On Brewing Bavarian Helles: Adapting to Low Oxygen Brewing

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> "I always thought something was fundamentally wrong with the universe."
> — Arthur Dent, The Hitchhiker's Guide to the Galaxy

1 Introduction

Bavarian beer is widely regarded as some of the highest quality beer in the world. Many beer aficionados believe that it possesses an "elusive" flavor quality that sets it apart on the world's beer stage. The simple fact is that there are no real "secrets" to brewing Bavarian beer, but it is brewed with the utmost dedication to quality. This means that there are quality control factors taken into account that are often completely overlooked by home and professional brewers alike throughout the rest of the world (though not without exception). Chief among these factors is the role of oxygen throughout the entire brewing process.

Ultimately, this guide is not just about brewing Bavarian beer, but about the importance of low oxygen brewing. That said, Bavarian Helles is the perfect showcase for low oxygen brewing because its flavor profile is *defined* by the unmistakable flavors of fresh malt undamaged by oxygen. Simply put, **you cannot make a proper Helles without employing a low oxygen brewing process.** After reading this guide, you will not only be properly equipped to brew an authentic Helles, but also to vastly improve the quality of every beer style that you brew.

These instructions assume you are already an avid home or professional brewer and have a good understanding of the basics of brewing. We assume you are an all grain brewer familiar with a precise temperature controlled mash schedules, and have the ability to hold a single infusion mash at a precise temperature. We assume you have dialed in a temperature controlled fermentation process, are familiar with yeast starters, estimating cell counts, practice procedures that assure basic (if not great) yeast health, and can monitor temperature changes as well as gravity during the fermentation process. We also assume you have some method of bulk storage for lagering and longer-term storage of your beers. We will discuss specific steps involved in better transfer, conditioning, storage and packaging of your beer to preserve freshness. Our goal is to deliver the most authentic results, in a method suited to your brewing equipment (with some critical changes applied), with a brew day that is likely not too different than what you already do.

You really don't want to skip a step in brewing this beer, because your results will only be as good as the weakest link in your process. If you do not keep the dissolved oxygen (DO) level of the wort below 1ppm (ideally below 0.5 ppm) throughout the entire hot side of your process, the fresh malt flavors will be gone before you even begin the boil. Indeed, by measuring DO levels alongside each batch, we have found that it takes less than 1 minute of oxygen exposure in excess of 1 ppm to completely rob the beer of the fresh malt flavor. In fact, if you can noticeably smell the fresh malt characters while you are mashing (or boiling), then you are losing them from your wort. Once they are oxidized and volatilized, they are no longer present in the wort nor will they be in your final beer. If you boil too hard or too long, then the flavors will be damaged and lost there as well. If the wort ferments too vigorously at too high of a temperature, then you can lose fresh malt flavor and aroma. If you pick up more than approximately 0.15 ppm of dissolved oxygen at packaging, then you will notice the fresh malt flavors begin to fade within a matter of weeks, if not days.

2 Wort Production

The topic of hot side oxidation (HSO) has long been debated and tested in homebrew circles, but every experiment which has previously been conducted has suffered from one fatal flaw: the malts are already oxidized before the experiment takes place. The strike water is already oxygen saturated before the grain is ever added, and the additional oxygen ingress from dough-in, as well as diffusion from the ambient air, is more than enough to spoil the wort. The oxidation of precious malt characters occurs in seconds to minutes. In short, the malt is oxidized before you are done stirring the initial dough-in.

If you have a dissolved oxygen meter, you can easily verify that the cold water coming out of your tap or RO system is saturated to a level of 8-12 ppm. While it is true that heating water will remove dissolved oxygen, at mash temperatures the solubility of oxygen in water is approximately 4-5 ppm. You might think that pre-boiling the strike water and rapidly chilling it before dough-in will solve the problem. What you will find is that pre-boiling and rapidly chilling your water can reduce the dissolved oxygen level to less than 0.5 ppm, doughing-in with the grist immediately adds between 1 and 3 ppm of dissolved oxygen. Furthermore, you can also verify with your dissolved oxygen meter that another 1-2 ppm of oxygen diffuses into the wort per hour from the atmosphere. In our experiments, we have found that even 1 ppm of dissolved oxygen present at any time during the entire hot side of the process is enough to ensure the loss of fresh malt flavors from the beer.

