

THE DEFINITIVE GUIDE TO
ALL GRAIN
BREWING
(PART 1)

Powered by



CONTENTS

BREWING

1. AN INTRODUCTION	P.1
2. MALT	P.2
3. HOPS	P.6
4. WATER	P.9
5. YEAST	P.13
6. MILLING AND SPARGING	P.17
7. BOILING	P.23
8. FERMENTATION	P.26
9. BOTTLING AND KEGGING	P.29

BREWING

1. An Introduction

Brewing, in some form or other, has been around for thousands of years, with evidence of recipes dating back nearly as far as 2000BC.

At one point, drinking beer was safer than drinking water, due to the fact that beer had been boiled. Women were responsible for making beer for the family who would sit down to each meal with an accompaniment of beer. In the ninth century, it was discovered that boiling beer with hops would help the beer to keep better. Previously, brewers would use other herbs, spices and flowers to make "Gruit" which, without the antibacterial qualities of hops, would stale much quicker than beer, explaining why all commercially produced beers today contain hops to some degree.

Beer quickly became the most popular alcoholic beverage in the world, with currently around 2 billion hectolitres being brewed worldwide, per year. In recent times this has largely been dominated by huge global brands producing consistent beer in huge volumes [predominantly lager]. Craft breweries, synonymous with innovation in flavours and often higher percentage beers are starting to take more of the market. Being smaller and less constrained by market forces means these breweries are able to push the boundaries and produce more exciting, diverse beers. The definition of craft beer is about as cloudy as the heaviest dry hopped beer, but our take on it is that a craft beer is one which is crafted, rather than simply produced. With quality and individuality the main driving forces, rather than cost and efficiency

As home brewers we are even less constrained, for us a good beer can be anything that we enjoy and we don't have to cater to other peoples tastes. In the quantities we brew it we will not be heavily affected if a batch turns out bad. We can experiment with flavours and techniques on a level that just isn't possible in commercial volumes and this can give us a real advantage. Some of the most interesting beers we have ever tasted have been made in someone's kitchen - and despite the term "home brew" being synonymous with the rocket fuel produced in a bath tub from years gone by, we would expect many beers made at home today would rival even the most highly regarded commercial brewery offerings. The availability of high quality, fresh ingredients these days makes this possible. With a Grainfather, you also have a tool to make this process easy, controlled and repeatable, whilst retaining the hands-on enjoyment all brewers feel while creating beer.



We designed the Grainfather to make it easy for anyone to make craft beer at home, regardless of their experience, using techniques that the best commercial breweries would use. This booklet is designed to be of use to brewers of all levels, whether you are just starting out and want to learn about the process or if you've had many successful brews and you're just after some recipe inspiration.

We want everyone to enjoy making beer!

BREWING

2. MALT

Malt is germinated, dried, cereal grain, forms the base of all beers providing the sugars which are converted to alcohol, the colour, flavour and body of our beers. There are a great variety of cereal grains which can be malted, but as brewers we will most commonly see barley and wheat. These are grains which have a naturally high starch content and starch is required for the formation of sugar and the eventual production of alcohol.

Before it can be used for brewing however, malt must be treated to allow the brewer to efficiently extract the sugar. The grains do not naturally contain the enzymes that are required for converting starch to sugar until they have gone through the malting process.

This process involves harvesting the cereal and then keeping it in conditions which speed up its natural development. To do this, the cereal kernels are soaked in water to be softened and kickstart the germination process. This process is then halted via kilning before the kernels sprout, when the acrospire is roughly three quarters of the length of the kernel. This germination process softens the endosperm of the grain, allowing for easier access to the proteins, enzymes and starches that the brewer requires.

From this point, malt is then treated in one of three ways. For pale malts they are lightly roasted and dried. They typically have a high level of the enzymes that brewers utilise in the mash but because they are roasted at a low temperature their starches are not converted to sugar, so these types of malts require mashing. Kiln dried malts, unlike the air dried base malts, are more thoroughly roasted which starts complex 'maillard' reactions which are responsible for the darkening of the malt. That is why kiln dried malts can be light brown through to black. These malts can provide a range of flavours and colours to beer such as toast, chocolate and coffee right through to highly bitter and acrid. Finally we have caramel malts. While these grains are wet they are heated before being roasted - this leads to the conversion of some starches into predominantly complex sugars which are less fermentable. These malts can provide body and sweetness in the final beer as well as imparting toffee and caramel flavours in some cases.

When formulating new beer recipes, pale malts should account for the majority of the malt in your beer. Kiln dried and caramel malts can be used in varying amounts to change the colour, aroma and flavour of your beer.

Protein content in beer is also derived from the malts used and protein has many effects on the final beer, such as how hazy it appears, the head size and retention and they are used by yeast to grow and develop.

CLASSIC EXAMPLES OF MALTED GRAINS

Pilsner Malt

This malt is actually kilned at a lower temperature than normal malt, making a light-coloured beer. It has a dry, crispy aroma to it. This malt has active enzymes, both proteases and amylases.

Ale Malt

This malt is either two or six-row malt, and has high diastatic power. The aroma is toasty and a little bread-like.

Munich Malt

This malt is darker than the ale malt and has a toasty aroma. It still contains some enzymatic activity but cannot be used at 100% of the malt bill.

Aromatic Malt

This malt is much darker than Munich Malt. It is kilned at a higher temperature; therefore it has less enzymatic power.

Biscuit Malt

This malt was designed to have a cracker/bread-like aroma. It is slightly darker than the aromatic malt. It is very limited in enzymatic activity.

Chocolate Malt

This malt is kilned at a high temperature. It contains no enzymatic activity. The aroma is somewhat like a burnt, non sweet chocolate. This malt is an excellent adjunct for porters and stouts.

Black Malt

This is one of the darkest malts you can find. It is primarily used for making stouts and other dark beers. This malt imparts a roasted, astringent flavour to the beer. It will also lower mash pH.

Cara-pils

This malt is very light in color. Its primary use is to improve head retention and give the beer better body and mouthfeel.

Cara-Munich

This malt is medium in colour. It is ideal for Oktoberfest styles of beer, along with being used in bocks and doppel bocks. It adds body and mouthfeel as well as caramel-like, nutty flavours.

Special B

This is a reasonably dark caramelised malt. It will add some body and mouthfeel as well, but is used mainly for its very strong, almost burnt caramel character.

Crystal malts

Crystal malts commonly come as pale, medium, or dark crystal. They have flavour profiles similar to the Cara-Munich, and Special B malts. The lighter the colour, the less caramel aroma that will be present. Nutty, toasty aromas will be present in the darker crystal malts.



ADJUNCTS – NON BARLEY MALTS AND UNMALTED GRAINS

Malted Wheat

Can be used very much like malted barley. Many recipes for hefeweizen style beers use up to 60% malted wheat. Both malted and unmalted wheat give a dryer, more thirst quenching flavour while also lingering longer on the tongue.

Rice

Used to lighten the colour of a beer and reduce the cost of mass produced beer. 30% or more can be used in without causing major flavour changes. Will cause lightening of the original flavour and possible banana-like flavour from ester production by the yeast.

Corn / Maize

Used to lighten the colour of a beer and reduce the cost of mass produced beer. Should be used sparingly as it tends to add flavour to the beer in concentrations of 25 percent or more. The beers tend to have more fusel alcohol flavours and medicinal flavours.

Rye

Gives a flavour similar to wheat but even dryer. Can add a pleasant spiciness and bread-like quality to beer. Can be used for up to 50% of a grain bill, as in roggenbier, but 10-20% is more common.

Oats

Gives beer a fuller body and silky mouthfeel. Often used to make stout. Stouts made with about 10% oats tend to have a sweeter, smoother flavour and between 5-10% in a Porter can help improve body and mouthfeel. Oats contain more oil than the rest of the grains.



BREWING

3. HOPS

In medieval times, ale was unhopped and instead herbs and spices were used to provide the bittering and aroma elements. This beer would rapidly spoil however as it lacked the anti-spoilage properties that hops provide.

Although hops were probably first used specifically for this preservative value, they provided a flavour and aroma to the beer which people enjoy. This is why they are still used today. It was discovered that the flavour and aroma was originating mainly in the resins and essential oils found in the lupulin glands of the hop. For brewers, the most important of these hop resins are the alpha acids. In most brewing situations, some amount of hops are boiled in wort for 1-2 hours, and it is during this time that the alpha acids go into solution and are isomerised into 'iso-alpha-acids', the main bitter element of beer. As a result of a vigorous boil that is required when brewing, a lot of the volatile aroma and flavour compounds present in the hops are boiled off and so many brewers will replace these by adding more hops either later in the boil or at some stage of fermentation.

The hop itself is a perennial climbing plant and requires a support for it to grow up. The hop cone is comprised of a central 'strig ' with bracts and bracteoles attached. The lupulin glands are mostly found at the base of the bracteoles but they are easily detached and will adhere to the bracts, strig and seed. The lupulin glands can contain up to 57% alpha acids. When we refer to hops as 'high alpha' or 'low alpha', we are referring to the amount of glands present, with high alpha varieties containing more lupulin glands than the 'low alpha' varieties.

For brewers, hops are available in a variety of different forms;

WHOLE HOPS - Some breweries and brewers like to use whole hops as they feel more organic but they are a bulky product and tests show that a whole hop cone only contains around 20% useful brewing materials. Whole hops have a tendency to float, require more for the same utilisation as pellets and also soak up more beer, lowering the total yield.

