Qualifications

The General Certificate in Malting (GCM)

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Section

CEREALS IN BREWING AND DISTILLING

The history of the cultivation of cereals and the production of beer and distilled spirits are closely linked. It is widely claimed that the invention of bread and beer was responsible for humanity's ability to develop technology and build civilisations, but this was not possible until the widespread development of the first 'domesticated' cereal grains which can be traced back to around twelve thousand years ago. It is these early Holocene farming communities in southwest Asia, and the development of the first crops of wheat and barley, that gave rise to the brewing and distilling industries we now take for granted.

Beer was first believed to have been brewed as early as 11.5 thousand years ago or shortly after cereal was first farmed. It is recorded in the written histories of Egypt and Mesopotamia, although it is probable that beer-like beverage were produced as a result of natural fermentation of starches or sugars throughout the world where cereals were available. Distillation has been around since around 2000 BC, with perfumes and aromatics being distilled by the Babylonians. Distillation was brought to Europe by the Moors, and its use spread through the monasteries, largely for medicinal purposes, such as the treatment of colic, palsy, and smallpox. Between 1100 and 1300, distillation spread in Ireland and Scotland, with monastic distilleries existing in Ireland in the 12th century. Since the islands had few grapes with which to make wine, barley beer was used instead, resulting in the development of whisky. Unlike beer production, it took the development of the art of distillation before specific distilled spirits were first available – rather than the availability of starch/sugar supply – and it wasn't until around 1400 when it was discovered how to distil from wheat, barley and rye beers and the beginnings of the 'national drinks' of a number of countries.

Wind forward to the present day and what has changed? Mankind's (and industry's) reliance on wheat and barley as food crops continues, and the demands for cereal crops today seem to come under the influence of more diverse factors such as climate change, exchange rates, sustainable industry, population growth etc.

CEREALS – PRODUCTION

Cereal grains are members of the monocot families Poaceae or Gramineae, more commonly known as grasses, cultivated for the edible components of their fruit seeds – the endosperm, the germ, and the bran. They are grown in greater quantities and provide more food worldwide than any other crop. As whole grains, their natural form, they are a rich source of vitamins, minerals, carbohydrates, fats, oils and proteins. When refined by removing the bran and germ the remaining endosperm is mostly carbohydrate and the remaining nutrients are lost. Cereals form the basic diet in some developing nations, with grains in the form of maize, rice, wheat or millet being prevalent. In the developed world, cereal consumption is a smaller portion of the diet but is much more varied and, in terms of total consumption, substantial.

Table 1 shows the growth in annual world cereal production from 1961, data from the Food and Agriculture Organisation of the United Nations. All but buckwheat and quinoa are true grasses (these two are pseudocereals).

Grain	Worldwide production (millions (106) of metric tons)					Notes
	2013	2012	2011	2010	1961	
Maize (corn)	1016	872	888	851	205	A staple food of people in America, Africa, and of livestock worldwide; often called corn or Indian corn in North America, Australia, and New Zealand. A large portion of maize crops are grown for purposes other than human consumption.
Rice	745	720	725	703	285	The primary cereal of tropical and some temperate regions. Staple food in India, Brazil, Korea, Japan and China
Wheat	713	671	699	650	222	The primary cereal of temperate regions. It has a worldwide consumption but it is a staple food of North America, Europe, Australia and New Zealand.
Barley	144	133	133	124	72	Grown for malting and livestock on land too poor or too cold for wheat
Sorghum	61	57	58	60	41	Important staple food in Asia and Africa and popular worldwide for livestock
Millet	30	30	27	33	26	A group of similar but distinct cereals that form an important staple food in Asia and Africa.
Oats	23	21	22	20	50	Formerly the staple food of Scotland and popular worldwide as a winter breakfast food and livestock feed
Triticale	14.5	14	13	14	35	Hybrid of wheat and rye, grown similarly to rye
Rye	16	15	13	12	12	Important in cold climates
Buckwheat	2.5	2.3	2.3	1.4	2.5	A pseudocereal, as it is a Polygonaceae and not a Poaceae or Gramineae, used in Eurasia. Major uses include various pancake and groats
Fonio	0.6	0.59	0.59	0.57	0.18	Several varieties of which are grown as food crops in Africa
Quinoa	0.10	0.08	0.08	0.08	0.03	Pseudocereal, grown in the Andes

Maize, wheat and rice together accounted for 87% of all grain production worldwide, and 43% of all food calories in 2003, while the production of oats and rye have drastically fallen from their 1960s levels. Other grains that are important in some places, but that have little production globally (and are not included in FAO statistics), include:

- Teff, popular in Ethiopia but scarcely known elsewhere. This ancient grain is a staple in Ethiopia. It is high in fiber and protein. Its flour is often used to make injera. It can also be eaten as a warm breakfast cereal similar to farina with a chocolate or nutty flavour. Its flour and whole grain products can usually be found in natural foods stores.
- Wild rice, grown in small amounts in North America
- Amaranth, ancient pseudocereal, formerly a staple crop of the Aztec Empire and now widely grown in Africa
- Kañiwa, close relative of quinoa

Several other species of wheat have also been domesticated, some very early in the history of agriculture:

- Spelt, a close relative of common wheat
- Einkorn, a wheat species with a single grain
- Emmer, one of the first crops domesticated in the Fertile Crescent
- Durum, the only tetraploid species of wheat currently cultivated, used to make semolina
- Kamut, an ancient relative of durum with an unknown history

Increased production of cereals over the last 40 years has largely kept pace with population growth over the same period of time (3.0 billion to 6.9 billion estimated). A fourfold growth in maize, a staple food of people in the Americas, Africa, and of livestock worldwide, has been the biggest driver of this increase. Wheat as the primary cereal of temperate regions, and barley grown for malting and livestock, have both increased threefold, whereas rice (as paddy, or wholegrain rice) as the primary cereal of tropical and some temperate regions has seen a doubling in production. Oats and rye have seen a fall in production as demand for them has fallen, oats once being the staple food of Scotland and other cold climates.

Today's brewing and distilling industry competes with a number of sources for this farmed resource. Traditional food and drink now is competing with other industries such as the bioethanol, and with world population expected to hit 9.5 billion people by 2050 it is expected that this growth in cereal production will continue. Some people may argue that we will reach crisis point with our abilities to feed ourselves, and sustainability of food and drink supplies of the future will become increasingly important or indeed critical, but I will leave these discussions to others and focus on the use of the cereals available today for the production of beer and distilled spirits.

Cereal crops, including malting barley, are traded as commodities around the world where grain from an area of surplus (lower price) is traded with an area of deficit (higher price). This matches supply with demand and brings prices together to make a global market and a global price. The availability, and therefore price, of cereal crops is determined in the short term by the crop size in any particular year and the stock level brought forward from the previous year.

A look at definitions of 'beer' available from various sources shows an interesting range of ingredients – as well as water, hops, and yeast various definitions also call for 'malted barley', or 'malted cereals', or just 'cereals' , so despite a reliance on barley crops during beer's long history there are alternatives to all-barley malt brewing. Clearly this is not a new proposition; looking back over the 125 years of the Institute of Brewing and Distilling's history there are many references to these 'alternative' uses of cereals. The Brewers Journal' of November 1886 reported "a very happy idea that was originated by Messrs Gillman, Spencer Ltd, who had a competitive exhibition of beers brewed with their patent rice and torrified barley malts. Over 100 brewers responded to the invitation, their prospects of substantial prizes apparently having proved an incentive not to be neglected." This 'idea' eventually evolved into the Brewing Industry International Awards, which today demonstrate how far the brewers have moved from being almost exclusively dependant on malted barley. There is also a long history of beers made with malted wheat around the world, as well as brewing in areas where the most popular cereals are not available, such as with sorghum and millet in Africa.

The distilled spirits industry, outside of the traditional of grain distilling, has managed to diversify during its development into fruit, sugar, and simple-starch based products as were able to be locally sourced. There has also developed a much more varied use of cereals, and less of a reliance on a supply of a single malted cereal. A good example of this is the North American whiskey industry where a wide variety of cereals, both malted and un-malted, are used to produce a wide range of whiskey styles.

Key types of American whiskies listed in the US Code of Federal Regulations:

- Rye whiskey, mash contains at least 51% rye.
- Rye malt whiskey, mash contains at least 51% malted rye.
- Malt whiskey, mash contains at least 51% malted barley.
- Wheat whiskey, mash contains at least 51% wheat.
- Bourbon whiskey, mash contains at least 51% corn.
- Corn whiskey, mash contains at least 80% corn.

WHY MALTED CEREAL?

Malting is the controlled rehydration and germination of cereals, followed by a termination of this natural process by the application of heat. Further heat is then applied to 'kiln' the grain and produce the flavour and colour required by the brewer or distiller. In simplistic terms, the maltster and the malting process fools the cereal grain into thinking it is spring! If this germination were allowed to continue then the resulting plant growth will consume all the starches and sugars that the brewer or distiller need for fermentation, the skill of the maltster therefore is to monitor this germination closely and know exactly when to stop the process.

The malting process, and the use of malted grain, therefore provides the basis by which the mashing process can fully convert the storage starches in the cereal grain into fermentable sugars.

From a brewing point of view there are two kinds of cereal in use within the mashing process, those that need to be mashed and whose primary function is to provide fermentable sugars (for alcohol production and 'base' malt flavours such as grainy or malty descriptors), and those cereals (malted or unmalted) that do not need to be mashed as they are used primarily for other reasons.

These basic light coloured malts, generically referred to as pale ale malt, lager malt, pilsner malt or malted wheat, make up the bulk of a wort's fermentable sugars. These traditional malts are now being complemented by a range of other malted cereals which are available from a number of maltsters for the use in a range of beer styles both new and old.

Malted wheat, when mixed with malted barley, can improve head retention and improve mouthfeel. Malted rye has similar qualities to malted wheat, but is said to introduce a toffee/caramel flavour at lower inclusion rates and a spicy after-palate at higher rates. Rye malt will also introduce a reddish colour to beers.

Malted oats can introduce a toasted, biscuit aroma and palate. Oat malts can also contribute beta glucans, otherwise known as soluble fibre, to add a health-promoting property to a beer, but this has to be balanced against increased mash and wort viscosity and a reduced ability to separate clear wort from spent grain.

Barley malts can also be kilned at a higher temperature to lend different tastes for example Munich, Vienna, or Brown malts. This darkening of colour by heat destroys some of their enzymes and makes them more and more (as time and temperature increases) unusable as sources of enzymes for production of fermentable sugars via the mashing process.

As well as these lighter coloured malts there are more 'speciality' malts which are used exclusively for flavour as they have no enzymic activity remaining. They typically have been heated to high temperatures during which the storage starches in the endosperm have been converted by heat and the moisture inside the grain to produce some complex, un-fermentable sugars. These 'crystal malts' can impart caramel or toffee flavours dependent on the degree of heating, and are available in a range of colour, fermentability, and flavour to suit the product style. Also available as speciality malts are the roasted malts which undergo an intense heating giving them a deep red tending to black colour due to the charring of the sugars, which impart more chocolate, roasted, or even treacle flavours to a product.

Malted barley is also widely used in the distilling industry, with a typical Pot Still Malt being produced to deliver high levels of fermentable extract and potential for subsequent distilled spirit yield. Malting therefore needs to be carefully controlled to maintain the correct degree of endosperm modification and kilning has to maintain the highest enzyme level to enable the high fermentability. A further specialism for some Scotch whiskies is that peat is burned during the kilning period so that the smoke, or 'reek', permeates the malted barley to give the distinct phenolic flavour characteristic of many west coast Scottish island malt whiskies.

The key raw materials used in brewing are:

- Yeast
- Water
- Hops
- Malt (primarily barley)

Barley traditionally and technically can be considered the most important. In its malted form barley provides the carbohydrate, protein and vitamins for yeast growth. Hydrolytic (reducing) enzymes derived from the malt release and convert these latter substances into assimilable forms for the yeast to metabolise. Malt also provides beer with its colour and flavour, whilst contributing a proportion of essential polypeptides and polyphenols to generate beer's characteristic foam. Hop products impart the bitter and related aroma effects and can confer microbial and flavour stability, whilst also supplying foam stabilising polyphenols.

Barley and other cereals such as wheat, maize, rice, oats, and sorghum belong to the family of grasses (**Gramineae)**. Barley is classified as:

- **Family = Gramineae.**
- **Subfamily = Festucoideae**
- **Tribe = Triticeae**
- **Genus = *Hordeum***

Maltsters commonly malt two species of barley:

- ***Hordeum vulgare* –** 6 rowed barley
- ***Hordeum distichon* –** 2 rowed barley

Malting is the controlled rehydration and germination of cereals, followed by a termination of this natural process by the application of heat. Further heat is then applied to 'kiln' the grain and produce the flavour and colour required by the brewer or distiller. In simplistic terms, the maltster and the malting process fools the cereal grain into thinking it is spring! If this germination were allowed to continue then the resulting plant growth will consume all the starches and sugars that the brewer or distiller need for fermentation, the skill of the maltster therefore is to monitor this germination closely and know exactly when to stop the process.

A simple way to consider a cereal grain is that it is composed of three parts:

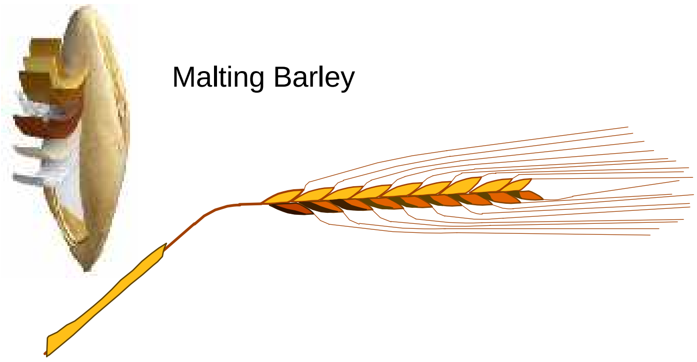
a) The embryo, or germ, which will eventually grow into the roots and shoots of the new plant.

b) The endosperm comprises hard insoluble starch, which is the food reserve to be used by the growing germ of the grain. The embryo calls for the release of enzymes and production of further enzymes which travel into the endosperm, breaking down the cell walls around the starch and make the starch available for subsequent breakdown into simple sugars.

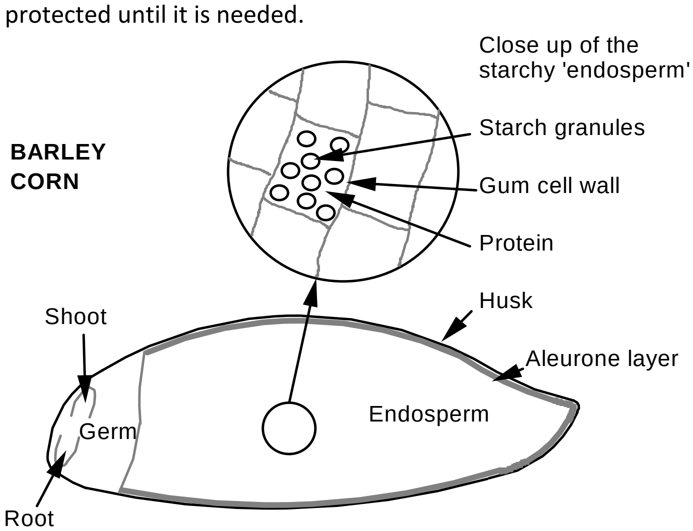
c) The husk, formed by two overlapping halves, which cover the grain surface, to protect the germ and endosperm.

The maltster's task is to get the endosperm modification to a certain point, and then stop the process, "locking it up" by reducing the moisture content. The brewer will then "unlock" the process when he mashes his milled malt, and completes the conversion to sugars which will feed the yeast to produce alcohol, whilst other characteristics in the malt produce strong contributions to the quality of the final beer. The malting process, and the use of malted grain, therefore provides the basis by which the mashing process can fully convert the storage starches in the cereal grain into fermentable sugars.

As stated before, malted barley is the main raw material used in the brewing of beer. Malt provides the sugar that will be fermented into alcohol in the brewing process. Barley is a cereal traditionally grown in mild varying climates and for centuries it has been used in the production of beer.



All cereals contain carbohydrates in the form of starch which is the source of food for the growing plant when the seed is germinating. Usually the starch is locked away or protected until it is needed.



The diagrams above illustrate the key features of the barley corn. It shows the location of the starch granules which are the main carbohydrate food reserves.

Starch is present as granules which are embedded in a protein matrix. This matrix is surrounded by cell walls containing a gum called β-glucan. The starch granules are therefore inaccessible and initially protected from attack by the amylase enzymes that are produced during germination.

