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Winemaking Notes

Understanding and eliminating sulfur-related aroma defects in wine

Reduced sulfur compounds (those formed in the absence of oxygen) are a perennial problem in winemaking because they usually smell very foul (rubber, swamp, cabbage, garlic) and they also reduce mouth feel and enhance bitterness. Unfortunately the chemistry of sulfur in wine is complex and not well understood, so we usually have only rough guidelines about what to do to minimize sulfur-related defects. These guidelines vary depending on where you are in the winemaking process.

The information in the following quick guide summary is developed more fully in the sections that follow. Remember that:

- People vary considerably in their sensory thresholds for volatile sulfur compounds, so what one person finds unacceptable may be unnoticed by others.
- People will also describe the smell of the same sulfur compound differently.
- Not all reduced sulfur smells are considered problems—some may add "complexity" and some may even be responsible for varietal character.

Quick Guide Summary

1. Sulfur has several reduced forms in wine:
 - Hydrogen sulfide is produced naturally during fermentation. You want to avoid excess production and to remove any H₂S that might remain at the end of the fermentation. Left untreated, H₂S will form mercaptans.
 - Mercaptans are formed toward the end of the fermentation and later. They are the cause of most of the offensive odors in finished wines, but they can be removed with copper.
 - Sulfides and disulfides are formed throughout the wine-making process and from the oxidation of mercaptans in finished wine. Sulfides usually have higher sensory thresholds than mercaptans, so they tend to be less of a problem. But if they are a problem, they are difficult to remove because they cannot be treated directly with copper. Also, disulfides can revert to more objectionable mercaptans in the bottle.

2. Measures prior to fermentation to reduce sulfur related problems:
 - Avoid grapes that have been sprayed with sulfur or copper compounds close to harvest.
 - Do not add more sulfite to your pre-fermentation grape must or juice than you need to.
 - Clarify white juice, and use some SO₂, but do not over-clarify.
3. Measures to control H₂S during the early part of fermentation:
 - Consider using a "safer" yeast, one that has lower nutrient requirements and that produces less H₂S as a normal byproduct of fermentation.
 - Feed your yeast carefully; not too little, not too much, and never feed nitrogen toward the end of the fermentation. Fermaid is better than DAP.
 - Use moderate fermentation temperatures and speed; i.e., avoid the extremes.
4. Measures to control H₂S during the latter part of fermentation:
 - Among its other benefits, délestage helps to control sulfur compound production through aeration and stirring the lees. Délestage can start quite early in the fermentation process and continue late.
 - If you detect H₂S toward the end of the fermentation, or just after it is finished, aerate or splash the wine. But be warned about possible complications.
 - Get your wine off the gross lees as soon as possible and delay sulfiting your wine for at least two weeks after fermentation is complete.
5. What do do with mercaptans and sulfides in completely fermented wine:
 - Use extended lees contact, but manage it carefully, and stir regularly.
 - Use copper sulfate to treat H₂S or mercaptan problems as soon as you sense a problem in your wine. If not treated promptly mercaptans can become disulfides which are less easy to detect but which can become mercaptans again later in the absence of oxygen.
 - For the off odors of disulfides that resist copper, try reducing them back to mercaptans for copper treatment. Be prepared for failure.

1. Sulfur and its reduced forms in wine

Elemental sulfur

Elemental sulfur is a pale yellow solid which has little odor and is insoluble in water (think of the huge piles sitting on the docks in the rain in North Vancouver). Sulfur is one of the important constituents of life. It occurs naturally in grapes from the soil. The oxidized forms of sulfur are often the winemaker's friend: for example, metabisulfite and SO₂ protect our wine and copper sulfate can eliminate mercaptans. So it is not sulfur per se that is the problem for winemakers. Left to itself, elemental sulfur will sink to the bottom of a fermentation vessel and be eliminated when you rack.

The problem is the forms sulfur sometimes takes in the absence of oxygen. These reduced sulfur compounds (sometimes called volatile sulfur compounds or VSCs) are usually foul-smelling in very minute quantities and can easily ruin a wine.

Sulfur sits just below oxygen in the periodic table, with similar valences, and therefore many of the common sulfur compounds have their direct analogs with oxygen compounds. The oxygen compounds come from oxidation; the sulfur compounds come from reduction when oxygen is absent.

