lacing effect in the head. Wheat malt and unmalted adjuncts also are rich in high-molecular-weight proteins, while overmodified, such as English 2-row, or underkilned malts are low. It follows that extended enzymic molecular breakdown during mashing will contribute to a poorer head.

Nitrogen is another important contributor to small bubbles and a creamy head. It readily forms complex compounds called proteoses that, when not combined with polyphenols, contribute in much the same way as the high-molecular-weight proteins to the bubble and foam quality.

Nitrogen is available in the wort through the organic compounds used to create it; principally malts. Boiling the wort, while producing isohumulones, will deplete the nitrogen. Some brewers, notably draft Guinness, will actually "carbonate" using some nitrogen. Homebrewers can make very

small bubbles in their beer when kegging by tapping and nitrogenizing.

Theoretically, we now should have a nicely carbonated beer with a long-lasting creamy head. The recipe is of a low refined sugar to high malt ratio with significant hops. Bubbles, however, lead a tentative existence and once formed may be devastated by a number of things.

Cleaning agents, oils and grease can destroy foam-stabilizing compounds. Incorrect handling either during brewing or serving is the most obvious way to introduce these substances. Old degenerating or autolyzed yeast will release fatty acids. Malt fats are drawn out of a mash by over-sparging with the final runnings reducing head retention.

Other observations have been made regarding carbonation and foam stability. Elevated volume of higher alcohols will reduce head stability, as will an excessively rapid fermentation. Homebrewers should be conscious of appropriate fermentation temperatures which can enhance rapid fermentation.

What about gushing? Well, the assumption still is that the beer is correctly carbonated. A number of factors contribute to gushing. Wet-harvested barleys create a compound called fusarium during the malting process that is instrumental in provoking some gushing problems. Homebrewers can be the recipients of such products.

Excess iron or precipitates of excess salts, such as calcium oxalate, will promote gushing. Certain isomerized hop extracts provoke gushing even though hops generally have antigushing qualities. For the most part, gushing problems for the homebrewer are the result of bacterial contamination and/or certain oxidation products. Excess gasses are produced in conjunction with the breakdown of foam-stabilizing compounds.

## Cooked Vegetables

By Kathryn Word

Cooked vegetable flavor is an unfavorable characteristic in beer. It is often more specifically described as cooked corn, cooked cabbage or cooked broccoli. This flavor should be carefully distinguished from a rotten vegetable note that indicates

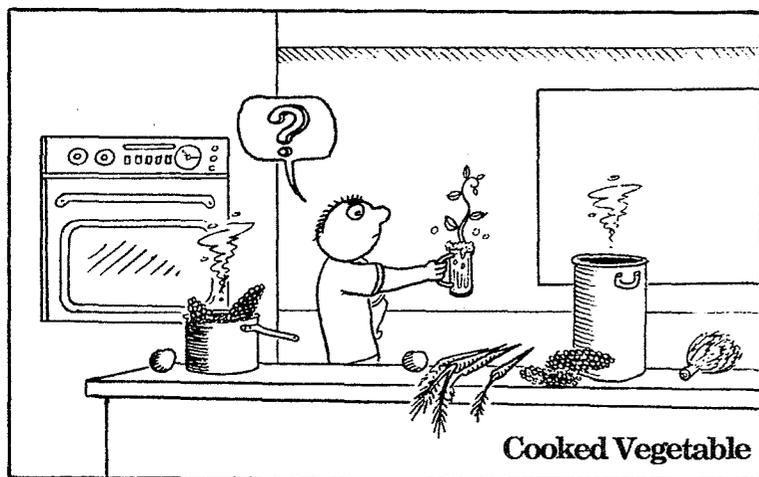
oxidation, or a fresh, raw vegetable character which is a pleasant flavor attributed to hops.

Cooked vegetable flavor is caused by sulfur-containing compounds. It is primarily perceived by aroma and to a lesser extent by taste.

In his comprehensive review of the threshold of flavor components of beer, M. Meilgaard identified three compounds that cause a cooked vegetable flavor. These compounds and their threshold value in beer are diethyl sulfide, 1.2 ppb; dimethyl sulfide, 50 ppb; di-isopropyl sulfide, 20 ppb.

It is important to point out that the threshold values of these compounds are very low, indicating that the presence of only a very small amount would cause a flavor effect.

A primary source of cooked vegetable flavor is the malt or malt extract used in brewing. Variations in the malting process may enhance the development of this flavor. Homebrewers who are



experiencing difficulty with this cooked vegetable flavor may find the simplest method of corrective action is simply to use a high-quality brand of extract. If the flavor persists, brewing process modifications may be necessary. A longer wort boil may eliminate the sulfur compounds by volatilization.

Bacteria may also produce sulfur compounds responsible for cooked vegetable flavor. Wort infection may be a source of such bacteria. Bacterial contamination in yeast is another source. The practice of using yeast several times may introduce bacteria and cause eventual flavor degradation. Using a pure yeast strain and brewing practices that ensure sterility are useful steps to eliminate the development of cooked vegetable flavor in beer.

## Diacetyl

By Norman Soine

Diacetyl, one of a class of organic compounds known as vicinal diketones, is an essential flavor component of beer. Most tasters can detect levels in excess of 0.15 ppm in most types of products, but it can be recognized as low as 0.05 ppm in delicately flavored pale lagers where its presence is unmasked by the absence of highly flavored components such as melanoidins.

Diacetyl is recognized by a butter to butter-scotch flavor often accompanied by a sensation of "slickness" on the palate. Although opinion varies, most people agree that low levels (0.1 ppm or less) contribute to a fullness of character in the beer.

Diacetyl in beers can be generated in two ways: by yeast, as a normal fermentation byproduct, and by beer-spoilage bacterial infection.

Yeast produces diacetyl from sugars via pyruvate and acetolactate metabolic formations. Diacetyl is produced in large quantities, often exceeding 0.5 ppm, during the early stages of fermentation. As the fermentation progresses, the yeast assimilates the diacetyl, converting it metabolically to acetoin and finally 2,3-butanediol, a compound with a high flavor threshold.

Fermentation conditions that influence diacetyl production and reduction by yeast include yeast strain, wort composition, and most importantly, temperature, storage time and amount of yeast in suspension.

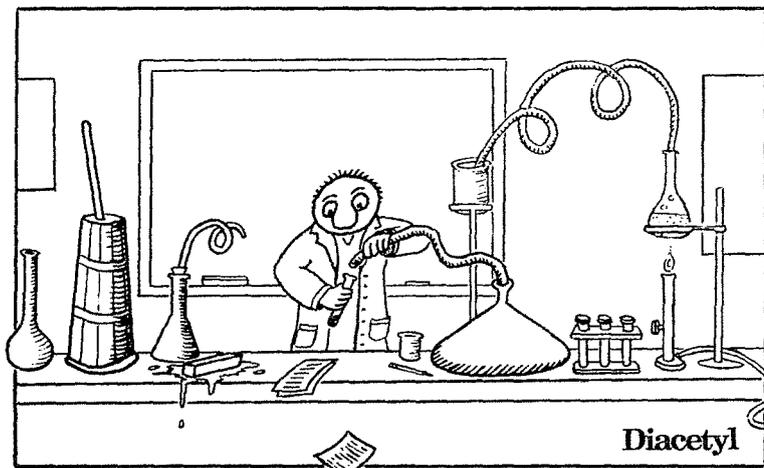
Extended warmer temperatures during fermentations tend to reduce diacetyl. Ales, being fermented at elevated temperatures, are less apt to be affected by yeast-produced diacetyl.

Worts with high adjunct ratios of sugar, unmalted grains, grits, starches, etc., tend to produce higher diacetyl levels.

The genetically inherited flocculation characteristics of yeast strains and the influence of wort constituents (such as calcium magnesium and sodium ion concentrations, presence of active, fermentable sugar-generating enzymes, available nitrogen levels) as they affect the flocculation characteristics can also affect diacetyl removal.

Early fermentation cooling, especially when coupled with post-primary fermentation fining, can result in higher diacetyl levels by virtue of reduced contact of beer with rapidly sedimenting yeast.

Agitated fermentations decrease diacetyl rapidly by inducing increased surface area contact



with what may otherwise be sedimented yeast.

Krausening the beer upon transfer to storage (10 to 15 percent of 8 degree Plato green beer, OE 12 degree Plato) among its other benefits provides fermented beer with active yeast in suspension, effectively reducing diacetyl levels.