HOP PELLETS - Hop pellets are created by drying the whole hop until it contains just 8-10% moisture. They are then cooled, crushed, mixed (to homogenize the resulting powder) and then pressed into a pellet. After hops have undergone this process they typically yield around 90 grams per 100 grams of hops but 98% of the alpha acids are recovered.

HOP PLUGS - Hop plugs are made from the hop flower by drying and compressing them. Originally developed by British brewers as a way of adding extra aroma to a beer in a cask before it was sent to customers, they are said to impart better aroma and flavour than pellets due to undergoing less processing but they are not as efficient for bittering so will require more than pellets.

HOP EXTRACTS - The alpha acids are extracted from the cones using heat and solvents. Hop extracts can be kept for long periods of time without spoiling and they reduce the amount of wort lost to hop absorption and trub. The flavour and aroma of the hop extracts is not a true representation of the hop though, as a result of the extraction process.

Hop oils - When freshly picked, hops contain around 80% moisture and will go mouldy quickly if not dried. Hops sold commercially typically contain around 10% moisture.

Once you have settled on the type of hops you are using and you may choose to use a mixture of different types, then you, as a brewer have a variety of options for the stages at which you add your hops to your beer. These are;

MASH HOPPING - Some brewers choose to add hops to their mash, claiming that it imparts desirable flavour and aroma to the beer. If you choose to do this you should be aware that due to the fact you are not boiling the hops, the alpha acids are not being isomerised and so you will get little to nothing in terms of bitterness contribution. Also, a vigorous boil drives off volatile aroma compounds so some brewers claim you are not even getting an aroma contribution. As always, experiment and decide for yourself but it is worth knowing that this is available to you.

FIRST WORT HOPPING - For instance a 'hop stand' technique (also called hop bursting) means to cool the wort first to around 77°C (170°F) then add hops. You would then whirlpool, recirculate or rouse the hops every few minutes for 30-40 minutes. The theory is that since the temperature has now dropped below boiling temperature you lose far less volatile compounds since there is a lower temperature, less steam loss and you end up with more layers of hop flavour. Usually a very limited amount of hops (or none at all) is used in the boil. Some brewers use this a way to shorten their brew day as well by doing a 30 minute boil as these will be hop forward beers, a large degree of wort caramelization and maillard flavours is not desired. This means that the hops are sat in the wort for the period it takes to heat your wort from mash temperature to boil and then the duration of the boil. This means the alphas acids are being isomerised and brewers who utilise first wort hopping claim that it provides a more rounded bitterness and complex aroma. There is a science behind this - adding hops during the sparge lowers the pre-boil pH and this helps increase utilisation, raising IBU's by as much as 10%.

KETTLE HOPS - this refers to hops added during the boil. Hops added early in the boil (typically with at least 60 minutes of the boil remaining) are referred to as 'bittering hops'. By boiling the hops the alpha acids are being chemically altered or isomerized and it is this isomerisation that provides bitterness. The later in the boil you add the hops the less isomerisation occurs and the more volatile aroma and flavour compounds are preserved in the wort. These late additions are called flavour or aroma hops. These flavours are released as hop oils such as humulene, myrcene, geraniol and limonene are dissolved into the wort.

WHIRLPOOL (OR FLAMEOUT) HOPS - A great technique for intense hop aroma and flavour, this technique means shifting your additions so the majority of your hops are high alpha varieties added once you finish your boil, with just a small bittering addition at the start of the boil. Think of this like dry hopping, so you're working in grams per litre initially. Say you're brewing a 23 litre IPA, you may want 6 grams per litre of hops and assume a 3% utilisation when adding this at the end of the boil. From there you can work out the IBU contribution you will get from that addition and then just use a small bittering addition at the start of the boil to make up the difference. There is some debate over whether to add your hops immediately at flameout (when the wort is at 100 degrees) or to allow the wort to cool to 80 degrees. Again, this is open to experimentation and what works for you.

DRY HOPPING - Back to a non-boil technique, dry hopping involves adding hops to the beer during or after fermentation to increase hop aroma and slightly improve flavour. Dry hops can be added at many stages and for varying amounts of time but a little active fermentation (when the beer is around 1.020) circulates the hop oils. Three days has also been proven to be enough time to impart maximum aroma and flavour and any longer than that can start to impart grassy or vegetative flavours.

TIPS FOR HOPPY BEERS IN THE GRAINFATHER

When you add your hops at any point before transferring to the fermenter make sure you stir them into the wort well. You want your hops (whatever form you use) to break up and be exposed to the wort. By stirring, you ensure maximum exposure and flavour and aroma extraction. Also, before beginning your chilling process make sure to give your wort a vigorous whirlpool - this draws all the hop particles down to the centre of the kettle and will help them to form a secondary filtration layer to improve the clarity of your finished beer.

You can use your mash paddle or specifically made tools like the Grainfather Whirlpool and Aeration Paddle, that can be attached to a power drill for a strong whirlpool.

BREWING

4. WATER

For many brewers, water is one of the last elements they will look at adjusting when making their beers. There is a piece of misinformation that has been around for as long as homebrewing which says, if your water tastes good enough to drink then it is good enough to brew with. For the most part, this is sadly untrue. There are often things present in tap water that you wouldn't want in your beer (at least not in any great quantity).

Some of these things include;

Chlorine (or chloramines) - Impart a sharp chemical taste or aroma (bleach, disinfectant, bandage smell & taste). Chlorine is present in most treated (municipal) water as a anti bacterial agent and affects the yeast during fermentation and is removed by boiling the water for at least 7 minutes before use.

Hydrogen sulphide - Gives the beer a rotten egg/sulfur aroma can be removed by boiling the water for at least 7 minutes before use.

Methylisoborneol - Pond scum taste or aroma can be removed by boiling the water for at least 7 minutes before use.

Iron - Metallic or blood like taste can be treated using water softeners however this will have other detrimental effects on the beer.

So it's easy to see why you wouldn't want these in your beer. If your water contains any of these, try using filtered water or distilled water for your brewing. Another option is to filter your tap water using a charcoal filter to remove some of the chlorine present, but this will not be as pure as filtered commercial offerings. If your water contains any of these, try using filtered water or distilled water for your brewing. Another option is to filter your tap water using a charcoal filter to remove some of the chlorine present, but this will not be as pure as filtered commercial offerings.

The effect of brewing water on beer is usually characterised by six main ions (these are the important ones to look at in the water report) - shown here with their ideal ranges for brewing.

Calcium [Ca ²⁺]	50-150 (ppm or mg/L)
Magnesium [Mg ²⁺]	10-30 (ppm or mg/L)
Sodium 1[Na ⁺]	<150 (ppm or mg/L)
Chloride [Cl ⁻]	<250 (ppm or mg/L)
Sulphate [SO ₄ -2]	50-350 (ppm or mg/L)
Bicarbonate [HCO ₃ -1]	0-250 (ppm or mg/L)

When looking at these ions and their ideal ranges you should always take into account the following;

Ca - Calcium plays a critical role in mashing and brewing chemistry. Levels between 5 and 200 mg/L, increase mash acidity, assist enzyme action, help to extract hop bitterness, reduce haze and decrease wort colour.

Mg - Magnesium is an enzyme cofactor and yeast nutrient. It accentuates beer flavour at levels of 10 to 30 mg/L but contributes astringent bitterness when present in excess.

Na - Sodium contributes a sour, salty taste that can actually accentuate beer flavours at reasonable levels. It is however poisonous to yeast and harsh tasting when present in excess.

SO₄ - Sulphates produce a dry, fuller flavour and some sharpness. They make beer strongly bitter if levels reach above 500 mg/L but this is characteristic of some British ales. Levels of less than 150ppm recommended

Cl - Chlorides enhance beer flavour and palate fullness. They increase the perception of sweetness, or mellowness. Increase beer stability and improve clarity. Usual levels are 1 to 100 mg/L in light beer, but can go up to 350 mg/L in beers greater than 1.050 in gravity.

CO₃ - Carbonates raise the mash pH but impede flocculation and contribute harsh bitter flavours. High concentrations of above 200ppm are advisable only to balance the acidity of dark malts.

It is also important to remember that there is a positive synergism between carbonates and dark malts: carbonates mellow the harshness of some complex Maillard reaction products. There is a negative synergism between carbonates and highly hopped beers: they impart a biting and crude bitterness. And there is a negative synergism between sulphates and dark beers: the effect they have is drying and an astringent afterfinish.

It is true that in some areas of the world, the levels of ions present in the tap water are ideal for certain styles of beer and this is why we see a proliferation of that style in that area (porters in London, lagers in Pilsen etc.) however, this also means that their water profiles are not suitable for other styles of beer. In order to brew a good pale ale in London for example, you will likely need to make some water adjustments.

Water is also important for its effect on pH. Conversion of starch to sugar, the primary function of the mash, is dependent upon the pH of the wort which is directly related to the quality of the water used. Bitterness and flavour derived from hops are also affected by wort pH and the performance of yeast is heavily affected by wort pH. So although water is not directly responsible for the flavour of your beer, it affects everything that is. Improper pH can lead to some of the following issues in beer;

INGREDIENT	IF PH IS TOO HIGH	IF PH IS TOO LOW
MALT	<ul style="list-style-type: none"> • Astringency and harshness from grain husks • Duller, less crisp malt flavour • Darker wort colour than expected 	<ul style="list-style-type: none"> • Sharper and tarter flavour • More acrid roast flavours • Lower beer body
HOPS	<ul style="list-style-type: none"> • Harsher hop flavour and bitterness • Grassy, chlorophyll flavour 	<ul style="list-style-type: none"> • Lower bittering than expected
YEAST	<ul style="list-style-type: none"> • Poorer flocculation • Greater potential for the growth of spoilage organisms 	

pH is the numeric scale on which we measure acidity in water, as determined by the concentration of hydrogen ions. We measure pH on a scale of 1-14 with 7 being neutral. Anything below seven is considered 'acidic' and anything above 7 is considered base or 'alkaline'.