There is far more to HSO than the formation of trans-2-nonenal precursors typically associated with a "cardboard" flavor. In fact, HSO should be thought of as both the loss of malt flavors, as well as the creation of staling compounds. Oxygen can react with a great number of compounds in wort, including aromatic malt phenols. These compounds posses fresh, pleasant flavors and aromas on their own, but upon oxidation they quickly polymerize to form bitter tasting polyphenols and tannins [3]. Oxygen can also react with Maillard products from darker malts (such as caramel malt), altering their flavors by muting them or making them cloying. Unfortunately, copper, iron, zinc and manganese will accelerate the oxidization of malt compounds, and must be eliminated from the brewing system altogether.

Professional, modern brewing systems such as those manufactured by Krones have a variety of measures in place to keep oxygen in check. All brewing water is degassed as a standard part of water treatment, and delivery pipes for malt can be purged with steam or inert gases, such as nitrogen. The malt and degassed water is mixed together inline in a non-aerating fashion with the use of a pre-masher, and modern mash tuns are often heated with arrays of steam jets from the bottom. Steam can be used to purge atmospheric air from the mash tun before the malt is pumped in, and vibrating mash agitation systems such as the Shakesbeer device produced by Krones can aid in knocking dissolved oxygen out of solution. Indeed, Kunze recommends not only gassing the grist with nitrogen before dough-in, but even mashing under a blanket of nitrogen gas if possible [4].

We have streamlined an elegant procedure suitable for homebrewers that does not require a closed system that can be purged of oxygen. At its very essence, it requires the brewer to eliminate all sources of dissolved oxygen and oxidation accelerants, as well as to take advantage of oxygen scavengers to control the ingress of new oxygen. It requires that you pre-boil all of your mash water immediately before use, quickly force chill it to strike temperature, add a modest dose of sodium metabisulfite (SMB), and completely eliminate all sources of splashing or aeration (such as leaky pump lines). The SMB will act as a chemical oxygen scavenger and protect the mash from oxidation throughout the hot side of the process. Over the course of the boil and fermentation, excess sulfites will be scrubbed away or consumed by the yeast [1]. We have measured the final sulfite levels of beers brewed this way using commonly available sulfite test strips, and found that the sulfite levels in the finished beer are actually very consistent with levels found in commercial German beers, but well below levels found in most wines. We do not assume all suflites in commercial beers come from SMB additions, as yeast will produce some level of sulfite during fermentation [2]. Measure a bottle of your favorite commercial ale or lager, and you will likely see 10-15 ppm. Now, on to the recipe...

2.1 Water

For now, keep your water as simple as possible. The use of SMB will introduce both sodium and sulfate to your water, so we recommend starting with reverse osmosis water and simply adding enough calcium chloride to achieve 30 to 50 ppm of calcium. A 100 mg/l dose of SMB will add 24 ppm sodium to your water, and 76 ppm of sulfur compounds (sulfur dioxide, sulfite, and bisulfite). The amount of sulfate formed will depend upon how much oxygen is introduced into your system and subsequently scavenged by the sulfites. Again, pre-boiling to drive off DO for any water that will come into contact with malts or wort at any point in the process is critical. The use of SMB should only serve to control the ingress of oxygen. We have found other methods capable of removing DO, such as degasing towers and vacuum systems, but is beyond the scope of this guide.