It should be noted that agitated fermentations and krausening can lead to the development of a slight appley or cidery acetaldehyde character.

The prime bacteriological generator of diacetyl is the beer-spoilage organism *Pediococcus damnosus*. Some subspecies of *Lactobacillus* also have been found to be producers. *Pediococcus* (formerly known as *sarcina*) seems to grow most rapidly during the later stages of fermentation, but can be found in storage and finishing beer as well. The organism appears to favor co-location with sedimented yeast, which can result in extended product infection should contaminated yeast be collected and used for subsequent pitching.

There is no remedy for treating beer infected with viable diacetyl-producing bacteria. Previously mentioned concepts in diacetyl control and reduction can be successfully applied when one is mindful of the following.

In general, most homebrewers do not employ sophisticated fermenter attemperation devices or techniques, but rather allow ambient conditions to prevail. This usually results in higher fermentation temperatures, which in turn favor not only production but assimilation of diacetyl by the yeast. Hence, very low diacetyl levels at the conclusion of primary fermentation should result.

A yeast-generated diacetyl presence can still develop, however, through ill-timed post-primary fermentation product processing. The yeast cannot be allowed to again produce diacetyl and then be removed from suspension so rapidly that subsequent assimilation is impaired. Therefore, avoid conditions where yeast is provided with both stimuli for activity (aeration, food—primings, wort, krausen) and immediate rapid removal from suspension (finings addition, rapid chilling).

*Pediococcus* and *Lactobacillus* infections may be prevented by thorough cleaning and sanitizing of brewing equipment and work areas with special attention given to yeast storage-related items.

Differentiation between yeast and bacteria-generated diacetyl presences is not easy for the homebrewer who lacks both

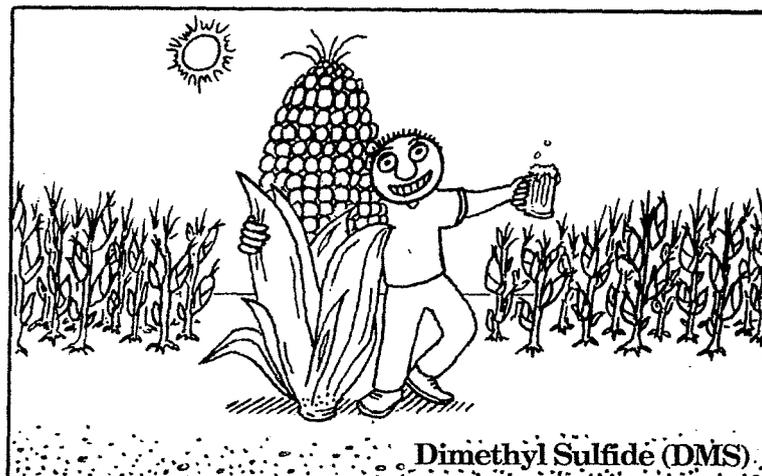
microscope and the ability to conduct plate culture evaluations. Use yeast sources assured to be free of spoilage organism contaminants, or simple yeast washing, as outlined in the following DMS monograph should be helpful.

## Dimethyl Sulfide(DMS)

By Norman Soine

Dimethyl sulfide is a volatile sulfur-based organic compound which, when present in excessive amounts, contributes to beer a flavor and aroma varying slightly in character with intensity from cooked corn, celery or parsniplike to almost shellfish or oysterlike in high concentrations. Generally found in very low (parts per billion) amounts, this flavor component is usually first perceived in beverage aroma, the threshold being about 30 ppb.

Levels of perception will vary with individuals but its presence in larger quantities gives an im-



pression of what most would characterize as an off-aroma or off-flavor. It is often found to be one of the subtle components of what is referred to as "Hausgeschmack" or house character, in which case all products produced by a brewer will contain traces of the compound. This, in turn, indicates a consistency of source.

The presence of this compound in beer can stem from two sources: bacterial infection of wort, and/or inefficient elimination or inadvertent entrainment of normally occurring DMS during beer processing.

The major source of high levels of DMS is usually attributable to the presence of an infecting bacteria *Obesumbacterium Proteus*, commonly referred to as "wort bacteria." This organism, which generates DMS as a metabolic byproduct, is sometimes found either in inadequately sanitized wort receivers or fermenters and associated transfer lines, pumps, sight glasses and CO<sub>2</sub> collection lines, or in trub mixed with, and infecting, collected yeast that is to be subsequently repitched.

Prime conditions for the bacteria's activity exist during the very earliest stages of fermentation where the pitched wort pH is greater than 4.5. Conditions such as low pitch rate or long yeast lag-phase can allow substantial growth resulting in the development of significant amounts of DMS.

The second likely source of DMS character in finished beer is related to process. DMS is normally found in the brewing process by virtue of the presence of its precursor, S-methyl methionine, an amino acid type, in malt. S-methyl methionine (SMM) is enzymatically formed in grain during the germination process.

During kilning of green malt some SMM is hydrolyzed into DMS (most of which is lost by evaporation) and homoserine (HS), an amino acid. A portion of DMS is oxidized to dimethyl sulfoxide (DMSO). During the mashing process more SMM is hydrolyzed to DMS and HS with a small portion of DMS being oxidized to DMSO. During kettle boil the majority of DMS present plus most generated by continued SMM hydrolysis is lost due to evaporation. Again, a portion of residual DMS is oxidized to DMSO. In the fermentation stage DMSO is reduced to DMS by the yeast, and virtually all DMS, from both SMM hydrolysis and DMSO reduction, is purged from the fermenting beer by CO<sub>2</sub> evolution leaving only trace amounts generally below 50 ppb. In systems where CO<sub>2</sub> is collected for reuse to produce carbonation, and where CO<sub>2</sub> scrubbing and deodorizing systems are either inadequate or inefficient, CO<sub>2</sub>-borne DMS

(and other volatiles) can be introduced into what would otherwise be a very acceptable product.

For the homebrewer, DMS can be avoided in a number of ways. First, clean and sanitize all brewing equipment thoroughly. Clean and sanitize any work areas that have received wort spillage. Boil wort for a minimum of one hour, especially if canned extracts are used. If one collects yeast for repitching and wishes to destroy any suspected bacteriological infection, one may elect to wash the yeast.

Do this by reducing the pH of a magnetically stirred, ice-water bath cooled beaker of yeast slurry to 2.2 with the dropwise addition of food-grade concentrated phosphoric acid. (*NOTE: This is a strong acid. Care in handling and use of proper personal protective equipment, including gloves, face shield and/or safety glasses is essential.*) Maintain this pH for at least three hours but no more than four hours. Do this procedure immediately prior to pitching so that yeast viability is not impaired. The obvious alternative is to not use any yeast suspected to be bacteriologically infected.

Reduce yeast lag times by premixing yeast with retained wort (try making a brew ahead of time and freezing the wort in one-quart plastic containers) and thoroughly aerating one day in advance to bring the yeast to an active condition by pitching time. Remember that the earlier the fermenting wort pH drops below 4.5, the more protected it will be from the influence of wort bacteria, if present.

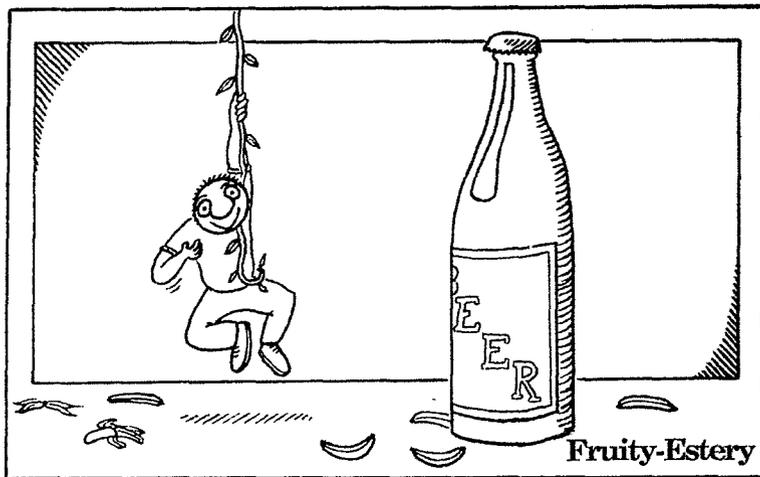
Corrective and preventative treatment of CO<sub>2</sub> scrubbing procedures are not discussed here because such activities are generally found only in commercial breweries and are beyond the scope of most homebrewing efforts.

