On Brewing Bavarian Helles: Adapting to Inert 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). Many factors constitute the *Inerte Arbeitsweise* in Bavarian brewing, and 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 in the *Inerte Arbeitsweise*. That said, Bavarian Helles is the perfect showcase for low-oxidation 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 an inert and low-oxidation 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 capable of step infusing mashing, and you have a temperature controlled fermentation system. We assume that you are familiar with yeast starters, estimating cell counts, procedures that assure basic (if not great) yeast health, and can monitor 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 1 ppm (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 0.10 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 small-scale 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 atmosphere during the mash, is more than enough to damage 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 to 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. While free dissolved oxygen is relatively harmless in solution, once catalyzed to oxygen radicals, or superoxides, it 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]. Superoxides 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 formation of superoxides and oxidization of malt compounds through a series of Fenton and Fenton-like reactions, 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 grist is milled in-line with the delivery pipe under a blanket of inert gas, and subsequently mixed in-line with degassed water in a non-aerating fashion with the use of a pre-masher. Filling always takes place from below, and modern mash tuns are not only closed, but often equipped with the ability to purge air using steam or inert gas like nitrogen. More exotic measures, like 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]. One of the most significant advantages a professional system has over a homebrew system is its size. As a 3-dimensional shape such as a cube is scaled up in size, its surface area increases proportionally to the square of its side length. However, its volume increases proportionally to the cube of its radius - this phenomenon is known as the Square-Cube law. A commercial-sized volume of 1,000 hectoliters of wort will have surface area to volume ratio nearly 20 times smaller than a homebrew-sized 20 liter volume of wort. Because the rate of diffusion of atmospheric oxygen into the wort is directly proportional to its surface area, this influx happens full orders of magnitude faster at the homebrew scale! This also applies to small-scale research systems in academic settings.

As we just outlined, the modern low-oxygen commercial brewhouse can rely on mechanical methods and the laws of physics to maintain extremely low levels of oxygen exposure during processing. These same methods are simply out of reach for homebrewers, so a different approach must be taken to keep oxygen in check. 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 sulfites 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. Using 1 mg/l of SMB will add 0.24 ppm sodium to your water, and 0.76 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. We recommend a starting dose of 40 to 50 mg/l SMB in the mash water and 10 to 15 mg/l SMB in the sparge water, so the amount of sodium and sulfate contributed to your water profile will depend on the ratio of strike to sparge water as well as your particular dose. 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.

It is important to note that the SMB dose is ultimately system specific and will need to be reduced as you "tighten up" your system and incorporate all of the basics of lodo brewing. Using copper immersion coils during chilling will mask the overuse of SMB as the copper will remove excessive sulfites. If you begin to notice residual sulfur (matches, eggs, etc.) in your beers (especially when making styles other than Helles), then you should begin experimenting with dialing back your SMB dose. It is important to note that not all strains of yeast will utilize or tolerate sulfites in the same manner as lager strains, and you may have to adapt the SMB dose accordingly.

2.2 Malt Bill

Bavarian Helles is commonly brewed in two forms, Helles and Helles Export; however, many smaller breweries in Bavaria produce a more rustic or Country style of Helles. Helles is slightly lower in gravity and generally posses a richer and fuller malt profile than Export. Helles Export is generally brewed slightly higher in extract and with lower percentages of specialty malts. Country Helles is a more robust interpretation of Helles, often registering up to a full 9 EBC due to increase percentages of specialty malts. We present three simple recipes consistent with the Narziss and Kunze guidelines for Helles, as well as the Export and Country variations, that are excellent baselines for showcasing the results from inert brewing.

Helles

- Original gravity 11-12 Plato, final gravity 2.5-2.7 Plato, 16-18 IBUs
- 85-86% German Pilsner malt
- 10% German Vienna malt
- 2% German Carahell malt
- 2-3% Acidulated malt

Export Helles

- Original gravity 12-13 Plato, final gravity 2.4-2.6 Plato, 18-20 IBUs
- 91-92% German Pilsner malt
- 6% German Carahell malt
- 2-3% Acidulated malt

Country Helles

- Original gravity 12-13 Plato, final gravity 2.5-2.7 Plato, 18-20 IBUs
- 77-78% German Pilsner malt
- 10% German Vienna malt
- 5% German Munich malt
- 5% German Carahell malt
- 2-3% Acidulated malt