2.2 Malt Bill

This recipe is a very basic helles recipe, but is a perfect showcase for low oxygen brewing:

- Original gravity 12 Plato, final gravity 2.5 Plato
- 88% German pilsner malt
- 6% German Carafoam malt
- 4% German Carahell malt
- 2% Acidulated malt

In the future, try tweaking the recipe to your tastes by exploring the wide range of caramel and specialty malts offered by German maltsters. For example, an addition of 1 to 2% Caramunich or melanoidin malt adds some extra depth to the beer. If this beer turns out too sweet for you, try cutting the Carahell down to 2 or 3%. For your first low oxygen brew, it's best to stick to the recipe above!

The acid malt addition here should give you a mash pH of approximately 5.35 to 5.4. You may find that when using SMB, your mash pH will be approximately 0.1 lower than predicted by the common brewing water calculators. For that reason, we suggest using a water calculator to adjust the amount of acidulated malt you will use. Target a pH of 5.45 to 5.5 with your water calculator, and you will likely find that your mash pH falls between 5.35 and 5.4.

It is recommended to condition the malt prior to milling with 1-2% water by weight. This will keep the husk intact and reduce the number of lipoxygenase and peroxidase enzymes into the mash, which would otherwise accelerate the oxidation of malt lipids and phenols [4]. Make sure that your malt is fresh and has been properly stored (do not attempt to brew this recipe with 3 year old malt), and crush it immediately before doughing in. The husk is an effective barrier against oxygen, but oxidative staling reactions rapidly accelerate the moment that the barley is crushed.

2.3 Hops

We recommend a simple hopping schedule using a single noble-type hop such as Hallertau Mittlefruh or Hersburcker. You will add 30% of the hops by weight during lautering as first wort hops, and the rest of the hops as a bittering addition in the boil. We recommend a simple formula for computing the hop addition:

$$W = \frac{B * V}{1000 * A * U} \tag{1}$$

where W is the total weight of the hops to be used in grams, B is the desired bitterness in IBUs, V is the final volume of post boil wort in the kettle in liters, A is the alpha acid content of the hops (4.7% AA means that $A = 0.047$), and U is the assumed hop utilization.

For our recipe, we will target 16 IBUs and assume a utilization of 28% (i.e. set $U = 0.28$ and $B = 16$). Utilization will vary from system to system; if your beer ends up too bitter, try raising the utilization to 30%, and if it ends up not bitter enough try lowering it to 25%. For example, assuming your post boil volume is 21 liters, your hops contain 4% alpha acids, and your utilization is 28%, you would use a total of 30 grams of hops. 9 grams would be used as first wort hops, and 21 grams as bittering hops at the start of the boil.

2.4 Mashing

First, heat your mash water and boil vigorously for 5 minutes. Then, force chill it to your strike temperature as quickly as possible. An immersion chiller works well for this, but again, do not use a copper chiller or any copper equipment whatsoever at any point in your process as the oxide layer is very soluble and promotes rapid oxidation of the wort.

Now, add 100 mg of SMB powder for every liter of mash water. If you don't have powder and are instead using Campden tablets, there is 440 mg worth of SMB in each tablet (the rest of the tablet is filler). We should note, potassium metabisulfite is not recommended, as an excess of 10 ppm potassium can be detrimental to the mash [5]. Mix the sulfite powder (or crushed Campden tablets) into the strike water very well, and let the water rest for 5 minutes before doughing-in to allow the sulfites to scavenge any remaining oxygen. Roughly speaking, it takes approximately 5 ppm sulfite to scavenge 1 ppm oxygen, so this dosage offers protection for up to 15 ppm oxygen (not a static amount, but total over time). In practice it is important to keep the concentration of the sulfites high enough to ensure that they can scavenge any free oxygen before it has the chance to damage any malt compounds.

By adding the SMB at different points in the process and measuring the resulting DO, we have learned that it is not sufficient to simply throw a few Campden tablets into the mash and hope for the best. Doughing in to oxygen saturated strike water and then subsequently adding the sulfites is too little too late; the oxidative reactions in the mash begin within seconds, and the peak reaction rate occurs within 30 seconds to 1 minute after dough in [4]. It is absolutely essential that the strike water's dissolved oxygen content is as close to zero as possible before the grain is added. For this reason, a dissolved oxygen meter is an extremely valuable investment. Without one, you are flying blind. With a meter, you can monitor oxygen throughout the entire process and identify any weak points in your system.