## Fruity-Estery

By David Logsdon

Esters formed in beer are aromatic compounds identified as fruity and estery at high levels. At lower levels, esters become part of the overall flavor profile. Esters are highly aromatic and the aroma is sometimes identified as bananalike or grapefruity.

Esters are developed in different ways. Some yeast strains produce more esters than others, and



higher pitching rates produce more esters. High amounts of aeration at the beginning of fermentation produces more esters. The fermentation temperature also affects ester formation. The higher the fermentation temperature, the greater the ester formation. High-gravity beers generally have more ester formation.

Nearly 100 esters can be identified in beer. Ethyl acetate is an ester commonly found in beer. Also, isoamyl acetate, 2-phenyl and isobutyl can be found at various levels.

The taste thresholds vary with different esters. Ethyl acetate at 30 ppm could be considered the likely threshold for most people.

The contribution of esters to beer is important. Depending on the type and style of beer, more or less ester formation is desired. Generally, drier, lighter beers are lower in ester formation, and richer, sweeter beers have higher levels.

The amount of ester formation in beer can be controlled. Temperatures during fermentation are crucial. Ales fermented in the low sixties should be low in ester formation and high if fermented in mid-seventies or higher. Lagers fermented at fifty degrees or lower should have low ester formation.

## Grassy

By George J. Fix

Flavor tones reminiscent of freshly cut grass have been detected in beer, although their presence is not very common. They are best detected by their unmistakable aroma.

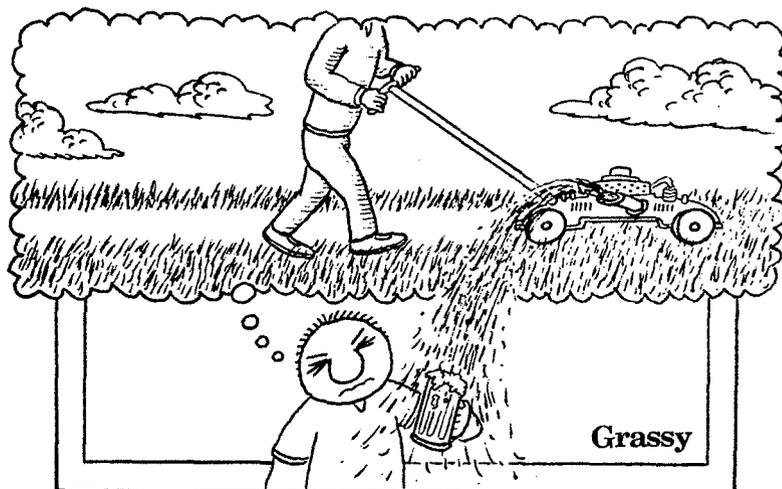
Barley is a member of the grass family, and thus it is not surprising that grassy flavor tones can arise from grains. Because this effect is uncommon it has not been given much attention. Nevertheless, it clearly arises from unfavorable

metabolic activity of various microorganisms and high moisture malt.

Musty smells will be detected in the malt. Various compounds are most likely involved, but the most important is the aldehyde called Hexenal (more precisely *cis*-3-Hexenal). Its flavor threshold is low — approximately .02 ppm. It is

sometimes called the “true leaf aldehyde” because of its flavor characteristics.

Grassy tones are unfavorable and reflect careless brewing practices.



The best practical measure for avoiding grassy flavors involves the proper storage of malt, which, like hops, is a perishable product. High temperatures and humid conditions should be avoided. Malt, given time, will absorb moisture until it reaches an equilibrium with its environment. Malt that has been ground will do this very quickly, and is very hard to store without deterioration taking place.

## Husky/Grainy

By Greg Noonan

Huskiness and graininess are among the potential flavors that malt and cereal adjuncts can contribute to beer. Grain flavors may constitute

part of the flavor band of a given beer and be in harmony with its overall flavor. A grain note in a beer is not necessarily a defect. The flavor is often detectable in commercial beers brewed with a high corn-adjunct content. Huskiness, on the other hand, is harsher, unpleasant and always a flavor defect.

Both huskiness and graininess are more likely to be perceived by tasting than by a beer's aroma bouquet, although staling beer often has a grainy smell. Grainlike flavors in a spoiled beer are usually masked by cardboard and papery tastes.

Both grainy and husky flavors can be sampled by tasting pale malt. Following with crystal or caramel malt points them up even more. The highly kilned, essentially saccharified malts have less raw-grain character than is experienced in the chewing of brewer's malt. The longer it is chewed, the more the initial flourlike and cereal flavors give way to drier, bitter, mouth-coating huskiness.

Huskiness is even more evident in the taste of the spent grains after sparging. It is a flavor that the taster will recognize ever after, and one that no brewer would want in the beer.

Extract brewers do not face these flavor problems so long as they brew with good-quality, reasonably fresh products. Grainy and husky flavors are more often hazards encountered by grain brewers. Quality control problems in malt crushing, mashing and sparging-lautering may give rise

to both flavors in a finished brew.

Homebrewers who mash commonly employ Corona-type grain mills. These require a grinding setting that judiciously balances a reasonably fine grist against severe shredding of the hulls. Tearing the husks is inevitable with such mills. It must, however, be minimized or husky flavors will mar the beer flavor.

Grossly inadequate crushing, on the other hand, leaves grits too large to be converted by amylolysis in the mash. These are at risk of subsequent decomposition that causes starchy,

floury flavors and premature staling.

Cereal flavors may also develop as a result of mash procedures. Carelessness during the wetting of the grist can cause starch to ball. The resulting complex polysaccharide balls can pass through saccharification unconverted and give similarly starchy results. Likewise, inadequate starch conversion caused by improper strike temperature, poor temperature dispersal or grossly improper pH will cause graininess in beer.

Grain flavor in a malty beer may not be objectionable. Graininess seldom dominates a beer's flavor profile, and tends to be less a problem for grain brewers than huskiness.

Husky flavors may not be caused only by overzealous crushing. Wherever a mash is direct-fired and grist is allowed to burn on the heated surface, harsh tannins will be leached into the extract. Decoctions are especially susceptible to this problem from the point at which heating is begun until boiling ensues. Decoction mashing generally extracts more husk fractions than other mashing techniques. With care, this need not cause a problem, however.

Mash and sparge water pH are more common causes of huskiness in all-grain homebrew. The more alkaline the pH, the more harsh and haze-forming polyphenols that will be leached from the husks. These oxidize during fermentation and aging to strongly astringent tannins.

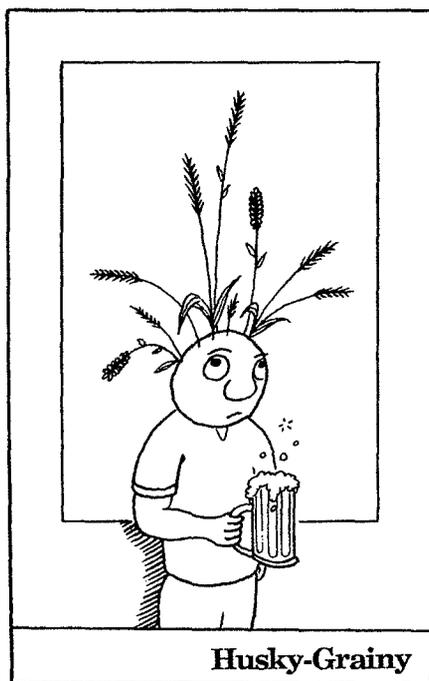
Where huskiness is detected in a brew, mash and lauter runoff pH should be monitored. Sparging should cease, or the sparge water be treated with calcium sulfate, whenever the runoff pH rises above pH 6.

Huskiness can usually be controlled by proper crushing of the malt, and by maintaining mash and sparge-water acidity within the acceptable pH range.