In the future, try tweaking the recipe to your tastes by exploring the wide range of base, karamell and specialty malts offered by German maltsters. Helles is built upon Pilsner, Vienna and Munich malts, using small amounts of bruhmalts and karamalts for rounding out the flavor profile. By adjusting the percentages and blend of Pilsner, Vienna and Munich malts, you can brew the entire spectrum of pale lagers from Helles to Festbier to Hellesbock. Country helles is the most provincial and least standardized, and thus provides the most latitude for exploration. Over time, explore different balances of Vienna to Munich and even reverse the recipe to only have one bruhmalt and two karamalts. Some incredible flavors can be achieved in Country Helles with simply the proper balance of Vienna to Munich malts or carahell to caramunich. But for your first low-oxidation brew and proven baseline, stick to one of the recipes above!

The acid malt addition here should give you a predicted mash pH of approximately 5.3 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 5.4 to 5.5 with your water calculator, and you will likely find that your mash pH falls between 5.3 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 in 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 (especially when conditioned).

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 to 20 IBU and assume a utilization of 26 to 28% for pellet hops (e.g. set $U = 0.28$ and $B = 18$). Utilization will vary from system to system, and will be lower with whole cones (approximately 22 to 23%); 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 24 or 25%. For example, assuming your post-boil volume is 21 liters, your hops contain 4% alpha acids, your utilization is 28%, and you desire 16 IBU, 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 Biological Acidification

In all German beers produced under the Reinheitsgebot, acidification of the mash and boil is performed solely with lactic acid produced by the action of bacteria found naturally on the surface of the malt. This can take two forms: sour malt, (also called acidulated malt or sauermalz) or sour wort (also called sauergut). Of the two, sour wort is widely preferred.

Biological acidification is not simply about conforming to a protectionist law, as many studies have found that the use of sauergut in the mash and boil brings additional benefits to the beer that technical acid does not offer by itself. Sauergut in the mash has been found to nearly double the amount of zinc extracted from the malt, an essential yeast nutrient whose presence is also purported to have positive benefits for foam and body. Additionally, many of the metabolic byproducts of the lactobacillus have a positive impact on the redox potential of the beer, and sauergut can in fact act as an antioxidant of sorts during the brewing process. Beyond these benefits, sauergut has a unique flavor signature reminiscent of Berliner Weisse, and when used in the production of light lagers like helles, it imparts a refreshing, faintly yogurt-like character to the beer that you will be able to recognize in most commercial examples of helles.

Making a sauergut mother culture can be summarized as follows:

1. Reserve some pre-boil wort at 10-12 degrees Plato (dilute if necessary).
2. Cool the wort to 48 degrees C
3. Drop the pH of the wort to 4.5, either by adding raw, uncrushed acidulated malt or already-made sauergut
4. Inoculate the wort with lactic acid bacteria either by adding some already-made sauergut or by adding approximately 20 grams per liter of raw, uncrushed Pilsner malt
5. Put the inoculated wort into a sealed, oxygen-free container which can easily be vented, as the souring process will produce some CO2
6. Incubate the wort at 48 C +/- 1 C until it reaches your desired acidity; this generally takes between 24 and 36 hours.

After it has soured, sauergut can be stored for several weeks, or even months, as long as it is kept in a sealed, oxygen-free environment at approximately 3 degrees C. When you brew, you simply measure out how much sauergut you need, and then top off the culture with fresh wort taken during lautering. It is important not to use hopped wort, as the hops will prevent the growth of lactic acid bacteria.

There are many ways to maintain a sauergut culture. A small keg fixed with an adjustable pressure relief valve makes a perfect incubator, as it can be purged with CO2, wrapped with heat wrap or put in a hot box during incubation, and then moved into a chest freezer or fridge for longer term storage. For smaller batches of sauergut, mason jars can be employed and incubated in a temperature controlled water bath. A sous vide works wonderfully for this, as does a slow cooker fitted with a temperature controller. Mason jars need to be burped periodically during incubation in order to release excess carbon dioxide.

The strength of the sauergut depends on how long it is incubated. Some strains of lactic acid bacteria are capable of producing up to 2% acid, but this can take quite some time. You can test the strength of your sauergut via titration, by using some in a mini-mash and measuring the pH drop after the sauergut is added, or by gradually adding it to your mash until your pH target is reached. However, generally speaking, the sauergut will reach approximately 0.8% acid very quickly (within about 24 hours), after which acid production slows dramatically. It is therefore reasonable to assume in practice that sauergut incubated for 24-36 hours will have an acidity of 0.8%.