During the malting process however, the cell walls and the protein will be dissolved by other enzymes which are produced naturally as the seed grows. The barley selected for processing into malt must meet certain specific requirements:-

- It must be capable of growth. The key stage of the malting process is germination when the barley seed starts to grow. This growth needs to be rapid and even; barley that is 'dormant' takes a long time to start growing.
- It must have a relatively low proportion of protein. The lower the protein, the higher the amount of carbohydrate. (Protein levels are measured by measuring nitrogen content.)
- The corns should be of an even size. That way they are more likely to grow evenly and will be more consistent in milling at the brewery.
- The corns should be bold. Bold corns contain more starch by proportion and therefore have a higher extract potential.
- The barley must be of a 'malting variety'. Malting varieties have a more open endosperm which accepts water readily during steeping, encouraging rapid and even breakdown of endosperm cell walls.
- The corns must be undamaged and free of disease.

THE MALTING PROCESS

There are three stages in the process of converting barley into malt:-

1. **Steeping:** Barley is soaked in water to simulate the conditions that start germination or growth. This is done in a steep tank and usually the tank is aerated to encourage fast moisture uptake by the barley.

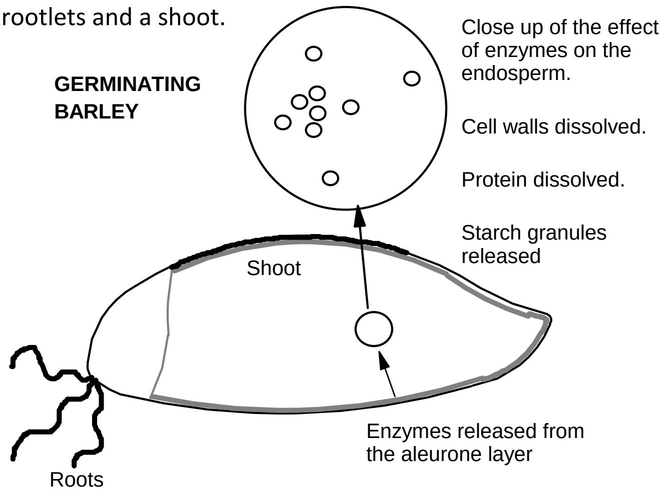
2. **Germination:** On completion of steeping, the barley seed is allowed to grow.

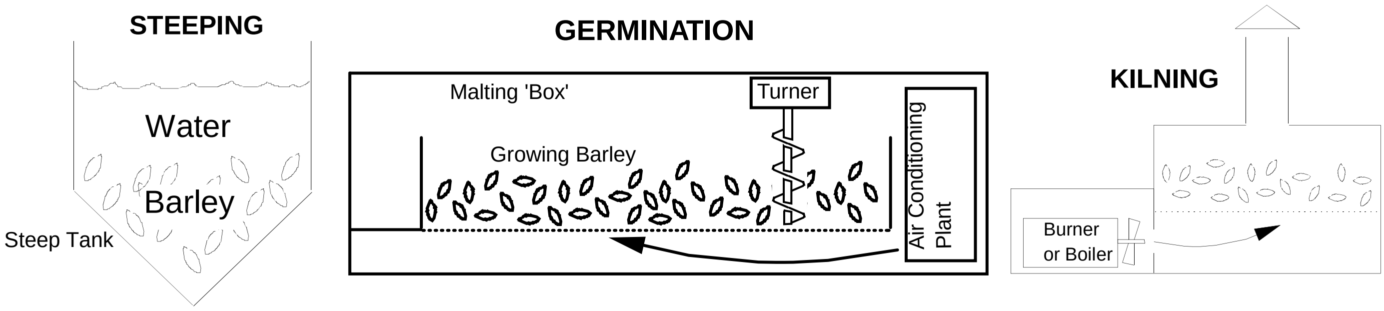
During germination two major changes occur:

Firstly, hormones stimulate the production of enzymes in the aleurone layer.

Secondly, these enzymes start to act.
During malting they will break down the gummy cell walls and break down the protein matrix. This breakdown releases the starch granules making them accessible for conversion into sugar.

The changes taking place during germination are called 'modification'. The maltster can influence the degree of modification during malting by controlling the moisture content of the grain, its temperature and the time allowed for germination. During germination the seed grows rootlets and a shoot.





The seed is soaked in water to start it growing → The barley grows under controlled conditions and the 'changes' occur inside the seed → The malt is dried out and colour and flavour are developed

Germination usually takes place in a chamber or vessel where air is blown through the growing malt to control its temperature and moisture content. Also turners mix the malt to prevent the growing roots from matting together.

3. **Kilning:** During this stage of the malting process, water is removed from the green malt. The malt then becomes stable and can be stored without deterioration. The malt also develops colour and flavour.

A combination of high grain moisture and high temperature could destroy the enzymes developed during germination. Some of the enzymes, for example those required later in the brewing process for starch and protein conversion must be preserved. The malt kilning process is manipulated so that the malt is dried at a relatively low temperature using high flows of air. Then when the malt is drier with a moisture content of around 10%, the kilning temperature is increased so that the malt develops colour and flavour. At the completion of kilning, the malt's moisture content will be 4-5%. The table below details the changes that occur during the malting process:-

The extent to which the barley is converted into malt is termed the 'Degree of Modification'. Lager malt specifications are sometimes less modified. For this reason, brews containing lager malt may require some additional processing, for example further protein and β - glucan breakdown, during mashing in the brewhouse.

TYPES OF MALTING PLANT

Floor Malting

Floor Malting is one of the oldest malting methods in use. Its use dates back to the origins of brewing and it was the only method of malting in use until the 1850's.

In floor malting, steeped barley is laid in piles on tiled or concrete floors and allowed to build up some heat and begin growth. At some point, the malt is manually levelled off to a depth of 10 to 15cm. The green malt is turned with

Parameter	Barley	Steeped Barley / Green Malt	Malt
Moisture.	About 12% after drying on the farm or after intake.	About 45% after steeping	4 - 5% after kilning
Extractable carbohydrate.	Very low, as enzymes have not developed.	Very high because the starch granules have been released. They are now accessible to enzymes that convert starch into sugar.	Kilning does not change the level of extractable carbohydrate but it does fix it by reducing moisture and stopping germination.
Colour.	Very low.	Very low.	Colour is produced when sugars and soluble protein react together at high temperature. An increase in colour occurs depending on the degree of kilning and the levels of sugar and soluble protein present.
Protein (measured from the Total Nitrogen content – % w/w TN x 6.25 = % Protein)	Malting grade 2 row barleys for pale ale malts have nitrogen levels of about 1.4% to 1.9%, depending on the brewer's malt specification (protein from 8.7% to 11.9%) Brewers in some countries may use 6 row barleys, which have protein levels up to 14% (2.0-2.3% nitrogen) and correspondingly higher enzyme content.	Nitrogen level reduces slightly during germination as rootlets and shoots are produced. Much of the protein is solubilised by enzyme activity. Important parameter is ratio of the Total Soluble Nitrogen (TSN) to the Total Nitrogen (TN) in the malt. Known as Soluble Nitrogen Ratio (SNR) or Kolbach Index.	Kilning does not change the nature of the proteins and carbohydrate but it does fix them by stopping germination. Kilning temperatures will reduce some enzyme activities by denaturing the protein. Lighter kilned malts (lower colour) tend to have higher enzyme levels). Roasted malts have no enzyme content.

wooden shovels to reduce heat build-up and to aerate the grain. Room temperature may be controlled to a limited extent by windows on the outside walls.

Figure 1 shows an old floor malting crew. For many years, malt houses employed crew such as this to produce high quality malt.

Figure 1 Floor Malting ***(Source: Warminster Maltings)***

It is important to note that in floor malting there is no air flow through the germinating barley and there is no automatic turning machine. This results in the need to turn the malt frequently by hand using shovels. As a result, floor malting is very labour intensive.

If done with proper care, floor malting can produce consistent malt; however it is very labour intensive. Also piece size is very small compared to modern malting methods.

Floor malting is most practical for small batch sizes. Because the grain is spread out fairly thin, a large amount of floor space is required for large-scale operations. There are currently no large-scale commercial floor malting facilities in existence. The last large commercial operation was in association with the Stella Artois company in Belgium. This operation shut down in the late 1980s. At the present time, floor malting, is only performed by small specialty maltsters and hobbyists.

Pneumatic Malting

In the 19th century, the first pneumatic maltings were developed. Pneumatic malting is any process alternative to floor malting that forces a stream of cool, humidified air through the germinating grain. The invention of pneumatic malting represented the first major advancement from floor malting. It was first introduced in the mid-1800s, and reached commercial success in the late 1800s.

Two Belgian malting engineers: Galland and his assistant Saladin, were responsible for major developments of the pneumatic malting process. Galland and Saladin are the most significant names in the development of the pneumatic malting process and are considered to be the fathers of modern malting equipment.

Galland introduced the first aerated rectangular boxes in 1873, but they required manual grain turning. Saladin introduced turning machines and helixes in the 1880s. Galland then moved on to develop drum malting.

Saladin Box Pneumatic Malting

The Saladin box or compartment pneumatic malting, with turning machines, became the dominant malting technology and is the process in use today across the world. The Saladin box eliminated manual turning and allowed green malt depths of 1m to 1.5m. This allows the greatest use of floor space, especially when compared to floor malting.

Saladin boxes are thought of as rectangular compartments because that was his original design, but as a process, round compartments are also pneumatic malting with turning machines and are a version of Saladin malting

Drum Malting

Galland developed the drum malting process and built his first plant in 1873. Drum malting would become the most common commercial malting process of the late 1800's and early 1900s.

Drum malting makes use of a rotating drum for germination. The rotation of the drum gently turns the green malt, preventing matting of the rootlets, provides temperature regulation, and facilitates air flow.

Figure 2 shows a typical drum malting system. A large door in the side of the drum allows for loading of grain into the drum via a loading conveyor. The same door is used for unloading when the drum is rotated such that the door faces downward to an unloading conveyor.

A mechanical drive system consisting of wheels and gears slowly rotates the drum. Drum motion is slow, nearly imperceptible to the human eye.

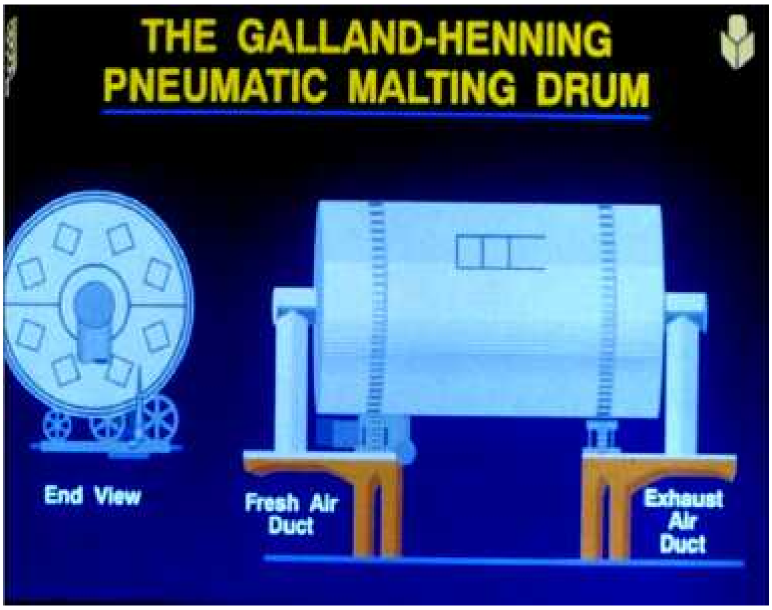


Figure 2 Drum Malting System

Air is forced through the grain bed by a system of air ducts and flapper doors. As the drum rotates, the flapper doors open and close in sequence to direct the air flow though the grain bed instead of the empty space above the grain.
Drum malting is best suited for small batch sizes due to the limitation of drum size. Automated turning allows for less manual labour compared to floor malting yet it is still relatively labour intensive. Other disadvantages include high maintenance costs and difficult sanitation. Maintenance problems are complicated due to the complex mechanical turning mechanisms that must be located in areas of high humidity. Figure 3 shows a typical layout for a drum malthouse. Note that a significant amount of floor space is dedicated to the drums and the supporting machinery.

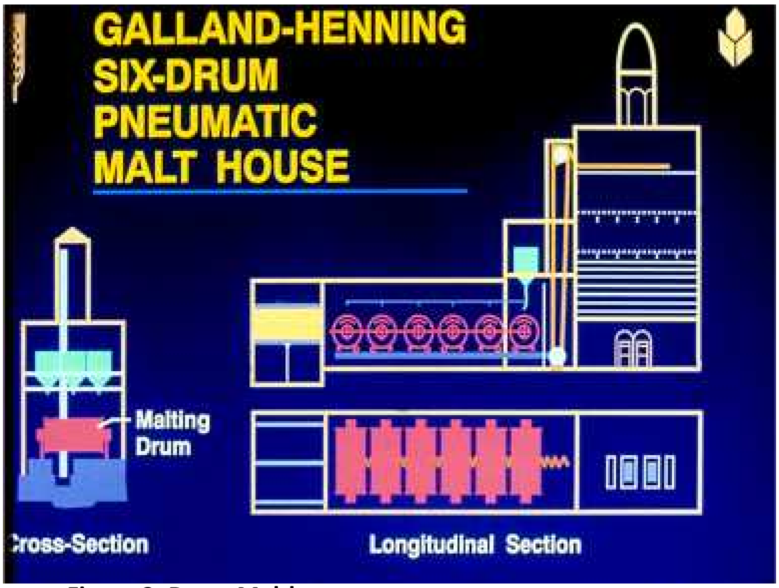


Figure 3: Drum Malthouse

The Wanderhaufen System

The Wanderhaufen system is another modern malt plant design. Unlike the other methods that perform the germination cycle in one place, the Wanderhaufen system is a moving batch process. The Wanderhaufen system uses a long bed area called a germination "street" that holds multiple pieces. A transfer conveyor that is similar to a large excavating machine advances the green malt to a new location on the bed in place of a turning machine. One advantage of this system is that the action of the conveyor reverses the bed top to bottom on each transfer.

The Wanderhaufen system has the following disadvantages:

- Poor batch integrity. The edges of the piece comingle.
- Irregular air flow. The edges of the piece are sloped.
- High maintenance costs, mechanically complex.
- Difficult sanitation

Because of the poor batch integrity, only one type of malt can be germinated. Otherwise, mixing of types would most likely result. These disadvantages outweigh the practical advantages and as a result this system has lost favour over the years. Figure 4 shows an example of the Wanderhaufen system. The newest piece is loaded on the bed from the steep tanks. The transfer conveyor moves the green malt from the steep tanks to the kiln as the germination cycle progresses.

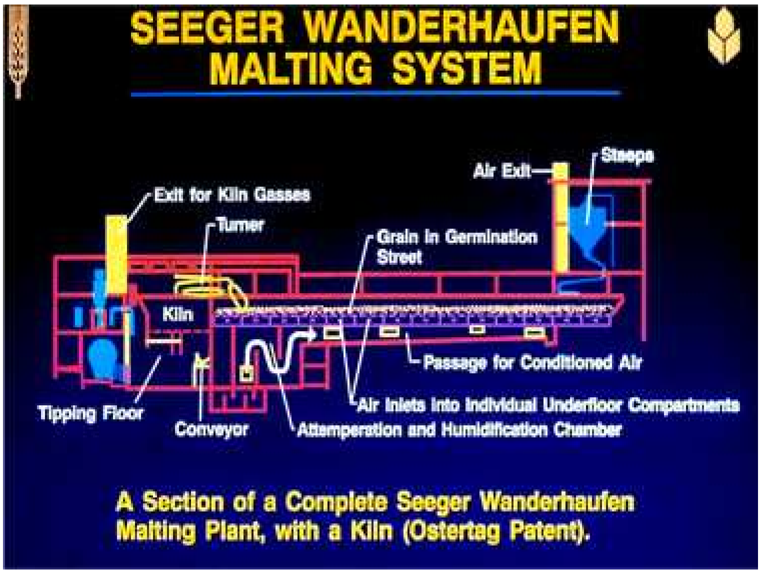


Figure 4 Wanderhaufen System

Lausmann System

The Lausmann system is another type of moving batch system, similar in many respects to the Wanderhaufen system. This system, shown in Figure 5, uses a series of moveable germination beds. The green malt is moved forward from one bed to the next as the germination cycle progresses. To accomplish this, the beds are equipped with jacks to raise and lower them as needed. As one compartment is raised, the turner moves the green malt from that compartment to the next compartment, which is slowly lowered as it fills with grain. As in the Wanderhaufen system, one advantage is that the conveyor reverses bed top to bottom on each transfer.
However, the Lausmann system has the following disadvantages:

- Batch size is limited.
- Irregular air flow. The edges of the piece are sloped.
- High maintenance costs. Mechanically complex.
- Difficult sanitation.

