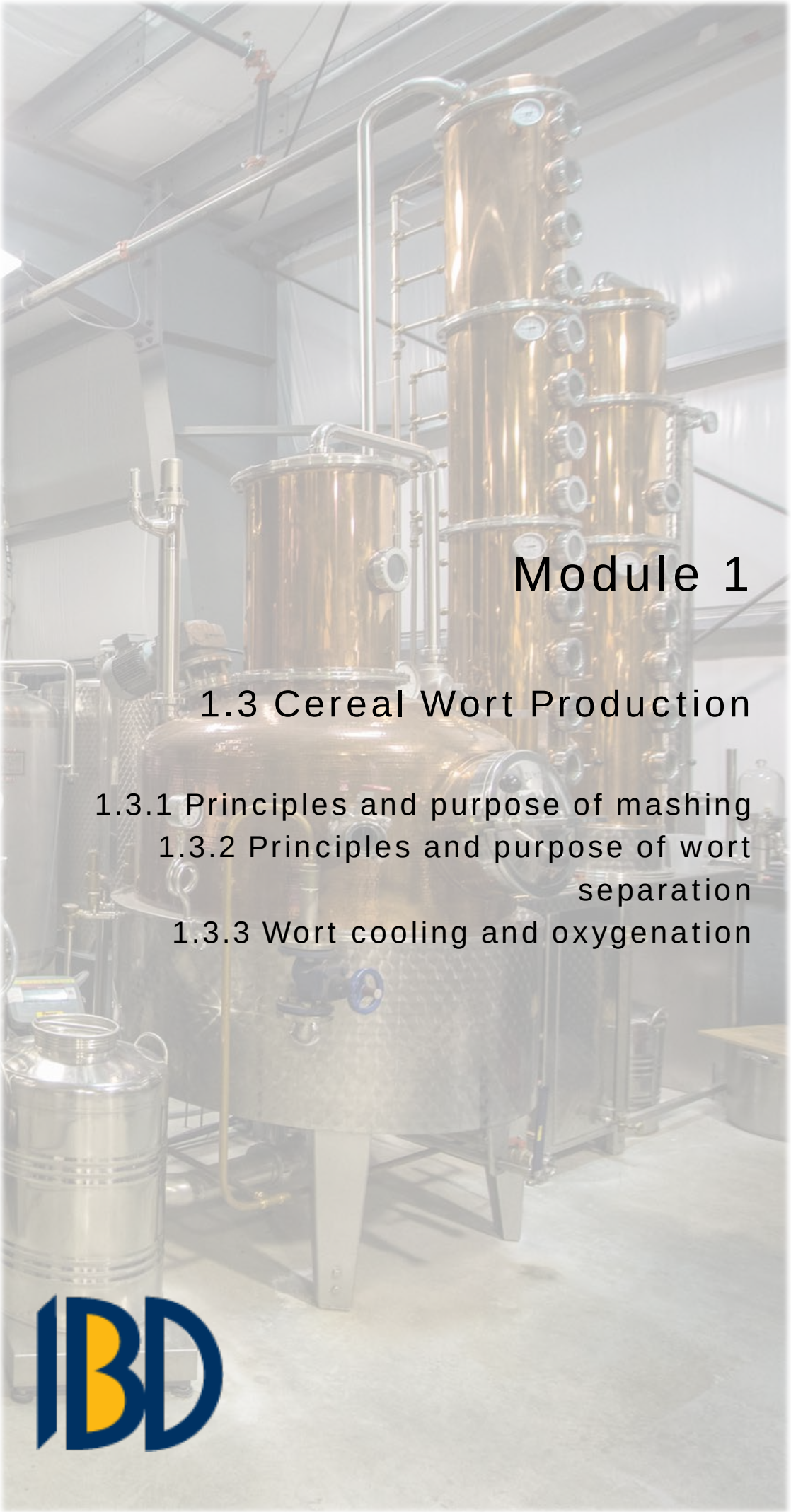

Module 1

1.3 Cereal Wort Production

1.3.1 Principles and purpose of mashing
1.3.2 Principles and purpose of wort separation
1.3.3 Wort cooling and oxygenation

DIPLOMA IN DISTILLING

Contents

Abstract

In this Unit of the Diploma in Distilling, 1.3 Cereal Wort Production, we will examine the distilling process from mashing and cooking to wort separation and cooling.

Firstly, in 1.3.1 we will examine the production of all-malt mashes, and then explore the use of non-malted cereals and supplementary enzymes.

In 1.3.2 the principles and methods of wort separation will be discussed.

Finally, in 1.3.3 we will examine the theory and practice of wort cooling and oxygenation.

Learning Outcomes

On completion of this section you should be able to:

1. *Explain the biochemical processes during all malt and mixed-cereal mashes.*
2. *Describe the methods of wort separation and their merits.*
3. *Understand the purpose of wort cooling and oxygenation prior to yeast pitching.*

Prerequisite Understanding

Basic scientific knowledge and terminology.

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1.2.1 Principles and purpose of mashing

Mashing Procedures for all-malt mashes

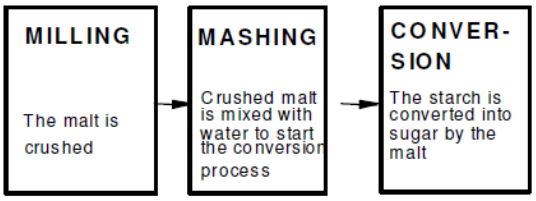
Mashing Overview

Malt whiskies have a distinct flavour that is due in part to the type of malt mashed.

The conversion of starch to sugars has already started during the malting process, following the breakdown of the cell walls and protein matrix surrounding the granules. This conversion was stopped by drying the grains. It is restarted by adding back the water but there is no point in doing this with whole grains because the distiller must extract from the mash:

- all of the partly solubilised starch,
- all of the sugars already formed and,
- all of the diastatic enzymes.

This cannot be done efficiently unless the grain has been milled to make the starch, the sugars and the enzymes accessible by water.



Mashing requires the following equipment:

1 A grist hopper from which to feed the grist in a controlled way to the mixer.
2 A supply of water that can be fed to the mixer through a heat exchanger to achieve a precise temperature
3 A grist/water mixer, often a tube fitted with a screw, for instance a 'Steels masher', that delivers the mix over the side of and into the mashing vessel and
4 A mashing vessel.

Mashing vessels of different designs are used for malt whisky production, but all of them have:

- a set of blades or a rake to stir the mash in a controlled way
- a slotted base that sits just above the outlet.

When the outlet valve is opened, the mash settles gently on the slotted base through which the liquid extract is withdrawn. The grain extract is the unfermented mash, also known more simply as 'wort'. It may be clear or slightly cloudy, depending on the type of mashing vessel in use and the manner in which it is operated.

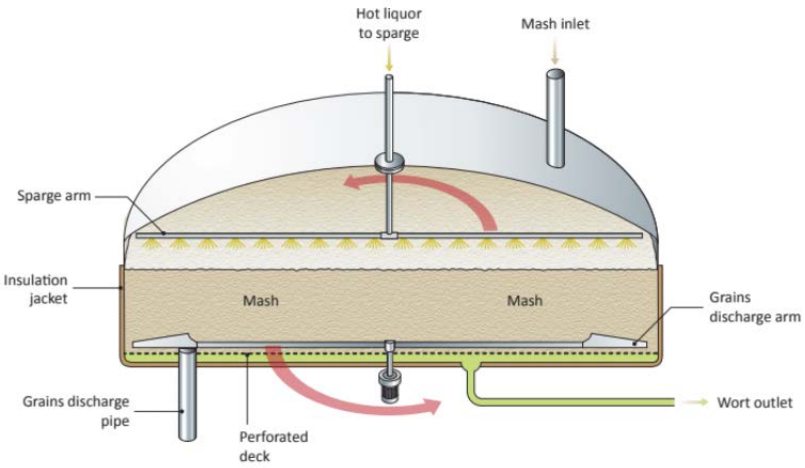


Figure 1 A 'mash tun', a combined mashing and separation vessel

Mashing is carried out in the following way. The grist is mixed with water that is called the first water because more water will be used later in the process. This mixing of the first water and the grist is called 'mashing-in'. Mashing-in is a critical step because the water must be at a precisely controlled temperature.