At 0.8% acid, it takes 60 ml of sauergut for every kg of malt in the grist to drop by a pH of 0.1 in the mash, and half that amount to drop by 0.1 in the boil. Therefore, if you were to use 5 kg of malt in your mash and wanted to drop the pH by 0.4, you would use $60*5*4 = 1200$ ml of sauergut in your mash. Later on in the same brew, if you wanted to drop the pH in the boil by 0.2 you would add $30 * 5 * 2 = 300$ ml of sauergut.

Acidification is generally performed in multiple stages, with a portion added to the mash and another portion added to the boil. The timing and amount of sauergut used in each stage is up to the brewer. Several strategies are outlined below:

- Acidify the mash to 5.2; do not perform a boil addition
- Acidify the mash to 5.2, acidify the boil to 5.0 between 5 and 10 minutes from knockout
- Acidify the mash to 5.4; boil 10 minutes or until hot break forms, and then acidify the wort to 5.2 and continue the boil; acidify to 5.0 a few minutes before knockout
- Acidify the mash to 5.4; acidify the boil to 5.0 a few minutes before knockout

The acidification strategy depends on the brewer's goals and individual system. There are many trade-offs to consider:

- 5.4 is a balanced mash pH which favors both alpha and beta amylase, and may produce a more full-bodied beer. 5.2 favors beta amylase, may produce a dryer and crisper beer, and better inhibits the action of oxidizing enzymes in the mash such as LOX and PPO.

- Hot break formation is optimal at 5.4-5.5; at 5.2, it becomes powdery. Cold break formation is optimal at 5.0-5.2
- The wort darkens more during the boil at 5.4 vs. 5.2
- DMS is driven off faster during the boil at 5.4 than at 5.2
- Hop utilization decreases with decreased boil pH. However, the quality of the bitterness may also be cleaner at a lower pH.
- The strength of the sauergut flavor that carries over into the finished beer is stronger when it is added late in the boil, compared to early in the boil or in the mash.

2.5 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, we do not recommend a copper chiller. Copper tends to leech into the wort, and it takes only a few parts per billion for the Fenton oxidation reactions to take place.

If you are going to sparge, add 40 to 50 mg of SMB powder for every liter of mash water. If you employ a no-sparge mash, reduce this dose to 25 to 30 mg/l. 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 no more than 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. The dose recommended here is on the higher side, and as you tighten up your system and improve your wort handling techniques you will likely be able to decrease your dose.

It is also worth noting that the SMB dose can be reduced when working in combination with ascorbic acid (AA) and Brewtan B (BB). Ascorbic acid is a proven antioxidant, though slightly less effective in solution at scavenging oxygen than SMB. However, enzymes exist within the malt that increase the effectiveness of AA as an oxygen scavenger. Using AA allows you to reduce the sulfur load in the wort, which is especially important when making ales. Brewtan B is a blend of gallotannins and serves to bind up Fenton-like metals and prevents the formation of superoxides in solution, thereby reducing the oxidation potential of any dissolved oxygen in the wort. Equal parts AA, BB and SMB is a good starting point when exploring the trifecta for blocking oxidation pathways in wort, but you should reduce the SMB to 25 to 30 mg/l regardless of lautering method.

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 step infusion mash with a 30 minute rest at 62-65C (depending on malt analysis specifications), a 30 minute rest at 72C, and a 10 minute mashout rest at 76c. 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 3-4 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. When using Vienna and Munich malts in your grain bill, you will also taste croissants, crescent rolls, cookie dough and graham crackers. This is the true flavor of wort, untarnished by oxygen damage!

2.6 Lautering

A no-sparge system is easier to keep oxygen free than a system that requires a sparge. However, if you do 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 10-15 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!

2.7 Boiling

While oxygen control is critical, control of heat stress on the wort is also essential to the Inerte Arbeitsweise and for preventing wort damage. 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 6 to 8%. 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]. Don't worry about DMS ending up in your beer, as 6-8% evaporation is more than sufficient, as the Cube-Square law works in favor of off-gasing volatile compounds on small systems. We also recommend that you boil with the lid partially or mostly covering the kettle, as this will limit exchange with the atmosphere and reduce the amount of heat that your burner needs to apply to maintain the boil.