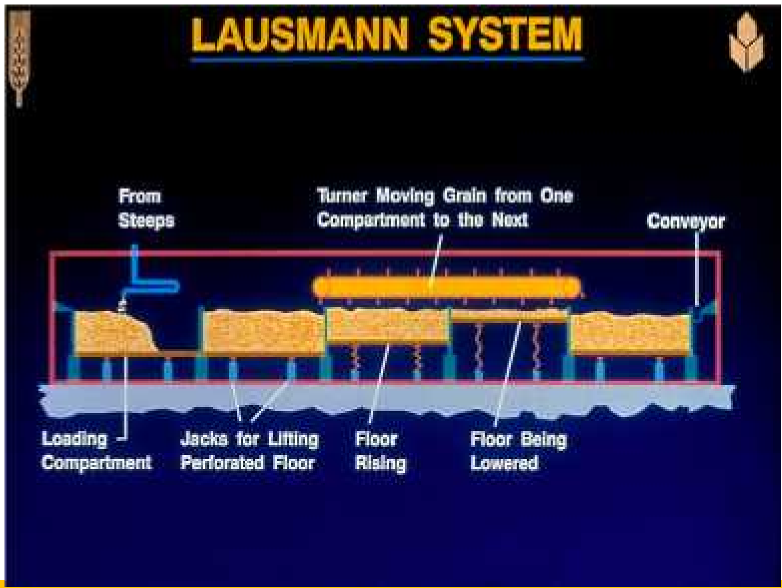


Figure 5 Lausmann System

Tower Malting

Tower malting uses the same malting process as rectangular design malt houses previously described in this course. The main difference is in the equipment configuration. In tower malting, the components in the process are stacked vertically to make maximum use of gravity and conserve space.

All vessels are round. Round vessels provide an ease of loading and unloading as well as providing superior evenness of the grain bed when compared to rectangular vessels.

The Germination compartments are stacked on top of each other. This stacked design requires the least amount of space for construction (small footprint). The vertical design also requires a lesser amount of grain conveying compared to earlier designs. Tower malting facilitates the uses of large flat-bottomed steeping vessels, but they are not mandatory.

A number of different tower-malting systems are used. Figure 6 shows one type of tower malting system called the Buhler-Miag System. In this system, the building forms the process vessels and therefore the utility functions are located outside the building. The steeping vessels are located at the top of the tower. Germination compartments are stacked on top of each other, each being individually controlled. The furnace for kilning is located at the bottom of the tower.

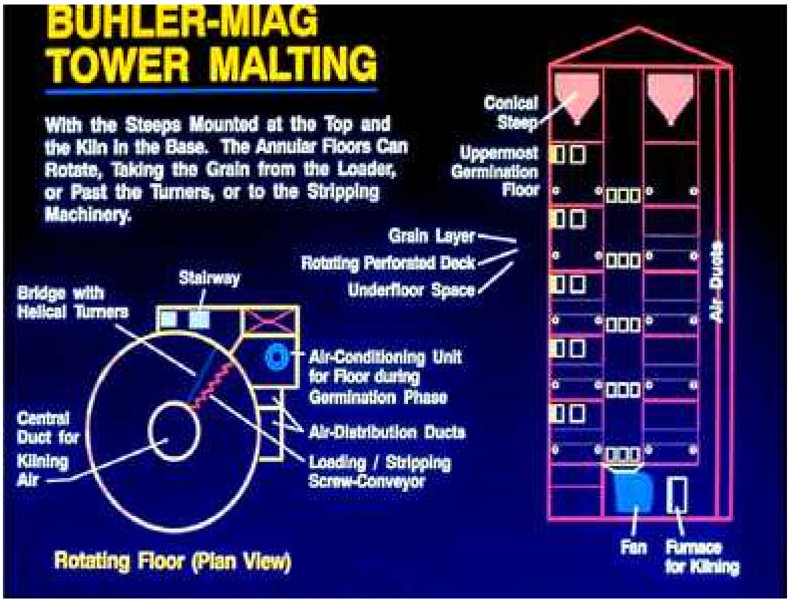


Figure 6 Buhler-Miag Tower Malting System

The Seeger tower design, shown in Figure 7, is another type of tower malting system. This system is similar to the Buhler-Miag tower malting system except that it uses a separate kiln building to house the kiln. For optimum kilning, the depth of the grain bed should be less than the bed depth in the germination bed. Having the kiln located in a separate building allows the kiln to have a larger diameter than the germination beds, resulting in more surface area and a thinner grain bed.

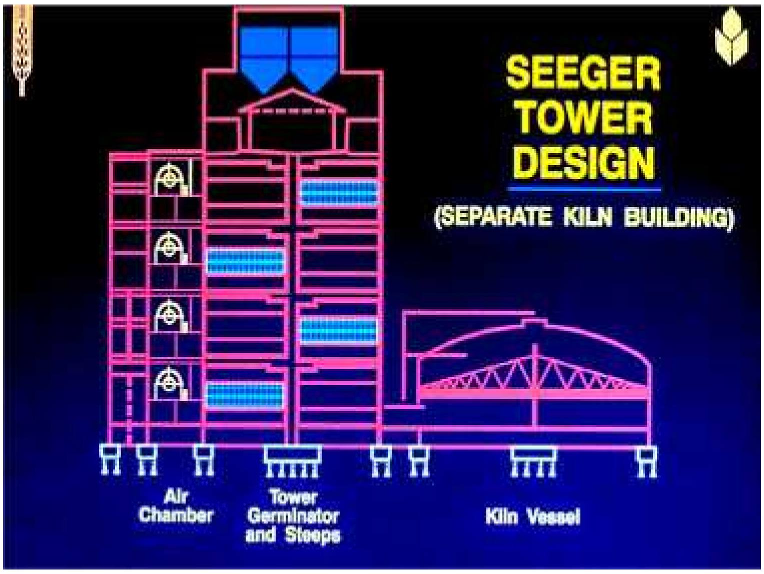


Figure 7 Seeger Tower Malting Design

Combined Germination and Kilning Vessels (GKV) Malting Systems

The Flexi Malt system is an example of a GKV design. This system, shown in Figure 8, has an enclosed germination bed that is similar to the Saladin box. The main difference is that that the germination compartment also doubles as a kiln. Green malt does not have to be transferred to separate kiln.

The primary advantage of this system is that is that malt is not moved for kilning and that germination box is heated each cycle for sanitation.

The main disadvantage of Flexi Malt systems is high energy consumption. A significant amount of energy is required to alternate the vessel between cool germination temperatures and high kilning temperatures. The repetitive thermal cycling also tends to shorten the life span of concrete structures. Another disadvantage is that bed depth is a compromise between germination and kilning levels

Flexi Malt systems were very popular in the late 1960s and early 1970s, however after the energy crisis of the 1970s, their popularity waned due to excessive energy costs. Recently there has been some new interest in Flexi Malt systems, particularly in Europe, where some Flexi Malt houses have been built using stainless steel structures instead of concrete. Construction of the vessels in stainless steel overcomes much of the energy potential associated with this design.

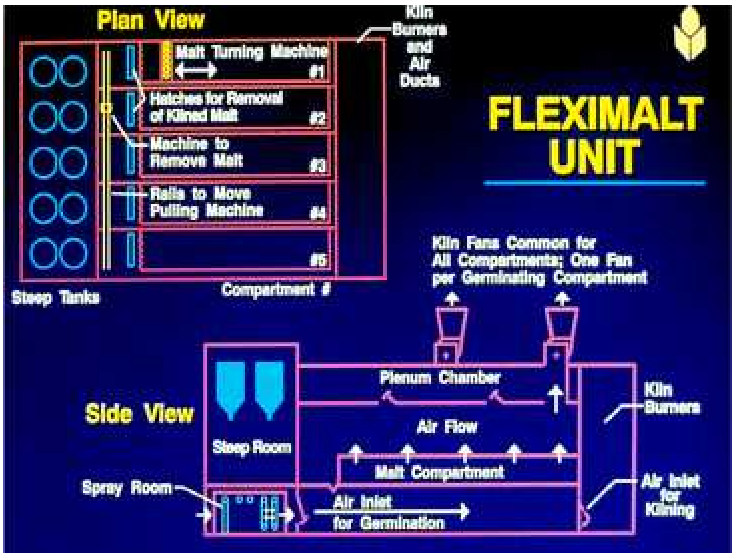


Figure 8 Flexi Malt Unit

MALTING LOSS

During the malting process, barley respires producing energy for growth. As the grain respires it consumes and expends integral substrates (e.g. carbohydrates and protein) in the production of new tissue, CO_2, water and heat energy. This consumption depletes the extract available to the brewer, recognised as a reduction in the total dry weight of the grain and represents malting loss. Malting loss is also enhanced as materials leach from the grain during steeping. Typically malting loss is described in Table 1.

Table 1. Typical malting loss expressed as percentage dry weight of the grain.

Malting Loss	**% Reduction in grain total dry weight**
Steeping	1%
Rootlet production	3.5%
Respiration	3%

What Affects Malting Loss?

In general, the longer the grain is allowed to germinate and grow, the greater the malting loss will be.

Reducing malting loss, however, works in opposition to requirements of the maltster and brewer alike. For trouble-free brewing, the malt must be sufficiently modified. To achieve good quality grain modification, the barley must have sufficient time to germinate. If this is allowed, extract potentials are reduced because the embryo is allowed to grow, not to mention the increased capital expenditure associated with an extended malting process.

- For example, low germination temperatures restrict embryo growth (reducing malting losses) but slow the synthesis, release, and diffusion of hydrolytic enzymes throughout the endosperm (elongating process time). However, modification will be thorough.

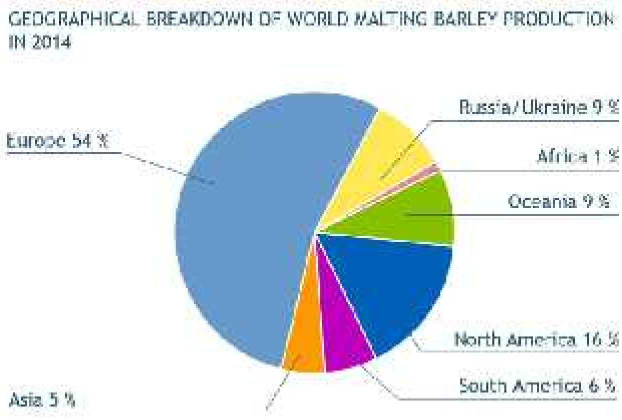
- High germination temperatures will accelerate modification of the grain, reducing process times. Malting loss can be reduced if the period that the embryo utilises nutrients from the endosperm is shortened. However, the quality of the malt produced will be inferior, with incomplete and non-homogenous modification.

Section 3 Barley growing and Harvesting.

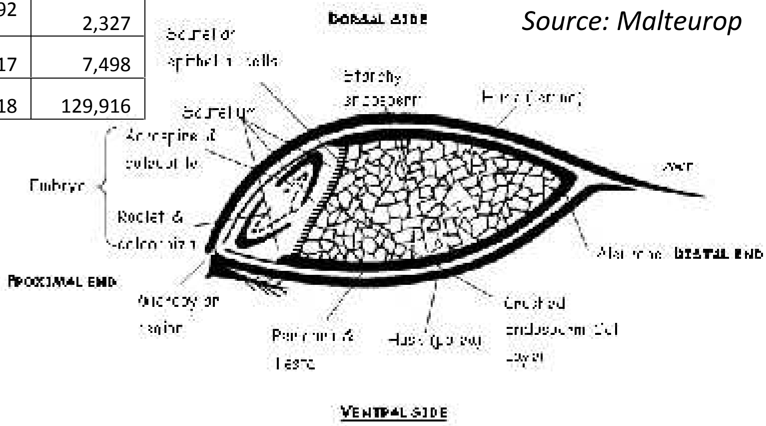
BARLEY GROWING

World Barley Production '000 Mt	2009/10	2010/11	2011/12	2012/13
North America	14,996	12,224	11,771	13,369
South America	2,443	3,869	5,535	6,604
European Union	62,149	53,511	51,826	54,372
Other Europe	1,407	1,292	1,363	1,376
Former Soviet Union - 12	35,988	21,682	32,245	25,977
Middle East	11,320	11,100	11,670	10,275
North Africa	7,340	4,589	4,448	3,408
Sub-Saharan Africa	1,933	1,865	2,049	2,058
East Asia	2,646	2,215	2,602	2,652
South Asia	2,330	1,957	2,192	2,327
Oceania	8,300	8,303	8,717	7,498
Total	150,852	122,607	134,418	129,916

Source USDA FSA

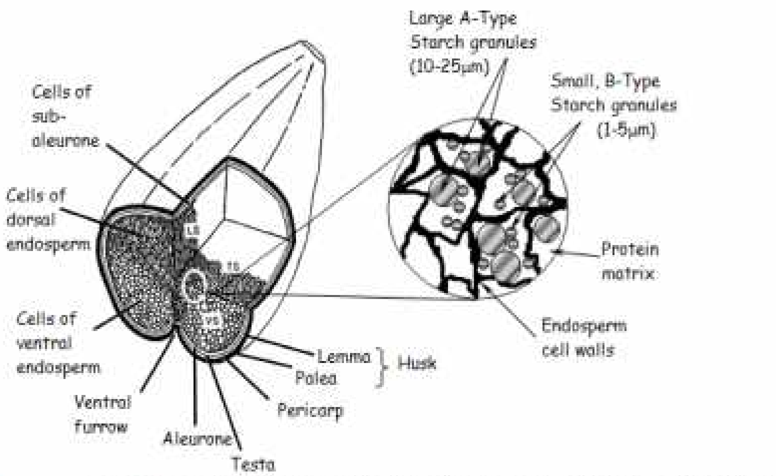


Source: Malteurop



Barley is a tough cereal, grown in a number of environments where other grains can't grow - from arctic latitudes and alpine altitudes to saline desert oases. Barley is the fourth most important cereal crop in the world after wheat, maize, and rice. Although generally a temperate crop, barley is also grown in many tropical countries, typically by poor farmers in hostile, dry, cool environments.

The main barley growing countries in the world are Russia, Canada, Germany, France, Ukraine, Spain, Turkey, UK, Australia, USA, and Denmark. In Tibet, Nepal, Ethiopia, and the Andes, farmers cultivate barley on the mountain slopes at elevations higher than other cereals. In areas with little irrigation in the dry regions of North Africa, the Middle East, Afghanistan, Pakistan, Eritrea, and the Yemen, barley is often the only suitable cereal. Developing countries account for about 18% of global production and 25% of the harvested area of barley.



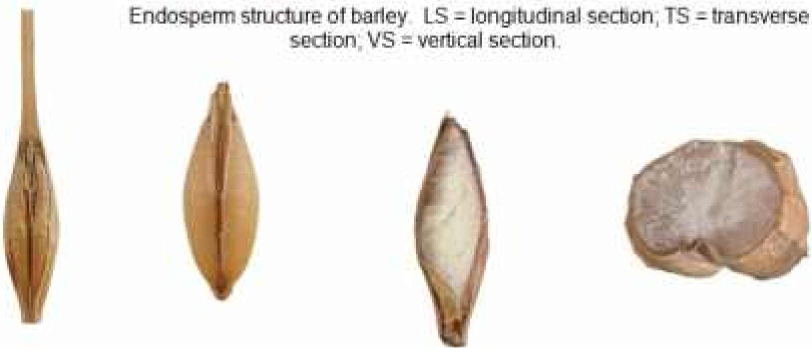
Endosperm structure of barley. LS = longitudinal section; TS = transverse section; VS = vertical section.

Barley and other cereals such as wheat, maize, rice, oats, and sorghum belong to the family of grasses (Gramineae). Barley is classified as:

- **Family = Gramineae**
- **Subfamily = Festucoideae**
- **Tribe = Triticeae**
- **Genus = Hordeum**

Brewers commonly malt two species of barley:

- ***Hordeum vulgare* –** 6 rowed barleytetrazolium
- ***Hordeum distichon* –** 2 rowed barley



1) Barley kernel with glume. 2) Barley kernel. 3) Barley Kernel – longitudinal section. 4) Barley kernel – cross section.

Source: GoodMills Innovation GmbH

1) Growth initiates with chitting, i.e the emergence of the coleorhiza from the proximal end of the grain. This extends and branches forming the seminal roots.

2) The coleoptile (leaf sheath) grows along the grain between the aleurone and testa, breaking the husk to emerge at the distal grain end.

3) Leaves then grow through a pore at the tip of coleoptile, each originating at a swollen joint or node. Leaves are numbered in order of appearance and used as developmental markers for the application of field treatments e.g. fertilisers and pesticides.

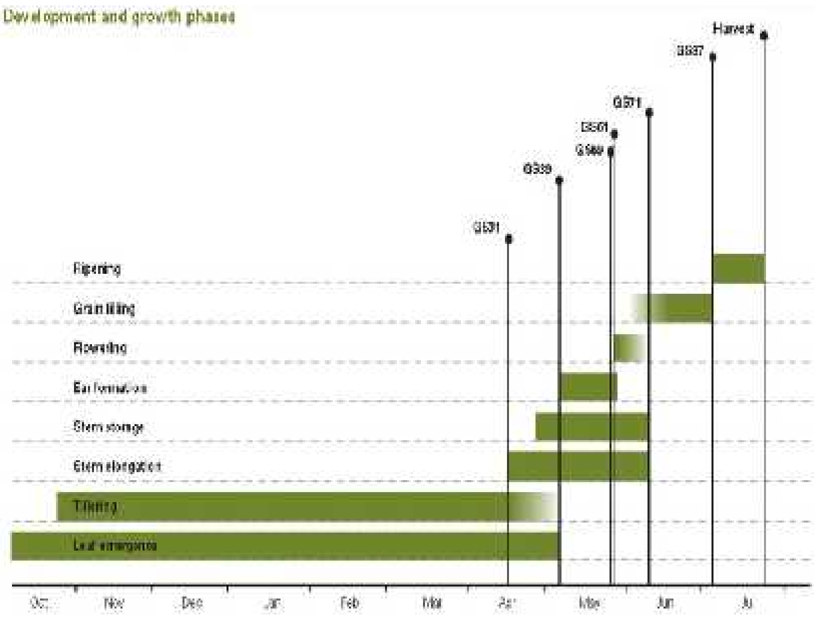
4) The first node develops into additional adventitious or coronal roots at the base or crown of the plant. These roots will sustain the plant into maturity.