Doughing-in is perhaps the most deleterious process in low oxygen brewing. Ideally, you have a bottom filling system and can first add the grist to your tun and slowly fill with water from below. If not, add the grain from above as gently and slowly as you possibly can. It is absolutely **critical** that you dough-in gently and do not splash or agitate in an aerating fashion. If your grain is floating, then you can assume there is air trapped in the grain. You want to avoid this at all costs, as it will both oxidize malt character and heavily consume the SMB.

You want to spend as little time as possible mashing, and introduce as little oxygen possible. We recommend a Hochkurz mash with a 30 minute rest at 62C, and a 60 minute rest at 72C. It is advisable to keep a lid on the tun for the entire duration of the mash with as little head space as possible. If your tun has a lot of headspace, consider fabricating an inset lid or "mash cap" that can float or otherwise sit nearly flush to the surface of the mash.

If you use pumps in your system, you need to check all of your connections for air leaks. Test your system with water and look for air bubbles getting sucked in the lines through leaks in the fittings; these leaks infuse air into the wort and must be completely eliminated. You should never need to pump quickly, and excessive flow will be detrimental to the wort, or at best consume the SMB more quickly. A flow rate of approximately 4 liters per minute is a good target, although 6-8 l/min may be necessary if using propane burners to supply heat for the mash steps. It is also essential that the return inlet be below the water level in the mash tun to avoid splashing. Under no circumstance should wort be allowed to drop or spray back into the top of the mash tun.

At this point, you should notice that your mash is far less aromatic than normal. This means all of the desirable malt aroma compounds are staying where they should be - in the wort! Upon completion of the mash, taste the wort. You have likely never tasted wort like this. Rather than tasting wort that is dull and cloyingly sweet with an off-putting background bitterness, if done properly you will taste fresh grain, maltomeal, and wildflower honey. This is the true flavor of wort, untarnished by oxygen damage!

2.5 Lautering

A no-sparge system is easier to keep oxygen free than a system that requires a sparge. However, if you are forced to sparge, all of your sparge water should be treated similarly to your mash water - that is, pre-boiled, chilled, and dosed with SMB. A dose of 10-25 mg/l SMB powder is sufficient for sparge water, and you must be absolutely sure to introduce the sparge water in a non-aerating fashion. Again, do not splash or sprinkle from above!

We recommend that you add your first wort hops to the boil kettle during lautering, so that they have a chance to steep in the wort for at least 30 minutes. We have noticed that the flavor and aroma from first wort hopping a low oxygen wort is extraordinarily fine, and carries through wonderfully into the finished beer. This may be due to the lack of oxidation of hop compounds that would typically occur when first wort hopping an oxygen saturated wort.

2.6 Boiling

As critical as oxygen control is, so is the control of heat stress. Heat stress on the wort can accelerate oxidation reactions and tarnish the flavor of the beer. We recommend a 60 minute boil, with a total evaporation of 10% or less. This will most likely look more like a simmer to you than a vigorous boil, but commercial German breweries routinely boil under pressure for as little as 30 minutes, and target evaporation rates of 4% [4]. If you have access to an accurate thermometer or use a PID, then you want to control your boil temperature by targeting 98-99C.

Your boil pH should begin around 5.4, and end between 5.1 and 5.2. You should see a natural pH drop over the course of the boil, but if you are on the high side, you can acidify 10-15 minutes before knockout by adding sauergut or lactic acid.

Once the boil is complete, chill your wort as rapidly as possible to 5-6 degrees Celsius. Do **not** aerate or do anything which would introduce oxygen into the wort! Again, copper imemrsion chillers should be avoided. It is okay to get cold break into the fermenter, but you should make every effort to keep the heavier hot break material and especially the hop trub out of the fermenter.