Hydrogen sulfide (H₂S)

This is the simplest and most common reduced sulfur compound in wine, at least during the fermentation. It is the sulfur analog of water (H₂O). Its rotten egg smell is detectable by humans at very low quantities (1-2 ppb). It is toxic and often leads to industrial accidents because humans cease to smell it at high concentrations. Even at low concentrations it causes sensory fatigue, which is why you should never assume you have cleared up a H₂S problem you have been treating without coming back to it later with a refreshed nose.

Some H₂S is inevitably produced by yeast during the fermentation process. The good thing about H₂S is that it is quite easy to get rid of.

- It is very volatile and much of it gases off with the CO₂ during the most active part of the fermentation or in splashing the wine at the end of the fermentation.
- Some of it is also converted to elemental sulfur, which sinks to the bottom of the tank and is left behind by racking.
- Some of it seems to get converted to other sulfur compounds, which may not be as smelly.
- It is treatable with copper after the fermentation is complete. (Never use copper before the fermentation is complete. Copper is toxic to yeast cells and they produce extra H₂S to combat it!)

The usual assumption is that H₂S turns into foul-smelling mercaptans and sulfides, and that if we have virtually no H₂S during the fermentation, or if we get rid of it immediately afterwards, we should be spared the problems of mercaptans and sulfides. However, it may not be that simple. Some of the more complex reduced sulfur compounds are being created at the same time as H₂S is being created. You can have a relatively "sweet" fermentation and still end up with sulfur problems.

Mercaptans

Technically, mercaptans are known as thiols, because of the SH (hydrosulfide or sulfhydryl or thiol) group they contain. Most mercaptans in wine are closely related to alcohols. Often the only difference is that a thiol (SH) group has replaced the hydroxyl (OH) group of an alcohol. For example:

- **Methyl mercaptan or methanethiol (CH₃-SH)** is formed when the hydroxyl group (OH) in ethanol (CH₃-OH) is replaced by the thiol group (SH). Methanethiol is the most common sulfur-related problem in post-fermentation wines. It has a very low sensory threshold (1-2 ppb) and has odors of swampy stagnant water and halitosis at the lower levels to rotten cabbage, burnt rubber, garlic, and onion at higher levels. It is often the mercaptan added to propane and natural gas to signal the presence of an otherwise odorless gas.
- **Ethyl mercaptan or ethanethiol (C₂H₅-SH)** is ethanol (C₂H₅-OH) with the hydroxyl group (OH) replaced by the thiol group (SH). It has a very low sensory threshold (1-2 ppb) and has odors of rubber, burnt rubber, garlic, and onion. At higher levels it has a fecal smell.

These are the most common mercaptans in wine, and everyone agrees they are foul smelling, even in minute quantities. Even below the sensory threshold, these mercaptans can make their presence known by masking the pleasant nose you would normally expect. Young wines with no fruit nose probably have a mercaptan problem, even if you don't smell rubber.

Some mercaptans based on alcohols have the thiol (SH) group in addition to the hydroxyl (OH) group of the alcohol. For example:

- **2-mercaptoethanol (SH-C₂H₂-C₂H₂.OH)** is ethanol but with the addition of a sulfur atom to one of the hydrogen atoms to form a thiol. This mercaptan is implicated in the production of a barnyard-like odor.

A more complicated mercaptan picture

People vary tremendously in their ability to perceive mercaptans. According to Stevenson (n.d.), even among the "normal" population (not the super-tasters or those with almost no sense of smell) the ability to detect mercaptans can vary by a factor of ten.

People also smell different things when experiencing the same level of a mercaptans. It can be confusing to read different studies of volatile sulfur compounds when they differ in describing how the same compound smells.

Not all mercaptans are necessarily bad-smelling. Many different alcohols are found in wine in small quantities and some of the mercaptans associated with them may add desirable aroma or complexity to wines, especially at lower concentrations. For example:

- **2-furfurylthiol**, the mercaptan of furfuryl alcohol, has attractive roasted coffee aromas at low concentrations.
- **Mercaptohexanol**, the mercaptan of hexanol, carries aromas of blackcurrant, grapefruit, and passion fruit.
- **4-mercapto-4-methyl-pentan-2-one** (4MMP, for short) is responsible for the varietal (catty, gooseberry) character of Sauvignon Blanc.

The first two of these are actually used as flavorings, and the third has recently been identified also as one of the sources of the desirable flavors in aged cheddar cheese. The implication of "good" mercaptans is obvious. If you treat wine to get rid of some bad mercaptan flavors, you might end up getting rid of some good ones too and having an uninteresting wines as a result.