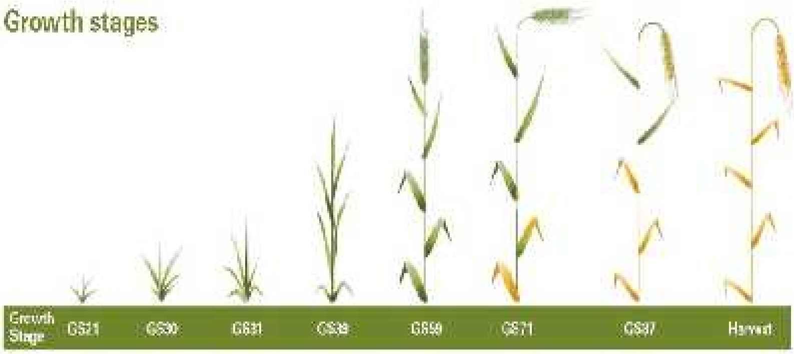
5) Apical bud(s) form, and new stems or “tillers” evolve from these (the tillering stage), forming a rosette close to the ground. The number of tillers that develop is variety dependent. Since only one ear of grain will form on each stem this is important in terms of yield and kernel size.

6) The stems elongate prior to flowering, elevating the ear, which develops at the apices of the uppermost leaf sheaths (flag leaf or boot stage). This phase is known as shooting or jointing.

7) The ear develops upon the rachis. The rachis is a differentiated extension of the main tiller. It is here on the rachis that flowers grow into the seeds (barley grains). The type of ear produced is determined mainly by the morphology of the rachis. A rigid strong rachis is required to prevent the ear shattering and breaking during maturation and harvesting.

8) The rachis, like the stem, is divided by nodes where at each joint spikelets form. Each spikelet has the potential to form a single grain. Every spikelet comprises, amongst other parts, the lemma and palea, which will envelop the flower and later form the husk of the mature grain.





Once formed, the spikelet develops its reproductive organs. The stamens grow anthers which develop and release pollen during anthesis. The ovary bears the style upon which the stigma rides to receive the pollen. Once released from the anther, the pollen grain germinates on the stigma of the translucent embryo sac, to produce a pollen tube. This pollen tube contains two haploid male nuclei (gametes). The pollen tube grows down from the stigma and penetrates the embryo sac. One of the male nuclei (containing seven chromosomes) fuses with the haploid female egg nucleus, to form the diploid embryo or germ containing fourteen chromosomes. The remaining male nucleus fuses with the two polar nuclei of the embryo sac to form a triploid endosperm (twenty one chromosomes).

Barley has evolved to be pollinated by neighbouring plants, their pollen dispersed and carried by the wind and insects. However, due to the close proximity of the anthers and stigmas of individual spikelets, self-pollination is most common.

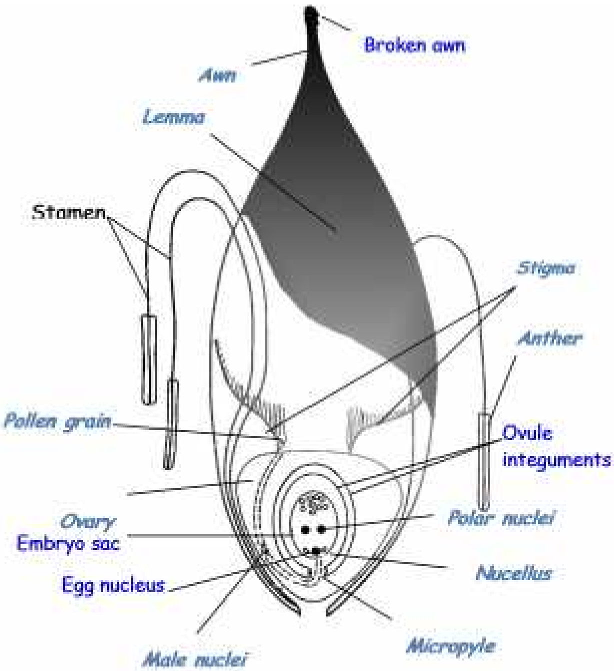


Figure 2 Internal structure of an unfertilised barley grain.

BARLEY VARIETIES

Two and Six Rowed Barley

Each individual spikelet (a floret) belongs to a triad of florets which, emerge at alternating nodes along the rachis. Each triad comprises one central and two lateral spikelets. The central spikelet is fertile in all barley.

- If only the central spikelet develops into a seed, one grain per node develops on the rachis, giving a two rowed barley ear.

- If all of the six spikelets are fertile and develop, three grains arise at each node. This generates a six rowed barley ear where the lateral spikelets are skewed either side of the symmetrical central spikelet.

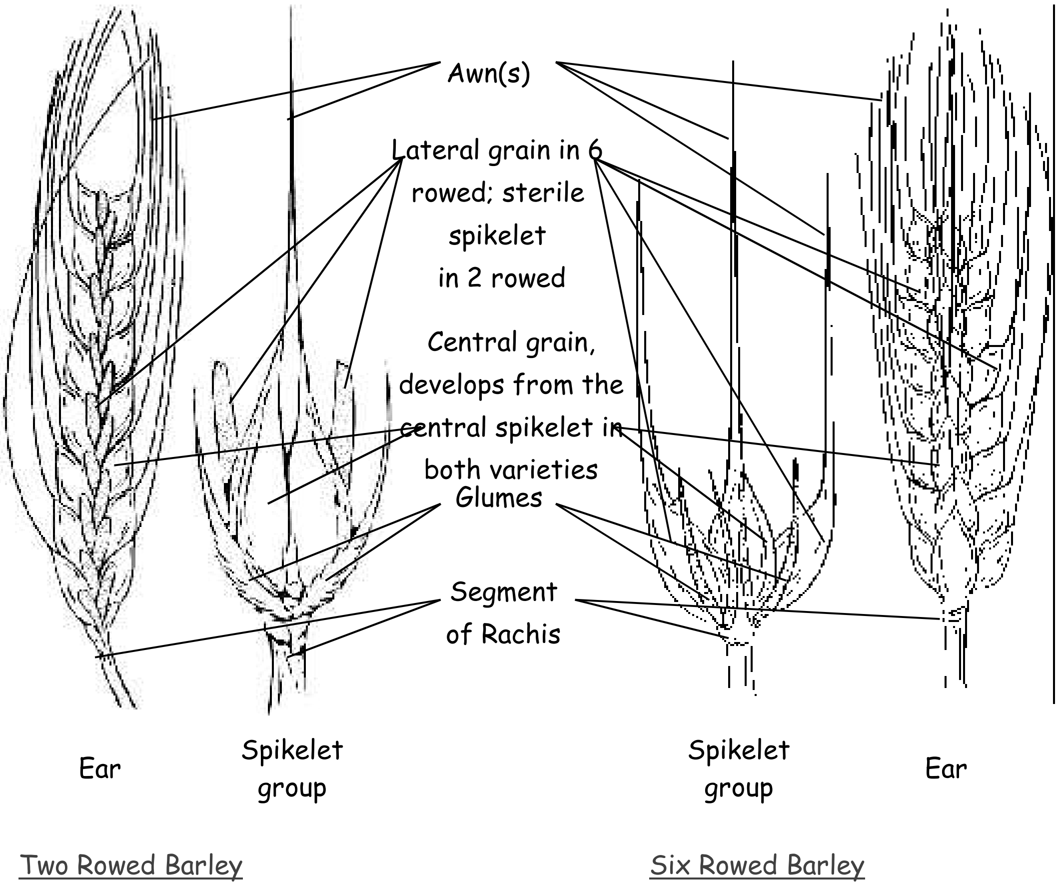


Figure 3. A diagram showing the structure of two and six rowed barley ears and individual spikelets.

Traditionally, European barley has been two rowed; six rowed barley is more commonly grown in the Americas. Two rowed barley varieties produce plumper more symmetrical grains than six rowed and as a result, six rowed barleys incur greater losses when harvested as smaller grains are screened out. Over the past thirty years there has been a global move towards growing and malting two rowed barleys.

Spring and Winter Barley Varieties

There are two types of barley grown for malting. These winter and spring varieties are grown primarily for agronomic and climatic reasons, the different species producing maximal yields under different growth conditions. By sowing varieties that ripen at different times or by planting fields of both winter and spring barley, the latter usually ripening later, the harvest can then be staggered. Staggering the harvest realizes added benefits including ensuring a continuous supply of barley for malting, without incurring excessive storage costs. Storage costs are further maintained through careful purchase and use. Staggering the harvest also assures a tide over supply if levels of spring barley are low and/or expressing high levels of dormancy.

For example, in the Northern Hemisphere

- Winter barley is typically sown in September and harvested in July.

- Spring barley is typically sown in March and harvested in August.

Typically in the U.K, malting quality barleys have been spring sown, but winter varieties such as Flagon have become more common. Some sources suggest that the earlier the seed is sown, weather permitting, the greater the starch accumulation and the lower the total grain nitrogen, but others believe it to be more the effect of warm summer ripening compared to cooler conditions during final development. This produces a crop with greater yield and potentially higher extract values.

- Spring Barley varieties include: *Concerto (UK), Harrington (USA), Commander (Australia), AC Metcalfe (Canada), Steffi (Germany)*

- Winter Barley Varieties include:
  Pearl (UK, Maris Otter (UK).

Harvesting

Traditionally, harvesting included the cutting of near-ripe plants, which were then bundled into sheaths and allowed to dry in the field. Threshing would occur later at the farmers' convenience. This technique was far from ideal as the cut grains were liable to microbial attack, which would reduce the quality of the grain.

Today, harvesting and threshing are combined with the use of the modern combine harvester. As one process that occurs in the field, the mature plants are cut, the grain threshed, separated and retained, whilst the straw baled to be discarded or collected later. However, the slightest fault in thresher adjustment can lead to incomplete threshing and significant grain loss. If threshing is too close, this results in damaged grains. These grains are unacceptable for malting as there is increased susceptibility to infection during storage and uneven germination will also occur.

The most important factor during harvesting is the moisture content of the grain. Following harvest the crop must be sufficiently dried to prevent germination and reduce the risk of microbial infections occurring prior to use. If dried incorrectly the quality of the grain will deteriorate in store.

The barley harvest differs from growing region to growing region because of weather conditions.

In some regions harvest weather conditions are typically dry, so the barley can be cut and immediately threshed. The mature barley kernel moisture content must be less than 13.5% before it can be harvested. Moisture content above 13.5% leads to quality problems during storage, such as loss of viability, increase in microorganism growth, development of off odours, and heat damage. However, elsewhere the cut barley is laid on the stubble to air dry for a few days before it is combined and threshed. Rain or heavy dews during the harvest necessarily alter the harvest time line.

European harvest practice is to cut and thresh the barley when its moisture content is about 15% to 25% and then lower the moisture to less than 13.5% with air dryers prior to storage.

Development of new varieties

Barley, rice, corn, and hops form the agricultural foundation of brewing and distilling. The higher the quality of these raw materials, the higher the quality of the finished products. Over time, these individual agricultural components have been manipulated to provide specific, desired characteristics.

Development of new crop varieties is driven by competition among plant breeders. Farmers and growers are forever looking for ways to increase the yield from their planted acreage. Therefore, breeders that develop higher-yielding varieties find a ready market for their seeds.

Why Develop New Barley Varieties?

Barley traits can be classified two ways: agronomic traits that are important to the grower and malting traits that are important to the maltster and to the brewer. The traits in each classification are shown in table 1.

Table 1 Agronomic and Malting Traits of Barley

Agronomic Traits	Malting Traits
Yield	Kernel Size
Plant Height (Ease of Harvest)	Extract Potential
Days to Maturity	Grain Protein
Grain Protein (Malt vs. Feed)	Grain Starch Content
Kernel Size	Enzyme Potential
Disease Resistance	Husk Strength (mash separation)

The grower wants varieties that have high yield, are easy to harvest, will mature within the local growing season, won't succumb to disease, and will garner the extra money when sold for malting. The grower is thus very likely to buy seed with improvements in any of these areas without reducing the quality of other traits.

Likewise, the maltster wants barley with plump kernels, high extract potential, moderate protein, high starch content, high enzyme potential, a strong husk for efficient mash separation in the lauter tun, and low beta glucan for good filtration in both the lauter tun and the beer filter. The maltster will encourage the grower to produce varieties that meet these malting needs.

If a plant breeder develops a variety that meets all the needs of the grower and the maltster, the breeder will sell a lot of seeds and benefit financially. Unfortunately, the perfect malting barley does not yet exist, and in theory it never will. The very foundation of breeding and the nature of the intricate end-use (brewing) requirements means that even the best current variety can be further improved for agronomic and malting characteristics.

BARLEY BREEDING

Traditionally barley breeding has involved the selection and crossing of varieties. Barley, as a self-pollinating crop produces genetically identical offspring. Breeders introduce variety by preventing self-pollination (removing the anthers) and then fertilising the plant with pollen from another. Superior plants from the progeny are then selected and allowed to grow and pollinate naturally. For example the variety Proctor was created in this manner.

In the simplest cases two parent barley varieties are crossed, seed is harvested and grown normally. The first (F1) generation grown from the cross, which contains chromosomes with genes from both parents, is said to be heterozygous and does not breed true.

Successive generations become more homozygous (purer) and selections are made initially for the first three or four generations on visual appearance and disease resistance. Occasionally backcrossing is employed where the F1 generation is immediately re-crossed to one of the parents. Alternatively, multiple crosses may be carried out where two F1 generations with different parents are crossed.

Various techniques have been developed to shorten the time taken between the initial cross and the production of a pure strain. The earliest method was to grow spring barley crosses in New Zealand during the UK winter and thus obtain two generations within a year.

Newer techniques involve producing haploid plants with half the normal number of chromosomes, treating them with a chemical (colchicine) which induces chromosome doubling, resulting in a diploid (normal chromosome number) homozygous plant. The haploid plants can be produced either by tissue culturing pollen from the F1 generation or by crossing the F1 generation with a wild barley *Hordeum bulbosum.* In the latter case, the chromosomes from *Hordeum bulbosum* are lost during division, resulting in a haploid plant.

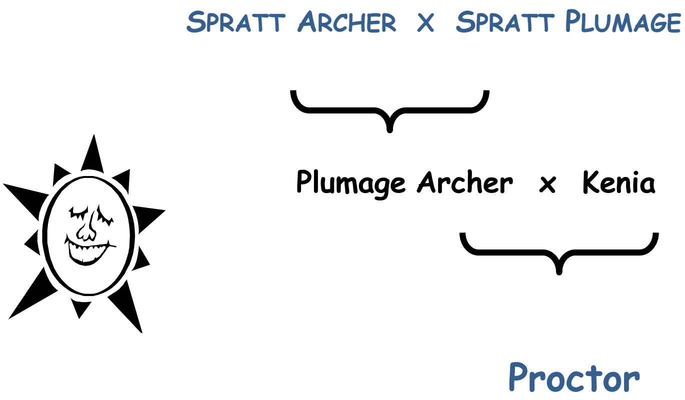


Figure 1. Crossing of barley varieties to produce a new cultivar.

Maris Otter is another variety generated through repeated hybridisation.

This method of cereal development is not as simple as may first seem. From initial hybridisation, to final release of the new cultivar into the market place takes a staggering ten years of rigorous trials and testing (see Table 1).

Following the initial cross, the seed is grown either in the field or in growth chambers. From these, certain selected plants (the F2 generation) are again grown out and the cycle continued. For a viable program to continue the new strain should show improvements in yield, malt quality and disease resistance by the third generation.

Potential new varieties must then pass through micro-malting and brewing trials before full plant trials prior to trade acceptance.

Alternative methods of plant breeding have involved producing induced mutations or have examined naturally occurring ones. However, many mutations are deleterious and many otherwise desirable mutations have associated characteristics that make them undesirable. Examples of mutated barley that has been successful or have created interest are Golden Promise (gamma-ray mutant of Maythorpe) and Glacier, a natural mutant of an American six-row barley. Glacier had 40% amylose in its starch instead of the normal 20%. There are various chemical mutants of Triumph that lack anthocyanogens.