The temperature of the mash in the mashing vessel must be:

- warm enough to gelatinise the remaining malt starch,
- cool enough to preserve the activity of the enzymes and

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- be near to the optimum temperature for the speed of action of the malt amylases.

The temperature that is the best compromise between these three requirements is in the range 62 to 65°C. Many distilleries use 64.0°C.

The mash is stirred occasionally and after a given time that could be between 20 to 70 minutes after filling. During this time the malt enzymes, alpha-amylase and beta- amylase, are converting (saccharifying) the starch to maltose and maltotriose. After the allotted time has elapsed, the wort is withdrawn from the bottom of the vessel.

This is called the strong wort because it contains a high percentage of sugar. It is pumped through a heat exchanger to cool it to the temperature that suits the yeast that is to be added. This is usually in the range of 15 to 25°C. From the heat exchanger the wort is transferred directly to the fermentation vessel. As soon as there is about 50cm of depth of wort at the correct temperature in the vessel, the yeast is added because it is essential for fermentation to start very quickly. Unyeasted fresh wort becomes heavily infected with Lactobacilli in a matter of hours.

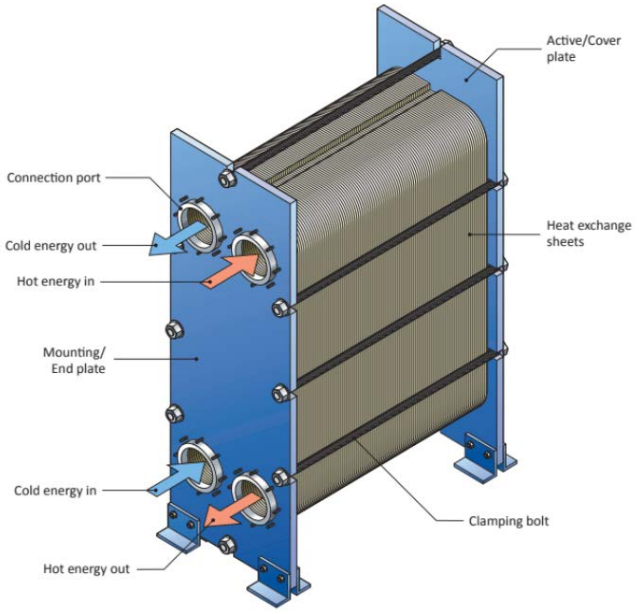

Figure 2 A plate heat exchanger.

Meanwhile, back in the mashing vessel the bed of grain still contains some materials that the distiller needs: a little more sugar and more starch that can be converted to sugar by the enzymes carried over into the fermentation vessel. So warmer second water is added (about 70°C), drained off, cooled and sent to the fermentation vessel. Then the hot third water (about 80°C) is used to wash any remaining sugar out of the grain. The third water is normally recycled to form at least part of the first water for the next mash.

This is the traditional method of "3-water" mashing in which the mash is stirred by a set of rotating paddles after the addition of each water and the wort run off to wash back, or to a storage tank for recycling into the next mash in the case of third waters. This method has been replaced by sparging the water onto the mash semi continuously (as in brewing) and the wort run off continuously until the required volume and gravity is achieved in the wash back.

At the end of the mashing process, the fermentation vessel is full of wort that is already fermenting rapidly. The mashing vessel contains the grain debris (draff), mainly husk, material that contains very little sugar or starch. This is used as feed for cattle or is disposed of in another environmentally friendly way.

The specific gravity of the wort depends on the amount of water added per tonne of malt, usually about 10 tonnes. The specific gravity is usually within the range of 1.050 and 1.070 and the pH value about 5.2. Maltose and maltotriose are the main sugars in the wort, together with smaller amounts of glucose and maltotetraose. All of these sugars can be fermented by suitable yeast strains but at the end of mashing only about 72% of the extracted wort is fermentable. About 15% of the remaining starch fragments called dextrins are converted in the fermenting wash. This is called the 'secondary conversion' without which the alcohol yield would be reduced by about 60 litres of alcohol per tonne.

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These processes are described in more detail in the following sections…

The Principles and Purpose of Mashing

The major objective of mashing and wort preparation is to extract all of the available carbohydrate from the raw materials and present it to the yeast in a fermentable form. A subsidiary but important objective is to extract other materials:

- that provide the yeast with nutrients leading to a successful fermentation
- other materials such as lipids which will eventually contribute to the flavour of the new make spirit.

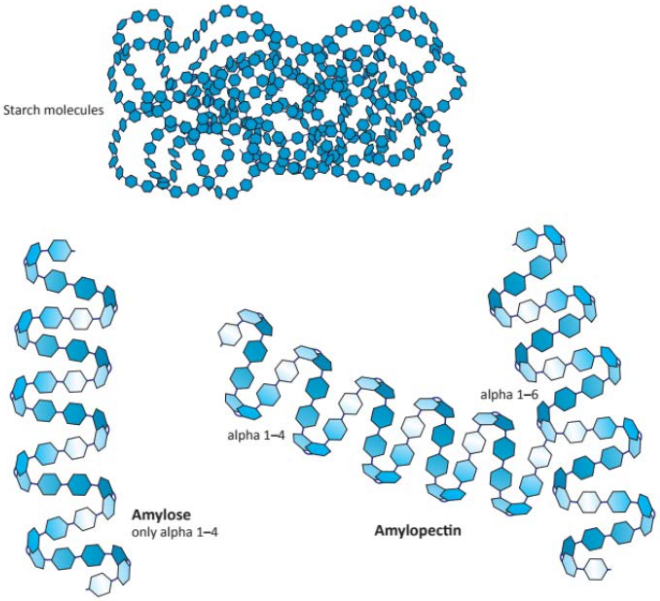
As mentioned above the final portion of conversion that takes place in the early stages of fermentation is known as 'secondary conversion' The extent of secondary conversion is also dependent on mashing conditions and can determine the limit of alcohol yield.

The conditions chosen by each distillery are therefore vital in obtaining:

- optimal extraction of potentially fermentable carbohydrate, additional yeast nutrients and the full complement of diastatic enzymes from the malt
- optimal conversion of the carbohydrate to fermentable sugars.

When present, protein-degrading enzymes (proteases) can produce smaller molecules such as amino acids which are essential for yeast growth early in fermentation. Malt does contain some protease and some additional amino acid is produced during mashing. However the bulk of the necessary amino acid is already in the malt and is produced during the malting process when the protein matrix surrouding the starch is being broken down.