For mashing, the ideal pH falls to the slightly acidic side of the scale - you should aim to be within the range of 5.1-5.8 and 5.2-5.5 would be considered ideal for the mash. This pH adjustment will also benefit fermentation.

When sparging it is also a good idea to check your pH - if your runoff is measuring over 5.8 then it is a good indication that you will be extracting tannins which lead to a harsh astringency and are undesirable in your finished beer. By the time your beer has finished fermenting the pH should be around 4.2 - 4.4 with anything higher suffering from a harsher character and anything below risking becoming thin and tart. In some styles, like a Berliner Weiss, the pH will be as low as 3.2 which is what gives the beer its tart, sourness.

You should also consider hardness in your water. This indicates the amount of calcium and magnesium ions that are present in your water and can be categorised as either 'temporary' or 'permanent'. Temporary hardness relates to how much calcium carbonate is present. If your water has a high level of temporary hardness you can boil the water for half an hour which will cause the calcium carbonate to precipitate out. You will be able to see this at the bottom of the water so you should rack your water off this precipitate before using it.

Permanent hardness on the other hand is related to the amount of sulfates and chloride's present, something which is very important to brewers, as the sulfate to

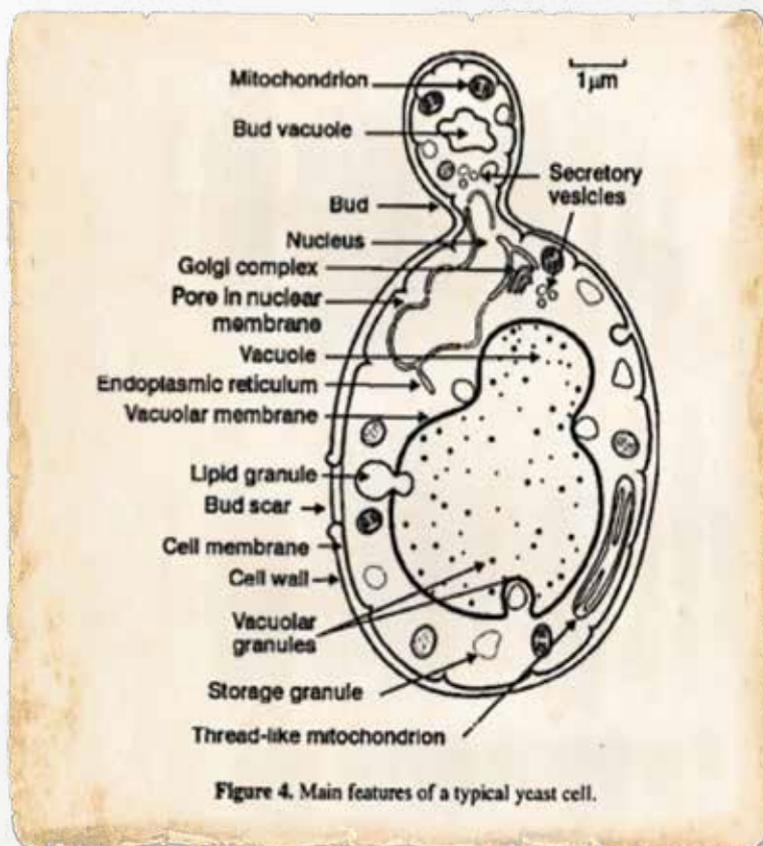
BREWING

5. YEAST

Yeast is the most important element of brewing. Many brewers understand that yeast convert sugar into alcohol and carbon dioxide but don't necessarily understand the full contribution that yeast can have to the end beer. Yeast is responsible for a large proportion of the aromatic compounds in your beer and the final taste. The yeast you use will also determine the amount of residual sugar that is left in your beer which will dictate how 'sweet' or 'dry' your final beer will be perceived.

Currently there are over 1,500 recognised species of yeast but only a small amount of these have been characterised. We do know however that the properties that we as brewers require from yeast, such as the production of alcohol, are not universal across all yeast. This is why brewers yeast has been specially selected for the job and the species in particular that is utilised as brewers yeast is *saccharomyces*, which means 'sugar fungus'.

Saccharomyces can then be further categorised into two basic 'types'; top fermenting or bottom fermenting. Top fermenting yeast is used to brew all types of ale. It favours higher temperatures than bottom fermenting yeast and collects on top of the beer at the end of fermentation when the loose clumps of cells are adsorbed to CO₂ bubbles and carried to the top of the beer. Top fermenting yeasts used for ale all belong to the species *saccharomyces cerevisiae*. *Cerevisiae* meaning 'of beer'.



In contrast, bottom fermenting yeasts, which are used traditionally for brewing lagers favour much cooler fermentation temperatures, typically around 7-15°C [45-59°F]. When fermentation is complete, the yeast flocculates and collects at the bottom of the fermenter.

Brewers yeasts are classified by three main characteristics;

Attenuation - how much of the available sugars they ferment.

Flocculation - how well they clump together after primary fermentation - a factor in how well the yeast drops out of suspension.

Flavour Profile - what flavours they produce.

And for the purpose of brewing the properties we look for are;

- A rapid fermentation rate and not an excessive amount of yeast growth
- An ability to withstand high alcohol levels and the stress caused by the brewing process
- Reproducible flavor production
- Desired and repeatable flocculation characteristics
- Efficiency (in terms of how the yeast uses the sugars present)

Yeast is dormant until it is pitched into wort (either directly or as part of a starter). At this point it will follow a four point lifecycle; lag, exponential growth, fermentation and stationary phase.

At the beginning of fermentation, yeast will take time to acclimatize to the new environment and to awaken from its dormant state. The yeast will begin to gather nutrients and amino acids, allowing it to begin creating the enzymes it needs for growth.

Oxygen will also be rapidly absorbed from the wort during the lag phase - fermentation in the brewing process is largely done anaerobically but to start properly, some oxygen must be available to the yeast. Oxygen is required for yeast to properly synthesise the sterols and unsaturated fatty acids that it requires in order to grow. It has been demonstrated that oxygen is necessary for normal yeast reproduction, although excessive amounts of oxygen in the wort can lead to undesirable flavours in the finished beer. This is done within the first few hours of fermentation so there is some research to suggest that reintroducing oxygen to the wort within 12 hours of pitching will have a beneficial effect on fermentation.

There should be no visible activity during the lag phase and dried yeast tends to have a longer lag phase than liquid yeast but this stage is highly important for allowing the yeast to do its job properly.

Next is the exponential growth/fermentation phase. Yeast begins to consume sugar and convert it to alcohol and CO₂. The number of cells increases and it is at this stage that the flavour compounds are produced. It is widely acknowledged that after 72 hours the flavour compounds have been formed and that any yeast added after

this period will have minimal to no effect on the taste and aroma of a beer. This can be extremely useful when brewing high ABV beers, as it allows brewers to pitch a yeast to get the desired flavour and aroma compounds from that yeast and then pitch a second, more neutral and alcohol tolerant strain to finish the job.

At the pinnacle of this growth phase yeast reaches what brewers refer to as 'high krausen'.

Finally we reach the stationary phase. At this point yeast begins to reabsorb off flavours that were produced during fermentation such as diacetyl. Diacetyl is produced as a by-product of healthy fermentation and its production peaks towards the end of the active growth period. It is reduced by the yeast to compounds with much higher flavour thresholds if the finished beer is left on the yeast long enough to allow it to do this.

Yeast will also begin to 'flocculate' and drop out of suspension. The flocculation level of yeast refers to how rapidly it falls out of suspension and how tightly it compacts together.

There are a few things to consider when choosing what strain of yeast you want to use;

ESTERS

Esters are the flavour component which impart flower, fruit-like flavours and aromas to your beer. At the right levels these flavours can be desirable but if you don't control your fermentation properly they can become unbalanced and overpowering.

As well as the strain of yeast that you choose there are many other factors which can have an impact on the formation of esters during fermentation. These include fermentation method, pitching rates, wort aeration and the temperature at which you ferment. One of the main reasons it's important to properly oxygenate your wort is because an increase in oxygen available at pitching directly links to a decline in esters formed in the final beer. Which esters form and to what extent is largely strain-specific.

In some circumstances an increase in wort gravity can lead to an increase in ester formation (so higher ABV beers would have higher ester levels) which can limit the gravities that brewers can achieve whilst still remaining true to style and within the accepted ester level.

When it comes to controlling ester production, proper aeration of your wort prior to pitching is key and then controlling the fermentation temperature as much as possible will really help your beers improve. Pressure during fermentation has also been shown to limit ester production (but can also reduce yeast growth) which professional brewers achieve by brewing in large, conical fermenters.

CARBONYLS

There are over 200 carbonyl compounds that can be found in beer and contribute in some way to the flavour. Homebrewers are most likely to have heard of diacetyl and acetaldehyde which are both carbonyl compounds. Carbonyls also play a significant role in your beer's stability.

Acetaldehyde is a common carbonyl and is what imparts the grassy/green apple flavour that brewers associate with a very young beer or a beer that has not been left on the yeast for long enough. Acetaldehyde builds up during the growth stage of the yeast cycle but typically declines when the yeast enters the stationary phase. As with ester formation, the level to which acetaldehyde will form and decline is largely dependent on the strain of yeast used. If you rack your beer off of the yeast too early the yeast is unable to remove the acetaldehyde that has formed which can lead to unacceptable levels being present in your end beer.