Sulfides and disulfides

Most sulfides (one sulfur atom acting as a bridge between two, usually carbon, atoms) and disulfides (two sulfur atoms acting as a bridge) in wine are based on the same alcohols that mercaptans are. Disulfides sometimes form directly from mercaptans if enough oxygen is present.

- **Dimethyl sulfide ($\text{CH}_3\text{-S-CH}_3$)** is formed from the methane parts of two methyl alcohol atoms bridged by a single sulfur atom. It is present in all wines and does not seem related to initial levels of H_2S production. At low levels (15-20 ppb in whites and 20-30 ppb in reds) it contributes roundness, fruitiness and complexity. DMS increases with wine age, leading to canned corn, quince and truffle sensory characteristics. At higher concentrations (greater than 30 ppb for whites and 50 ppb for reds) DMS can contribute vegetative, cooked cabbage or sulfide smells to wine. DMS does not respond to copper treatment.
- **Dimethyl disulfide ($\text{CH}_3\text{-S}_2\text{-CH}_3$)** is a combination of two methyl mercaptans ($\text{CH}_3\text{-SH}$), with the H stripped from the SH group through oxidation. Dimethyl disulfide has an odor described as vegetal, cabbage-like, or (at higher levels) onion-like. The sensory threshold is 10-12 ppb, which is unusual because it is lower than for the corresponding sulfide.
- **Diethyl sulfide ($\text{C}_2\text{H}_5\text{-S-C}_2\text{H}_5$)** is formed from the ethane parts of two ethyl alcohol atoms. It has a rubbery odor, which can be garlic-like at higher concentrations. Eventually, it smells pretty much like H_2S . Sensory threshold is low (1-2 ppb).
- **Diethyl disulfide ($\text{C}_2\text{H}_5\text{-S}_2\text{-C}_2\text{H}_5$)** is a combination of two ethyl mercaptans ($\text{C}_2\text{H}_5\text{-SH}$). It has the smell of garlic or burnt rubber. Sensory threshold is 3-5 ppb, which is low for a disulfide.
- **Carbon sulfide (CS)** has a rubber-like odor.
- **Carbon disulfide (CS_2)**, the analog of CO_2 , has an odor described as sweet, ethereal [whatever that is], slightly green, sulfidy. Sensory threshold is 5 ppb but it is usually not considered a problem even at higher concentrations. May contribute positively to wine aroma.

Disulfides can smell bad (sometimes worse than mercaptans). Their advantage is that they usually have higher thresholds of detection than mercaptans. Thus, through oxidation, you can convert an unpleasant level of mercaptans into an undetectable level of disulfides. However, the bad news is two fold; (1) you cannot easily treat a wine with a disulfide problem and (2) disulfides can morph back into mercaptans in the bottle in the

absence of oxygen (wine in the bottle is considered to be in a reducing environment, not an oxidative one). Thus, you can think you have eliminated mercaptans only to be surprised later when you uncork your wine.

The challenge for winemakers is to prevent the production of mercaptans at the outset, and, if that proves impossible, to eliminate them before they turn into disulfides.

2. Before the fermentation—preventative measures

Vineyard management

Good wine starts in the vineyards, and so can sulfur problems.

The oldest and most common explanation for sulfur problems in wine is the excess or late application of sulfur in the vineyards to control powdery mildew. More than 5 mg/L of residual elemental sulfur in grape must seems almost guaranteed to produce problems. Thus, the rule is not to use sulfur sprays in the vineyard within five or six weeks of harvest. Presumably every responsible grape grower knows this by now, so this should seldom be the cause of today's sulfur problems in wines. Also, there seems to be a growing suspicion among researchers that this old explanation is not as important as was once thought. Residual elemental sulfur from the vineyard was just the most obvious suspect for later problems.

Copper sprays are also a problem. Copper is toxic to yeast, and yeast produce additional H₂S to combat the copper.

Excess sulfite in wine

If it seems strange to add sulfur (in the form of potassium metabisulfite) to wine when sulfur causes so many problems, it may be. The rule at present is to keep sulfite additions below 80 ppm, while prudence suggests not adding any more than necessary.

3. Early phase fermentation—preventative measures

Butzke (1997) points out that there are two distinct phases of fermentation and the causes and consequences of H₂S are different in each phase.