Before the new cultivar can be recognised and recommended by national regulatory body's (e.g. DEFRA in the UK, or The Malting Barley Research Institute in Canada) it must first be seen to show distinctiveness, uniformity and stability. This is known as the DUS test and this test can take up to three years to complete. National List (NL) trials establish DUS.

DUS is the acronym for:

- **Distinctiveness** - that a variety is in some way distinct from other varieties.
- **Uniformity** - that a variety is not a mixture.
- **Stability** – that the variety will remain the same over the trail period, i.e. it will not out-pollinate.

After each challenge has been accomplished is it surprising to note that less than one in every 100,000 crossed offspring make it to variety status.

Below is an overview of the evaluation process for new UK malting varieties. Similar protocols exist around the global barley industry.

F8
NL1 (National List 1)
Up until NL1 a varieties progression has been solely up to the breeder.

At NL1 varieties are taken for official trials and enter the approval system. Assess all varieties for yield, disease resistance and agronomic characteristics. Varieties showing promise progress to NL2.

F9
NL2 (National List 2)
Varieties progressing from NL1 undergo further Micro-malting. All NL1 and NL2 trial data is pooled and assessed.

F10

RL1 / Scottish Variety Trials (SVT)

Varieties progressing from NL2 in England undergo micro-malting trials carried out by the English micro-malting group and in Scotland by the Scottish micro-malting group. Pilot Malting and Brewing trials are also carried out at Brewing Research International (BRi). Data on all varieties is collated and scrutinized by the respective micro-malting groups. Recommendations on varieties with malting potential are made to the English and Scottish working parties that in turn make decisions on which varieties remain on the list. These decisions are then taken to the Malting Barley Committee which effectively "rubber stamps" them and deals with any subsequent appeals. Successful varieties progress to **Provisional Approval 1**.

F11

RL2 Provisional Approval (1)

Candidates for Full Approval will normally have been awarded Provisional Approval 1 based on micro-malting results. To gain Full Approval, the Malting Barley Committee must have evidence of satisfactory pilot scale and commercial performance in the maltings/brewery/distillery.

For Full Approval in the UK

1 pilot malting and brewing trial (BRi)2 commercial malting and brewing trials (if lauter tun trial undertaken)

Or

2 commercial malting and 3 brewing trials (if mash filter trial undertaken)2 commercial malting and distilling trials

For Full Approval for Brewing

1 pilot malting and brewing trial (BRi)2 commercial malting and brewing trials (if lauter tun trial undertaken)

Or

2 commercial malting and 3 brewing trials (if mash filter trial undertaken)

For Full Approval for Distilling

2 commercial malting and distilling trials

F11

Provisional Approval (2)

A variety should normally progress to Full Approval with one year of commercial trials. Where there has been insufficient satisfactory malting, brewing or distilling trials to award Full Approval in one year of commercial trials, the Malting Barley Committee may award Provisional Approval 2 to denote that a variety has not been rejected and is still progressing through the approval process.

A variety should progress to Full Approval within two years of commercial trials. Any variety failing to gain Full Approval within two years will be removed from the List.

F11

Full Approval

In commercial use

Marketing options for barley include the open market or forward contracting based on quality. This option may provide a premium for growers.

Malting barley is commonly grown under contract to a malt house or brewery, and most contracts specify a premium for grain that meets specified quality standards.

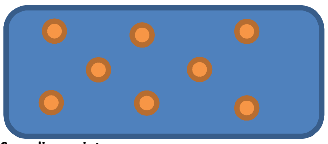
BARLEY INTAKE AND STORAGE

Barley Intake at Maltings

Barley may be delivered directly from the grower – usually undried – or barley that has been dried and stored by growers or merchants will be delivered to the maltings. This can be by road, rail or water. Both primary destinations and subsequent destinations will need analysis of the load to plan storage allocation and to ensure that the barley is as expected – that is it matches the important parameters of the purchase/sale contract.

Sampling

Prior to discharge, each load should be representatively sampled by approved methods. The grain can be analysed in a few minutes for germinative capacity (GC), moisture content, screening level, total nitrogen content, and contamination/admixture. If all of these parameters are within specification the load should be allowed to proceed to the intake point. If, however, the load fails on any analytical parameter it should be re-sampled, re-analysed and may be rejected if found still to be out of specification. For some parameters, there may be a scale of deductions to the price if the load is accepted out of specification. Once sub-standard barley has been taken into a maltings it is an expensive and troublesome operation to return it to the supplier through the maltings despatch system, especially when these plants are operating at maximum production capacity.



Sampling points.

The sampling probe takes several representative samples. Barley trapped in the probe is vacuum transferred to the lab for analysis. Before testing, the samples are thoroughly mixed to ensure the test is representative of the entire shipment. There are considerable differences in sample numbers and sizes with numbers varying from 1 to 10 samples and sizes from 0.4kg to 11kg.

Characteristics of Malting Barley

Introduction

It is essential to buy barley of the desired quality at reasonable cost, then dry and store this valuable raw material so that it remains viable and does not deteriorate before use. Barley drying, screening and storage may be managed completely "in-house" or can be outsourced, in whole or part, to barley merchants. Barley may be purchased in several different ways and there are a number of different criteria on which the final purchase price is based.

- In any delivery of barley a minimum proportion of the corns must be alive – this specification varies between countries, but is generally at least 96%. If the delivery fails to meet the standard it should not be accepted at any price. See Section 5 (b), (d) and (e) for analysis methods.

- At harvest intake it is essential to establish that the supplier has not damaged the grain by poor drying on-farm. Drying at too high a temperature can result in damage to the embryo and subsequently in failure to germinate. Farm drying may be suspected if the moisture content of a load is less than that of loads being received from other farms in the area. The drying operation costs money so this is reflected in the price paid for the barley – if the moisture exceeds contract maximum, an allowance will be taken against the price to reflect this.

- Barley must be free from insect infestation. Again, this is non-negotiable and infested barley will be rejected outright.

Other criteria are carefully thought about when assessing barley for purchase and these are described in the following text.

(a) Nitrogen (Protein) Content

Part of the premium paid for malting barley is associated with its low nitrogen content compared to feed barley, giving the farmer a lower yield. Nitrogen is used as a measure of protein content because most of the nitrogen in barley is in the form of protein; 1% nitrogen is equivalent to 6.25% protein. At high nitrogen content, the grain could be 'steely' and difficult to hydrate properly in steep, yield too little soluble extract and may bring about processing problems. It would therefore be rejected. In certain years when barley growers encounter a very dry summer it may be impossible to obtain sufficient barley at the specified nitrogen content. The nitrogen specification would have to be relaxed in this situation, and processing parameters adjusted accordingly. Nitrogen contents are measured using automated equipment usually using near infra-red (NIR) technology which is calibrated against a standard wet chemistry method. NIR machines give rapid and repeatable results, coping with the intense workload at harvest time.

(b) Moisture Content

This specification will vary from country to country: grain harvested at around 12% moisture in a relatively dry country will not require drying. Grain harvested above this level will need to be dried to maintain the barley in good condition in storage. UK standard moisture is 14.5%: above this level a calculated allowance against purchase price is applied, which just reflects the reduced dry matter in the grain as the moisture rises. Above 18%, the charge rises to match the cost of fuel used in drying the grain.

High moisture in grain can cause rapid deterioration, through loss of germination capacity to mould growth. HGCA have published a guide to safe storage times at a range of moisture contents: drying plans should be made using such information as guidance.

(c) Grain Size

At intake barley is assessed by passing it through a sieve or screen. The larger the average corn size the less barley will pass through a 2.5 mm screen, and there will be a lower **screenings** content. Larger corns have the potential to produce higher soluble extract, and a good malting barley should contain >90% corns larger than 2.5mm and <5% corns smaller than 2.25mm.

Uneven corn size distribution causes:

- Variable rate of moisture uptake.
- Uneven germination.
- Increased screenings and losses.
- Milling and brewhouse processing problems.

Another method of measuring grain size is **Thousand Corn Weight (TCW)** which is simply the weight of a thousand corns. Although laboratory equipment is available for counting out corns, this takes time and is impractical under harvest intake conditions – it is no longer a key parameter during intake but is often carried out before processing.

(d) Mycotoxins

In most seasons, barley will not be at significant risk of mycotoxin contamination above legal limits. A due diligence approach will indicate random sampling to confirm low and legal levels. Rapid test kits are available for the commonly sought mycotoxins such as deoxynivalenol (DON), zearelenone (ZEA) and ochratoxin A (OTA).

(e) Dormancy

In the natural environment it is important that the grain does not start to grow until conditions are ideal. There is a biological system within the grain that holds it in a dormant state for a certain length of time. The duration of this dormancy varies with barley variety, location and crop year.

Severely dormant barley cannot be malted and therefore it is important that the level of dormancy can be assessed before allocating this barley for production. Using the GE Test assesses the level of dormancy and vigour, also parallel water sensitivity (WS) test can be undertaken to guide steeping schedules.

(f) Endosperm Cell Wall Composition

The overall levels of β-glucan in the cell walls can be dependent both on variety and on growing season. Drought years tend to produce varieties with high levels of β -glucan. Some varieties also have inherently high levels of β -glucan. This may not be a problem if the variety produces high levels of β -glucanase. However a combination of high β -glucan and naturally low levels of β -glucanase could result in malts with high wort viscosities. The approval of new varieties of barley for malting will assess this tendency, but may not catch a seasonal peak which may therefore cause difficulties in later commercial use.

(g) Endosperm Structure

The endosperm structure can be influenced by nitrogen content. Mealiness (when the endosperm of the barley is low in protein and appears “mealy”) and steeliness (when the endosperm is higher in protein and more densely packed, appearing “steely/glassy”) have an effect on water uptake steelier grains will have a lower rate of water uptake. A Farinator may be used to reveal mealiness/steeliness in grain kernels.

(h) Pre-germination

In very wet years at harvest time, grain may begin to germinate in the ear. In the malting process, such grain will initially germinate very rapidly compared with other corns in the bulk. However, if stored for any length of time the corns tend to die. In either case the result is unevenly modified malt.

(i) Husk Content

Malting varieties tend to have thin husks allowing more rapid moisture uptake, whereas feed barley has thicker husks resulting in slower rates of water uptake and less extract.

Hand Evaluation and Inspection

Barley quality is influenced by the environment in which it is grown, handled, and stored. The degree to which barley is affected by certain deficiencies in quality can be determined by a physical, non-chemical examination of a sample of the barley, although some determinations do require laboratory analysis. The sample to be evaluated must be representative of the entire lot, so proper sampling techniques are very important to ensure the quality evaluations are correct with respect to the crop, truck delivery, or rail car.

Visual Inspections

Visual inspection is an essential component of barley evaluation. A good inspector identifies potential problems that might otherwise not appear until much later in the process. Visual inspection with the husk intact covers the following barley characteristics. Skill in hand evaluation of barley may be gained from training courses, but particularly by experience on the job.

- **Colour** — Barley colour varies from bright golden to dull brown-black. Weathered barley has a grey or steely appearance and may not be acceptable.
- **Odour** — Barley should smell fresh and clean. Off odours include musty, raisin or winey and chemical (from pesticides).
- **Ergot** — Hard, reddish-brown or black grain-like mass of parasitic fungi. Presence will cause rejection of the load.
- **Insect presence** — Insect infestation – even a single dead insect – will normally cause rejection. If the insect is a field insect, not a storage pest, the load may be accepted.
- **Insect Damage** — Kernel has holes or evidence of chewing.
- **Foreign Seeds** — Any non-barley seed in the sample, including wheat, wild oats, weeds etc.
- **Varietal Purity** — Separate other varieties using morphological identifiers (rachilla hair length, awn smoothness, husk adherence, husk smoothness, number of lateral vein barbs) on varietal identification flowcharts.
- **Blight** — Tan to dark brown spots distal to the germ or dark brown to black coloration at the germ end of the kernel. Fusarium infection can manifest as pink corns.
- **Mould** — Microflora growth along the crease of the kernel.
- **Skinned and Broken Kernels** — One third or more of the husk is missing or a loose husk that exposes the germ, or part of the germ is missing.
- **Immature Kernels** — The kernels are green.

PREPARATION OF BARLEY FOR MALTING

Barley and malt are stored in deep silos, some with capacities in excess of 3000 tonnes, or flat stores which may be much larger. As a living tissue, prolonged storage in such conditions can suffocate the barley grain. To prevent the interruption of grain respiration, the barley is ventilated during storage, or may even be moved between stores. Such movement of the grain may be combined with cleaning and pest fumigation, in preparation for malting.

The silo transfer equipment consists of machinery that is used to transfer, store and clean either barley or malt. The system is designed to provide efficiency, reliability, and flexibility. Separate machinery is used for the transfer of barley and malt, though in some cases systems may be cross-connected to allow grain transfer under special conditions. System design and operating procedures must prevent inadvertent mixing of malt and barley. Different choices may be made with regard to conveyor selection, bearing in mind prevention of grain damage, flexibility of multiple points of origin and discharge, hygiene, and energy efficiency.

The grain first passes over revolving or vibrating screens and sieves, in combination with air jets and magnets. These act to remove any non-barley material that is not of equal size or weight. The material that is removed can contain twigs, leaves, straw, stone, pieces of metal and dust.

Throughout malting, and indeed any grain-handling environment, great care is taken to remove both dust and any material that could generate a spark. This is to prevent dust explosions which can be both violent and dangerous. Each machine is hooked up to a dust collection system and will not run if the dust collection system is not running.

Barley Separation

Separation takes place in long, rotating cylinders (Figure 1) that remove all grains that are shorter than barley, including broken half grains and small weed seeds. The cylinder has pockets or indentations on its interior surface into which only the weed seeds and half grains will fit. Only debris is retained in these indentations. As the cylinder rotates further the retained material is ejected at the apex into a central trough for extraction. Broken grains are especially undesirable as they will not malt normally; they pick up moisture easily and they harbour bacterial and fungal infections.

Barley Grading

The barley is next subjected to grading, a relatively slow process. Grading is used to segregate grains of different sizes. Different sized grains germinate at different rates, leading to non-homogeneous batches of malt. For instance, small grains will hydrate and respire vigorously expending oxygen faster than large grains. The small grains will bolt, malting more rapidly and modify to a greater extent than the larger grains. If unchecked, the malt will contain proportions of under-modified large grains, and over modified small grains, each of which will behave differently in the brewhouse.

During grading barley flows over vibrating screens or sieves fabricated with slots of defined sizes (Figure 2). Plump grains pass over the screen, whilst the thinner grains fall through and are subject to further screening.

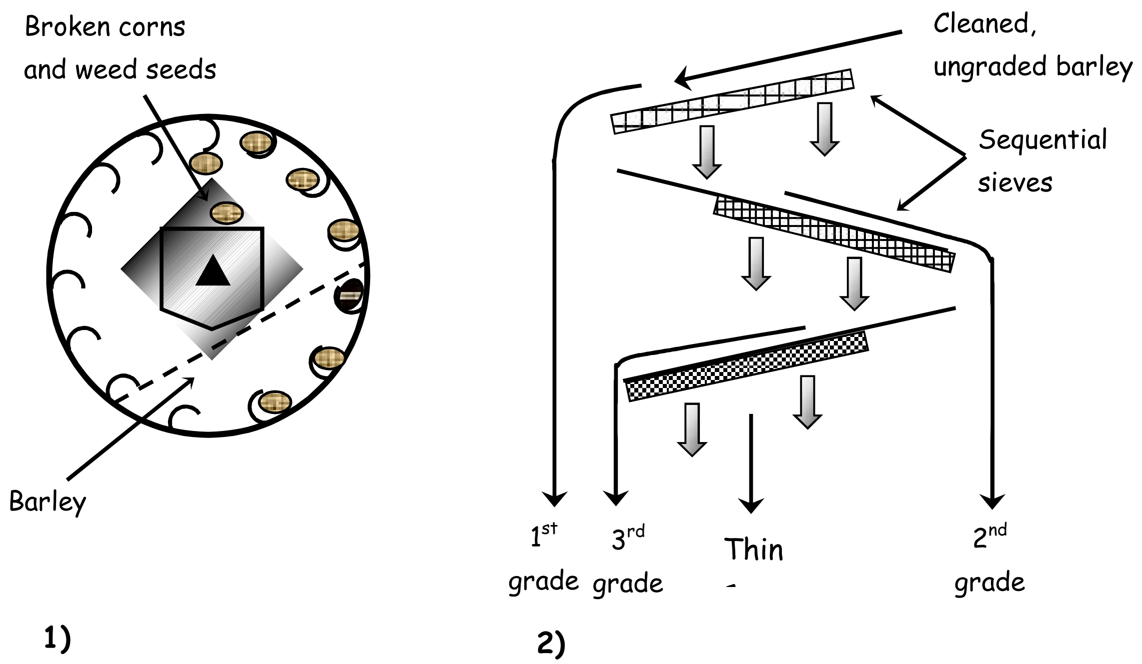


Figure 2. Schematic representation of 1) barley separation and 2) barley grading.