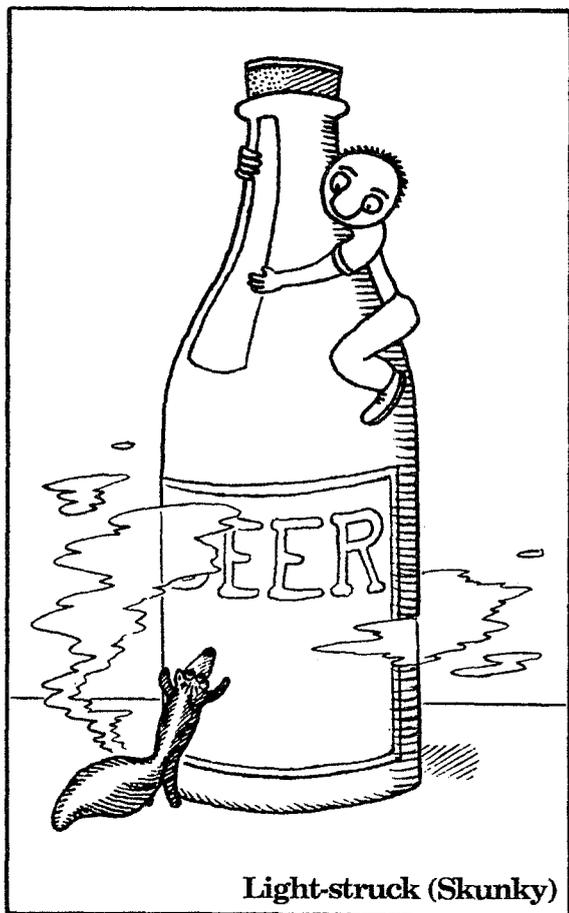
## Light-Struck

By Fred Eckhardt

Light-struck is an olfactory-based taste perception, having the characteristic smell of a skunk. It is in the sulfury area of the taste classifications. The major constituent is the sulfur compound, 3-methyl-2-butene-1-thiol. George Fix tells me the threshold "has been variously rated at 0.1 to 1.0 ppb. Dr. Morton Mielgaard, a pioneer who has



Husky-Grainy



**Light-struck (Skunky)**

done much research in the field of beer flavor, feels that all thiol measurements are suspect, and its threshold could be lower than rated. It does have powerful flavors.”

The light-struck or sun-struck flavor also is related, in some cases, to the hoppiness, especially in those European imports in green bottles that have been exposed to fluorescent light.

One brewer told me that his daughter perceived light-struck as a “friendly” characteristic of Euro lagers. She didn’t like beer unless it had that character, and when my friend exposed some green bottled beer to sunlight for an hour she was delighted with the result!

Sunlight has a very deleterious effect on beer, a fact brewers have known for well over a hundred years. This comes mostly from altering the hop flavors to sulfury compounds. Beer in clear glass bottles is most affected by sunlight, though beer in green glass bottles is also susceptible. It has been found that fluorescent light is perhaps even more damaging than sunlight.

Some breweries help protect their beer against some light damage by using preisomerized hop extract instead of regular hops, pellets or hop extract. Preisomerized hops are less prone to break down into skunklike aromas.

Amber-brown bottles are the best protection

against light damage. One rarely sees green bottles in Europe, and one never sees clear bottles there.

The light-struck flavor is readily perceived as skunkiness, and easily identified as such by some. For others, however, it can be quite confusing, and some folks need to be “hammered” with it. I have found that advanced skunkiness is often accompanied by a sediment of flakes that is easily disturbed. If you find such a bottle, sample carefully. The real sun-struck flavor of skunkiness will be “hammered” in.

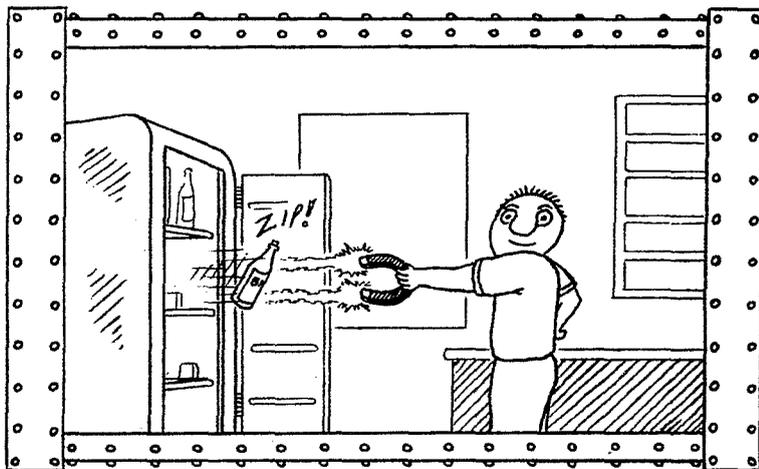
One sample is enough to sensitize even the most jaded olfactory sensors. Stand a green bottle of any less popular of the German imports in fluorescent light for a week of two, or in sunlight, chill, and Prosit—Ugh!

## Metallic

By Rao Palamand

Metallic flavor in beer is a sensation produced by certain chemicals. It can be characterized as a harsh and unpleasant note produced typically when our taste sensors come in contact with certain metals, notably iron.

This sensation was originally thought to affect only the taste sensors. It is now known to play a broader role that includes the effect produced on odor receptors as well. Imagine examining the odor of a rusty nail as well as its taste.



**Metallic**

Typically, metallic flavor sensation is perceived more readily on the tip of the tongue and on the front upper (mouth) arch (right above the teeth) when the stimulus is present at low concentrations. When significant levels of the stimulus are present its flavor sensation may be felt throughout the tongue and other mouth parts.

When referring to metallic flavor one thinks of iron as the basic stimulus for this sensation, but it is important to note that a number of organic compounds totally unrelated to the element iron can and do produce the sensation of metallic odor and taste. Also, certain specific forms of iron are more effective than others in producing this sensation.

The following table lists flavor thresholds for various constituents responsible for metallic flavors in beer.

Metallic flavor is definitely an undesirable flavor when present at a readily detectable level. At very low levels (trace concentration) it may be tolerable, but well above the threshold level beer becomes undrinkable, and so should be minimized if it cannot be totally eliminated. Metallic flavor adversely affects the drinkability of beer by building up in the mouth.

The following steps are effective in controlling

the metallic flavor in beer:

1. Eliminate all sources of iron contamination, such as mild steel equipment, and avoid contacting beer with iron surfaces, either by not using any iron metal at all in the brewery (in areas where the product comes in contact with beer) or by making sure that any iron or mild steel surfaces are thoroughly coated with a protective layer of tin.

2. Use only stainless-steel equipment, pipe fittings, etc.

3. Use only high-quality ingredients (malt, rice, corn, etc.) free of iron contamination and store them in an nonoxidizing atmosphere away from moisture.

Hydrolysis of the cereal lipids followed by oxidation of unsaturated free fatty acids generates a variety of compounds that produce metallic flavors.

4. Use only high-quality processing materials, such as celite filter aid that is thoroughly acid washed or otherwise treated to reduce or eliminate beer-soluble iron (ferrous iron).

If the above recommendations are followed, homebrewers should not have any particular problem in avoiding metallic flavors in their beers. However, some of the steps suggested will, in all likelihood, increase the cost of the process.

## Metallic Flavor Constituents

Constituent	Source	Threshold
1. Iron (Ferrous) (Fe <sup>++</sup> )*	1. Exposed mild steel surfaces, if any. 2. Processing aids such as celite.	0.04 parts/million
2. 1-octen-3-One  3. 1,5-Octadien-2-one	Lipids from malt or brewing adjuncts such as rice, corn, etc.	25 parts/trillion
4. N-methyl-pyrrol-2-yl-methyl sulfite 5. N-methyl-pyrrol-2-yl-ethyl-sulfite 6. N-methyl-pyrrol-2-yl-methylthiol acetate	The reader is referred to "Pyrroles in Foods" by J.S. Maga in the <i>Journal of Agriculture and Food Chemistry</i> , 29:4, July/August, 1981, pp 691-694, for a complete explanation of sources.	Thresholds not well established.

\*Iron salts occur in two oxidation states, the ferrous (++) (lower oxidation state) and the ferric (+++), the higher oxidation state. It is the ferrous ion and its salt that is soluble in beer (so-called-beer-soluble iron) that produces metallic taste. Ferric iron is not involved in producing the metallic taste.

# Moldy

By Greg Noonan

Moldiness is a clearly recognizable flavor. Thankfully it is not a common defect in beer. It is evidenced by a cellarlike, damp-earth or rank, cabbagey odor. The smell is usually more pronounced than the flavor, which may be woody or sour.