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 until after yeast has been pitched. Again, copper immersion chillers should be avoided. It is okay to get some 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 Fermentation

Fermentation is one area that separates an ale from a lager, and especially a good lager from a great lager. Classic Germans fermentations are broken down into primary and secondary fermentation with specific purposes for each that are generally unnecessary with ales. Additionally, we present two proven variations on primary fermentation, including the classic cold and classic warm fermentation. These are just classic examples of lager fermentations [4, 5, 1]; many others exist, including fast ferments and 21 day lager schedules. We encourage you to experiment and find the schedule which works best for your system and chosen yeast strain.

3.1 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 radicals. 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 can recommend WLP835, WLP833, WLP838/WY2308, WLP860, WY2206, and WLP830/WY2124 as producing excellent results with classic fermentation profiles. 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.

We recommend following the classic cold fermentation schedule for best results, however the classic warm fermentation can be used and is actually recommended for dunkel. For the classic cold fermentation, the yeast should be pitched at 5 to 6C, then the temperature of the fermenting beer should be allowed to rise to 7 to 8C over the course of 48 hours. It should then be held at 7 to 8C until approximately 45-60% apparent attenuation is reached, at which point it should be cooled by 0.5 to 1 degrees Celsius per day. The target is for the beer to reach 3 to 5C by the time that its gravity is 1 Plato above the expected final gravity. A fast ferment test is a great way to predict this final gravity. The classic warm fermentation follows the same principles, except that the pitch temperature is 7 to 8C, target temperature is 10 to 11C and the target temperature for secondary fermentation is 5 to 6C.

3.2 Secondary, *Schlauchreife* and Spunding

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 Plato above your expected final gravity, rack the beer into a CO2 purged keg. Be careful not to rack too early, as you don't want to carry too much yeast into the lagering keg, which can result in autolysis and accelerated flavor loss. Filling the keg full to the rim of the opening with sanitizer or boiling water 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 0.3-0.5C per day. Until you evaluate the reliability of a new yeast in your system with your propagation methods, or are simply unsure of your yeast health, you may want to simply hold the beer at 3-5C until terminal gravity is reached. If you know your yeast will work colder, continue dropping until you hit 1 to -1C depending on your capabilities. Once the beer is fully attenuated, hold it at 1 to -1C for at least another 2-4 weeks for it to drop clear. 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!

3.3 Lagering

Lagering is often referred to as cold stabilization. Once the beer has reached terminal gravity and pressure is no longer being released from the spunding valve, you can begin cold lagering to clarify the beer and impart that deep, refined lagering character some call "tank taste". Though yeast activity mostly subsided, residual sulfur compounds and other off-flavors will also continue to be removed over time. Additionally, unwanted compounds like polyphenols and tannins will settle out of suspension, and esters will be reduced. While the beer will continue to slowly evolve, clarify, and improve in flavor during the lagering process, we encourage you to steal the odd sample to taste along the way. You may find that the length of lagering time for your own personal sweet spot is different, and will likely vary by style as well. However, you will notice that the flavor of the beer is very different than what you are probably used to, and after the beer has fully cleared you will be rewarded with a beer rivaling that which you would be served in a Munich beer hall.

4 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 few instances where we observed off-flavors resulting from the yeast that settled during spunding and deep cold lagering; however, autolysis from carrying over too much yeast into the spunding vessels will accelerate oxidation and flavor loss. 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 (such as by filling with degassed sanitizing solution or boiling water and pushing it out with CO2) and that all connections are completely airtight and will not introduce oxygen into the beer through a venturi effect. This includes all threaded fittings and especially all o-rings on pin and ball lock keg posts. 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.

5 Conclusions

Although mostly foreign in the American home and craft brewing communities, inert and low-oxidation brewing (LODO) 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.

Inert 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-oxidation brewing, 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 inert 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-oxidation methods and basic principles of *Inerte Arbeitsweise*. 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 these methods. It is our hope that the members of the German Brewing Forum, along with other groups of brewers, continue to research, adapt and improve methods of inert and low-oxidation brewing. Lastly, we hope that those who try these methods finally achieve the elusive *Bier Gemütlichkeit* with their own brewing.

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