Diacetyl is another 'flavour-active' carbonyl and similar to acetaldehyde, the level to which it is present in the final beer is determined in the fermentation stage. Diacetyl imparts a "butterscotch" flavour and aroma to beer. Diacetyl in very small levels is usually acceptable by the BJCP in almost all ales and possibly even in Czech style pilsners but typically lagers will not contain diacetyl which is why brewers include a diacetyl rest in their lager fermentations, to allow the yeast time to clean up any diacetyl that has formed.

PHENOLICS

Phenols are a chemical compound which can be responsible for several off flavours in a beer such as clove and banana, spicy or medicinal. In certain quantities and certain styles (such as clove and banana in a Belgian beer or a traditional wheat beer) these flavours can be somewhat desirable though in many other instances they are considered a flaw.

All yeast strains will produce phenolics to some extent though some German, British and Belgian strains are developed to produce higher levels. Your brewing water and your method for mashing and sparging may also contribute to high concentrations of phenols.

When it comes to mashing and sparging, if you mash at too high a pH (usually 5.5-5.2 is preferred), sparge with too much water or sparge with water that is too hot, then you are likely to extract polyphenols - more commonly known as tannins. This can lead to harsh astringency or bitterness in your finished beer as well as contributing to cloudy beer.

You should also be aware of your water chemistry when mashing, as high levels of chlorine can form chlorophenols which impart band-aid flavours. Chlorophenols are always considered an off flavour in beer. If your water is particularly high in chlorine (above 200 mg/L though preferably below 150 mg/L) then you should either run it through a carbon filter or boil it for 20-30 minutes before brewing.

Which yeast to choose?

So you can see that there are several considerations when choosing a yeast strain which will affect the end flavour of your beer. What beer style is the strain particularly suited too? What level of esters and phenolics is it described as providing? Is the strain particularly prone to high levels of diacetyl and if so, do you have the necessary temperature control in order to do a diacetyl rest?

BREWING

6. MILLING, MASHING AND SPARGING

As all grain brewers, we understand that the purpose of the mash is to allow enzymes to work on the starch present in grains and convert that starch to sugar. This can be made easier by crushing your grain very fine. The finer the crush, the greater the mash efficiency as it is easier for the enzymes to reach and convert the starches present in the grain as gelatinisation of the starch granule can occur much faster.

100% efficiency in laboratory conditions is achieved by crushing the grains to a very fine flour, including all the husks. In contrast to this, if your grain is poorly crushed and contains a lot of husks and uncrushed grains, your efficiency will be dramatically reduced. A longer mash might help to improve this but ultimately if the enzymes are unable to work on the starch granules they will not be able to convert the starch to sugar - a process known as saccharification.

So if crushing the grains to a powder increases efficiency (and therefore reduces the amount of grain you need to use to reach your target gravity) why are brewers not crushing their grains this fine, husks and all?

Unfortunately, crushing the grain this fine extracts unwanted tannins; the bitter, astringent compound that is undesirable in a finished beer. Mashing with grain flour will also cause problems when it comes to the sparge, greatly reducing your sparge efficiency as water will not be able to run through the grain efficiently. This is where issues like a stuck sparge can occur.

So what is the 'ideal' crush?

Essentially you are looking to ensure that the centre of the grain (called the endosperm) is well crushed but that the husk has firstly been removed (as it's entirely possible for this to remain in one piece) and secondly, has not been ground too small as the husks will help with sparging. It is okay to have some grain flour in your grain bill but this should be at a maximum 25% of your bill. This will enable you to reach a good compromise between maximum mash efficiency without negatively affecting the sparge or producing undesirable flavours in your beer. For the Grainfather, we have found that a medium crush provides the best results - though finding your 'ideal' will require some experiment. Here are some images of what constitutes good and bad crush;



MASHING

Mashing refers to the process where enzymes in the grain convert complex starches into simple fermentable sugars.

During the mashing stage, certain enzymes are activated to extract flavour and convert the starches in grain into fermentable brewing sugars.

Enzymes are proteins that are composed of amino acids. They specifically catalyse (accelerate) biochemical reactions including the necessary conversion of starch in the grain into fermentable sugar. They are mostly affected by temperature and pH which is why the right mashing temperature is so important. The mashing temperature is based on the optimal temperature for the desired enzymes to convert the starches into sugars.

Starch

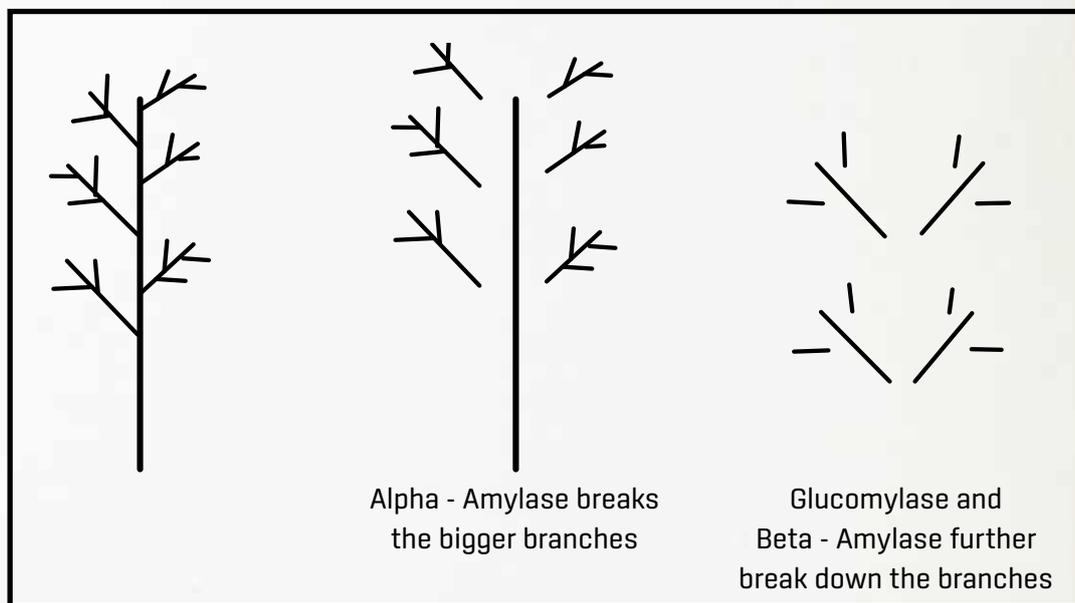
Starch is a carbohydrate present in grain. Starch exists in two forms, amylose (linear chains) and amylopectin (branched chains).

In order to make beer, enzymes need to convert starch into simple fermentable sugars. This is accomplished in a two-step process which happens during the mashing process.

Liquefaction - Starch is broken down into shorter fragments (dextrins) by the enzymes (alpha amylase), resulting in a porridge-like consistency.

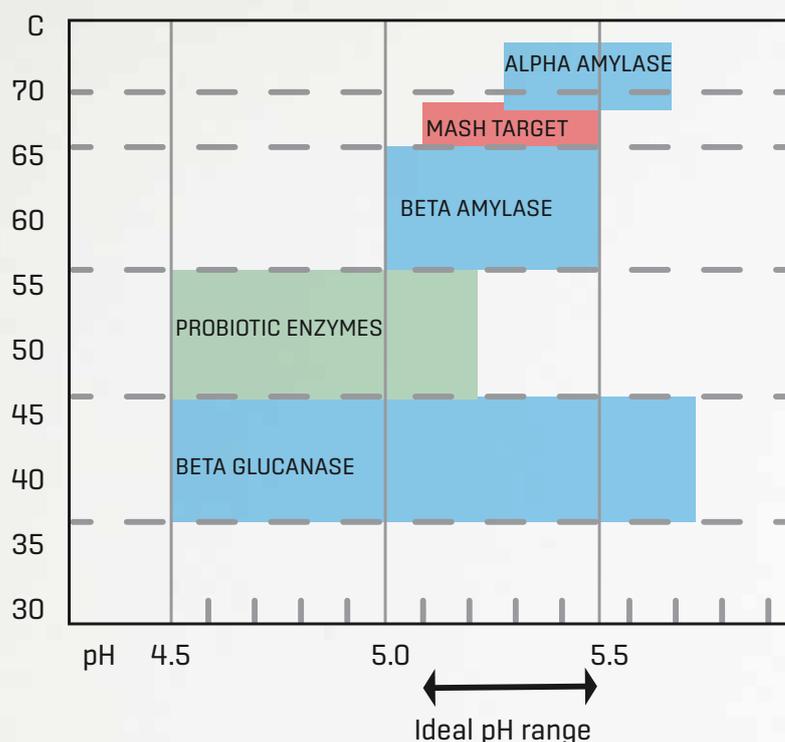
Saccharification - During this stage, the porridge-like consistency thins out more as dextrins produced during liquefaction are further broken down into the two main fermentable sugars used in brewing: glucoamylase (produces glucose) and beta amylase (produces maltose).

An easy way to think of this is to think of a tree. The tree has branches and these branches need to be broken down (first stage - liquefaction) and then broken down again (second stage - saccharification) until only a single stick is left. This single stick is the fermentable sugars.



Mashing Temperatures

This chart shows the effects temperature and pH have when mashing. As you can see, the ideal mashing temperature is between 65°C - 68°C [149°F - 154°F] as at this temperature you are activating the beta amylase and alpha amylase enzymes which are the enzymes most effective in carrying out the job of converting starches into the fermentable sugars you need for brewing.