Repeated sieving can result in two or three grades of barley:

- **1st grade:** The plumpest grains, usually comprising over 95% of the grain bulk, used to produce standard malt.
- **2nd grade:** Thinner grains, may be used for speciality malts.
- **3rd grade & "thins":** Are unacceptably small for malting and are sold as animal feed.

Usually two grades are sufficient separation – one bold grade for malting, and the smaller corns (screenings) to be sold into the feed grain market. Once graded the barley is stored ready for use. Grain is transported around the maltings in various ways including:

- Bucket elevators.
- Screw conveyors.
- Pneumatic systems.
- Endless belts.

The barley and malt cleaning processes result in the creation of a significant amount of co-products. While these co-products represent barley mass that cannot be turned into malt, they are not simply thrown away.

Three types of by-products are generated.

- **Feed barley** - Small kernels of barley that pass through a 2.25mm screen during barley cleaning.
- **Offal or dockage** - Straw, husk, hull and some dust from the aspiration of all machinery. (Mainly barley cleaners and dust systems)
- **Culms (also rootlets or sprouts)** - Small malt kernels, rootlets, husk, and husk from kiln and malt cleaning.
- Any material which has safe nutritional value to animal feed may be pelleted for ease of storage and transportation. This would not normally include barley screenings (feed barley) as it is easy enough to handle by itself.

Drying and Storage

Grain harvested from the field will vary in moisture content from around 12% in some growing regions, to 15% in a dry year in others, to 30% in a wet year. Whatever the moisture at intake, the grain must be dried down to 12 - 13% (or less) for safe storage. Above 13% moisture, barley is susceptible to insect or mite attack and since the grain may be stored for many months it is obviously essential that this risk be removed. Even if the eggs of grain weevil or saw tooth beetle are present they are unable to grow and multiply if the moisture of the grain is less than 12% and the temperature is below 15^{o}C.

If moisture levels exceed 13%, the grain can start to respire and generate heat, leading to moisture transfer through the bulk and possible condensation in cooler areas. If action is not taken to correct this, further heat build-up will occur and further respiration. Concentrated areas of heat known as “hot spots” can occur in the grain silo or store. Hot spots both harbour and promote microbial growth whilst the heat itself can kill the embryo making it unsuitable for malting. To avoid heat build-up, the grain must be ventilated, which both cools the grain and removes CO_2 from respiration. However, if moisture levels fall below 12% the grain will dehydrate and become more susceptible to skinning and breakage during handling.

Whilst safe storage is the principle reason for drying barley we also benefit in a second way. The process of drying barley accelerates the grain from its natural dormancy. The actual mechanism by which this works is still unknown but experience shows that barley that has been dried is ready for steeping sooner than that which has not. This phenomenon has been taken one stage further – research indicated that if the grain was stored warm (after drying) then the recovery from dormancy was accelerated further.

In cooler countries the harvest will be slightly more moist, whilst warmer countries will yield drier grain at harvest. Maltsters often take on this responsibility themselves, in the belief that they can accomplish the task more successfully than the farmer can, although specialist store keepers will also have the expertise to dry grain carefully. The basic principle of grain drying is the use of warm, dry air to heat the grain and remove the excess water vapour. Drying is a delicate process, as undried grains are more prone to heat damage than grains with lower moisture.

After drying, the grain is cooled (either immediately or after a number of weeks) and stored until it is ready for use. During storage the grain respires, albeit at a low rate, and must be kept fresh by aeration. All medium to long term barley silos are fitted with low volume fans for this purpose. As mentioned earlier the grain in store has to be protected against fungal growth and insect infestation. This is achieved by drying the grain to 12% moisture and holding the temperature below 15°C.

Regular temperature monitoring and physical inspection of grain in store are essential to ensure that localised infestations are not occurring and pre-cleaning/fumigation of silos/stores is imperative.

Over-cooling of grain must be avoided, however, since it is possible to chill the barley back into dormancy. Timing of warm storage, cooling and aeration is important so that recovery from dormancy is optimised and pest free storage is guaranteed.

There are two principle methods for barley drying, continuous and batch, and both will be described.

Drying Methods

(a) Continuous Drying

By definition the barley being dried is continuously moving and leaves the dryer at the required moisture (12%). Movement of the grain is achieved either by gravity (as in the case of a tower dryer) or by mechanical conveyance (i.e. a tray or compartment dryer). The most commonly used dryer of this type is the tower dryer where the grain is elevated to the top and then allowed to cascade down through the plant, being dried in the process.

The tower is constructed with 3 or 4 sections; the bottom one of which is used for cooling. All sections are serviced by fans and those sections used for drying have either burners or radiators. As the grain falls through these sections warm air is blown through an arrangement of ducts. The warm air then passes through the grain, removes moisture and exits the dryer through a second set of ducts.

In all types of dryers it is essential that the grain temperature does not rise above 35-40°C otherwise severe heat damage will result. In a tower dryer the actual air temperature has to be between 60-65°C in order to allow drying to be achieved from a relatively low volume of air. Extreme caution, therefore, has to be taken to ensure that localised overheating of the grain does not occur. At higher moistures, the temperature must be lower in order to avoid grain damage. Guidance tables of temperature at different moisture contents are available.

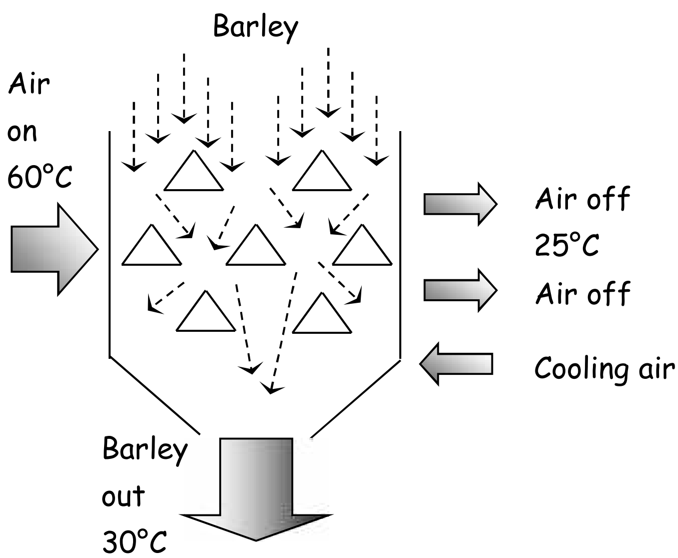


Figure 1. Schematic representation of a Cimbria dryer (Source: Cimbria).

The manufacturer Cimbria offers a drying system which is a tower dryer, schematically shown in Figure 1. If cooling is turned off the grain will exit and be stored at 40°C. At this temperature, grain dormancy will be broken after only 2-3 weeks storage.

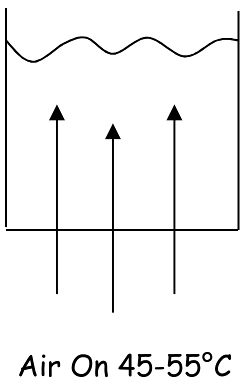
If the grain is stored in such a condition (at 40°C) daily monitoring must be carried out to check for infestation. It is normal practice to store the grain at 30°C for a short time before being cooled to ambient temperatures. Cooling relies on ambient temperatures being cool enough to ventilate the bulk, and may happen best overnight if summer daytime temperatures are high.

The first main difference between a batch dryer and a continuous dryer (Figure 1) is that the dryer is charged, fired, cooled and discharged in steps as opposed to continuously. The second difference, and perhaps the most important, is that normally the fan arrangement of the batch dryer is such that a much greater volume of air is available. This means that the actual air temperature required to dry the grain is much lower (typically 40 – 45°C) and the risk of heat damage is much reduced. This means that the grain is dried with a higher volume of cooler air than in a tower dryer.

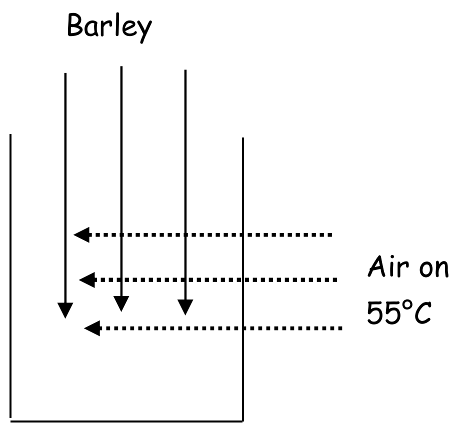
Dedicated batch dryers are expensive compared to tower dryers for a given throughput.

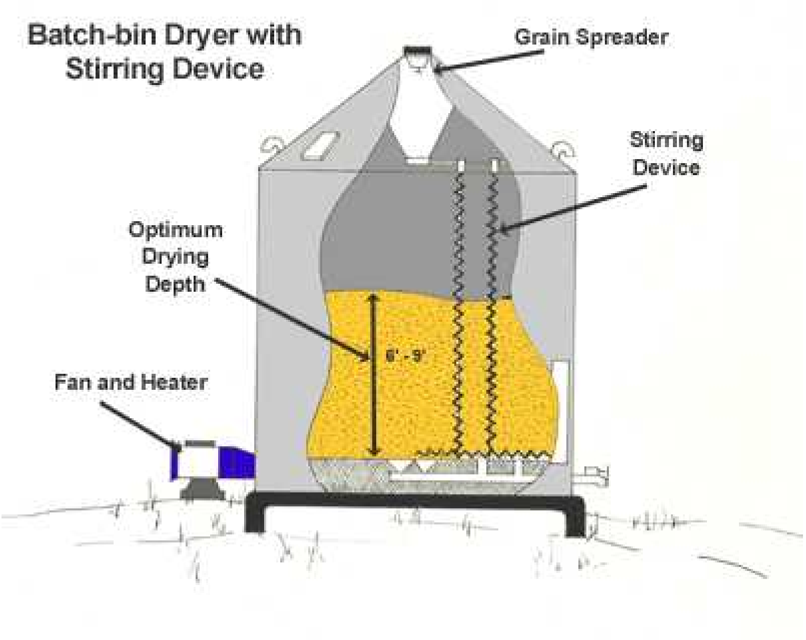
(b) Batch Drying

In batch drying the grain is dried un-homogeneously due to a lack of turning. The grain at the bottom dehydrates most and is more susceptible to heat damage than grains nearer the top of the silo. Batch drying may be undertaken on a maltings kiln, with malt production suspended for the duration of harvest.



On-farm drying can be poorly managed, as dryers are often specified for drying feed wheat, which can be done at higher temperatures and therefore higher throughput rates. This information is misleading to those unaware of the vital importance of germ viability to malting barley. In itself, on-farm drying is not a problem - it is the management and control that has given rise to problems in the past.





(Source: USDA)

The majority of the barley crop is harvested in late summer. However, malting, brewing and distilling are year-round activities, necessitating the need for storing barley until it is ready to be used. Harvested barley may be stored at the barley store (elevator) or it may be stored on the farm if the farmer has adequate facilities. Whether on the farm or at the elevator, barley is usually stored in large metal bins that have been cleaned and which may have been sprayed with insecticide.

Fumigation

Insect infestation in barley creates sanitation problems in the storage bins and malt house, and can damage barley quality. If infestation is detected in a bulk, specialist contractors can be employed to administer phosphine treatment, usually from solid formulations such as aluminium phosphide. The time of treatment needs to be long enough to kill active insects as well as insects subsequently hatching from eggs.

Phosphine is the only fumigant approved by some brewers for direct contact with barley. It is extremely poisonous to insects (and people), but leaves no post-application residue. Phosphine is usually not detectable 7 to 10 days after fumigation.

Aeration and Temperature Control

The storage bins are equipped with aeration fans to control temperature. Lower temperatures (to 10^{o}C) are preferable to high temperatures. A low temperature minimizes insect activity and allows barley to be stored for long periods of time and still remain in a desirable "cool, sweet" condition. Barley may be stored for as long as 18 to 24 months before being shipped to a maltster for processing into malt. If it is properly stored, there is no discernible deterioration in quality.

Proper temperature of stored barley is maintained by operating aeration fans as needed. Keep in mind that it takes a long time to reduce the barley temperature by a significant amount. Typically, barley arrives at the barley elevator or into a maltings at an average temperature of 18^{o}C. After drying it may be at 30^{o}C, after which it may take two weeks of constant or overnight ventilation to lower the barley to a more desirable temperature of 10^{o}C. Temperatures below 10^{o}C will stop insect activity from occurring.

Proper aeration will also maintain moisture content throughout the bin and will prevent hot spots in the bin. Stored barley is a population of living organisms. Even though the kernels may be dormant, the embryos are alive. If the kernel moisture content exceeds 14 per cent, the barley respires at an accelerated rate. It takes in oxygen and produces moisture, CO_2, and heat. If the moisture and heat are not dissipated properly, the respiration rate will continue to rise. When the available oxygen is depleted, respiration will turn anaerobic, that is, without oxygen. Fermentation may begin and additional heat will be generated, leading to heat damage, mould development, and loss of viability.

The objective of steeping is to raise the moisture content of the barley to a level which will start the germination process and then allow it to continue so that the enzymes of the grain modify the starchy endosperm. The aim of modern steeping is to have the grain uniformly chitted but no root growth at the end of the steeping period. The grain should be uniformly hydrated and have a rapid, uniform and controllable growth rate.

It is crucially important that the moisture content of the resultant germinating barley is distributed as evenly as possible between each kernel. If this were not the case then each kernel would grow at a different rate and unevenly modified, poor quality malt would result.

METHODS FOR ASSESSING MALTING BARLEY

Using some basic analytical methods and data it is possible to predict the eventual malt quality. Some of these methods are described below. The predicted data are compared with customer malt specifications and barley is then provisionally allocated to individual customers or malt types. It is common to keep details of each barley reference including variety, merchant, location, contract specification and tonnage. Additionally it is good practise to keep analysis results for nitrogen (TN), TCW, and the Varietal Constants for each variety. This information may be used for calculating extract potential.

(a) Micromalting

Micromalting is a laboratory process where small samples of barley can be germinated using processing conditions resembling those in the commercial malting plant. During micromalting, measurements are recorded for water uptake and evenness of germination so that recommendations can be made about the readiness of the barley for malting, the processing conditions to use, and the likely quality of the finished malt.

Barley samples that have recovered from dormancy naturally, or conditioned in the laboratory, are micromalted to determine the actual malt quality that will be achievable when the barley is fully mature. There are different methods for micromalting ranging from glass jars to sophisticated commercial equipment. Although these methods are useful in predicting malt quality they have their pitfalls if the sample size is too small. Basically, the bigger the sample the more representative it will be of the batch of malting barley.

With this detailed information at hand, confident decisions can be made when committing large tonnages of barley for production. This information also provides realistic targets for the maltings production teams to aim at, together with indications of processing.

(b) Germinative Energy

The germinative energy of the grain sample is the percentage of kernels that germinate at the time of testing and gives a measure of the dormancy potential of a sample.

Method: 100 grains are placed on top of filter paper in a petri dish and 4 ml of water added. The number of grains that have chitted each day are counted and removed from the plate. After incubation for 72 hours at 18°C, the grains that have germinated are expressed as a percentage of the total.

(c) Water Sensitivity Test

The objective of this test is to determine the potential of the grain sample to grow in excess water – this reflects conditions during steeping. The method is similar to the GE test, but 8 ml of water replaces the 4 ml and corn counts are made at 24 hour intervals. Water sensitivity is expressed as the difference (as a percentage) between germination in 4 ml of water and germination in 8 ml of water.

Example

After 72 hours incubation, 91 grains of the 100 grain sample have germinated in 4 ml water; only 75 of the 100 grains placed in 8 ml of water have germinated.

Therefore, Water Sensitivity = (91-75) = 16

(d) Germinative Capacity

The germinative capacity of the grain sample is an attempt to quantify the percentage of viable corns within a sample. This may include the forced growth of grains expressing degrees of dormancy. Most commonly this is achieved using a solution of hydrogen peroxide, to supply the corns with excess oxygen forcing the viable, yet dormant grains to germinate.

Method: 200 corns are steeped in 200ml of 0.75% (v/v) hydrogen peroxide for two days at 18-21°C. The corns are then strained and 200 ml of fresh hydrogen peroxide added and the barley again incubated at 18-21°C for one day. The germinated grains are counted and the germination capacity expressed overleaf.

Germination capacity % (hydrogen peroxide) = *200 – n*

n = corns that do not show roots

In the IBD official recommended methods corns that fail to germinate after three days are peeled back and allowed to grow for a further 24 hours. The additional number of corns that germinate are divided in half and subtracted from n.

Example
After 3 days germination 158 grains out of the 200 tested have germinated. So, GC = (200-42)/2 = 79% After a further 24 hours incubation another 12 grains have germinated.
The adjusted GC = (200-30)/2 = 85%

(e) Tetrazolium Viability Test

Staining the grain with Tetrazolium chloride is used for rapid assessment of the potential viability of the embryo. This method relies upon the action of dehydrogenase enzymes that reduce tetrazolium salts causing them to turn red. Viable grains are split in half along the ventral furrow and incubated in tetrazolium chloride solution. Red embryos and aleurone layers indicate active dehydrogenases are present and that the grain is viable. Although this test is important in the initial screening of barley for potential germinability, the red coloration of the embryo does not necessarily guarantee that the embryo will germinate and that the grain will malt satisfactorily. It is quite feasible for dead grains to contain active enzymes.