'Conversion' or 'saccharification' are the terms used to describe the enzymic production of fermentable wort from starch. In the starch granule there are two different types of polymer both consisting of long polymers of glucose units alpha-1-4 linked together. Each polymer is linked to one or more similar chains by alpha 1-6 linkages. About 20% or more of the starch consists of amylose which has very few inter chain alpha 1-6 linkages. Amylopectin, on the other hand has a 1-6 linkage for every 25 glucose units arranged as shown below:



Malt enzymes attack the long chains of glucose units that make up the starch molecule and convert them into fermentable sugars. For ease of demonstration the diagram below shows the effect of malt enzymes on a small fragment (dextrin) of amylopectin. In the intact molecule there is, on average, one "branch" chain to every "main" chain. Each chain is 25 glucose units in length and in the intact molecule the "free" reducing end demonstrated below is connected to another "main" chain resulting in a huge polymer of branched chains. In the granule the chains of amylopectin lie almost parallel to one another in a semi- crystalline fashion and since granules are almost spherical in appearance the amylose fills in what would inevitably be fissures on the surface. These parts of the granule are amorphous and do have gaps which allows access to amylolytic enzymes during malting. In barley the starch granule is enclosed in a membrane and is surrounded by a protein

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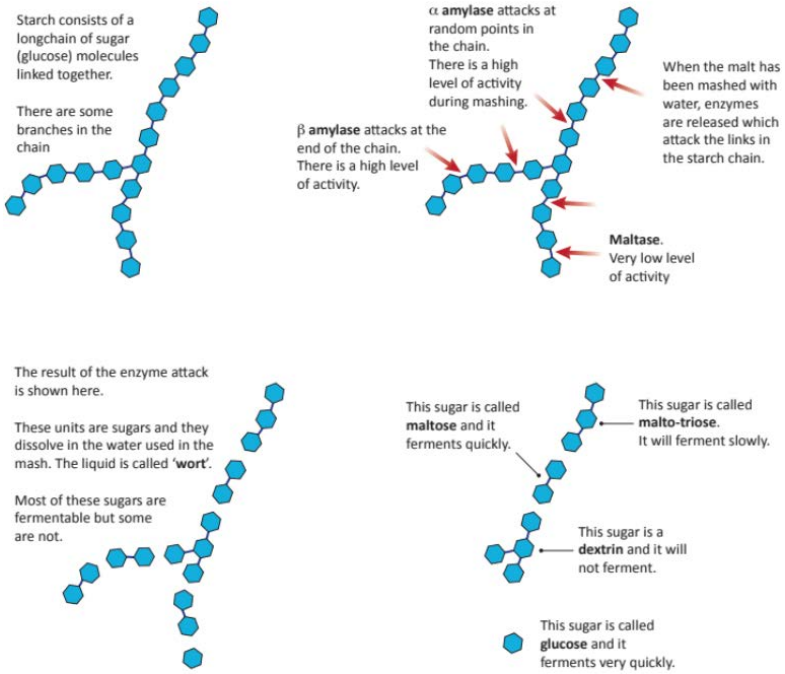
matrix both of which are broken down during endosperm modification to allow enzymes to start hydrolysing the starch within these fissures giving the malt starch granules a pitted appearance. Furthermore, during modification most of the small starch granules are preferentially hydrolysed. So apart from surface pitting the malt starch granules are almost intact and have the full complex of hydrolysing enzymes adsorbed so that they can restart starch degradation immediately in the mash tun. This is the major difference between an all malt mash and a grain distilling mash which requires the non-malted cereal starch to be gelatinised before hydrolysis. Malt starch on the other hand will dissolve and saccharify, albeit slowly, at much lower temperatures.



α-Amylase is very active during mashing. It attacks randomly in the chains of both amylose and amylopectin to produce a mixture of maltose (2 glucose units), maltotriose (3 glucose units) and a whole range of dextrins (from 4 to 20 units) like the one depicted above.
β-amylase is also very active during mashing. It works its way along chains from the branch ends (non-reducing) releasing maltose as it progresses.

The amylases can only come within one or two units of the branch points so that the so called "limit dextrins" surrounding each branch point will contain between 4 and 8 glucose units like the one depicted in the diagram. It is easy to calculate that if there are two branch points for every 50 glucose units then approximately 12% of the original molecule would remain as a limit dextrin. However, malt contains small amounts of two secondary enzymes, limit dextrinase and alpha glucosidase (maltase) which have the effect of breaking down at least half of the residual limit dextrins in the fermenting wort. In the model shown above the limit dextrin containing the branch linkage would be broken at the branch point by limit dextrinase to create two new linear dextrins, one with three units (maltotriose) and one with five. The 5-unit molecule could then be broken by further action of the amylases to create one molecule of maltose and one of maltotriose. All of the new fragments would then be fermentable.

The maltase enzyme is shown breaking maltose into two units of glucose in the above diagram but it can also break down maltotriose and to a lesser extent maltotetraose (4 glucose units).

Both of these minor enzymes are heat sensitive so some of their activity is lost during mashing. **Nevertheless, they do make an important contribution to the additional 15% of fermentability gained by secondary conversion.**

Knowing the action of the four different enzymes allows a simple mathematical model of fermentable extract (FE) and secondary conversion to be created. For this model it is assumed that for 100g of dry barley, with a protein content of 10%, there is a 10% malting loss yielding 90g of malt which, at 82% extraction will deliver 74g soluble extract. The 74g of potential extract is derived from 59g of starch, 9g of pre- hydrolysed starch sugars, 4.5g of soluble protein (assuming a 45% SNR) and 1.5g of other solutes such as glucan/pentosan residues, minerals, etc.(see

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composition tables above) If we assume that the 59g of starch consists of 20% amylose and that all of it will be hydrolysed to fermentable sugar, then this will contribute 11.8g to the FE.
Referring to the diagram of amylopectin above and assuming that:

- there is no action from limit dextrinase and alpha glucosidase (maltase) and
- the amylases cannot come closer than two glucose units to an alpha 1-6 linkage (the black circles in the diagram) and
- there are four branch points for every hundred glucose units (i.e. the ratio of A- chains to B-chains is 1:1)

then the amylopectin will be broken down to 28% dextrin (4x7 glucose units around each 1-6 linkage) and 72% fermentable sugars so yielding 34g of fermentable sugar from the 47.2g of amylopectin. So, the model of fermentable extract is;

Preformed sugars in the malt	9g
FE from amylose hydrolysis	11.8g
FE from dextrinised amylopectin	34g
Assimable amino nitrogen & other nutrients	0.2g
Total FE	**55g**
Total extract	**74g**
Apparent Fermentability	**74.3%**

This is the same order of magnitude for the fermentability of a boiled wort derived from a cured lager malt, with no secondary conversion post run-off.
Using the same data we can now estimate what the FE would be if all the branch points in amylopectin were to be hydrolysed:

Preformed sugars in the malt	9g
FE from amylose hydrolysis	11.8g
FE from amylopectin hydrolysis	47.2g
Assimable amino nitrogen & other nutrients	0.2g
Total FE	**68.2g**
Total extract	**74g**
Apparent Fermentability	**92.2%**

So the range of spirit yields expected from a malt with 82% dwb extract would be 369 l.alc./t and 458 l.alc./t. The latter figure equates to a yield of 435l.alc./t for a malt at 5% moisture mashed and fermented as "all-grains-in"* at ambient temperature. The limits of fermentability derived from this model are therefore realistic. If we then take the range of fermentability as 18% then a malt with a fermentability of say 87.5% indicates that about 73% of the available dextrin has been hydrolysed.

Since the dynamics of amylolysis are such that some dextrins are rendered undegradable by limit dextrinase and some branch points are so close together that the enzymes cannot access them, it would appear that a fermentability of about 88% is the maximum that can be achieved by conventional mashing. Only when all four enzymes act in concert on an intact starch granule at ambient temperatures do we know that complete saccharification is achieved. Using the "all-grains-in" test, laboratory yields of 435l.alc./t are easily achievable indicating that an appropriate form of programmed mashing could substantially increase fermentability of distilling malts.

The secondary enzymes limit dextrinase and maltase are therefore vital in achieving the maximum fermentability in distilling malt. Total saccharification is only achievable at low temperatures when the kinetics of hydrolysis of a hydrated starch granule are completely different from a gelatinized granule in a 64^0C mash. The mashing temperature also partially inactivates limit dextrinase and maltase but there is still sufficient activity to completely hydrolyse the starch at lower temperatures.