Step Mashing

In a lot of instances a technique known as step mashing is used. This just means to mash at different temperatures for a certain amount of time to utilise different types of enzymes which alter the consistency, flavour and mouthfeel of the beer. Step mashing is often used when using unmodified malts or using wheat, as these grains need a wider variety of enzymes to act on them due to their nature and the desired characteristics of the beer styles they are typically used for.

NOTE: The following timings for step mashing do not include the time taken to raise the temperature between mash steps.

Acid rest - 40°C (104°F). The enzyme phytase breaks down a molecule called phytin and releases phytic acid, which lowers mash pH and breaks down the gums in the cell walls which can cause a stuck mash. Some debranching of the starch molecule occurs at this temperature also. A 20 minute rest here can improve your yield.

Ferulic acid rest - 43°C (109°F). For Hefeweizens can increase the level of ferulic acid which can then be converted by certain yeasts in to the ester that gives the characteristic clove aroma and flavour.

Protein rest - 50°C (122°F). You don't want a lot of longer chain proteins in your wort as these big proteins can lead to haze and instability. However, you do want medium length protein chains because they are good for a beer's body and for head retention.

However, most malts that you buy have already had these conversions take place. During the malting process, gums (glucans) in the cell walls of the barley are broken down. Likewise, proteins are broken down into amino acids that are necessary for yeast health as well as, and lowering the possibility of, haze or biological instability in the finished beer. Finally, malting causes the barley to produce the starch-degrading enzymes needed in the mash.

With the Grainfather you can step mash easily by just raising your set temperature.

Mash Out

The Mash out is a step where the temperature is raised to above 75°C (167°F). This stops all the enzyme action and makes the grain bed and wort more fluid in preparation for sparging.

Above 78°C (172°F) tannins begin to be extracted from the grain husks, causing astringency in the beer.

Recirculation

After mashing in and allowing the grain bed to settle (around 10 minutes) the recirculation arm can be attached to the Grainfather and recirculation of the wort can begin.

Recirculation improves the efficiency of your mash and allows the grain bed to filter out debris and cloudy proteins in preparation for lautering (collection of the wort). You will notice the wort becomes clearer as the recirculation goes on. This is due to both the grain bed filtering out debris as well as the cloudy starches being converted to smaller sugar molecules (clear).



SPARGING

Sparging is the process of rinsing the grains with water that is between 75°C - 78°C (167°F - 172°F). Sparging is used to rinse any residual sugars from the grains and to bring up the volume of the wort to be boiled.

Fly Sparging or Continuous Sparging

This, as the name suggests, is a continuous flow of water over the grain bed.

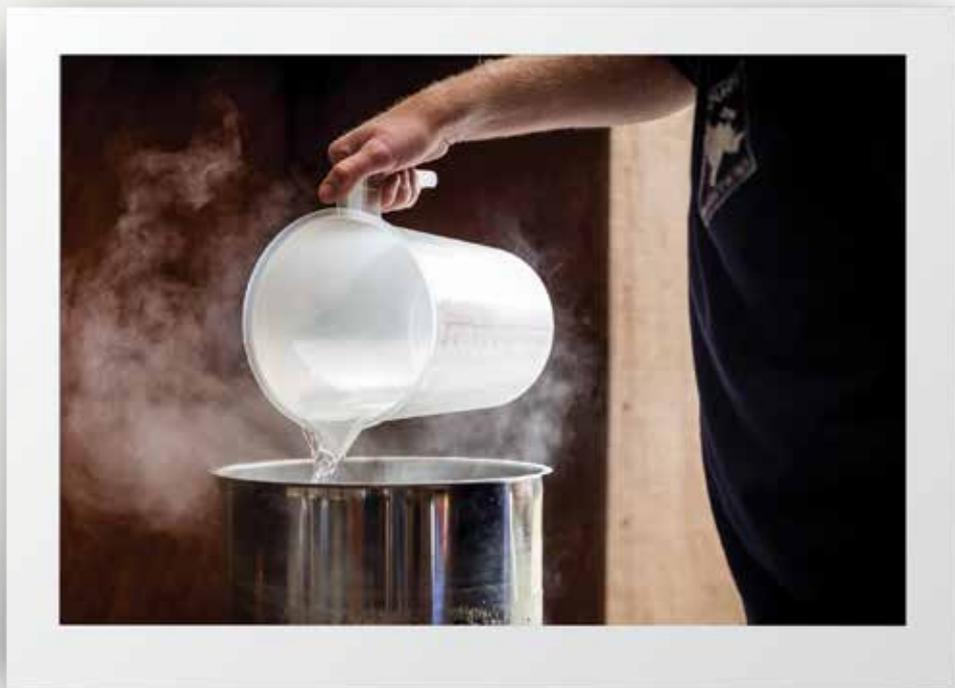
Batch Sparge

This is where the wort is drawn off the grain bed, then the mash/lauter tun is filled again with water and drained off a second time. This process is then repeated until the desired amount of wort is collected. This method is less efficient than continuous sparging.

If you are using a very fine grain crush or large grain bill then it may take a long time to sparge. So again it is very important to just crack the husk of the grain and not over crush it.

After Sparging and just before the boil you should be taking you pre-boil gravity reading. You can either use a hydrometer or refractometer to take this reading. This is used to show you how much sugar is in the water (how efficient your mash was). The higher the reading, the more sugar in the wort.

If you check the pH of your runnings when you sparge they should be below 5.8. Any higher and you risk extracting unwanted tannins and imparting a harsh astringency into your beer.



BREWING

7. BOILING

Wort boiling is an extremely important stage in the brewing process and is important for so many more reasons than a lot of brewers give it credit for such as;

Stopping Enzyme Activity

It's largely dependent on the enzyme as to what exact temperature this occurs, but within a range of 50 - 75°C [12°F - 167°F] most enzymes become denatured [hence the reason for a 'mash out' step when mashing] and once the wort reaches boiling point there is typically no enzyme activity occurring. This is important as enzymes will alter the fermentability of the wort and therefore alter your finished beer. We would typically recommend you add a mash out step to your mash schedule, simply by raising the beer to 75°C [167°F] at the end of the mash and holding it at that temperature for 10 minutes.

Concentrating the Wort

As wort boils, the water content is driven off (visible as steam). The more water content is driven off, the more concentrated your wort becomes and so, up to a point, the higher your original gravity [OG]. This is why knowing your rate of evaporation is important when it comes to calculating your OG (for those wondering, it should be around 2.5 L [0.6 US Gal] per hour on the Grainfather).

The calculation is;

Pre boil volume x pre boil gravity = post boil volume x post boil gravity.

To work out your post boil volume you take your evaporation rate from your pre boil volume - e.g. 28 minus 2.5 L [7.3 minus 0.6 US Gal] = 25.5 L [6.7 US Gal] after a 1 hour boil.

So now you can put 25.5 [6.7 US Gal] into the equation. For this example we have a 1.050 pre boil gravity and 28 L [7.3 US Gal] pre boil volume.

$28 \times 50 = 25.5 \times \text{post boil gravity}$

$(28 \times 50) / 25.5 = \text{post boil gravity}$

$1400 / 25.5 = \text{post boil gravity}$

54.9 = post boil gravity

So your post boil gravity is going to be 1.055, meaning if you calculate this early enough you can make adjustments such as adding more water to reduce the original gravity or boiling for longer to increase it.



Isomerising Alpha Acids

Alpha acids, which are what brewers take into account when calculating the bitterness for their beers, are actually insoluble in wort. It is only by boiling that they are converted to iso-alpha acid which is much more soluble. Research shows that isomerisation of iso-alpha acids occurs quickly at boiling temperatures, with somewhere above 90% of the wort bitterness imparted within the first 30 minutes of the boil. This means if you did want to cut your boil short and were purely concerned with getting your bitterness correct then you could assume a 10% loss in utilisation and just do a 30 minute boil (though obviously your post boil gravity will be lower). Maximum isomerisation should occur within 60-70 minutes of boiling, which is why in a 90 minute boil you typically wouldn't add your bittering hops until there were 60 minutes remaining - you're not getting any extra utilisation by leaving them in longer.

Increasing Colour

When you boil your wort there are three reactions that take place that each contribute to the increase in colour that your wort will undergo. The first is the Maillard reaction, a chemical reaction between carbonyl and amino acids which is also responsible for food browning. The caramelisation of sugars is also occurring and contributing to colour change and lastly some oxidation of polyphenols is occurring.

Reduction of Wort pH

As you boil your wort, calcium compounds react to form insoluble compounds meaning by the end of the boil, at least half the calcium that was present in the wort has been separated from the liquid and this is largely responsible for the decrease in wort pH during the boil. If you're wondering what pH levels your beer should be at during various stages, you should aim for a pH of 5.2 - 5.5 in the mash to assist with enzyme activity, your pre boil pH should ideally be around 5.2 - 5.4 as lower will have a negative effect on your hop utilisation and higher will increase perceived

bitterness. Boiling the wort will drop your pH by 0.1 - 0.2 giving you a fermenter pH somewhere around 5.0 - 5.3 and then fermentation will lower the pH even further. Your final beer should be somewhere in the range of 4.2 - 4.6.

It's important to achieve the required pH drop in the boil as it helps with things like, improving your clarity, improving beer flavour, encouraging yeast growth and inhibiting the growth of bacteria.