3 Primary Fermentation

Even after the wort is chilled, it is still vulnerable to oxygen damage. For that reason, it is not advisable to leave the wort overnight or for a prolonged period of time without active yeast in suspension to scavenge the free oxygen. Every effort should be made to reach pitching temperature (5-6 degrees Celsius) and add the yeast as quickly as possible. In fact, from this point forward, yeast is the best protection against oxidation damage. The pitching rate we recommend is approximately 20 to 30 million freshly grown cells per milliliter of wort for a 12 Plato beer [4]. This rate is considerably higher than what many pitching rate calculators estimate, but necessary for the classic cold fermentation schedule. We recommend WLP838 or WY2308, but have had excellent results with WY2124, WLP835 and WLP860 as well. We do not recommend dry W34/70 yeast. The yeast should be well mixed into the wort, and oxygen or sterile air added only after pitching, with a target DO level of approximately 8 ppm [4]. In our experiments, we have measured the oxygen consumption of the yeast to be approximately 2-3 ppm per hour after pitching, with scavenging beginning within minutes. With a cold pitching temperature and plenty of yeast, you will find that you have no need for a diacetyl or maturation rest at a high temperature.

The temperature of the fermenting beer should be allowed to rise to 8C over the course of 48 hours. It should then be held at 8C until approximately 45% apparent attenuation is reached, at which point it should be cooled by 0.5 to 1 degrees Celsius per day. Your target is for the beer to reach 5-6C by the time that its gravity is 1.5 Plato above your expected final gravity. A fast ferment test is a great way to predict this final gravity.

4 Secondary and Lagering

We recommend racking the beer to a keg while fermentation is still active and there is still fermentable extract remaining. At this point, the beer temperature should be approximately 5-6C. Once your beer's gravity is approximately 1.5 Plato above your expected final gravity, rack the beer into a CO2 purged keg. Filling the keg full to the rim of the opening with sanitizer before pushing it out with CO2 is essential for removing as much oxygen as possible. After flushing the keg you want to fill the keg as close to the brim as possible with the incoming beer; however, this can be limited by the length of the gas dip tube. If the beer level is above the level of the dip tube, then beer will be forced out the spunding valve during carbonation and you will also be left with more headspace in the keg than is optimal. An effective trick is to cut the gas dip tube short, so that the beer can safely fill the keg nearly to the brim. After racking, attach a pressure relief valve (spundapparat, but commonly called a spunding valve) set to 0.8 bar. You can now continue dropping the temperature approximately 0.5C per day, but may want to hold the beer at 3C until final gravity is reached - this may take a couple weeks. At that point, you can continue dropping the temperature until you hit -1C, where the beer should be held for 2-4 weeks. Make sure that your lagering keg is capable of sealing without internal pressure, otherwise the carbon dioxide will leak out and oxygen will leak in! If none of your kegs are capable of this, try seating the lid by pressurizing the keg to 0.3 or 0.4 bar after filling it.

You may be wondering why spunding is so important, and the answer again is oxygen control. In our previous experiments, we measured that the standard homebrewing kegging practices pick up 0.8 to 1 ppm of dissolved oxygen, even with careful purging. A volume of air smaller than would fill a shot glass, if trapped in the keg, contains enough oxygen to raise the dissolved oxygen level of a 20 liter batch of beer by more than 0.2 ppm. With a dissolved oxygen level of 0.8 ppm, the fresh flavor of the beer fades within a week, even at cold temperatures. The lowest level of dissolved oxygen in the packaged beer that we were able to achieve without spunding was 0.4 ppm, and in this case the beer's fresh flavor began to fade after approximately 4 weeks in the keg. Not only will spunding provide you with exquisite natural carbonation, it is also the most effective means of oxygen control available to a brewer. Active yeast at kegging will leave the beer with an oxygen content of practically zero!