(*this is a laboratory test in which finely ground malt is mashed at room temperature and to which distilling yeast is added. The spirit yield is determined in the normal way and represents the maximum which can be achieved from that malt.)

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The range of sugars produced during conversion determines the fermentability of the wort. If the enzyme attack is complete, the wort will be highly fermentable as the above model demonstrates. If the enzyme attack is incomplete, the wort will be only partially fermentable. Enzymes are very sensitive to the conditions that they work in. They are affected by how much water is present, temperature and pH or mash acidity. They take time to work, so the length of time that is allowed for mash conversion will affect the degree of conversion.

There are optimum conditions for mashing and these are summarised in the table below:

Condition	Low	Optimum	High
Temperature.	Low temperatures do not affect the enzymes much, but the starch must be gelatinised first to achieve quick conversion. Gelatinisation temperature for malt starch is 60-65°C.	65°C	High temperatures inactivate enzymes, including α and ß amylases and limit dextrinase. The action of amylases is stopped at temperatures over 70°C.
pH.	Acidic conditions kill the enzymes. Enzyme action is stopped at pHs below 5.0	5.4	High pHs slow enzyme action, but it does continue at pHs of 7 or above.
Water. (Mash thickness)	Enzymes are more sensitive to heat in a thin mash. There is a lower concentration of enzyme and starch in a thin mash.	Between 2.5 and 3.5 litres of water per kilogram of dry grist.	Enzymes are less sensitive to heat in a thick mash. There is a higher concentration of enzyme and starch in a thick mash.
Time.	Enzymes take time to attack the starch. Conversion will be incomplete in less than 30 minutes.	30 minutes	Conversion will be almost complete after 30 minutes. A longer time will not increase the yield of sugar but may make it more fermentable, but not if the temperature is ~65°C.

Calculation of Mash Tun Extract in a Malt Distillery

The ratio of water to malt grist (i.e. the concentration) used in a mash determines the volume and the subsequent alcoholic strength of an all-malt wash. Calculations are therefore required to ascertain how much of each component is needed to end up with the desired volume and strength of wash.
This equation involves using a Specific Gravity (SG) figure The SG of a solution, such as wort, is defined as 'the weight of a solution divided by the weight of an equal volume of distilled water at the same temperature (both weights in air)' The temperature is usually 20^0C. An example is 1.055, where 1 ml. of water weighs 1
gram and 1ml of the solution weighs 1.055 grams.
The SG as defined above is often expressed as a multiple of 1000 (i.e. on the basis that water's SG=1.000, would now be 1000). When expressed in this manner it is often referred to as simply the 'gravity', e.g. 1055 (or 'Ten fifty five')
The SG can also be written in the form (1000 x SG) – 1000 (in this case 55). The solution-in this case wort- is said to have 55 degrees of excess gravity. In the equation that follows, the excess Original Gravity (OG) figure is 55. The OG is the SG at the beginning of fermentation, before any alcohol is produced. If the volume (litres) of wort and the weight of malt mashed (Kg) are known then the amount of extract (%) in the wort can be calculated by measuring the OG:

$$\text{Soluble Extract (\%)} = \frac{\text{litres wort x excess Original Gravity}}{3{,}87 \text{ x kg malt mashed}}$$

The example below now illustrates the necessary calculation to estimate the quantity of malt required to achieve 50,000 litres of wash with an O.G. of 1060 in a malt distillery using a malt with an extract of 77.5% as is:

Kg malt mashed =(50,000 x 60)/(77.5x 3.87) = 10,000 = 10tonnes

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Mashing Procedures for mixed-cereal mashes

In mash bills consisting of 85 – 90% unmalted cereal, plus 10 – 15% malted barley, the saccharification enzymes come from malted barley. Therefore the process is similar to that described for the 100% malt mash above, particularly as regards the temperature at which the conversion takes place.

The main difference is that most of the starch to be saccharified comes from unmalted grain, often maize and wheat. As described above, in unit 1A.5, the starch granules in malted barley are partly broken down in the malting process, they gelatinize at a relatively low temperature of about 64°C. Starch granules in maize and wheat on the other hand gelatinize at higher temperatures, can be heavily encased in protein, and are enclosed in undegraded cell walls.so require cooking.

When malted barley is being used as a source of enzymes to convert the gelatinized starch to sugars, it also provides its share of the total starch needed. As in 100% malt whisky production, the malt must be milled and mashed to release the enzymes and allow them to disperse into the liquid of the mash.

In contrast to the use of malted barley in malt whisky production, relatively intact husks are not necessary; either the wort is filtered on a series of sieves or it is pumped to the fermentation vessel without any filtration. Therefore, the malt is ground to fine flour in a hammer mill for ease of mixing into the rest of the mash.

The required quantity of malt is added to the cooled maize mash at a temperature of about 64°C. This is often done in the fermentation vessel itself. As soon as the vessel has received the correct amount of mash, the temperature is reduced to that required for the start of fermentation (15 to 25°C) and the yeast is added immediately.

The specific gravity of the wort usually lies within the range 1.060 to 1.080 and the pH value in the region of 5.5 to 5.8. Maltose and maltotriose are the main sugars in the wort, together with smaller amounts of glucose and maltotetraose. All of these sugars can be fermented by suitable yeast strains.

A significant amount of starch remains to be converted to sugar in the early stages of fermentation. Without this secondary conversion, the alcohol yield would be about 15% lower.

Cereal Cooking

In mashes containing unmalted cereals, the cereals must be cooking first to gelatinize thei starch content. Maize and wheat are the main unmalted cereals used by distillers.

Gelatinized starch is accessible for saccharification by enzymes, but ungelatinized starch is not. The gelatinization is achieved by cooking the grains. Many different methods of cooking are used. The following is one example that illustrates the basic principles of most cooking methods:

- grain, for instance maize, is mixed with warm water in a slurry vessel, using about two and a half tonnes of water per tonne of grain,
- when this is well mixed, it is transferred to a pressure vessel fitted with a stirrer to gently mix the grain as it is cooking,
- steam is injected into the cooker to raise the pressure above that of the atmosphere to achieve a temperature of 130°C,
- this temperature is held for 5 minutes and the steam supply is cut off,
- then the vessel is opened in a carefully regulated way to remove the contents, this is called blowdown, and finally
- the cooked cereal is cooled to below 70°C as quickly as possible.

Variations to this process include:

- hammer milling the grain to a flour to help mixing and gelatinization and

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- the addition of backset (stillage from the beer column of the continuous still) to the water, reducing the water usage rate.

The combination of the cooking and sudden release of pressure ensures that the starch in the maize is completely gelatinized and in perfect condition for the saccharification enzymes.

Batch cooking

Cooking is carried out in pressure vessels that are equipped with stirrers in order to prevent the grain from settling and cooking unevenly. Cookers vary in load capacity from about 2 tonnes to about 20 tonnes. Whole or milled grain is added to the vessel with the appropriate amount of water.
In some distilleries, backset (spent wash) may be added along with the fresh water.

Steam is then injected into the vessel to flush out all air at which point the vessel vents are closed and the steam injection continued until the desired pressure is attained. The steam used for direct injection must be "pure water" steam.

Three factors determine the effectiveness of cooking:

- the pressure and temperature reached (these are directly linked),
- the duration of the elevated pressure conditions and
- the solid/liquid ratio in the cooking vessel.

Cooking conditions vary widely between grain distilleries. The following table compares a low pressure, short duration cook with a high-pressure cook.

	LOW TEMPERATURE	HIGH TEMPERATURE
Time to reach hold temp.(mins)	80	40
Maximum temp.(°C)	103	150
Hold pressure (psig)	15	68
Hold time (mins)	0	30

Continuous Cooking

Continuous cooking equipment is more complex in construction and more difficult to control and to clean than batch cooking plant. This is at least partly due to the need to maintain 'steady-state' to achieve the required cook without overcooking and energy waste.