In flavor profile, moldiness is grouped with staling characteristics (see *Beer Flavor Terminology* by Meilgaard, Dalglish and Clapperton, 1979). Oxidation, skunkiness, papery, cardboardy and leathery spoilage are classified as similar quality defects. Mild, barely detectable mustiness that develops in a bottled beer is an aging defect caused by a comparatively slight contamination. Where it is pronounced, moldiness-mustiness is the result of serious fungal contamination. The contamination may be a result of airborne fungi, or from equipment or packaging the beer has contacted.

Molds, like yeast, are fungi. Barley, malt, wort and beer are ideal substrates for the growth of a range of different fungi. Black bread molds, slimes and mildews can all grow in wort or beer. Brewing in a damp or musty environment risks contamination of the cooled wort or fermenting beer by any of a host of airborne fungi.

Secondary fermentation and aging in a moldy smelling cellar risks contamination by reverse passage of atmospheric air through the fermentation lock (sudden cooling) and by contact of the beer with exposed fermenter surfaces. Where the fer-

menter's cap or stopper seals against its rim offers a concealed, often moist area for fungal growth. Uncapping the brew for racking or priming risks contamination. Even a strongly fermenting beer should never be uncovered in a damp cellar. Even after transfer to a more sterile area the opening should be effectively sanitized.

If airborne contamination can be reasonably eliminated as the probable source of infection, fermenters themselves and other articles and equipment contacting the brew must be suspect. In such cases more attention obviously needs to be paid to their sanitation. Adequate post-cleaning contact time with a .05 to .5 percent sodium hypochlorite solution (.33 to 3 fluid ounces chlorine bleach in five gallons of water) acts as a most effective fungicide.

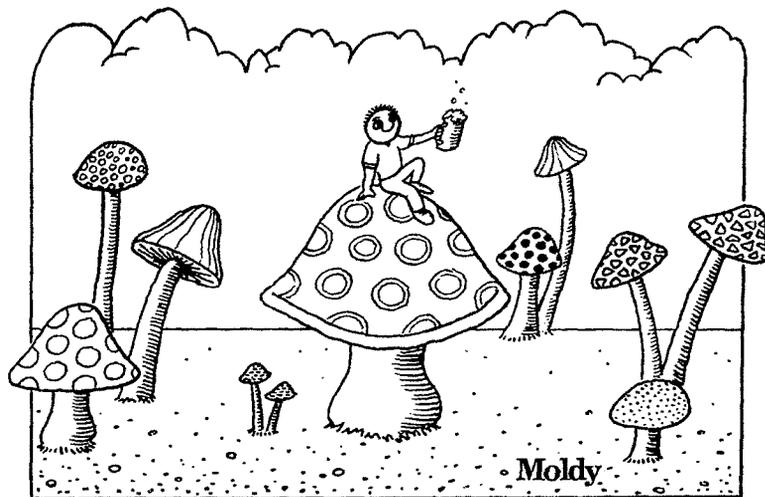
The most obvious solution is indicated where moldiness is encountered sporadically in bottles from the same batch. Although airborne contamination at the point of bottling must always be suspect, more thorough sterilization of all bottles should be pursued. Promptly rinse bottles to be reused on emptying them, and sanitize by wet heat or soaking in a chlorine solution before refilling.

# Nutty

By Fred Eckhardt

Nuttiness is an olfactory (aromatic) sensation, as in Brazil nuts, hazel nuts or sherrylike. Olfactory sensations are perceived through cytoplasmic extensions up to the mucous in the nose. Our human olfactory abilities are relatively limited compared to other mammalian species, but unlike them, we rarely take note of odors, even those emanating from the food we eat.

Actually, our human olfactory receptors are better than even those of our sight and hearing! Our olfactory glands can detect an almost unlimited number of odors. Our sense of smell may actually be our best sense. Sadly, the only time we take our olfactory sensations seriously is during the actual





Nutty

ingestion of food and drink, when they modify our taste sensations to a perception of what we may actually be tasting.

Nuttiness is just such an element. Generally speaking, nuttiness is considered a negative flavor character in beer. It may also be perceived as walnut, coconut, beany or almondy. Only the latter, and sherrylike may be viewed as positive flavor elements in beer, and those very seldom.

Nuttiness, in flavor sensation, usually is the result of oxidation, or prolonged overheating during the aging process or after bottling. It can be prevented, or at least minimized, by excluding air from the secondary or aging cycle. Leave your beer alone while it is aging, and avoid aerating your beer when bottling (injecting bottles with CO<sub>2</sub> gas before filling them can be helpful but is a lot of effort), and avoid prolonged exposure to heat at all times.

## Oxidation

By Dave Schroedl

The flavor descriptors for oxidation discussed here are oxidized-stale, sherrylike-winey and rotten pineapple-garbage.

The oxidized-stale is described as cardboard, paper and wet paper, and is perceived both in

aroma and flavor-by-mouth (FBM). Sherrylike-winey is described as brandy, prunes, plums, rotten apple, cider, sour white wine and over-ripe fruit. This characteristic is perceived in aroma but more in FBM. Rotten pineapple-garbage is described as rotten vegetable, canned pineapple, rotten silage, old tomatoes and old celery. This characteristic is perceived in aroma and more in FBM.

All three of these descriptors are produced as the beer ages. They are influenced by the amount of oxygen in the package, the temperature at which the beer is packaged and stored, and by the amount of oxygen introduced in the brewing process.

The oxidized-stale flavor is caused by a compound called Trans-2-nonenal with a threshold level of .2 ppm (threshold = just barely detectable). The sherrylike-winey is caused by acetaldehyde (25 ppm threshold) and furfural compounds. The rotten pineapple-garbage is caused by higher alcohols and the same compounds as listed above. All of these flavors are unfavorable for most domestic beers but are some of the predominant flavors in imported beers.

All beer changes flavor as it ages, so these flavors cannot be stopped, but they can be slowed down in their formation. Some of the methods to control these changes are:

1. Keep extra oxygen out of the process, particularly during bottling or kegging; i.e., purge the bottles with CO<sub>2</sub> before filling.
2. Control the temperature throughout the process. Maintain appropriate fermentation temperatures and store in a cool environment. Warmth acts as a catalyst in furthering oxidation.
3. In fermenting, use air traps to reduce the influx of oxygen.

In conclusion, oxidation is a common phenomenon in all brews. It cannot be eliminated, but it can be controlled.

## Phenols

By George J. Fix

A variety of flavors can be produced by phenolic constituents found in beer. For example, hop alpha acids are phenols and have their own unique flavoring. In practical brewing, however, it is the phenols that impart a "medicine chest" flavor that

is the subject of "trouble shooting." These can be tasted, yet they are best detected by smell.

Phenols are compounds that are built up from elements containing the following aromatic ring:

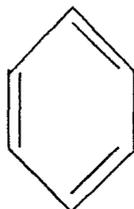


Figure 1

Chlorophenols are examples involving chlorine sidechains. Some of these have very powerful flavors with thresholds in the parts per billion range. Unfortunately, it is not uncommon for civic water supplies to contain these elements; moreover, they can partially survive the brewing process and be passed on to the finished beer. Small



residuals from chlorine-based sanitizers also have been implicated.

Phenols can be extracted from malt during the mash and sparge. These compounds are sometimes called tannins, a term without precise meaning in brewing except as a generic expression for polyphenols, i.e., phenols having a large number of complicated aromatic ring structures. Their primary relevance occurs in the finished beer where they can interact with proteins to form chill haze and permanent haze. If oxidized during the preparation of hot wort, they can oxidize fusel alcohols, fatty acids derived from wort trub and iso-alpha acids in the finished beer.

The final class of phenols important to brewing are those purposely created in the fermentation by yeast. Strains differ dramatically in their propensity to create these compounds. Aromatic alcohols, or what are sometimes called phenol alcohols, are examples. Tyrosol is typical, and has the following structure:

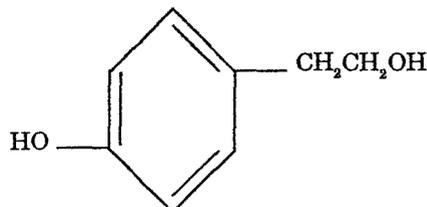


Figure 2

For most strains of brewing yeast this alcohol will be well below its threshold of 200 ppm. However, there are some strains where this is not the case, and a bitter chemical flavor tone will be present.