While the beer will continue to slowly ferment, clarify, and improve in flavor during the lagering process, we encourage you to steal the odd sample to taste along the way. You will notice that the flavor of the beer is very different than what you are probably used to, and approximately 6 to 8 weeks after racking to the lagering keg, you will be rewarded with a beer rivaling that which you would be served in a Munich beer hall.

5 Packaging

Serving out of the vessel in which the beer was naturally carbonated eliminates any risk of oxygen getting into the beer once the yeast have gone dormant from lagering. To date, we have had no instances where we observed off-flavors resulting from the yeast that settled during spunding and deep cold lagering. However, if you are concerned about yeast during very long storage periods or need to transport your beer, you can jump from one keg to another (umdrücken), leaving the yeast and precipitated particles behind. The risk of this method is that is you are transferring without the protection of active yeast. Great attention must be paid to ensure that all oxygen is fully removed from the final serving vessel and that all connections are completely airtight and will not introduce oxygen into the beer through a venturi effect. Because it only requires such a small volume of air trapped in the destination keg to oxidize a 20 liter batch of beer, this method is extremely risky and requires further refinement before it can be recommend for anything but short term storage.

Additionally, you can use a counter pressure bottling unit for transferring from the lager vessel to glass bottles. The same risks apply as with jumping between kegs, but you have more efficient control over purging small bottles over a large keg. While the risk of introducing oxygen during packaging is very high, you can still utilize yeast and oxygen scavengers to control oxidation. Bottling with krausen is the most complete way to ensure that all oxygen will be consumed in the bottle. An addition of 5-10 mg/l of SMB can provide some oxygen scavenging protection during packaging and bottling, but is nowhere near as effective as active yeast.

6 Conclusions

Although mostly foreign in the American home and craft brewing communities, Low oxygen brewing is common practice not only in Germany but also in the world's macrobreweries. Indeed, beers from Kirin to Guinness to even Budweiser have the characteristic low-oxygen flavor if you look for it. Typically, the flavor is more subdued compared to German beer because of the high proportion of non-malt adjuncts and low proportion of caramalts used in the brewing process, the low starting gravity of the beer (or the post-fermentation dilution of the beer), and the tight filtering employed which provides the beer with prolonged shelf stability but robs it of flavor.

Low oxygen brewing completely transforms the flavor of every malt, but especially caramel malts. With hot side oxidation damage, caramel malts become cloying and unpleasant; with low oxygen, their flavor is sweet in a crisp and refreshing way, and they greatly enhance the malt character of the finished beer. You will soon take pleasure in experimenting with blending different caramel malts in proportions as high as 5-10% for regular ales and lagers, and even up to 15% in beers like hefeweizen! Without the bitter flavor of oxidized base malt and the cloying flavor of oxidized specialty malt, the effects of other variables in the brewing process become far more pronounced, such as the flavor improvements offered by short, gentle boils, first wort hopping, and classic cold fermentation with lager yeast strains.

There is a wide-open world of possibilities when it comes to future work and improvements that can be made for the low oxygen brewing process at home. Alternative degassing methods such as packed columns or even ultrasonic sonotrodes could be employed instead of pre-boiling the mash water, and may even find use in the mash. Steam heating systems mounted at the bottom of the mash tun and boil kettle would provide a convenient way to purge the vessels of atmospheric air, as well as scrub any oxygen out of solution that does manage to find its way in. Such techniques could even possibly eliminate the need for chemical antioxidants such as sulfite.

There are a vast number of questions still to be answered and many new styles, recipes, processes and ingredients that need to be tested using the low oxygen method. It is our belief (and has been our experience) that many variables we once thought to be insignificant, such as fermentation temperatures, yeast strains, pitching rates, barley strains, maltsters, etc., will now be far more noticeable when tested using low oxygen methods. It is our hope that the members of the German Brewing Forum, along with other groups of brewers, continue to research, adapt and improves methods of low oxygen brewing. Lastly, we hope that those who try these methods finally achieve the elusive Bier Gemütlichkeit with their own brewing.

References

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