Factors common to the various types of continuous system are:

- fine ground cereal, e.g. wheat through a hammer mill, to aid quick cooking,
- addition of a small amount of malt, the 'pre-malt', to reduce the viscosity of the slurry (action of alpha-amylase converting the large starch molecules into the smaller dextrins); in gns production microbial alpha-amylase is used.
- grain slurry pumped through a relatively narrow tube,
- control of residence time,
- use of high pressure and temperature which can be higher than those economically achievable in batch cooking

Cooling after Cooking

At the planned time, the contents of the cooking vessel are blown by the internal pressure of the vessel to the mash tun, or holding (conversion) vessel, or to the washback.

Temperature control is vital, each distillery having a target final mash temperature. This is often about 63°C.

However, throughput constraints or other operational factors could require a quite different cooling regime with the cooked material being added directly to the washback with the malt slurry.

Cooling of the cooked grain can be achieved in a variety of ways:

- by drawing a vacuum in the cooker
- by using flash/vacuum vessels

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- in a heat exchanger between the cooker and the mash tun
- by simultaneous addition of cold water to the mash tun at blow down.

It is possible to supplement the cold water with backset, which is acidic and can help accelerate the breakdown of cereals in the cooker. The malt grist can be added to either the cooker or the mash tun as long as the temperature is appropriate.

In summary, the procedures for cooling the cooked grain and the sequence of the transfer to the washback can differ widely in different distilleries.

All distilleries have the objective of achieving their desired throughput and their target conversion temperature from the first moment when the malt meets the grain.

The selection of exogenous enzymes for mashing

In the production of Scotch Whisky, only endogenous enzymes are allowed. This means that the only enzymes permitted are those present in the raw materials, which in practice means the malt and yeast.

Exogenous enzymes are permitted in the production of GNS. They are used in the conversion of starch to sugars in mashing and can, if desired, totally replace the use of malt. These enzymes are extracted from microbial sources (bacteria & fungi) by specialist enzyme companies. They are sold as purified preparations of specific type and power of activity and recommended conditions of use. All enzyme preparations have to be selected carefully and targeted at the requirement of each individual distillery. Enzyme supplying companies offer advice on the conditions of use as defined by four criteria:

- the type and quantity of starch to be broken down,
- the prevailing pH and temperature at the point of use,
- the equipment being used and
- the time available.

The types that are used in GNS production for starch breakdown are α-amylase and amyloglucosidase (sometimes called glucoamylase). In some cases, pullulanase and protease might also be used.

These enzymes can accomplish an almost complete conversion of starch to fermentable sugar.

Thus, the yield of alcohol in GNS production is potentially higher than that in Scotch Whisky production.

alpha-Amylase

This enzyme breaks the starch molecule into smaller units, called branched maltodextrins and oligosaccharides, but produces some maltose and maltotriose. Important physical effects of this enzyme are increased liquefaction and a reduction of the viscosity of a starch suspension. Microbial α-amylase preparations act in a similar manner to the malt enzyme chemically. However, they are can work at higher temperature and lower pH than the malt enzymes.

Amyloglucosidase (glucoamylase)

Amyloglucosidase is a saccharification enzyme, that is to say it can convert nearly all of the maltodextrins to glucose. It breaks down α1-4 bonds of the linear parts of the starch molecule quickly and α 1-6 bonds of the branched parts slowly. This is an advantage over the malt enzymes, which cannot break the α 1-6 bonds. Again, the commercial preparations are very stable in relatively extreme conditions such as high temperature.

Pullulanase (debranching enzyme or limit dextrinase in malt)

This enzyme is specific for the breakdown of α 1-6 bonds. It is also known as debranching enzyme because the α 1-6 bonds are the

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branch points of some of the starch molecules. It would be used in combination with amyloglucosidase.

Protease

In wheat, the starch granules are encased in a protein matrix. Proteases can be used to hydrolyse the protein. This exposes the starch granules and improves the effectiveness of the alpha-amylase. Proteases in use include: neutral protease of microbial origin; the plant enzyme, papain and a 'side' activity of some preparations of amyloglucosidase.

Other activities

When enzymes are extracted from biological material, it is usual for more than one type of enzyme to be present. The subsequent partial purification of the target enzyme is designed to remove unwanted enzymes and to concentrate the one needed. However, one or more of the minor enzyme constituents might be of use in the final application. An example is the possible presence of protease and/or β-glucanase in amyloglucosidase.

Mashing with exogenous enzymes

The major objective of mashing and wort preparation is to extract all of the available carbohydrate from the raw materials and present it to the yeast in a fermentable form A subsidiary but important objective is to extract other materials:

- that provide the yeast with nutrients leading to a successful fermentation
- other materials that will eventually contribute to the flavour of the new make spirit

Various quite different procedures are employed successfully in the preparation of cereal based worts for Scotch Whisky and GNS production,
It must be stressed that although it takes time to saccharify starch using the malt enzymes (or in G NS production, the exogenous enzymes), it is not necessary to have all of this complete before starting fermentation. The final portion of conversion that takes place in the early stages of fermentation is known as 'secondary conversion'. In many distilleries at least 1 5% of the starch saccharification remains to be completed in the washback. At the other extreme, in some distilleries simultaneous saccharification and fermentation is practised. For instance, in a Scotch Whisky grain distillery it would be possible to add the malt suspension along with the cooked and cooled wheat (plus the additional water needed) to the washback and add the yeast at the same time. Thus, the process stage called wort preparation that is described below can be reduced to a minimum of mixing cereal suspensions in the washback.

Mashing is the process where the milled and/or cooked cereal is mixed intimately with hot water at the appropriate striking temperature (under specified conditions) to achieve the required temperature in the mash.

The conditions chosen by each distillery are vital in obtaining:

- optimal extraction of potentially fermentable carbohydrate from the cereal
- optimal conversion of the carbohydrate to fermentable sugars.

When present, protein-degrading enzymes (proteases) could produce smaller molecules such as amino acids that can have a beneficial effect on yeast growth early in fermentation. Malt contains some protease.
In most malt distilleries a mashing-in machine (Steel's masher) is used.
Purified and concentrated enzyme preparations (known as exogenous enzymes because they do not enter the production system in the malt or the yeast) may be used for GNS wort preparation. The examples shown below include two such enzymes, amyloglucosidase and pullulanase.

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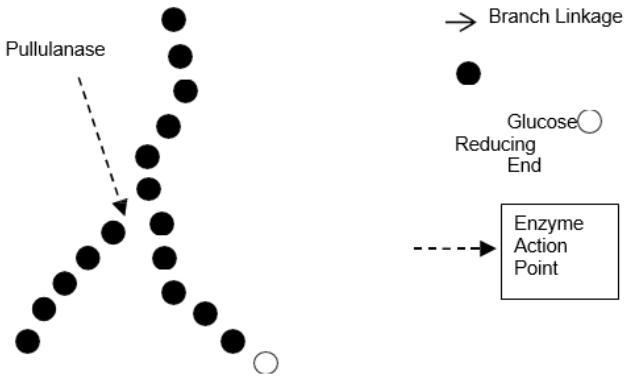
'Conversion' or 'saccharification' are the terms used to describe the enzymic production of fermentable wort from starch. The conversion of starch from unmalted cereal by the enzymes from malted barley is exactly the same as shown in the malt mashing section.

In the presence of the exogenous enzymes (i.e. externally added), amyloglucosidase and pullulanase, the attack on the starch molecule is different. Amyloglucosidase can break all of the linkages between the glucose molecules (including the branch points) by itself although the branch points are broken more slowly.. If heat resistant pullulanase is used along with amyloglucosidase, the pullulanase specifically and quickly attacks the branch chain link allowing the amyloglucosidase to rapidly convert the debranched molecules to glucose.