Driving Off Volatile Compounds

As you boil your wort you drive off unwanted volatile compounds such as DMS (dimethyl sulphide) with the steam. DMS is largely undesirable in beer as it imparts a 'sweetcorn' taste. By controlling the duration and strength of the boil it is possible to control the level of DMS. With the Grainfather, it is important to leave the lid off during the boil to allow these volatiles to be driven off.

Cooling

After you have boiled your wort you should cool it quickly. There are a variety of reasons why brewers do this. With the Grainfather we recommend using the included counterflow wort chiller to rapidly cool the wort. The wort needs to be cool enough to pitch your yeast - usually around 20 - 22°C (68 - 72°F) for ale yeast or 7-14°C (45 - 57°F) - to avoid shocking your lager yeast.

There are other reasons to chill your wort rapidly. When you chill your wort, solids will form and drop out of solution - what is known as the 'cold break'. When you transfer your wort to the fermenter the majority of this break material should be left behind which will help with creating clearer beer.

Rapidly cooling your wort can also help to slow the production of dimethyl sulfide (DMS) - the volatile substance which can be produced in wort - particularly worts which contain a large proportion of pilsner malt. This is the substance that causes the 'cooked corn' off flavour which can be made worse by covering the kettle during the boil.

Cooling the wort quickly can also minimise the risk of spoilage of your wort. As you get below 71°C (160°F) your wort becomes ideal for spoilage organisms to grow and spoil your wort. By reducing the temperature as quickly as possible you can pitch your yeast quickly which reduces the impact these spoilage organisms will have.

It is also important to note that when you finish your boil, DMS can still be produced and is no longer being driven off by a vigorous boil. Leaving your wort to cool over a long period of time can impart that butterscotch, buttery flavour that is largely undesirable.

And lastly rapidly cooling your wort helps to preserve those delicate flavour and aroma compounds that you get from your end of boil hop additions. These compounds are driven off in the boil but if you cool your wort quickly after making your last addition more of the hop character will survive through to the wort.

BREWING

8. FERMENTATION

Once you have pitched your yeast fermentation will typically start within 12 hours though may take up to 24 and though there are usually some visual signs that fermentation is going on such as the airlock bubbling, or a froth build up on top of the beer these are not always guaranteed and you should always use hydrometer readings as a sure sign that fermentation is occurring.

During this 'primary fermentation' yeast are converting sugar in the wort to alcohol and CO₂ but there are also important flavour compounds being created at this stage. Depending on which yeast strain you use and the temperature at which you ferment, different levels of phenols and esters will be produced.

'Esters' are the responsible for imparting fruity flavours and aromas in beer. Some beers which taste like bananas, apples, strawberries or pineapple have those tastes as a result of esters that have been produced during fermentation. Ester production is largely undesirable when brewing a lager but is a key characteristic of many styles of ale and is a distinctive element of most styles of ale to some degree.

Esters are formed once the need for lipid production ends. Lipids are formed by the yeast early on in fermentation but once the production ends the compounds the yeast creates as part of this process will form esters, which are a combination of alcohols and fatty acids.

Typically ester production happens later in the fermentation process and the level of esters produced will increase in higher gravity worts. It is thought that this is because yeast growth is inhibited in higher gravity wort. If you are not looking for a high level of esters in your high gravity beers then properly oxygenating your wort, or even re-introducing oxygen can help with yeast growth which will reduce ester production.

Ester production can also be increased by fermenting at warmer temperatures, restricting the amount of oxygen in your wort or restricting the level of yeast growth.

'Phenols' are also produced during fermentation. They will always be present in your finished beer to some degree but have a fairly low flavour threshold and can be undesirable in higher quantities. They are responsible for clove or smoky flavours and can come from several sources. Firstly, they may come from your ingredients - large amounts of smoked malts can impart smoky phenols that would be somewhat desirable in a smoked beer but could be considered an off flavour in other styles. Your water may also contain phenols which can be difficult to remove from a finished beer,

for example, water that is high in levels of chlorine can give your beer a terrible TCP/medicine taste which is a severe off flavour. Hops can also introduce phenols in the form of tannins which give your beer a puckering astringency.

Finally, your yeast selection will play an important role in the levels of phenols that are produced. Particular strains (such as the Belgian style yeast strains) are designed to impart greater levels of phenols such as the clove-like aroma and flavour present in a lot of Belgian beers.

Higher alcohols will also be produced during fermentation. The alcohol that is produced during fermentation is mostly neutral flavoured ethanol. However, the more volatile 'higher alcohols' can also be produced and, if present in high quantities, can be responsible for solvent like flavours in your beer. They are also thought to be a contributing factor to hangovers.

Although considered a fault in most styles when present in high quantities, the production of higher alcohols is a natural part of fermentation directly related to the way in which yeast use amino acids present in the wort and once higher alcohols have formed they will not be removed by aging the beer (as might happen with diacetyl).

Luckily as brewers we have a few methods available for controlling the production of these higher alcohols which mostly revolve around good control over yeast growth. Similar to ester production, higher alcohol production is encouraged by higher fermentation temperatures. Highly active fermentations, with a lot of movement in the wort also encourage yeast growth and this can be aided by properly oxygenating your wort before pitching your yeast.

Research has shown that the majority of flavour compounds produced by yeast are formed within the first 72 hours of fermentation so there are some brewers who will pitch a second, alcohol tolerant, neutral strain when fermenting a higher ABV beer. This allows them to get their desired characteristics from their initial yeast and then ensure that fermentation finishes without adding additional flavours and without the first yeast strain becoming stressed in a higher alcohol environment and producing off flavours.

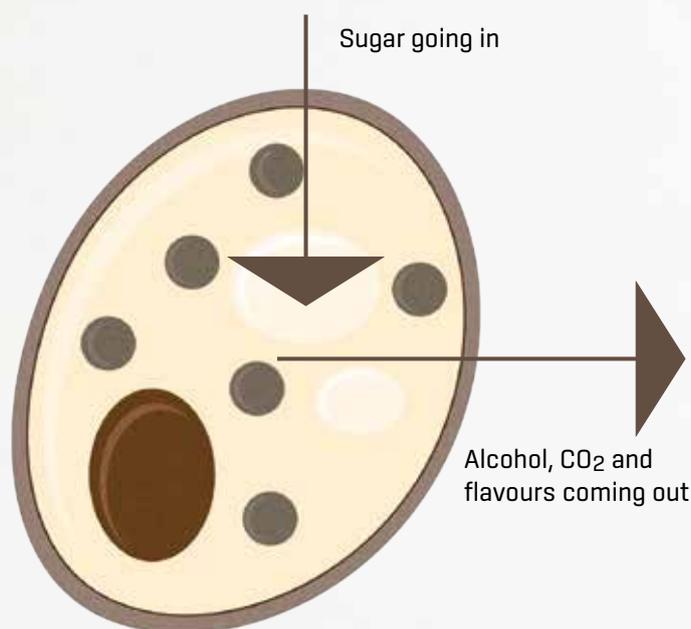
So, the most important considerations for fermentation are;

- Choose a yeast strain based on the flavour profile you want in your finished beer
- Pitch a sufficient amount of yeast - underpitching may increase formation of esters and phenols as well as other off flavours, overpitching can lead to low ester production, thin bodied beer and issues with autolysis. But these effects will vary depending on the yeast strain, while some yeasts also benefit from a level of under pitching compared to pitching rates of other yeasts.
- Control your temperature - all yeast strains ferment best within a given temperature range. As best as possible you should keep your temperature at a

constant and within that range. Fluctuation in temperature can lead to off flavours as can too high a temperature and too low a temperature can prevent your beer from fermenting fully.

- Higher gravity worts and worts that use a lot of non-malt adjuncts such as sugar are typically low in levels of amino acids that the yeast needs to grow. In these cases the yeast will start to produce the amino acids itself and this process increases ester production and higher alcohol production. If this is not desired then you should consider these when formulating a recipe.
- Oxygenate your wort before pitching - wort that is not properly oxygenated will reduce yeast growth which will result in higher levels of esters, phenols and higher alcohols. This process will reduce yeast lag.

Of course, in some styles you want these characteristics. Due to the high levels of adjuncts and the warm fermentation temperatures, Belgian ales are characterised by their high ester levels and often significant higher alcohol levels. If this is what you are after then take into consideration the way the above affect production of these flavour compounds.



Yeast cell fermentation process.

BREWING

9. BREWING AND KEGGING

When it comes to packaging your beer at the end of the process there are several options available to homebrewers. The most popular of these choices is bottling or kegging. Bottling is the cheaper alternative for those just starting out with brewing their own beer and is relatively simple compared to kegging your beer - it is also easier to transport your beer and share it out amongst friends, at least until you've got your home bar set up.

When it comes to selecting bottles you also have a few options. You need to make sure that the bottles you use are designed to take the pressure of carbonated drinks and they need to be clean and sanitised. The cheapest option is plastic fizzy drinks bottles. They come in a range of sizes, are designed for carbonated beverages and the labels are fairly easy to remove. The downside is that they are often clear which leaves your beer at risk of being exposed to sunlight which reacts with hop compounds in the beer and causes 'skunking'.

Re-using commercial beer bottles can also be good. If you have the bottles anyway then it is simply a case of cleaning and sanitising them and re-capping them. Labels can be difficult to remove from some commercial bottles and you may end up with bottles of all different shapes and sizes [if consistency is important to you].

Finally you can purchase new bottles from your local homebrew store. You can get bottles for capping which require bottle caps and a specialist 'capper'. These bottles look good and it's easy to get a consistent look and you can use different colour caps for different beers. You can also buy 'swing top' bottles that come with the re-usable tops. They are easy to use and are re-usable without the need to purchase caps each time.