Cross section with the embryo stained red by tetrazolium dye, showing that it is capable of full germination. *Source: MAGB.*

KEYPOINT: A viability test determines the proportion of living cells or organisms in a sample.

For germinative and viability tests maltsters demand a high proportion of viable grains – 98% in the UK, down to 92% for some European futures contracts. Maltsters have no way of separating live kernels from dead, so the final malt will always have a small proportion of dead grain.

(f) Extract Potential

The extract potential of malt may be determined by the IBD mixed mash method. There are other methods and here the Bishop Equation is described. This equation predicts how well a barley sample should malt, using a numbered scale.

- Good grades (7-9)
- Average grades (4-6)
- Poor grades (1-3)

KEYPOINT: Maltsters quote hot-water extract in litre-degrees per kilogram (l°/kg), expressing how many litres of wort each kilogram of malt will yield.

E = A – 11.0TN + 0.22TCW

E = Extract potential [x 2.96 = (l°/kg)]
A = Varietal constant
TN = Nitrogen level (% dry weight)
TCW = 1000 corn weight

The Bishop Equation derives potential soluble extract from the relationship between thousand corn weight (TCW), total nitrogen content (TN) and a varietal constant. This last parameter represents the capability a particular variety has for achieving good soluble extract. The higher the varietal constant then the higher the malting grade of barley.

The varietal constants for several of the malting barley varieties are shown in Table 1.

Table 1. Varietal constants for the 1991 barley crop.

Varietal Constant	Barley Variety	Malting Grade
114.5	Chariot, Derkado, Prisma	High
114.0	Alexis, Camargue, Halcyon, Puffin, Sprite, Volga	
113.5	Pipkin	
112.0	Tyne	Low

The varietal constant depends on the following criteria:

- Germination potential.
- Potential to produce gibberellic acid.
- Rate of transport of gibberellic acid to the aleurone layer.
- Potential of aleurone to produce endosperm degrading enzymes.
- Rate of enzymatic breakdown and modification of the starchy endosperm.
- Proportion of starchy endosperm material in the corn.

THE MALTING PROCESS

STEEPING

Introduction

Malt is the major raw material used in brewing and malting is therefore an influential process. Malt determines final beer quality. Put simply, the process of malting is the controlled growth of the barley grain, with the maltster directly manipulating the grain to achieve the required modification.

Endosperm modification is achieved by malting the grain. By allowing the grain to germinate under controlled conditions, the ability of the grain to produce hydrolytic enzymes can be manipulated. Hydrolytic enzymes released during germination are required to partially degrade (or modify) the starchy endosperm during malting and later to release fermentable extract during mashing.

The processes that take place during steeping are:

- Moisture content of the grain is increased to 44% - 47%.
- Increased respiration rate.
- Initiation of enzymatic activity that will continue during the germination phase.
- Washing dust off and leaching of substances from outer layers of grains.
- Production of waste steep liquors with high biological or chemical oxygen demand (BOD or COD).
- "Chitting" - the appearance of the coleorhiza, surrounding the first rootlet.

KEYPOINT: Grain modification is the overall enzymatic action in the endosperm during malting, which transforms the hard starchy endosperm of barley into friable (crushable) malt.

The malting process combines three separate stages: -

1. **Steeping**: Initiation of growth through grain hydration.

2. **Germination**: Controlled growth of the grain to effect endosperm modification.

3. **Kilning**: The termination of grain growth to fix extract potential and malt specifications through grain dehydration.

The Steeping Process

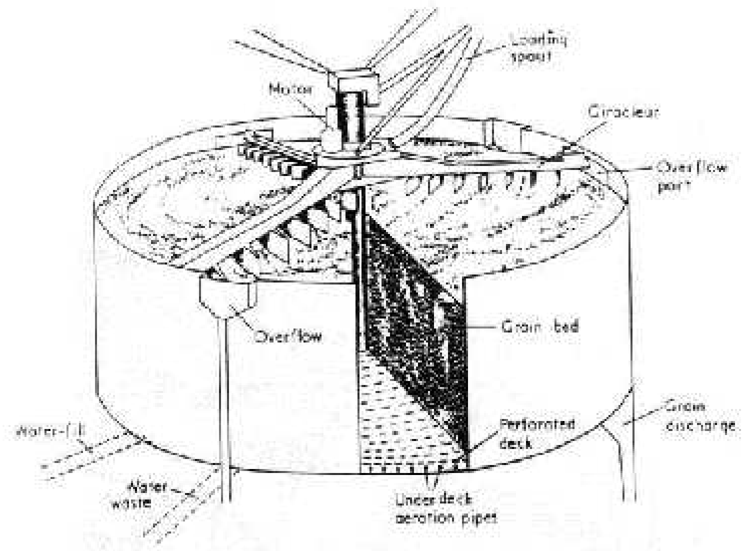
During steeping, barley grains are placed in vessels with capacities ranging from 15-500 tonnes. During the steeping process, the grains are submerged in steep water, which is changed between one and three times as required. During wet phases, air is blown through the grain suspension; between wet phases, the grain is left in air (known as an air rest) and ventilated for the following reasons:

- To remove CO_2.
- To remove toxic metabolites.
- To discharge excess heat.
- To replenish oxygen.

Steeping can be carried out in dedicated conical or flat bottomed vessels, combined steeping & germination vessels (SGV's) or steeping, germination and kilning vessels (SGKV's). Most modern maltings utilise micro processor control systems throughout the process such as SCADA, DCS and PLC.

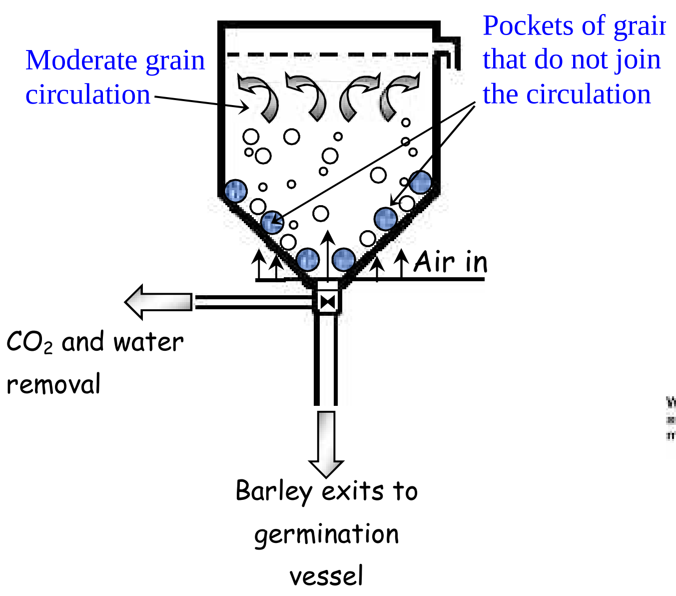
Conical steeps

Conical steeps (more properly called cylindro-conical steeps) have limited air flows due to the small area of perforated plate available for the passage of air and CO2. Rates are approximately 30-50 cfm/te. The air flow can be increased by enlarging the perforated cone area (ventilated conical steeps) with a resulting greater degree of flexibility in steep cycles. A ventilated cone is shown in below. Both conventional and ventilated steeps are often fitted with compressed air aeration, which is used in the immersion stage of steeping to overcome pressure and temperature gradients. In some vessels, this rousing is assisted by a vertical central pipe.



Flat bottomed steeping

In terms of degree of aeration and air distribution, flat bottomed steeps have major advantages. Water and effluent costs, however, are higher when compared with a conical steep due to the volume of the space under the grain floor. Flat bottomed vessels are also more difficult to clean due to the difficult to reach space under the grain floor. A diagram of a 'Nordon' type of flat-bed steep. Provision is made both for aeration from below the perforated deck, and for carbon dioxide extraction from beneath the grain bed during air rests. Such steeps may be large, e.g. have capacities for more than 200 tonnes of barley.



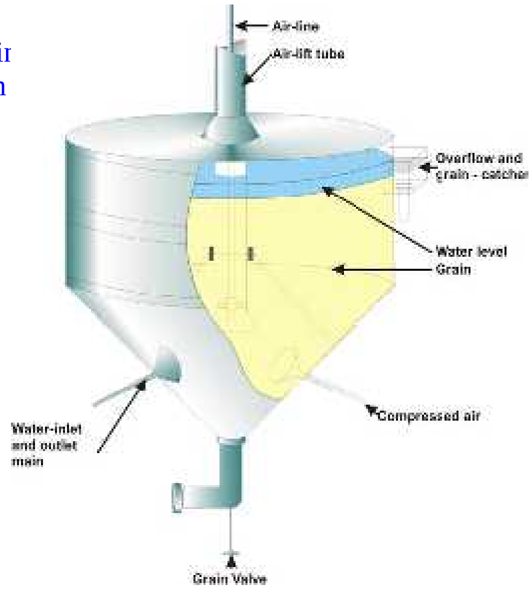


Figure 1. A traditional steep system. The rising air separates and mixes the grain, dispersing the heat generated by grain respiration, whilst also providing aeration. The conical vessel bottom allows easy liquor and grain extraction when casting to germinating vessels. These pockets of grain that do not join the circulation within the steep are likely to grow less well than the rest of the grain and so such pockets should be avoided where possible by good steep design.

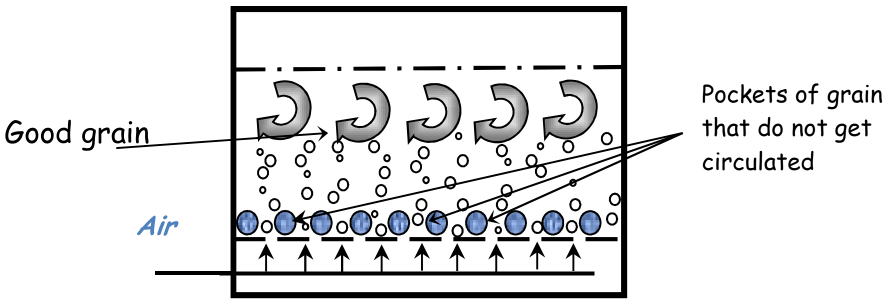


Figure 2. A Flat bottomed steep vessel. Mixing of the grain in these vessels is more even compared to the conical vessels. Removal of the grains is by rotating arms to push the grain out.

During steeping, hydration stimulates the embryo into growth and respiration commences, slowly at first, but quickly gaining vigour. Grain respiration (the production of energy to drive metabolic processes) produces heat, CO_2, and metabolites.

Encouraging Even Malting

If unchecked, the heat generated during steeping as the grain respires has a cumulative effect and forces the grain to respire more rapidly. Uncontrolled respiration causes the grain to hydrate quicker, but in an irregular fashion throughout the grain population. The malt that results will be non-homogeneous and poorly modified with the potential to cause brewhouse problems.

To encourage even malting, the grain can be turned or agitated during steeping. Mixing of the steeping barley takes two forms:

- The grain can be agitated by bubbling air through the steep, as seen in Figures 1 and 2.
- The whole grain slurry can be pumped and re-circulated to effect mixing, as shown in Figure 3.

Steep Water

The steep water can also be removed and changed to maintain optimal temperatures. Substitution of the steep water has additional benefits. Throughout steeping the grain produces metabolites such as ethanol and CO_2. Such metabolites are, in sufficient quanitites, toxic and can stifle grain growth and hydration. This can lead to the production of poorly modified malt. Refreshing the water reduces the accumulation of these compounds and so lessens their toxic effects. In addition, a specific germination inhibitor is leached from the grain, and it is useful to remove this by changing the water.

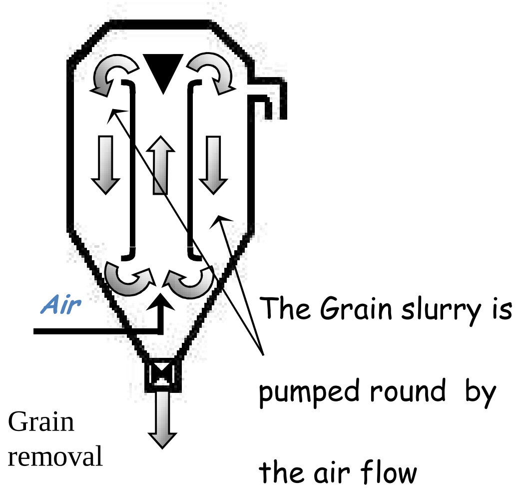


Figure 3. A Conical steep vessel with central circulation. The grain slurry is circulated around the vessel aided by the action of the rising air. The vessel design gives easiest grain removal, either under gravitational force or pumped to exit.

The steeping process physically washes and cleans the grain, leaving dirt suspended in the steep liquor. This can be removed when steep liquor is changed.

The phenolic components leached from the barley husk are important as they can contribute an astringent character to beer. If the steep liquor is not refreshed the phenol build up will taint the malt and be conveyed into the beer. The maltster may use alkaline steep waters to combat the astringent contributions of leached phenolics. Chalky, alkaline waters also check microbial growth, as well as extract the astringent phenols. Caution must be taken as highly alkaline treatments can kill the grain. Effective methods can involve the use of sodium carbonate or sodium hydroxide, used in short immersions at the start of steeping. These preliminary steeps also help to clean the grain, remove musty odours and lighten the grain colour.

Additives may be used for various reasons:

- Reduce microbial contamination: add to steep water any of the following: hypochlorite+ or chlorine, alkali, hydrogen peroxide or formaldehyde (0.1%). + hypochlorite deactivates gibberellic acid (at high concentrations).
- Reduce soluble polyphenol content (associated with beer haze): add formaldehyde or alkalinity builder (CaOH, NaCO3, NaOH) to steepwater.
- Reduce soluble nitrogen: add bromates or salts of octanoic acid to final steep (or spray onto green malt).
- Reduce malting loss: sodium or potassium bromates added to final steep (or sprayed onto green malt) at 50-125mg/kg –reduce respiration and rootlet growth (hence NDMA levels) but inhibits some proteolytic enzymes and suppress DMS precursor (so avoid using bromates for lager malt). A mix of gibberellic acid (GA) and bromate may reduce malting loss by 2%.
- Improve germination: add hydrogen peroxide, ozone or gibberellic acid* to steep water.

* As gibberellic acid treated malt increases the soluble nitrogen content of beer, bromate may be used in conjunction with GA to control these soluble nitrogen levels. Gibberellic acid is not efficiently absorbed by un-germinated embryos. Application rates are 0.05-0.25mg/kg.

Gibberellic acid increases-

- Extract (initially)
- Soluble protein
- Colour
- α- amylase
- Friability

GA Decreases

- C/F diff
- Malting loss

Steep Regimes and Air Rests
Reliable information regarding the quality of barley to be steeped from laboratory tests, determines the steep regimes to be used. These tests could include variety, moisture, germination energy, water sensitivity tests, total nitrogen, TCW and screenings, steeping and germination data, soluble extract and modification analyses of the micromalt. With this information it is possible to confidently select a steeping cycle. Typically, multiple steep regimes will incorporate several air rests. The only critical factor in determining the frequency of air resting is the economics of malting, with the quickest and most efficient process the most profitable – as long as the malt meets specification. A selection of typical commercial regimes can be seen below.

(1)	**(2)**	**(3)**
8 hours steep ↓ 16 hours air rest ↓ 24 hours steep	8 hours steep ↓ 10 hours air rest ↓ 10 hours steep ↓ 2 hours air rest	6 hours steep ↓ 10 hours air rest ↓ 6 hours steep ↓ 6 hours steep ↓ 6 hours air rest

During air resting, air is passed through the grain. Although barley has no capillary action, spraying during air resting can prevent grain dehydration. Replacing the surface film of moisture also helps prevent heat build up, as barley respires more vigorously when out of water. Spray steeping was originally developed to reduce water consumption (by approx 20%) and hence effluent costs, while maintaining malt quality. Water channelling in the steep tanks leads to uneven moisture content and therefore uneven germination and difficulty in producing good quality malt. Spray steeping is more successful when used in the production of lager malt. Lager malts tend to be less well modified than ale malt and have a requirement for SMM which is found in the acrospire - spray steeping may enourage more acrospire growth.

(a) Even modification - Multiple Steeping

Barley is immersed in water at a given temperature in order to increase the moisture content and to initiate germination. It is important that the moisture content of the resulting germinating barley is distributed as evenly through each corn as possible. If this were not the case then uneven, partly modified malt may result. Also, the steeping of water sensitive grains must be considered. These requirements can be met by the use of multiple steeping cycles where an air rest with good CO_2 extraction follows each immersion. In the case of water-sensitive grains, experience has shown that if the amount of water taken up by the grain in the early stages of steeping is limited then the water sensitive grains will begin to germinate.

(b) Initiation of Germination

If the grain moisture can be raised to a suitable level to initiate germination (30 - 33%) and then a long air rest is carried out, the grain will be able to accept more water without being damaged. If too much water is given too quickly the grain will be saturated and slower to progress to chitting.