Thus, glucose will be almost the only sugar present in the wort. It is possible for malt to be used, for its enzymes or other reasons, in addition to exogenous enzymes in GNS production

The range of sugars produced during conversion determines the fermentability of the wort. If the enzyme attack is complete, the wort will be very fermentable. If the enzyme attack is incomplete, the wort will be only partially fermentable. Enzymes are very sensitive to the conditions that they work in. They are affected by how much water is present, temperature and pH or mash acidity. They take time to work, so the length of time that is allowed for mash conversion will affect the degree of conversion.

In the production of GNS, added enzymes are allowed. The main ones in use are alpha-amylase, amyloglucosidase (an alternative name is glucoamylase) and pullulanase, all of microbial origin. The action of microbial alpha-amylase is the same as that of malt. Amyloglucosidase works its way along the dextrin sugar chain releasing glucose molecules as it progresses. Pullulanase is a starch debranching enzyme. The stability and temperature and pH optima of these exogenous enzymes vary according to their source.

In general, these exogenous enzyme preparations are more stable than malt enzymes. Wort produced by exogenous enzymes alone (no malt used) contains only glucose, a sugar that is easily fermented by a wider range of yeast strains than is the case with the malt mashes used in Scotch Whisky production.

There are optimum conditions for mashing and these are illustrated in the table below:

Condition	Low	Optimum	High
Temperature.	Low temperatures do not affect the enzymes much, but the starch must be gelatinized first. Gelatinization temperature for malt starch is 60-65°C.	65°C	High temperatures inactivate enzymes, including α and ß amylases and limit dextrinase. The action of amylases is stopped at temperatures over 70°C.
pH.	Acidic conditions kill the enzymes. Enzyme action is stopped at pHs below 5.0	5.4	High pHs slow enzyme action, but it does continue at pHs of 7 or above.
Water. (Mash thickness)	Enzymes are more sensitive to heat in a thin mash. There is a lower concentration of enzyme and starch in a thin mash.	Between 2.5 and 3.5 litres of water per kilogram of dry grist.	Enzymes are less sensitive to heat in a thick mash. There is a higher concentration of enzyme and starch in a thick mash.
Time.	Enzymes take time to attack the starch. Conversion will be incomplete in less than 30 minutes.	30 minutes	Conversion will be almost complete after 30 minutes. A longer time will not increase the yield of sugar but may make it more fermentable, but not if the temperature is ~65°C.

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In general, grain distillers do not use a similar equation to that used in determining the extract from malt They rely on simple but effective indicators in order to ensure that mashing has proceeded as normal. Gravity and pH are the main indicators, combined with a close watch being kept on temperature during the stage of the primary conversion of the cooked starch. In those distilleries where the grain is crushed before cooking, mash samples will be checked for presence of whole corns, an indicator of screen failure.
A higher gravity than normal may indicate overcooking of the grain. A lower gravity could indicate lower than normal conversion, concerning which the temperature and pH history are highly relevant. Too high a temperature on too low a pH would lead to a more rapid inactivation of the malt conversion enzyme complex. This is critical in grain distilling because malt is a relatively expensive source of starch compared with other grains. There is thus a permanent incentive for the grain distiller to consider the minimum amount of malt that would provide sufficient enzyme activity to convert the starch in both the malt and the cooked cereal.

1.3.2 The Principles and Purpose of Wort Separation

Introduction

When conversion is complete, the mash will consist of a sugar solution called wort and the husks of the malted barley. The purpose of wort separation is to remove these husks and any other particles that are not wanted in the wort.
The objectives of effective wort separation are the removal of unwanted material while at the same time extracting all the available wort. Wort is separated from the spent malt grains in every malt distillery since unwanted "grainy" flavours would be ectracted in the fermenting wash and the wash still.

Effective wort separation means:

- Maximising extract recovery.
- Absence of particles in the wort.
- Absence of starch in the wort.

To achieve these objectives, wort separation systems use some common principles:

- Filtration using the husk as a fine filter supported by the slotted base in the case of a mash or lauter tun.
- Control of wort flow to ensure wort clarity and maximise filtration efficiency.
- Sparging with hot waters to extract the maximum amount of soluble extract (wort).
- Spent grain (waste husk) removal and disposal on completion of filtration.

There are many systems in which wort can be separated from the mash, the most common in the Scotch Whisky industry being:

- The traditional mash tun.
- The lauter mash tun.
- the semi-lauter mash tun

Unlike the brewing industry where mash filtration is now quite a common practice, there is presently only one distillery in Scotland which operates a mash filter. The operation of different wort separation systems, including a mash filter,is illustrated in the diagrams below:

All types of mash tun act both as a conversion vessel **and** as a wort separation vessel.

Mash Tun

In a traditional mash tun, filtration through the deep bed gives bright wort, but it is relatively slow.

Wort flow is controlled by adjusting the taps on the outlet main or by a manometric or (differential pressure controlling) device such as a balancing underback (see below). Strong wort (called the **first water**) is run off slowly because its high concentration and the mash bed must not settle on to the plates too quickly. When the first water is fully drained, a second water at a higher temperature is added through the mashing machine at a temperature of 75 -77^{0}C and mixed into the drained mash. This second water is again allowed to drain off, before a

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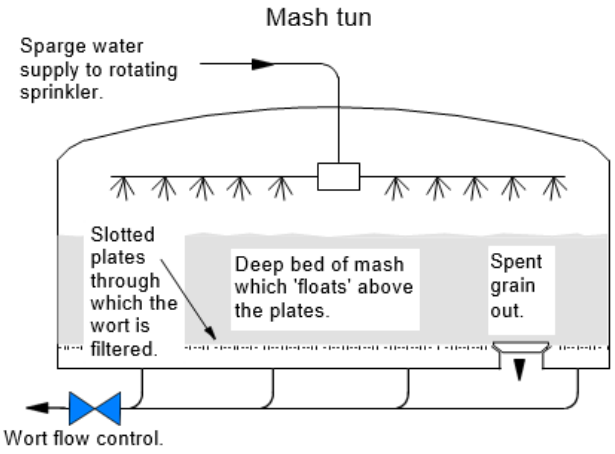
final, third water is added at 77 – 87^{0}C and again mixed with the rotating paddles. This final water or “sparge” is not cooled and pumped to the wash-back but is retained as mashing water for the next mash.
When all the wort has been run off, spent grain is removed through a port in the base either manually or by discharge gear rotating arms

Such deep bed mash-tuns with traditional paddle mixers are now very rare because the majority of Scotch whisky distilleries firstly converted their mash tuns to a “semi-lautering” system by installing rotating sparge arms as shown below



The traditional mash tun is a simple but effective system involving only one vessel for both the mash conversion and wort separation processes. It gives good quality wort but has a slow turn round time and is less efficient for extracting and transferring the enzymes, which are required to continue their activities in the washback.

The underback is a vessel through which the wort flows and it is used to control its run-off rate. It is important that the malt bed is not pulled down on to the mash tun plates, when it would impair drainage. Most malt distilleries are equipped with a balanced underback, in which the wort level in the mash tun and underback are equalised, allowing close control of the run-off rate.

Semi - Lauter and Lauter Tun

The first semi lauter mash tuns were run essentially in the same manner as the traditional mash tun, but instead of adding and mixing separate waters and filtering to almost dryness, sparge (hot water) is sprayed gently over the grain, usually in two or three batches (waters) in much the same way as a true lauter.

This system was an interim technology whereby a traditional mash tun was fitted with a rotating sparge arm or with sparge rings instead of adding separate waters through the Steeles masher and mixing with rotating paddles. The **first and second waters** are then pumped to the fermentation vessel (washback) and any subsequent water is returned to the sparge tank for use in the next mash.