We would recommend that if you are using glass bottles you use brown glass over clear as this will help preserve your beers shelf life and also, make sure you thoroughly check any bottles for chips, scratches or imperfections and do not use bottles if they are damaged.

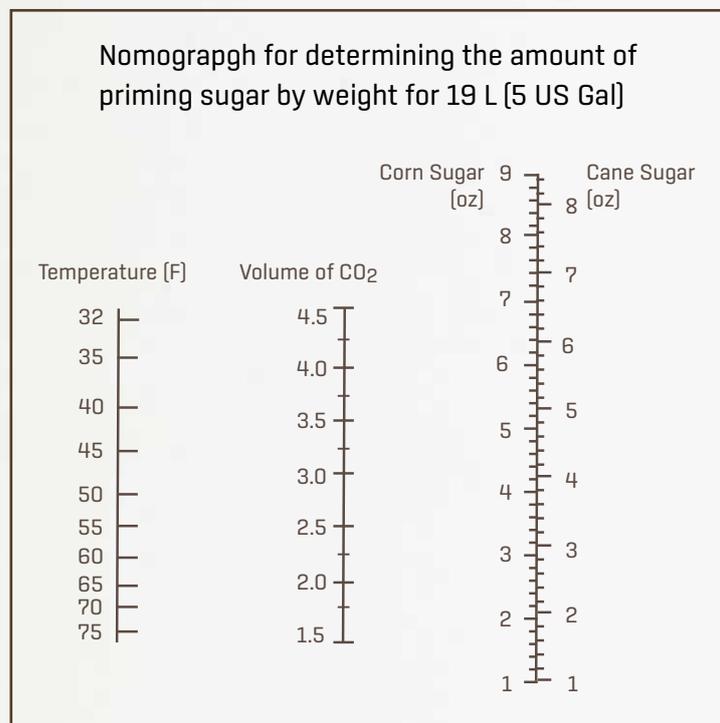
Before you come to bottle always check the gravity of your beer with a hydrometer. You should get a stable reading over two days (eg. 1.010 for two days). If you take a reading and it has changed from the previous day your beer is still fermenting and should not be bottled. This is extremely important as bottling beer that is still fermenting can lead to bottle bombs.

Priming

Priming is the brewers term for adding a set amount of sugar, either directly to your bottling bucket or individually to each bottle, after primary fermentation is complete. The purpose of this is that priming will provide the yeast with just enough sugar to undergo a small secondary fermentation, producing more CO₂ but in an environment where the gas can't escape, therefore carbonating the beer.

CO₂ is produced during primary fermentation but is mostly released through the airlock which is why your beer is largely flat when it comes to bottling. However, there will be a small amount of residual CO₂ which you should take into account when calculating your priming sugar.

Batch priming is the term used to describe the technique of adding the full amount of priming sugar directly to your fermenter. If you look at this diagram you can see that certain styles of beer require more or less carbonation (determined as volumes of CO₂) and to work out how much sugar you need you draw a line from the temperature of your beer, through the desired volume of CO₂ to determine total amount of sugar to add.



[How to Brew, John Palmer, 1999, Brewers Publications]

British ales 1.5-2.0 volumes

Porter, Stout 1.7-2.3 volumes

Belgian ales 1.9-2.4 volumes

American ales 2.2-2.7 volumes

European lagers 2.2-2.7 volumes

Belgian Lambic 2.4-2.8 volumes

American wheat 2.7-3.3 volumes

German wheat 3.3-4.5 volumes

To make up your priming sugar solution, boil a small amount of water (475 ml or 2 cups for 113 grams/4 oz) and dissolve the required amount of sugar into this before allowing it to cool to the same temperature as your beer. Boiling the water first is necessary to keep everything sanitary. Once this is cool either pour the solution into a separate bottling bucket (a fermenter bucket with a tap) and syphon your beer directly on top of it or else pour your priming solution into your fermenter and stir with a sanitised mixing paddle. If you pour directly into your fermenter, don't forget that you will need to let the beer settle again before bottling or else you will be transferring a lot of yeast and hop sediment.

Cleaning and Sanitising

It is vital that everything your beer will come into contact with on bottling day is clean and sanitary as the process of bottling can leave your beer largely exposed to bacteria and infection. Similarly you should aim to avoid introducing oxygen into your beer as much as possible as this will reduce your beers shelf life. Avoid splashing or transferring beer more than is necessary.

Make sure that you clean and sanitise;

- Bottles
- Caps
- Syphon or bottling wand
- Bottling bucket (if using one)
- Bottle capper (if using one)

Conditioning

Once you have transferred into your bottle you should leave them somewhere warm for secondary fermentation for a period of two weeks before moving them to a cooler environment for a further two weeks. Make sure the bottles are kept out of sunlight and are left standing upright. There are several 'off flavours' that are naturally created by the process of fermentation and many will be cleaned up by the yeast if it is given a long enough time to do this so if you taste your beer early and are disappointed, a longer maturation period can help.

Kegging

Bottling is relatively easy and cheap and doesn't require too much equipment but a 23 litre batch can mean cleaning and sanitising around 40 individual bottles, preparing priming solution, transferring beer into a second clean and sanitised bottling bucket and syphoning into each bottle. It can be messy and time consuming and for many brewers it is worth investing in a good kegging set up to not have to worry about bottling day.

When it comes to kegging you will require;

- A keg
- CO₂ cannister
- A gas in connector
- A liquid out connector
- A cleaner/sanitiser
- Gas line
- Beer line
- Beer tap

Begin by pouring hot water into your keg and adding a good cleaner. Place the lid on the keg and add a small amount of CO₂ to seal. Shake the keg thoroughly to soak all the inner surfaces in cleaner solution and then leave the keg to stand for ten minutes. After ten minutes shake the keg thoroughly again before running some of the cleaner solution out of the liquid out line.

Release the pressure on your keg and take the lid off to pour what is left of the cleaner out of the keg. Fill with hot water and pressurise again before shaking and running water out of the liquid out line. Then make a sanitiser solution before pressurising the keg once more and shaking. Allow the keg to soak in sanitiser solution as per instructions before shaking up and running some sanitiser solution out of the liquid out line. Then tip what is left of the sanitiser out of the keg.

Once your keg is clean and sanitised, you a clean and sanitary syphon to transfer your beer from the fermenter into your keg before clipping the lid on.

Reading the CO₂ regulator

A CO₂ regulator is designed to give you more control of the pressure of the gas coming from the tank into your keg. When you look at the regulator you will see two gauges, one on top and one to the side. The gauge on top of the regulator reads the 'adjustable pressure' which you can set by turning the screw in the middle of the regulator - tightening the screw increases the pressure.

The gauge on the side of the regulator reads the pressure from the CO₂ tank though you will likely find this stays pretty steady until the tank starts to run out of gas at which point it will rapidly drop.