Early phase fermentation and the nitrogen problem

During the early phase the 6-carbon glucose molecule (C₆H₁₂O₆) is broken down into two 3-carbon molecules, which in turn are broken down into two 2-carbon molecules called acetaldehydes and CO₂. In this phase, there is usually adequate oxygen available, and the main problem yeasts will encounter is inadequate nitrogen and nutrients. If this happens, yeast, especially some yeasts, produce excess H₂S in an effort to synthesize the sulfur-containing amino acids they need for growth. This problem is alleviated by feeding the

yeast extra vitamins and nitrogen through "yeast nutrients" and Fermaid. The DAP (diamonium phosphate) in these mixtures reacts with H₂S to form the sulfur-amino acids the yeasts need. There will be some excess H₂S during this phase, no matter how much nitrogen is present, but it is usually not a problem. H₂S is very volatile and it is carried away with the CO₂ as the ferment "boils" vigorously.

While you will probably always be able to smell traces of H₂S during fermentation, you definitely should not have a fermentation that is "stinky" (rotten eggs).

Steps to avoid problems

1. **Feed your yeast vitamins and nitrogen.** Ensuring your yeast has adequate nutrients (vitamins and nitrogen) is the most important thing you can do. Rehydrate yeast with Go-Ferm and fortify the must with yeast nutrients or Fermaid-K according to the recommended pattern. Yeast hulls can also be used. (DAP by itself can provide nitrogen, but not the other required ingredients, and research suggests these other requirements may be even more important than nitrogen.) If you do not know the YAN (yeast available nitrogen) level of your must, assume you have low nitrogen and be prepared to add extra nutrients after the fermentation is underway. (For more on this critical topic, see [Proper nutrition for yeast](#)—TBD). And stand on guard with your sniffer. If ever you get a pronounced smell of H₂S before your specific gravity has dropped below 10° Brix, add nutrients. But don't add too much. Some people have said that you cannot add too much yeast food or DAP, that any excess will just drop out eventually, but this seems not to be true. Formation of H₂S late in the fermentation is positively associated with high levels of nitrogen.
2. **Select a low H₂S-producing yeast.** Some yeast require more nitrogen than others, and some naturally produce more H₂S as a by-product of their metabolism. If you are having H₂S problems, it makes sense to choose a yeast a yeast that minimizes these problems—for example, D-254. If you are unsure about the characteristics of your yeast, check the manufacturer's website. (For more on this topic, see [Selecting your yeast](#)—TBD).
3. **Ferment at moderate temperatures.** It seems there are fewer H₂S problems with cooler ferments for reds—e.g., 25° instead of 30°. This tendency to ferment red hotter for better extraction partially explains why H₂S is usually more of a problem with reds. However, Mueller and Fulegang (1996) report that whites fermented cold (55°F, 13°C or less) can develop a trithiane problem which ends up producing H₂S and mercaptans later in the bottle.

4. Late phase fermentation—preventative measures

Late phase fermentation and the oxygen problem

If yeasts had their ideal environment, they would continue to have lots of oxygen, in which case they would transform the acetaldehydes to water and CO₂ ($C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$), which would be sad because we would get no alcohol. It is the absence of

oxygen that leads yeast to transform the acetaldehydes to alcohol. This transformation to alcohol is the second stage of the ferment. H₂S can be produced during this stage too, but it will not be because of a lack of nitrogen. In fact, too much nitrogen increases H₂S during this stage. The reductive environment (lack of oxygen) during the later stage of fermentation is a cause of H₂S and other reduced sulfur compounds. H₂S produced late in the fermentation is also more likely to stay in the wine because CO₂ production is slowing and therefore the H₂S is less likely to be blown off.

Steps to eliminate H₂S

1. **Délestage helps prevent sulfur problems.** Délestage (draining the cap and reflooding) has a number of benefits for wine making, and Delteil (2003) reports that it also helps control sulfur problems. Some of the ways délestage helps are aeration, stirring the lees, and gassing off H₂S (also see the benefits of splashing). Delteil is in favor of the frequent use of délestage from an early stage in the fermentation process.
2. **Splash or aerate your must.** This the classic solution to H₂S near or at the end of the ferment. Several mechanisms are at work here.
 - Splashing or bubbles coursing through the must assist the volatile H₂S to escape. When a winemaker is concerned about introducing too much oxygen to the must (which can be more of an issue with whites), CO₂ or nitrogen can be bubbled through the must. The disadvantage of any kind on intense aeration, however, is that you will also tend to lose some of desirable volatiles as well.
 - Racking the wine while splashing it to a new container takes a wine off the gross lees, which seems to be a source of H₂S and mercaptan production. This is more of an issue in reds than whites. If whites have been properly clarified beforehand, there will not be much gross lees.
 - Some additional oxygen can help the fermentation. This is a tricky matter. Too much oxygen and you ruin the wine, especially with whites. Also, you must remember that adding oxygen can help mercaptans make the transition to disulfides.