A true lauter tun is depicted below with a much shallower bed , proper lauter knives and rotating sparge arm or sparge rings. Because the mash is added
directly to the lauter via the mashing machine and not to a separate mash conversion vessel these lauter tuns are sometimes also referred to as “semi-lauters” In a lauter tun, filtration gives bright wort through a shallow bed; often the first runnings of cloudy wort are recirculated, a process known by the German term vorlauf. In this system sparging is continuous while the shallow mash-bed is raked by the slowly rotating lautering knives. The sparge temperatures are ramped up at suitable time intervals to mimic the old three water system. However the extraction is much more efficient and higher working gravities can be achieved.

Wort flow is controlled by taps on the outlet main, by a manometric (differential pressure controlling) device such as a balancing underback or by automated flow control valves. Strong wort is run off just as described above for the mash tun. Rakes are used to reduce bed compaction in order to increase wort flow if it has slowed down. This affects

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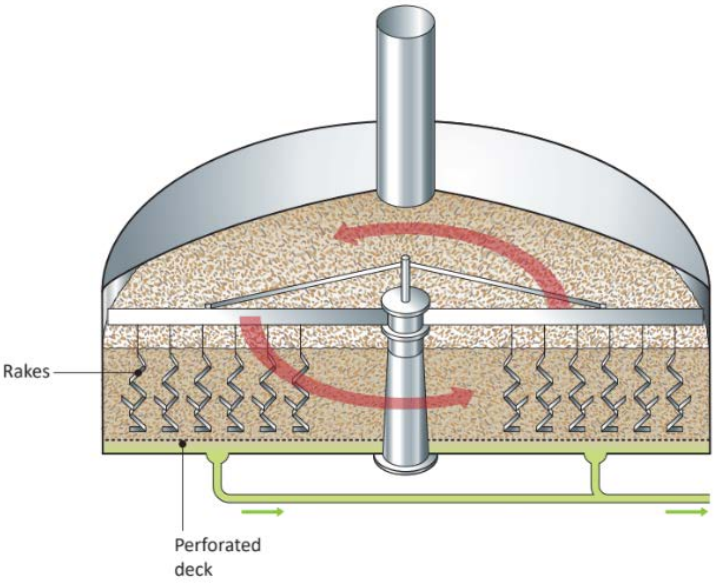
filtration performance and can cause the wort to go cloudy for a significant period but such cloudy wort is still transferred to the washback.

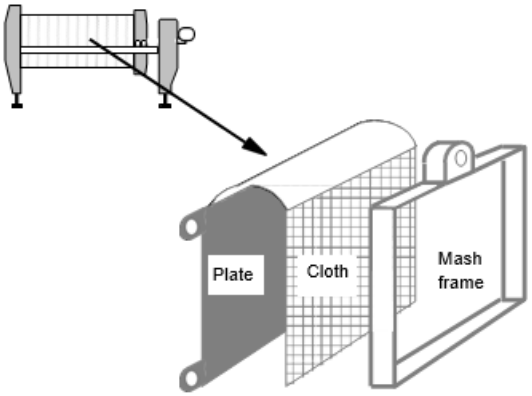
Sparge is sprayed over the grain bed as shown above and the last high temperature sparge is retained, as in the traditional method, for subsequent
The shorter run-off times of lauter tuns are beneficial to the enzymes, helping preserve their activity for use in the washback.

Spent grain is removed through a port in the base by discharge gear attached to the rakes.



Mash Filter

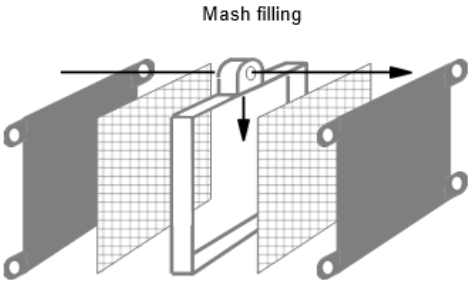
A Plate and Frame type of filter can be used to obtain wort in distilleries. The mash filter's numerous small bed depths rather than a single deeper bed enables a very fast run-off of wort and effective sparging.
The filter is constructed of alternate frames to hold the mash and plates to channel wort run-off and sparging, all separated by filter cloths which hang over the plates:



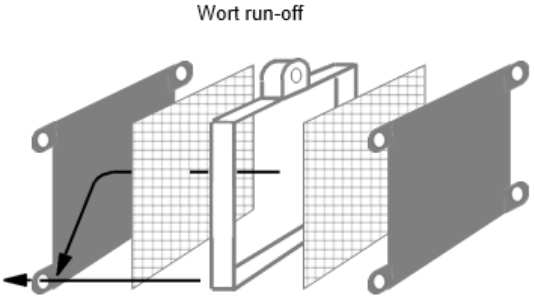
Classical mash filter

The operating principles of the classical mash filter are explained below:

1. The filter is first flushed with hot water before the converted mash from the mashing vessel is transferred into the mash frames through the top central channel. This channel bypasses the plates.



2. When the filter is full, wort drains from the mash into the plate on one side of the frame (the wort plate) and down



into the wort channel.
The spent grain is dropped from the filter at the end of the cycle when the filter is opened.

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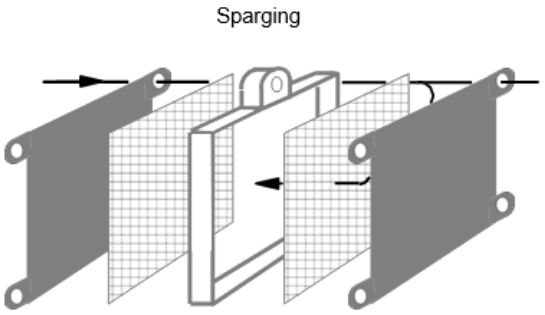
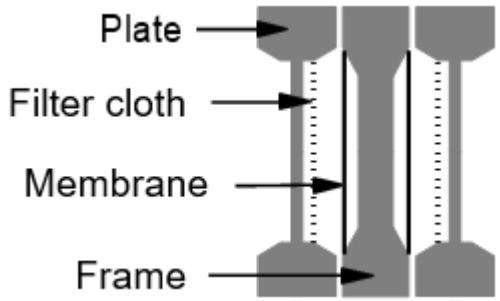
3. Sparging, to wash out all the wort from the mash is achieved by pumping water into the plate on the other side of the frame (the sparge plate), across the mash bed and then through wort channel.



The spent grain is dropped from the filter at the end of the cycle when the filter is opened.

Modern mash filter

The modern thin-bed mash filter operates on the same principle but it has several important refinements as can be seen in the diagram below:



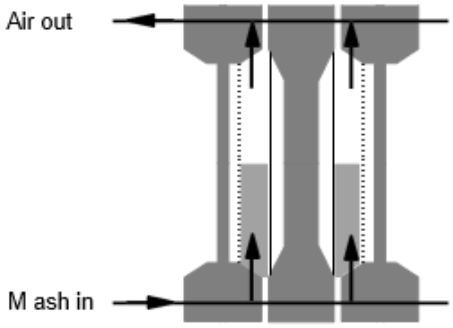
- The mash frames are fitted with an expandable membrane, which is inflated in order to squeeze the mash beds gently and improve yield (extract). This also gives a much drier spent grain cake with a lower effluent loading.

- The filter is filled from the bottom channel, which reduces mash aeration and fills the chambers homogeneously.