Another phenol that can result from the fermentation is 4-vinyl guaiacol. Certain yeast strains — most notably variations of wild yeast like *S. diastaticus* — produce this compound from minor wort phenols. The following is typical:

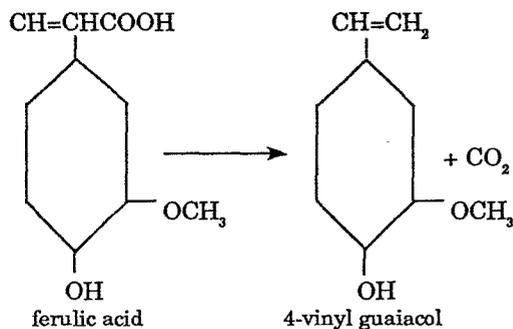


Figure 3

At or above its threshold of .3 ppm it will impart a distinct medicinal flavor tone.

In most beers phenolic aromas are unfavorable. The one exception is Bavarian wheat beers. Here, special yeast is used that yields 4-vinyl guaiacol levels significantly above the threshold. The resulting clovelike phenolic tones, however, are balanced with a clean acidity and significant CO<sub>2</sub> snap. This combination makes these beers refreshingly delicious when they are in peak condition, and virtually undrinkable otherwise.

The brewer can take a number of practical steps to avoid phenolic off-tones. First, one should avoid water supplies that have even trace levels of chlorophenols. Second, one should be careful with residuals from chlorine sanitizers. Many brewers are now phasing out chlorine in favor of products like peracetic acid—its residuals are more natural to beer.

Excessive extraction of malt-derived phenols can be controlled with a proper sparge. Of greatest importance is to avoid excessive amounts of sparge water, and in particular the sparge should be terminated when the pH of the liquid collected nears the 5.8 to 6.0 range. Sparge water with alkalinity above 25 to 50 ppm should be avoided, as well as sparging temperatures above 167 degrees F (75 degrees C).

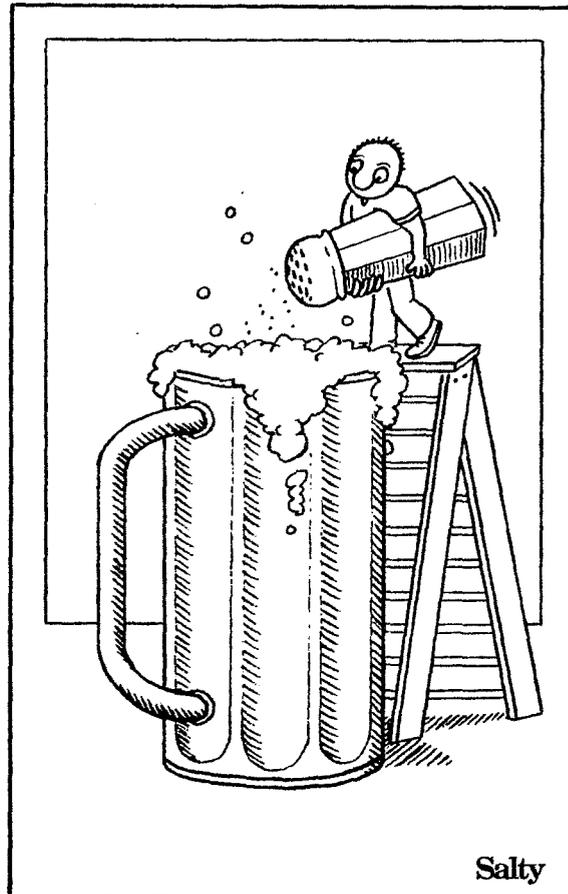
Phenols produced via the fermentation can be avoided with a proper strain selection. It should be noted that once wild yeast like *S. diastolicus* are introduced into a brewing environment they are almost impossible to remove. This is particularly the case with polyethylene fermenters. Such fermenters may have to be discarded to avoid further problems.

## Salty

By Fred Eckhardt

Like sugar, salt (NaCl, sodium chloride) is one of the four basic tastes (the others are bitter and sour). The taste of salt is quite difficult to describe, but everyone is familiar with its taste, and a touch of it on the tongue is very educational. The perception of saltiness is localized in the gustatory receptors at the upper sides of the front of the tongue, to the rear of those for sweetness.

The taste of salt is totally imperceptible in normal beer, and anytime it can be detected it



constitutes a flaw, although it may be an underlying factor in some so-called "Burton" ales.

Salt is found naturally in only miniscule quantities in the cereals used in the beermaking process, and I doubt any comes from the hops. Most salt found in beer is from the water supply, or from the water adjustment used to prepare water for the mash sequence. It is my opinion that noticeable salt found in beer is the result of the brewer's addition of that ingredient, a mistake few commercial breweries make.

## Solventlike

By Terence Foster, PhD

This is a pungent, or even acrid aroma, which is followed up by a harsh, burning (not warming) sensation on the tongue. It may linger on the back of the palate in bad cases.

Solventlike is a very general term—the flavor could arise from any number of causes. In commercial beers, such flavors have arisen from lacquers used to line cans. However, the most common source is the presence of ethyl acetate produced by a biosynthetic route during fermentation, in which ethanol is esterified by acetic acid. As with most esters, it tends to be produced in increasing amounts at higher fermentation temperatures. Certain wild yeasts are capable of producing large amounts of ethyl acetate, especially if the fermentation is aerobic. The taste threshold of ethyl acetate is only 33 parts per million.

This has to be regarded as an undesirable flavor component of most beers, although amounts well above the threshold level have been detected in Belgian lambic and gueuze beers. The presence of a solventlike flavor may be acceptable in a strongly flavored dark beer, but can be very objectionable in pale beers, especially in light lagers. If the solvent flavor arises from some outside contamination, such as reaction of plasticizers present in plastic brewing equipment, it clearly represents a major beer defect.

Good brewing techniques should prevent any problem occurring with this off-flavor. If you use plastic equipment, make sure it is food-grade, soak it with a solution of one teaspoon washing soda per gallon of water, and rinse with two teaspoons of chlorine bleach diluted in one gallon of water before use.

Be scrupulous in sanitizing all your equipment, and avoiding contact with air at every stage to prevent bacteria or wild yeast from getting into the wort or beer. Use a good-quality, true beer

yeast, and control ester production by keeping fermentation temperatures from rising too high. This means not above 75 degrees F for ales, and preferably not above 55 degrees F for lagers, especially the lighter, paler varieties.

## Sour/Acidic

By David Logsdon

Sour and acidic flavors in beer are readily identifiable through the sour aroma and tartness or vinegarlike flavors. The two most prevalent souring acids in beer are acetic and lactic acid. Bacterial infection can sometimes be identified by turbidity and ropiness in beer.

The sour aroma can be perceived as bacteria spoilage or putrefaction. Acid stimulates the sides of the tongue; at high acid levels stimulation can be felt all the way down the throat.

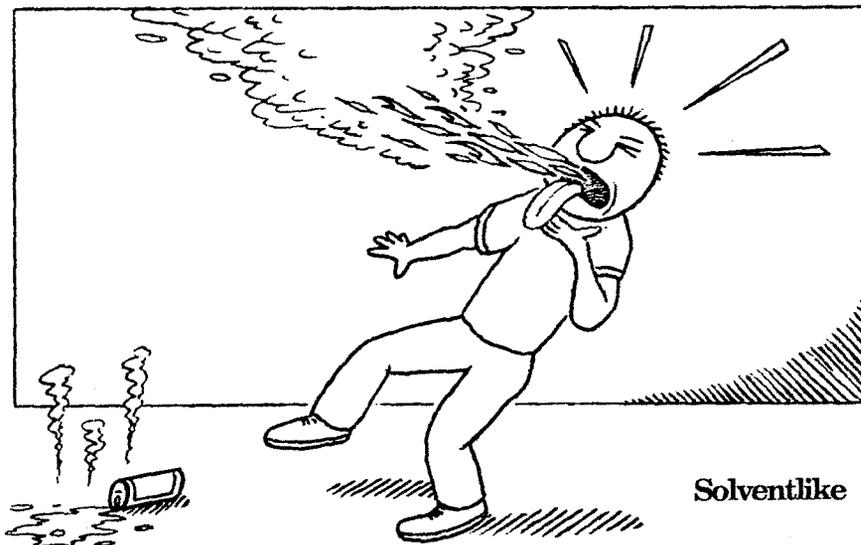
Certain yeast strains produce more acid, giving beer a citrus flavor. Lactic acid produced by lactobacillus and pediococcus bacteria can be introduced by low mash temperatures, by airborne infection in open fermenters, and by unsanitized equipment in contact with beer after the kettle boil.