When you splash, splash vigorously. Simply running the siphon down the side of a clean carboy is not likely to accomplish much. Try running the siphon stream through a sieve or colander in the air before the wine drops through a funnel into its new carboy. Wine, especially red wine, can take, and benefit from, some pretty rough handling near the end, or just after the end, of the yeast fermentation.

But also see the discussion in the next section on extended lees contact.

3. **Consider Bőcksin.** This is not a widely used strategy, but might be the only one available if you do not want to splash a white wine or use copper. Bőcksin is a German product available through Spagnol's. Bőck is German for the "rotten egg" smell of H₂S. Bőcksin is added to wine just at the end of the fermentation to help

eliminate H₂S. It does not work on mercaptans, just basic H₂S, and some people are not convinced it does much for H₂S either.

4. **Add sulfite and splash again after the fermentation is over.** You should NEVER add sulfite to your wine until the fermentation has been over for about 10-14 days. But if you detect H₂S at this point, a traditional recommendation is to splash again with the addition of sulfite. Add 50 ppm sulfite and then rack with a vigorous splashing. Beside blowing off some H₂S in the standard way, the SO₂ from the sulfite combines with H₂S to form elemental sulfur which falls to the bottom and gets removed in a racking two or three weeks later. Eisenman (n.d.) describes this technique. However, this runs the risk of oxidizing the wine and converting mercaptans to disulfides. It is probably better to proceed directly to copper treatment.

5. After the fermentation—lees contact and copper

Extended lees contact

Zoecklein (2003), citing French researchers, notes that extended light lees contact has been recommended for all premium wines, red as well as white. If this lees contact is managed carefully, it may reduce the level of reduced sulfur compounds in wines. If managed poorly, it can increase them.

The traditional recommendation is simply to stir the lees often (at least once a week) to make sure the lees does not start releasing reduced sulfur compounds.

French research has shown, however, that reduced sulfur compounds in a recently finished wine are best treated by separating the lees from the wine, racking and aerating the wine, keeping the lees stirred, and then returning the lees to the wine after 48 hours. Additional lees contact actually reduces sulfur compounds more than just racking off the lees and aerating. Apparently parts of the yeast cells form disulfide bonds with some of the volatile compounds in the wine.

Distinguishing mercaptans and sulfides

Most of the foul smelling (especially rubber) smells in young wines are mercaptans. These can be treated successfully with copper. Thanks to George Gibson, most of us are familiar with the "penny test" for mercaptans: put a penny (or a coil of copper wire or a silver spoon) in a small glass of wine and swish. If you have mercaptans, the bad smell will disappear almost immediately.

Incidentally, the term mercaptan is medieval in origin and comes from a combination of *mercurium* [mercury] *captan* [seizing]. Alchemists noted that the foul sulfury smells associated with some solutions disappeared almost instantly in the presence of mercury. Today, a piece of copper or a silver spoon provide safer ways to test for mercaptans.

Being careful with copper

If the fermentation is over and you have already splashed and sulfited, and if you still smell H₂S or mercaptans, you have little choice except to treat the wine with copper. Various strategies of using direct contact with copper have been suggested (splashing through a copper scrub pad, throwing some coils of copper wire in the carboy). But these are not recommended because they introduce an unknown amount of copper into the wine. Too much copper is a bad thing for two reasons:

- Health. Copper is a heavy metal, and although it does not accumulate in the body, too much is considered hazardous. Regulation in Europe permit only 0.2mg/L copper in wine; in the US it is 0.5mg/L. This may be a little more caution that is necessary for health. Multi-vitamins can contain daily doses of copper many times this level, and the WHO says 10-12 mg is probably safe on a daily basis. However, it makes sense not to put more copper in your wine than is necessary to do the job. And it usually doesn't take much.
- Appearance. Excess copper in white or rosé wine can create cupric casse (a copper haze). This happens only after the wine is in the bottle in a reductive environment. The symptom is fine dusty appearance, where the dust on close inspection is a reddish brown. The dust will eventually settle, producing a brown streak down the side of the bottle. Cupric casse can also combine with the more common protein casse. (See Peynaud (1984) for more information on casse and how to avoid it. The point here is only that too much copper is not good for the appearance of white wines.)

To control how much copper you put in your wine, always use a stock solution of copper sulfate and do bench tests to see how much solution you need per liter.