Carbonating your beer

PSI (Pounds Per Square Inch)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
30°F	1.82	1.92	2.03	2.14	2.23	2.36	2.48	2.60	2.70	2.82	2.93	3.02	3.13	3.24	3.35	3.46	3.57	3.67	3.78	3.89	4.00	4.11	4.22	4.33	4.44	4.66	4.77	4.87	4.98	4.98
31°F	1.78	1.88	2.00	2.10	2.20	2.31	2.42	2.54	2.65	2.76	2.86	2.96	3.07	3.17	3.28	3.39	3.50	3.60	3.71	3.82	3.93	4.03	4.14	4.25	4.35	4.46	4.57	4.68	4.78	4.89
32°F	1.75	1.85	1.95	2.05	2.15	2.27	2.38	2.48	2.59	2.70	2.80	2.90	3.00	3.11	3.21	3.31	3.42	3.52	3.63	3.73	3.84	3.94	4.04	4.15	4.25	4.36	4.46	4.57	4.67	4.77
33°F	1.71	1.81	1.91	2.01	2.10	2.23	2.33	2.43	2.53	2.63	2.74	2.84	2.96	3.06	3.15	3.25	3.35	3.46	3.56	3.66	3.76	3.87	3.97	4.07	4.18	4.28	4.38	4.48	4.59	4.69
34°F	1.68	1.78	1.86	1.97	2.06	2.18	2.28	2.38	2.48	2.58	2.69	2.79	2.90	3.00	3.09	3.19	3.29	3.39	3.49	3.59	3.69	3.79	3.90	4.00	4.10	4.20	4.30	4.40	4.50	4.60
35°F	1.63	1.73	1.83	1.93	2.02	2.14	2.24	2.34	2.43	2.52	2.63	2.73	2.83	2.93	3.02	3.12	3.22	3.32	3.42	3.52	3.62	3.72	3.82	3.92	4.01	4.11	4.21	4.31	4.41	4.51
36°F	1.60	1.69	1.79	1.88	1.98	2.09	2.19	2.29	2.38	2.47	2.57	2.67	2.77	2.86	2.96	3.05	3.15	3.24	3.34	3.43	3.53	3.63	3.72	3.82	3.92	4.01	4.11	4.21	4.30	4.40
37°F	1.55	1.65	1.74	1.84	1.94	2.04	2.14	2.24	2.33	2.42	2.52	2.62	2.71	2.80	2.90	3.00	3.09	3.18	3.27	3.37	3.46	3.56	3.65	3.75	3.84	3.94	4.03	4.13	4.22	4.32
38°F	1.52	1.61	1.71	1.80	1.90	2.00	2.10	2.20	2.29	2.38	2.48	2.57	2.66	2.75	2.85	2.94	3.03	3.12	3.21	3.30	3.40	3.49	3.59	3.68	3.77	3.87	3.96	4.06	4.15	4.24
39°F	1.49	1.58	1.67	1.77	1.86	1.96	2.06	2.15	2.25	2.34	2.43	2.52	2.61	2.70	2.80	2.89	2.98	3.07	3.16	3.25	3.34	3.44	3.53	3.62	3.71	3.81	3.90	3.99	4.08	4.18
40°F	1.47	1.56	1.65	1.74	1.83	1.92	2.01	2.10	2.20	2.30	2.39	2.47	2.56	2.65	2.75	2.84	2.93	3.01	3.10	3.19	3.28	3.37	3.46	3.55	3.64	3.73	3.82	3.91	4.01	4.10
41°F	1.43	1.52	1.61	1.70	1.79	1.88	1.97	2.06	2.16	2.25	2.34	2.43	2.52	2.60	2.70	2.79	2.88	2.96	3.05	3.14	3.23	3.32	3.41	3.50	3.59	3.68	3.77	3.86	3.95	4.04
42°F	1.39	1.48	1.57	1.66	1.75	1.85	1.94	2.02	2.12	2.21	2.30	2.39	2.48	2.56	2.65	2.74	2.83	2.91	3.00	3.09	3.18	3.26	3.35	3.44	3.53	3.62	3.70	3.79	3.88	3.97
43°F	1.37	1.46	1.54	1.63	1.72	1.81	1.90	1.99	2.08	2.17	2.26	2.34	2.43	2.52	2.61	2.69	2.78	2.86	2.95	3.04	3.13	3.21	3.30	3.39	3.47	3.56	3.65	3.74	3.82	3.91
44°F	1.35	1.43	1.52	1.60	1.69	1.78	1.87	1.95	2.04	2.13	2.22	2.30	2.39	2.47	2.56	2.64	2.73	2.81	2.90	2.99	3.07	3.10	3.24	3.33	3.41	3.50	3.58	3.67	3.76	3.84
45°F	1.32	1.41	1.49	1.58	1.66	1.75	1.84	1.91	2.00	2.08	2.17	2.26	2.34	2.42	2.51	2.60	2.69	2.77	2.86	2.94	3.02	3.11	3.19	3.28	3.36	3.45	3.53	3.62	3.70	3.79
46°F	1.28	1.37	1.45	1.54	1.62	1.71	1.80	1.88	1.96	2.04	2.13	2.22	2.30	2.38	2.47	2.55	2.64	2.72	2.81	2.89	2.98	3.06	3.15	3.23	3.31	3.40	3.48	3.57	3.65	3.74
47°F	1.26	1.34	1.42	1.51	1.59	1.68	1.76	1.84	1.92	2.00	2.09	2.18	2.26	2.34	2.42	2.50	2.59	2.67	2.76	2.84	2.93	3.02	3.09	3.18	3.26	3.35	3.43	3.51	3.60	3.68
48°F	1.23	1.31	1.39	1.48	1.56	1.65	1.73	1.81	1.89	1.96	2.05	2.14	2.22	2.30	2.38	2.46	2.54	2.62	2.71	2.79	2.88	2.96	3.04	3.13	3.21	3.30	3.38	3.46	3.54	3.63
49°F	1.21	1.29	1.37	1.45	1.53	1.62	1.70	1.79	1.86	1.93	2.01	2.10	2.18	2.25	2.34	2.42	2.50	2.58	2.67	2.75	2.83	2.91	3.00	3.07	3.15	3.23	3.31	3.39	3.47	3.56
50°F	1.18	1.26	1.34	1.42	1.50	1.59	1.66	1.74	1.82	1.90	1.98	2.06	2.14	2.21	2.30	2.38	2.46	2.54	2.62	2.70	2.78	2.86	2.94	3.02	3.10	3.17	3.25	3.33	3.41	3.49
51°F	1.18	1.26	1.34	1.42	1.49	1.57	1.64	1.71	1.79	1.87	1.95	2.02	2.10	2.18	2.26	2.34	2.42	2.49	2.57	2.65	2.74	2.82	2.90	2.97	3.05	3.13	3.19	3.27	3.34	3.42
52°F	1.16	1.23	1.31	1.39	1.46	1.54	1.61	1.68	1.76	1.84	1.92	1.99	2.06	2.14	2.22	2.30	2.38	2.45	2.53	2.61	2.68	2.76	2.84	2.92	3.00	3.06	3.13	3.22	3.30	3.37
53°F	1.14	1.21	1.29	1.36	1.44	1.51	1.59	1.66	1.74	1.81	1.89	1.96	2.03	2.10	2.18	2.26	2.34	2.41	2.49	2.57	2.64	2.71	2.79	2.86	2.94	3.01	3.09	3.16	3.24	3.31
54°F	1.12	1.19	1.27	1.34	1.41	1.49	1.56	1.63	1.71	1.78	1.86	1.93	2.00	2.07	2.15	2.22	2.30	2.37	2.45	2.52	2.59	2.66	2.74	2.81	2.89	2.96	3.04	3.10	3.17	3.24
55°F	1.10	1.17	1.24	1.31	1.39	1.46	1.53	1.60	1.68	1.75	1.82	1.89	1.97	2.04	2.12	2.18	2.26	2.33	2.40	2.47	2.54	2.62	2.69	2.76	2.83	2.89	2.97	3.04	3.11	3.18
56°F	1.07	1.15	1.22	1.29	1.36	1.43	1.50	1.57	1.65	1.72	1.79	1.86	1.93	2.00	2.08	2.15	2.22	2.29	2.36	2.43	2.50	2.57	2.64	2.71	2.78	2.85	2.92	2.99	3.06	3.13
57°F	1.05	1.12	1.19	1.26	1.33	1.40	1.47	1.54	1.62	1.70	1.77	1.83	1.90	1.97	2.04	2.11	2.18	2.25	2.32	2.39	2.46	2.53	2.60	2.66	2.73	2.80	2.87	2.94	3.00	3.08
58°F	1.03	1.10	1.17	1.24	1.30	1.37	1.44	1.51	1.59	1.67	1.74	1.80	1.87	1.94	2.01	2.08	2.15	2.21	2.28	2.35	2.42	2.48	2.55	2.62	2.69	2.75	2.82	2.88	2.95	3.02
59°F	1.02	1.09	1.16	1.22	1.29	1.36	1.43	1.49	1.56	1.64	1.71	1.77	1.84	1.91	1.98	2.04	2.11	2.17	2.24	2.31	2.38	2.43	2.50	2.57	2.64	2.70	2.77	2.84	2.91	2.97
60°F	1.01	1.08	1.15	1.21	1.28	1.34	1.41	1.47	1.54	1.62	1.62	1.75	1.82	1.88	1.95	2.01	2.08	2.14	2.21	2.27	2.34	2.40	2.47	2.53	2.60	2.66	2.73	2.79	2.86	2.92
61°F	0.99	1.05	1.12	1.18	1.24	1.31	1.37	1.44	1.50	1.57	1.63	1.69	1.76	1.82	1.89	1.95	2.02	2.08	2.14	2.21	2.27	2.34	2.40	2.47	2.53	2.59	2.66	2.72	2.79	2.85
62°F	0.96	1.02	1.09	1.15	1.21	1.27	1.34	1.40	1.46	1.52	1.59	1.65	1.71	1.78	1.84	1.90	1.97	2.03	2.09	2.15	2.22	2.28	2.34	2.41	2.47	2.53	2.59	2.66	2.72	2.78
63°F	0.93	0.99	1.06	1.12	1.18	1.24	1.30	1.36	1.42	1.49	1.55	1.61	1.67	1.73	1.79	1.85	1.92	1.98	2.04	2.10	2.16	2.22	2.28	2.35	2.41	2.47	2.53	2.59	2.65	2.71
64°F	0.91	0.97	1.03	1.09	1.15	1.21	1.27	1.33	1.39	1.45	1.51	1.57	1.63	1.69	1.75	1.81	1.87	1.93	1.99	2.05	2.11	2.17	2.23	2.29	2.35	2.41	2.47	2.52	2.58	2.64
65°F	0.88	0.94	1.00	1.06	1.11	1.17	1.23	1.29	1.35	1.41	1.46	1.52	1.58	1.64	1.70	1.76	1.82	1.87	1.93	1.99	2.05	2.11	2.17	2.23	2.28	2.34	2.40	2.46	2.52	2.58

TABLE KEY

- Blue = Under-Carbonated, 0 - 1.40 volumes CO₂
- Yellow = Stouts and porters, 1.50 - 2.20 volumes CO₂
- Red = Lagers, Ales, Ambers, most beers, 2.20 - 2.60 volumes CO₂
- Green = Highly carbonated ales, Lambics, Wheat beers 2.60 - 4.0 volumes CO₂
- Grey = Over-carbonated [except for certain specialty ales] 4.1+ volumes CO₂

The above chart shows recommended PSI btd on the temperature of your beer in the keg. Keep in mind that CO₂ is absorbed faster at colder temperatures so the colder you can store your keg the faster it should carbonate. Allowing the CO₂ to saturate the beer over time is the recommended method for carbonating your beer in a keg. If you are in a rush however it is possible to force carbonate your beer though it should be noted that this methods can leave your beer over carbonated.

To do this, set your pressure to 40-45 psi and shake, rocking the keg gently from side to side [You might also swap connections so the gas is flowing down the dip tube so it rises through the beer and absorbs easier]. This should take about 60 seconds.

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