Acetic acid is most often produced by the bacterium acetobacter through airborne infection during fermentation or via the red-eyed fruitfly, drosophila.

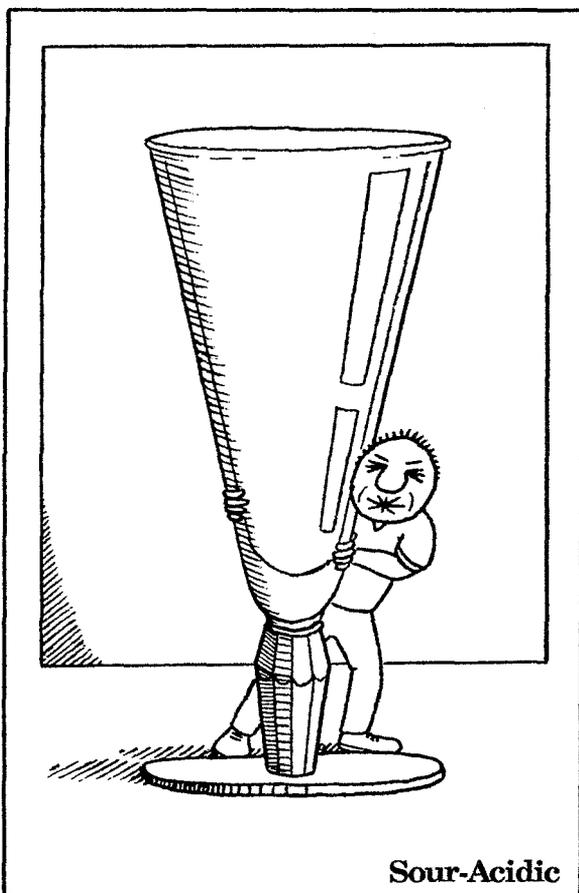
The flavor threshold of acid is approximately 300 ppm.

Sour and acidic flavors are generally unfavorable. However, Belgian lambic style beers are acidic because of open fermentation producing a balance of lactic acid and fruity sweetness and tartness. Having the proper sugar-to-acid ratio creates the balance in this style of beer.

Unwanted lactic and acetic acid is con-



Solventlike



**Sour-Acidic**

trolled by maintaining post-mash temperatures above 160 degrees F and by maintaining a rolling boil in the kettle. Sanitize all parts of all equipment before and after use not when you happen to have time. This is more important than any other part of making good beer. Don't use any porous container that is scratched enough to see with a magnifying glass. Use clean, healthy yeast pitched in rapidly chilled wort. Keep air off of the ferment and finished beer.

## Sulfury-Yeasty

By E.L. Van Engel

All beers and ales contain some degree of complementary sulfury and yeasty odors and tastes that at times can become both pronounced and most unpleasant.

To demonstrate the presence of these odors in your beer or ale, even when overshadowed by other aroma characteristics, you can use the odor screens developed by Brenner and Laufer (1972). To one of three glasses add a few milliliters of a 1 percent solution of copper sulfate, to another glass

add a few milliliters of a 1 percent solution of zinc sulfate and use the third glass as a control.

Fill each glass 1/4 to 1/2 full with the product being tested, swirl a few times to mix the ingredients and compare their odors. The zinc sulfate will screen out hydrogen sulfide ( $H_2S$ ) and the copper sulfate both  $H_2S$  and mercaptans. You should find a degree of difference in the aroma between each glass. **However, be sure you don't drink from the treated glasses.**

The primary source of these odor compounds in beer and ale are the amino acids cysteine and methionine that are in malt and are utilized by yeast as metabolites. They are hydrolyzed during mashing and are degraded by heat during processing. In addition, brewers yeasts also are capable of metabolizing inorganic sulfur, sulfite and sulfate, and some of the organic sulfur compounds found in hops.

For many years the American Society of Brewing Chemists (ASBC) under the direction of M. Meilgaard has been compiling an extensive Sensory Analysis addition for its publication "Methods of Analysis." This should be available in 1987. The ASBC has published a Beer Flavor Terminology section, (Meilgaard, 1979) with 14 major classes of beer flavors. Class 7, as outlined here, lists four subgroups in the sulfury-yeasty category.

### Class 7

Subgroup	0710	Sulfitic-sulfur dioxide
Subgroup	0720	Sulfidic
	0721	Hydrogen sulfide
	0722	Mercaptan
	0723	Garlic
	0724	Lightstruck
	0725	Autolyzed yeast
	0726	Burnt rubber
	0727	Shrimplike
Subgroup	0730	Cooked vegetable
	0731	Parsnips-celery
	0732	Dimethyl sulfide
	0733	Cooked cabbage
	0734	Cooked sweet corn
	0735	Cooked tomato
	0736	Cooked onion
Subgroup	0740	Yeasty
	0741	Meaty

These various odors and tastes, composed of sulfides, thiols (terpenoids and mercaptans) and thioesters are formed, to different degrees, depending upon the malt, hops, processing procedures and yeast strain being used. How these compounds are formed and how they can be controlled is the subject of the rest of this report.

During the brewing process, small but desirable amounts of sulfur dioxide ( $\text{SO}_2$ ) are produced, usually less than 10 milligrams per liter (parts per million - ppm). Because it takes over 20 milligrams per liter for  $\text{SO}_2$  to be detected by odor or taste, producing a sharp, biting sulfurous odor, the only effect this naturally occurring  $\text{SO}_2$  has is to help retard harmful oxidative changes that impair fresh beer flavor and shorten shelf life.

Therefore, to maintain as much natural  $\text{SO}_2$  in the beer as possible, keep oxygen out of the wort and the beer when brewing, except for aerating prior to pitching the yeast. Some brewers add additional  $\text{SO}_2$  to beer, in the form of sulfite, to help maintain shelf life. However, if the total  $\text{SO}_2$  content exceeds 10 milligrams per liter at the time of packaging, a new Federal law effective Jan. 9, 1987, requires a declaration of sulfite content on the label.

Hydrogen sulfide ( $\text{H}_2\text{S}$ ), the stuff that smells like rotten eggs, is detectable in beer at a level of 5 micrograms per liter (parts per billion-ppb). Although a small amount of  $\text{H}_2\text{S}$  is produced during the kettle boil, more in the presence of copper ions, most of the  $\text{H}_2\text{S}$  found in beer is formed by yeast during fermentation; the amount can vary with the strain being used. Fortunately, almost all of the  $\text{H}_2\text{S}$  formed, along with the other volatile sulfur

compounds that are present, is driven off with the carbon dioxide ( $\text{CO}_2$ ); even more is driven off with warmer ale fermentations than when making cool fermented lager beer.

Flushing out these volatile off-aroma compounds is the primary reason for maintaining low fermenter back pressure. In rare cases a pantothenate or pyroxidine vitamin-deficient wort results in interference with methionine biosynthesis (Wainwright, 1970) and an increase in  $\text{H}_2\text{S}$  formation. Mutant yeasts that have defective sulfur metabolic pathways also can produce excessive amounts of  $\text{H}_2\text{S}$ . Smelling the gases produced by your yeast during fermentation should give you a good idea of the sulfur characteristics you can expect in the final product.

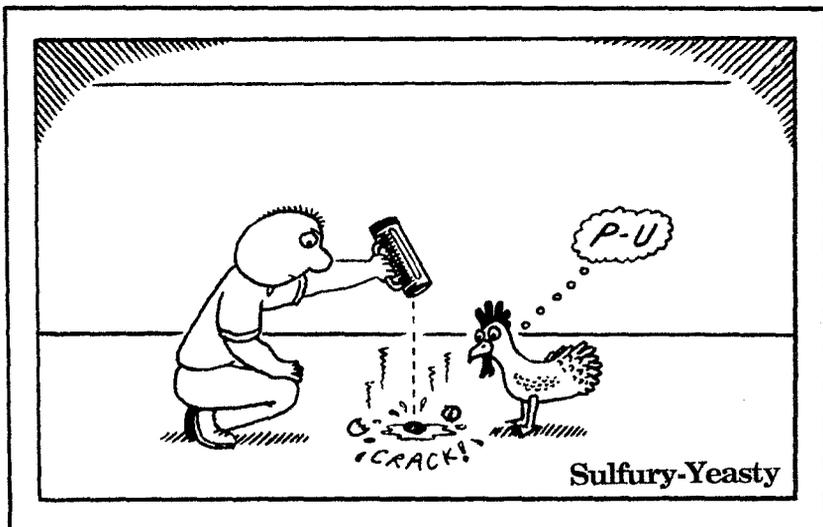
In addition, several varieties of bacteria, (*Zymomonas* and *Pectinatus*, gram-negative rods and *Megasphaera*, a gram-negative coccus first isolated from spoiled beer in Finland in 1984) produce  $\text{H}_2\text{S}$  in finished beer. Of course, the best control against problems like this is sanitation.