Steps in using copper

This is the procedure recommended by George Gibson. It assumes you have already used the "penny test" to determine that you have a mercaptan problem that can be treated with copper, so the only remaining issue is how much copper to add to a batch of wine.

1. Create a stock solution using 1 gram of copper sulfate in a liter of distilled water. [Be sure the CuSO₄ is dry, because it is quite hygroscopic and you will not get the right proportions if it has taken on water.] Each ml of your solution contains 1 mg of CuSO₄, which is 25% elemental copper. Therefore you will be adding 1 mg of copper for every 4 ml of stock solution.
2. Pour some wine into a glass for your standard. Then draw off a liter of wine and begin adding the copper solution to it one drop at a time. After each drop, mix thoroughly and pour off a glass for smelling and tasting. Compare with your standard. If the off-odor has not disappeared, pour the wine back into the liter and add another drop of solution. Record the drops you add and continue until the additions of the solution just eliminates the problem. [If you have a small pipette, this is a better than just relying on drops.]

3. Determine the amount you need for your wine. A drop is 0.5 ml, so if it took four drops in the liter to eliminate the problem, you need to add 2 ml/L to the remainder of the batch (remember you have already treated one liter). George Gibson's experience with 2001 wines is that 1 or 2 ml/L will be sufficient. The usual advice is not to go beyond 4 ml/L (although this is still well below health-concern levels). Pour the required amount of the solution into the wine and stir gently.
4. Remove the residue. The copper sulfide created from the reaction of the copper sulfate solution and the mercaptans should be removed from the wine. It is insoluble and will tend to settle. You can either fine/rack or filter or do both. One reason (according to some) you want to remove the copper sulfide is that the process is reversible, so with the passage of time your mercaptans can return.

Dealing with sulfides

Apart from H₂S, most common sulfides and disulfides in wine are not amenable to copper treatment. Because of their higher sensory thresholds, sulfides are usually not as much of a problem as mercaptans, but they can be for two reasons:

- They can add off-putting odors if the concentration is sufficient.
- Disulfides can revert, in reductive conditions found in the bottle, back to mercaptans.

There are only two approaches to disulfides, neither very satisfactory (which is why is best to catch H₂S and mercaptan problems at the outset).

The old way was to mix olive oil or mineral oil with your wine and agitate well several times, so that all the wine came into close contact with the oil. Sulfides are soluble in oil, so the oil attract the sulfides, after which you can skim the oil off the top of the wine. Needless to say, this is an act of desperation.

The newer way is to assist the reductive process by adding ascorbic acid to the wine, which helps scavenge oxygen, and leads (over time) to disulfides reverting to mercaptans. Then copper sulfate can be added to deal with the mercaptans. This is not a quick fix and not a sure one either. If you think you are up for it, consult Collings (2002).

Sources

Butzke, Christian E. (1997). Of rotten eggs, burnt rubber and cooked cabbage: a review and update on sulfide formation in wine. *American Vineyard*, March 1997.
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Good overview of the the mechanics of volatile sulfur compounds in wine. Builds on research done at UC Davis.

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Sets out the basic schema to test for and correct both mercaptans and disulfides. Note that Collings uses a copper sulfate solution stronger than some other schemes, which accounts for his low doses. His scheme of splashing a fresh wine through a copper scrubber is not recommended because it introduces an unknown quantity of copper to your wine.

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Muller, J.J. and K.C. Fugelsang (1996). "Post-bottling hydrogen sulfide in wines: 2,4,6-trimethyl-1,3,5-trithiane as a source." California Agriculture Technology Institute Publication #960303. <http://cati.csufresno.edu/verc/rese/96/960303/index.html>

Examines why some wines, especially cool-fermented whites, develop hydrogen sulfide and mercaptans in the bottle, even though there was no apparent sulfur-related problem initially. The culprit seems to be trithiane, which has a "dusty," "earthy" or "nutty" odor to begin with but which morphs in the bottle.

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Stevenson, Tom (n.d.). "Mercaptans," a section in his *Aromas & Flavors*. <http://www.wine-pages.com/guests/tom/taste6.htm>

Useful because it the perspective of a serious wine taster.

Zoecklein, Bruce (2003). Series of notes on sulfur-containing compounds in wine.
Enology Notes #70 (February 26, 2003), #71 (March 5, 2003), #79 (August 25, 2003).
<http://www.vtwines.info/>

Relies heavily on Butske (1997) but adds useful recent information based on French experiences.

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