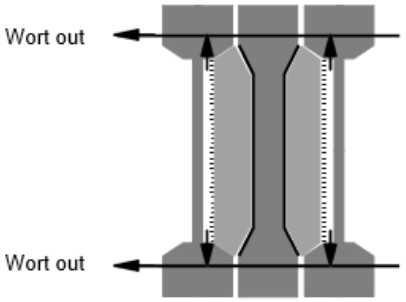
- The filters have polypropylene plates as opposed to the cast iron or stainless steel of the classical filter, making them lighter and easier to handle

The operating principles of the **modern mash filter** are explained below:

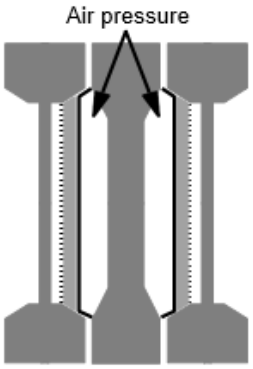
1. The filter is filled from the underside:



2. Wort is filtered through the grain bed supported by the cloths:



3. The grain bed is compressed to extract the maximum amount of strong wort (wort is still being filtered at this stage):



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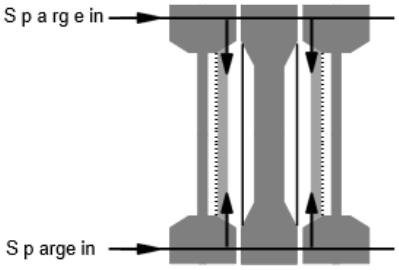
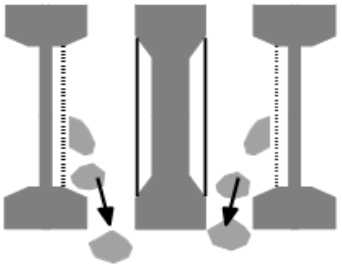
4. Sparge is run in through the mash infilling system (wort is still being filtered at this stage):



5. The grain bed is compressed again to extract all the weak wort.

6. The spent grain is dropped from the filter at the end of the cycle when the filter is opened.



The mash filter is being developed and improvements are being made all the time. The latest plant gives good quality wort; excellent extract recovery and a fast turn round time.

Spent Grain Discharge.

The waste husk after the wort has been removed is a valuable co-product because it can be utilised as cattle food. Often referred to as draff, the spent husks are discharged from the mash-tun or lauter by the paddles or rakes sweeping the draff roud and dropping it down through a port in the false bottom. It is then conveyed mechanically or pneumatically to a draff hopper from whence it can be transported directly to local farms as a direct cattle feed or to a “dark grains “ plant where it is died and processed along with pot-ale from the distillery.

Prevention of Microbial Contamination.

Because wort contains a high percentage of sugar, it is cooled and transferred rapidly to fermentation vessel in order to prevent any microbial contamination from adversely affecting fermentation before yeast can start to grow.

It is pumped through a heat exchanger to cool it to the temperature that suits the yeast that is to be added. This is usually in the range of 15 to 25°C.

From the heat exchanger the wort is transferred directly to the fermentation vessel.

As soon as there is about 50cm of depth of wort at the correct temperature in the vessel, the yeast is added because it is essential for fermentation to start very quickly. Unyeasted fresh wort becomes heavily infected with *Lactobacilli* in a matter of an hour of so.

Preservation of Enzyme Activity in Wort.

A significant amount of starch remains to be converted to sugar in the early stages of fermentation. This is called the ‘secondary conversion’ without which the alcohol yield would be about 15% lower.

Unlike brewing, distillery wort is not boiled prior to fermentation in order to preserve the enzyme activities to carry out this secondary conversion.
Keeping sparge temperatures lower is also important here.
The shorter run-off times of lauter tuns are beneficial to the enzymes, helping preserve their activity for use in the washback.

Similarly, the modern mash filters not only give good quality wort, with excellent extract recovery, but the fast turn round time also helps preserve enzyme activities.

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Wort Properties.

The specific gravity of the wort depends on the amount of water added per tonne of malt, usually about 10 tonnes. The specific gravity is usually within the range of 1.050 and 1.070 and the pH value about 5.2.
Maltose and maltotriose are the main sugars in the wort, together with smaller amounts of glucose and maltotetraose. All of these sugars can be fermented by suitable yeast strains.

Nearly all of the sugars formed from the barley starch during mashing can be used by yeast.
The wort also supplies the following nutritional requirements for yeast:

- Nitrogenous compounds in the form of amino acids. These are created from the barley protein during malting and mashing.
- Lipids or fatty material
- Vitamins
- Trace metals
- Oxygen

1.3.3 WORT COOLING AND OXYGENATION

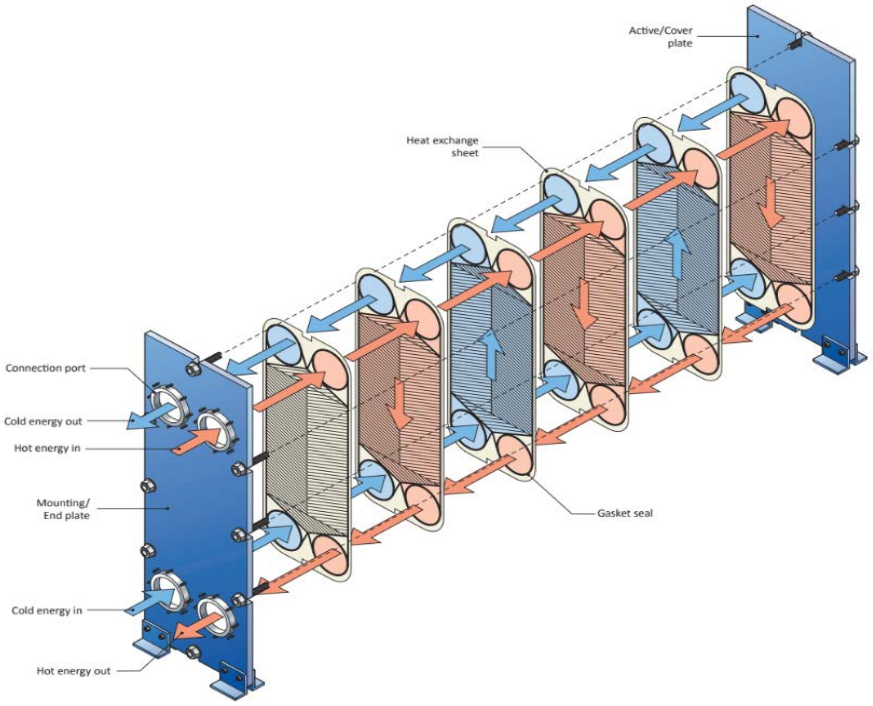
Wort Cooling

The wort must be cooled prior to yeast being added. The optimum temperature for the start of fermentation, depending on the yeast strain, will be between15 to 25°C.

Although in the past, vertical open coolers were common, today the plate heat exchanger is almost universally used. This is because:-

- Plate heat exchangers are very efficient and can cool the wort down in a short time. There is a large plate surface area for wort/coolant and the liquids' flow across the surface is very fast
- Nearly all the heat from the wort can be recovered to generate a hot water supply for brewing and other production uses.
- They are enclosed and are easy to clean in line. Therefore, they keep the wort sterile.

The principles of how the plate heat exchanger works are illustrated in the diagram below:



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The wort that leaves the cooling system is now ready for the next stage of fermentation. It should have the following characteristics:

- The required mixture of sugars, most of which will ferment into alcohol
- It should contain soluble protein. Barley protein will have been broken down into soluble form, for example into amino acids. Soluble protein is required in the wort because it provides food for the yeast.
- A temperature that suits the yeast and encourages a start to fermentation.
- Absence of any spoilage micro-organisms.
- Traces of materials like calcium and zinc which are essential for healthy yeast growth.
- Other nutrients that will encourage yeast growth, for example oxygen.

Wort Oxygenation / Aeration

Yeast needs oxygen to encourage growth and the wort cooling stage is the ideal time for aeration. Unlike brewing where air or liquid oxygen is injected into the cooled wort stream, the small batches of malt wort are aerated naturally as the wort is pumped into the wash back.

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