Mercaptans, which include thiols and terpenoids, produce some of the world's strongest and most unpleasant odors often noticeable at levels less than 1 microgram per liter. Sulfuring hops, a procedure no longer used in this country, often resulted in the formation of terpenoids in the hop oils, producing a garlicky odor, or a s-methylhexane thionate, a compound that has a cabbagelike odor and is detectable at a level of 0.3 micrograms per liter. Mercaptans also can be formed by the interaction of  $\text{H}_2\text{S}$  with other beer components.

However, the one mercaptan odor in beer that is the most familiar is lightstruck or skunky. This

is the result of light rays interacting with light-sensitive hop iso-alpha acids to produce 3 methyl - 2 butene - 3 thiol (Kuroiwa and Hashimoto, 1961).

There are at least three ways to help control this problem. The most common and effective is to package the beer in brown bottles that screen out most of the damaging light rays — those that have a wavelength between 400 and 520 nanometers (nm).



If you feel you must package your product in clear or green glass completely enclose the bottles in the six-pack and/or a sealed case. Finally, you can use a reduced isomerized hop extract, the one hop product used in brewing that is insensitive to photochemical reactions.

The formation and control of dimethyl sulfide (DMS) in beer has been well documented during the past 10 to 12 years (Arness and Bamforth, 1982). DMS positively contributes to the flavor of beer at concentrations over 30 micrograms per liter but can produce cooked onion, corn or shrimp-like off-flavors at levels over 100 micrograms per liter.

The precursors to DMS in wort and beer, *s*-methylmethionine (SMM) and dimethylsulfoxide (DMSO), are formed during the germination and kilning of barley as it is being malted. Low moisture and temperatures during processing increase a malt's SMM and DMSO content, resulting in increased DMS levels in the wort.

The DMS is formed by the thermal degradation of the SMM. A vigorous kettle boil will drive off most of the volatile DMS, which has a boiling point of 38 degrees C (100 degrees F), that is formed in the kettle, and a short hot-wort hold will help reduce final wort DMS content.

Brewers yeast, varying with the strain, reduces small amounts of DMSO to DMS, while some yeasts are capable of producing excessive amounts of DMS during fermentation, resulting in an unpalatable beer. However, under normal conditions most of the DMS, along with  $H_2S$  that is formed, exits with the  $CO_2$ .

Normally ales, which are generally brewed with slightly overmodified malts and are fermented at higher temperatures, contain a lower level of DMS than lagers. In fact, it is the underlying difference in DMS odor and taste that helps distinguish ales from lagers.

An infection with the wort bacteria, *Enterobacter*, also results in the conversion of DMSO to DMS producing a parsnips-celerylike odor in the wort or beer. Normally, the small number of wort bacteria that is usually present is outgrown by the yeast and dies off as the pH drops and the beer ferments. The only control for this problem is to maintain a sanitary wort system and a healthy yeast.

In large breweries that reclaim the  $CO_2$  from the fermenters for recarbonation during finishing and packaging, it is imperative that the  $CO_2$  be deodorized before reuse to prevent the reintroduc-

tion of volatile sulfur compounds into the beer (Morrison, 1981). This usually is done by pumping the  $CO_2$  through a water scrubber and an activated charcoal filter. The simplest way to check  $CO_2$  purity is to bubble the  $CO_2$  you are using through a water trap for about 15 minutes and then to smell and taste the water.

Finally, there are the sulfur-related yeasty odors and tastes in beer that do not require an extensive amount of discussion. Fermenting and aging beer and ale with and in the presence of millions of yeast cells per milliliter imparts a normal, pleasant low-level yeast taste to those products. It is different from the yeast odor and taste of fresh bread because, in baking, the yeast remains with the product.

However, if the yeast being used in beer production is in poor condition, requiring more time to ferment the beer, and is being held longer in beer at warmer temperatures, flavor changes for the worse can occur.

Yeast, as it autolyzes, or digests itself and dies, releases some of the hop resins that were attached to the cells, as well as excretes excessive amounts of nitrogen-containing compounds that raise beer pH. The beer or ale then becomes harsher and astringent, and develops a spoiled-yeast taste that is not hard to identify. This problem can be controlled by maintaining a healthy yeast that ferments vigorously, removal of the bulk of the yeast from the beer at the end of fermentation and adequate refrigeration.

## Sweet

By Fred Eckhardt

The sensation we call sweet is a genuine taste, or gustatory sensation, one of the four basic gustatory stimulations, and not an olfactory element (odor), as are most of our taste perceptions. Our gustatory receptors react only to certain molecules—those that are both sapid (taste-bearing) and liquid. Therefore the perception of sweet is not actually a taste in the usual sense, and for that reason it is difficult to describe, although everyone is quite familiar with the taste of "sweet." Anyone can reinforce this perception with a touch of sucrose (household sugar) on the tongue.

The perception of sweetness is almost entirely localized in gustatory receptors, or taste buds,

called fungiform papilla, at the front tip of the tongue. There are some 3,000 similar protuberances on the surface of the tongue, each of which is connected directly to the brain by a nerve. In beer, the sensation of sweetness ordinarily is imperceptible, or at least of very low intensity, unless the beer is unbalanced. For that reason, sweetness in beer often is noted as a flaw.

Sweetness in beer is caused primarily by the reducing sugars maltose and maltotriose, but also including some glucose and fructose. Sucrose also may be present, but it is not a natural constituent of beer worts; rather it is the result of priming the beer, or of supplementing the natural wort of sugars.

Glycerine is another sugar present in finished beer, and is a direct result of the ferment. In addition, dextrans are sometimes perceived as sweet, and in some commercial beers utilizing enzyme additives, the conversion of dextrans to sugars is not halted by pasteurization and the resulting sugars continue to add sweetness to beer.

Some fermentation effects may be perceived as sweetness. These include oxidation or staleness that may result in a honey perception, and of course most of the flavors we perceive as fruity have elements of sweetness in their character. These include the flavors of apple, banana, black currant, melon, pear, raspberry and strawberry. Diacetyl will occasionally be perceived as sweet, as will caramel and licorice elements. Those can all be fermentation side effects.

The main source of fermentable extract in beer is the sugar maltose,  $C_{12}H_{22}O_{11}$ , which is

formed from starch by the action of the enzyme amylase.

The threshold level of sugar detection in a beverage such as beer seems to be from 0.5 to 2.5 percent, although the average seems to be 1 percent (by weight) for most folks.

The presence of reducing sugars in beer is usually complementary to the taste, unless they are present in large amounts. (Reducing sugars are fermentable sugars that are left over after fermentation has ceased.) If that happens, then they may have a negative effect on taste. In most cases, if the sugar can be perceived at much more than a threshold sensation, then the beer is defective, but of course there are exceptions, as in the case of some strong ales and dark beers, such as some barley wines.

The most important cause of reducing sugars remaining in the beer is the failure of the yeast to fully ferment them. This can be by design of the brewer, in the selection of lower alcohol-tolerant yeast, or it may be from exceptionally high original gravity, also by design of the brewer, used with a particular yeast strain.

Top-fermenting yeasts normally have slightly higher alcohol tolerance than bottom-fermenting yeasts, and the cold temperature ferments in lager beer production have the effect of slightly reducing the fermentability of a wort.

The length of time a yeast is in contact with the beer is another factor. All in all, the brewer has the ability to control fermentation and thus the desired amount of sugar in the final beer. Thus any perception of sugar that presents itself as "too much" or "too little" for the style and balance of beer must be considered a defect.

Finally, alcohol itself contributes to our sensation of sweetness. Sweetness also can mask acidity, and the presence of just a little common table salt can enhance the impression of sweetness.

The brewer can control the presence of reducing sugars by control of mashing times and temperatures, by the selection of yeast and by the style of ferment.