Other benefits arising from the use of multiple waters are that germination vigour can be enhanced and higher moistures can be achieved in shorter times compared with a single immersion. The duration of the air rest periods is dictated by the volume of air available (i.e. fan size) for CO_2 and heat removal. Also in multiple steeping there is efficient removal of substances leached from the grains that provide a medium for the growth of microbial populations.

(c) Air Rest Temperature

As a general rule, air rest temperature should not exceed 21-23^{o}C as damage to the embryo could occur and certain enzyme systems can be impaired – especially proteases that break down the protein matrix in which the starch grains are embedded. A consequence of this could be that less starch is available to the brewer leading to reduced soluble extract, increased viscosity leading to poor mash tun run-off – both of which would reduce the throughput of the brewery. Once germination has commenced it is important that steeping raises the moisture of the grain to a level that will promote the production, distribution and activation of the enzymes. Generally moisture of 44 - 47% is typical for malting but, as stated previously, it is important that this moisture is distributed as evenly as possible throughout each grain.

(d) Steeping Cycles

Two typical examples of steeping cycles are shown below. The first programme is designed to cope with water sensitive barley and produce malt using a conical steep system. The second programme is designed for fully mature vigorous barley to produce malt using a flat-bottom steep system. In example two the use of only two steeps also has the added benefit of economising on water use.

Example 1

Grain profile: 4 ml test = 96%; 8 ml test = 79%; water sensitive; average nitrogen (1.7%).

Malt type required: well modified, high enzyme, medium – high moisture (47.5-48%).

Programme	Hours	Comments
1st S	5	Short first steep to combat water sensitivity.
1st AR	14	Long air rest to promote germination.
2nd S	5	Increased water uptake.
2nd AR	14	Long air rest to encourage vigorous growth.
3rd S	5	High moisture to help enzyme development.
3rd AR	5	Short time in steep to prevent heat build-up.

Example 2

Grain profile: 4 ml test = 99%; 8 ml test = 96%; low nitrogen (1.6%); small grain size (20%<2.5mm).

Malt type required: well modified; high enzyme; medium – high moisture (47.5 – 48%)

Programme	Hours	Comments
1st S	14	Long first steep to attain moisture of about 37%.
1st AR	20	Long air rest to promote germination.
2nd S	12	Long second steep to achieve final moisture.
2nd AR	12	Extended germination period by holding in steep.

To save on water use and effluent production, or to prevent mature vigorous barleys from growing too quickly, 2 wet steeping may be practiced.

- 1st wet to bring moisture up to around 37% (higher than the first wet in 3 wet steeping).
- 1st air rest is longer than typical for 3 wet steeping to get the barley active and generating heat.
- 2nd wet to bring barley up to final moisture.
- 2nd air rest to get barley active

Note that the total time under water will be longer for 2 wet steeping than for 3 wet steeping to give the same cast moisture.

2 wet steeping Pros and Cons

Pros	Cons
Can be used to slow growth of vigourous barley	Will result in reduced malting vigour
Less water use	Not suitable for water sensitive barley
Less effluent generated	Less "washing" of grain, higher BOD and solids in reduced effluent volume
	More difficult to control final moisture – often resort to spraying in germination vessel
	Fewer but longer air rests and fewer but longer wets mean total steeping time is often increased.
	Temperature control at end of the longer air rests may be more difficult

(e) Monitoring of Steeping

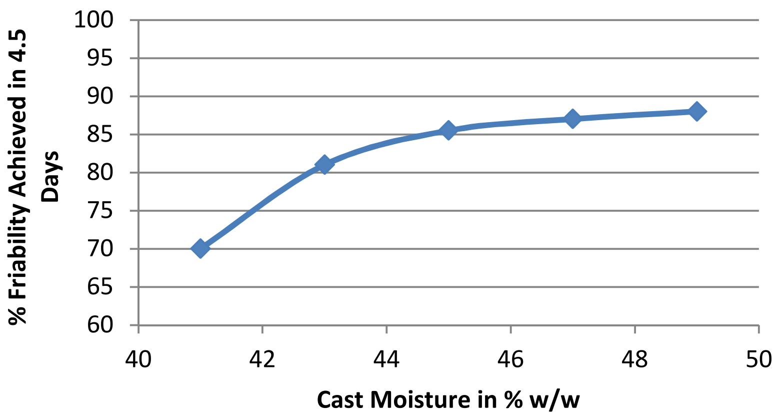
From the outline on the previous page of practical steeping it is obvious that certain key parameters must be monitored and recorded in order to control the steeping process. The main considerations are temperature, moisture content and germination count.

The temperature of the incoming steep fill and re-fill water is monitored and controlled so that the initial mix temperature of the 1st steep is attained (12-16°C depending on individual barley requirements). The temperature at the end of each air rest is recorded, and also the time taken to attain this temperature in order to maximise these periods in subsequent batches. The laboratory analyses grain samples from the end of the 1st steep, end of the 2nd steep and cast stages of steeping to ensure that the moisture targets are being attained.

Growth counts are performed after casting to ensure the batch is germinating adequately and evenly. Generally more than 80% of the grains should be chitting at this stage.

(f) After Steeping

The germinating barley is transferred (cast) into the germinating vessel by gravity or conveyor, depending on the individual malting plant. The empty steeps are then cleaned to maintain adequate hygiene standards. Normally, grain is cast "dry" from the steep but "wet" casting may be practiced. In wet casting the grain is transferred from the steep as a slurry in water. The pump design must be chosen so as not to impair the grain by mechanical damage from the pump impellor or by excessive pressure (>1bar) being applied to the grain. Cast moisture has a major effect on rate of germination, generally the higher the cast moisture the faster the rate of germination – up to a maximum of around 49% moisture at which point the kernels begin to lose viability (they can be thought of as "drowning"). The graph below uses Friability achieved at 4.5 days as an indicator of modification



Attaining Optimal Malt Steep Pattern Considerations

The steeping process is focused on the goal of providing the optimum steep moisture characteristics in the barley. Many factors are considered when developing the times and temperatures that make up a steep pattern recipe. Major factors include:

- Barley characteristics, crop year impact:
  - Maturity/water sensitivity
  - Kernel plumpness
  - Barley type – 2-row vs. 6-row
- Steep Time
- Temperature
- Steep Pattern Layout

Barley Quality Characteristics

The quality characteristics of barley can vary significantly, especially from one crop year to another. To avoid unwanted surprises, we perform testing of new crops as early as possible. From this testing, we are able to develop optimal steep patterns.

Barley Maturity

Mature, non-water sensitive barley *hydrates*, or absorbs water, in a predictable manner. Although small amounts of water enter through the distal end and through the longitudinal crease in the husk, called the *ventral furrow*, most water absorption occurs in the embryo; and most of the water that enters the kernel enters at the embryo end. A typical steep cycle for normal, mature barley is shown below.

NORMAL STEEP CYCLE

Phase	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Time (hr)	4	5	4	4	3	4	3	3

Total Immersion Time	18 hr
Total Dry Air Rest Time	20 hr
Total Steep Time	38 hr

Barley Moisture Content at Steep Completion: 43 - 44%

Immersion Time to Total Steep Time Ratio: 47%

NormalSteepCycle.vsd

Normal Barley Steep Cycle

Mature barley hydrates very rapidly during the initial immersion. Kernel moisture rises from its initial value of 11 or 12% to about 28 -30% in the first 4 to 6 hours, but the rate of moisture rise then slows.

Table 2 lists the moisture uptake of various kernel tissues as a function of steeping cycle time.

Table 2 Moisture Uptake by Normal Barley Kernel Tissues

Kernel Tissue	Percent Moisture After Steeping at 13°C			
	2 hr	4 hr	6 hr	24 hr
Embryo	26	40	51	58
Pericarp and Aleurone	11	16	27	36
Endosperm	10	13	21	35
Husk	41	43	45	47
Whole Kernel	21	25	28	38

The final 12 to 16 hours of steeping is critical to allow the endosperm to become completely hydrated. Incomplete hydration of the endosperm cells results in uneven or incomplete modification during germination. On the other hand, if the barley is over-steeped, it will become waterlogged, resulting in over-modified malt with a high level of soluble protein and a higher than normal malting loss. At very high moisture levels, above 49%, the kernels begin to lose viability (they can be thought of as "drowning")

Water Sensitivity

In the first 2 to 4 months after harvest, some barleys exhibit water sensitivity. Water sensitivity is a condition where some barleys fail to germinate due to being sensitive to prolonged immersion in water during the first wet. Barley that is harvested in cool, damp conditions is mostly likely to be water sensitive. It is quite common for some Midwestern US 6-row barleys to exhibit water sensitivities, and very often Canadian-grown barleys are water sensitive because of the shorter growing season and generally cool, damp climatic conditions during harvest.

Water sensitive barley requires a longer steep cycle than non-water sensitive kernels. A typical steep cycle for water sensitive barleys is shown below. Note that the water sensitive kernels require less immersion time and much longer dry air rest time. The immersion time to total steep time ratio is 36% for water sensitive barley compared to 47% for non-water sensitive barley.

Water-Sensitive Steep Cycle

It is important to achieve a short initial hydration of the barley kernel followed by a long initial air rest to break water sensitivity. Water sensitive barley needs more exposure to oxygen than non-water sensitive barley which is usually more mature. Below is an example of a water sensitive steep cycle:

Phase	Wet	Dry	Wet	Dry	Wet	Dry
Time (hr)	1	(10)	7	(8)	7	(5)

Total Immersion Time: 15 hr

Total Dry Air Rest Time: 23hr

Total Steep Time: 38hr

Barley Moisture Content at Steep Completion: 40 – 42%

Immersion Time to Total Steep time Ratio: 39%

Kernel Plumpness and Barley Assortment

Barley assortment is basically a measure of kernel width. Generally, larger kernels yield higher extract. Thinner kernels are higher in protein and yield more enzyme activity. Kernel uniformity is most important to the brewer. The hulls of plump malt are generally intact for better performance in the brew house.

The rate at which a barley kernel can be completely hydrated is a function of its size. Larger, plumper barley kernels require more hydration time than thinner kernels. This makes sense since water must migrate through the endosperm for complete hydration. If the endosperm is thicker, then more time is needed for water to migrate to its centre.

The sizing of the finished malt product when preparing to ship to the brewery should be kept as plump as possible. If it is discovered that the malt assortment is too low, one must determine where the origin of the problem lies. If a lack of plumpness in the incoming barley is not the cause; we must then look at problems in the production chain. If an excessive malting loss is seen, growth problems may be involved. A likely cause is possible damage done while transferring barley or malt throughout the malt house. If an off-kiln sample shows proper assortment parameters, elevator transfer systems or practices could be the cause. It has been found that rough handling may be the source of assortment problems.

Barley Type – 2-row vs. 6-row

Steeping times based on barley type are partially based on kernel size. 2-Row barley kernels are usually larger than 6-row kernels, so 2-row barley requires a longer steep time. Also, for well-modified malts of uniform quality, we try to raise the moisture content of 2-row barleys to around 44 – 46% and 6-row barleys to around 42 – 43%.

Steep Time

Steep time has a major effect on water uptake. In regard to total steep time, other things being equal a longer total steep time will result in higher water uptake. While the 2-day steep cycle is the established norm, it is possible to modify this time to provide the different results. In addition to overall steep time, it is possible to modify the individual steep and cycle times for immersion and CO_2 removal. The CO_2 removal fans remove CO_2 caused by grain respiration during the dry rest period. Long CO_2 removal periods can generate more heat. This heat can be used to make the water uptake on the next fill step faster.

Temperature

Barley absorbs warmer water faster than it absorbs colder water, so one might think that steeping would be more efficiently performed with warm water. Unfortunately, barley steeped at warmer temperatures develops less α-amylase, which is critical for mashing. Also, when the maltster uses warmer water the total immersion time is usually shortened, often resulting in the embryo end of the kernel being saturated with water but the distal tip being in a moisture deficient condition.

The benefit of using colder steep water and a longer steep cycle is that there is a more uniform water uptake and hydration throughout the entire kernel. This tends to get the metabolic activity off to a slow but balanced start, resulting in low consumption of endosperm starches and reduced malting loss. Thus, even though steeping with colder water takes more time, it does have some benefits. For best results, barley should be steeped at a temperature between 12°C and 16°C. Hot water steeping has been used to reduce root growth and hence malting loss. Water at 30-40oc is applied for 8 hours to kill the embryo. This reduces root growth and respiration losses. No turning is required during germination. Gibberellic acid may be used to ensure modification is not adversely affected. In practice excess acrospire growth occurs so that malting loss shows little improvement and malt quality is poor.

Two temperatures affect steeping temperature: steep water temperature and barley temperature. Some malting plants can control steep water temperature; others cannot. Those that cannot control the steep water temperature must use water as it is received, whether it comes from a well or a municipal supply. In the winter, water temperatures may be as low as 5°C and require as long as 56 hours for a normal steep cycle.

Grain temperature is only a factor for the first immersion. Grain is stored outdoors in large metal bins, so its temperature depends on the outside air temperature. In the winter, grain temperatures can be close to freezing and, in the summer, as high as 28°C. After the barley is received at the plant, its temperature rises a bit from indoor cleaning and handling. The maltster must adjust either the steep water temperature or the immersion time to compensate for the grain temperature.

Steep Pattern Layout

Moisture content alone does not determine the effect of the steeping process or germination characteristics of the barley. By making minor adjustments to the temperature and time settings of the steep pattern layout, the maltster can influence when the majority of water take up will occur in the process (whether water take up will occur early or late in the steeping process). If a significantly, large amount of water take up occurs early in the steeping process, the barley will ultimately solubilize more protein. In this case, you are essentially starting the germination process earlier (in the steep tank). By the same measure, barley that experiences late water take up will solubilize less protein.

IMPORTANCE OF AERATION AND CO2 EXTRACTION

As the barley kernels take up water, they begin to swell and respire, absorbing oxygen and releasing CO2. To allow the kernels to take up water and respire, the steeping process consists of cycles of water immersion followed by dry airflow through the kernels. These two phases are called:

- The immersion phase
- The dry air rest phase

Immersion Phase

In the immersion phase, barley in the steep tank is totally immersed in water. The primary reason for immersion is to raise the moisture content of the barley from about 12% to approximately 45% at the end of the steeping process. At the start of the phase, barley is dropped into steeping tanks that already have some water in them. This is called a wet steep-in. This procedure cushions the barley to prevent skinning, husk removal, and embryo damage.

During the immersion phase, air is forced into the tank bottom through the aeration rings. The initial aeration agitates the barley and raises any extraneous material that was not removed during cleaning to the water surface where it is skimmed off into the overflow for removal. Aeration of the steep water during the immersion phase improves grain activity and mixes the grain to achieve more even water uptake.

Another function of steeping is to leach undesirable components from the barley husks, primarily polyphenols and tannins. Polyphenols give beer an astringent, mouth-puckering flavour. Tannins are oxidized polyphenols that give beer similar flavours. Leaching these components from the husks requires large amounts of water—up to four total water changes are needed per steep tank; and the tanks may be overflowed during most of the immersion periods. Leaching during the steep does not remove all the polyphenols from the malt.

Dry Air Rest Phase

Each immersion phase is followed by a dry air rest phase. The water is drained from the tanks. Room air is drawn in from the top of the tank, through the wetted barley, and exhausted out the tank bottom by a CO_2 suction fan.

Steep Tank in Dry Air Rest Phase

As the embryo respires, it absorbs oxygen and releases CO_2 and heat. If the CO_2 were not drawn off the tank it would accumulate and eventually displace the oxygen. CO_2 build-up has two undesirable effects, listed below.

- CO2 buildup causes respiration to slow and eventually stop, resulting in anaerobic glycolysis.
- α-Amylase enzyme production slows dramatically. α-Amylase enzymes are needed to convert starches to fermentable sugars during mashing. If the malt does not contain enough α-amylase, the wort will contain unconverted starches.

During the air rest periods, the moisture that has penetrated the husk migrates into the endosperm and eventually hydrates it most uniformly. It is important not to extend the dry air rest period too long, or the kernels will begin to dry as they take up the available moisture. Since water is a primary transport mechanism for the organic reactants and products throughout the kernel, drying out slows the reactions and impairs the kernels' continued growth.

During the rest period, air is drawn in from the top of the tank and out the bottom. To help keep the barley at the top of the tank from drying out, cool, humidified air may be supplied to the tank room. Each dry air rest phase except the last is followed by another immersion phase.

Analysis of Steeping-Related Malting Specifications

There are many variables that affect the final product in the malting process. One of the most difficult jobs of the maltster is determining the cause of undesirable characteristics that may appear in malt and establishing a controlled approach for correcting problems. Often the cause and effect relationship of certain process variables is very subtle and complex. This is truly the "art" of the maltster.

Summary of factors governing water uptake	
Temperature	Initial water uptake is a purely physical process, but if germination is initiated, the rate of water uptake increases. The higher the temperature of the steep water the faster the rate of uptake, especially after germination is initiated
Grain size	Above approx 2.3mm the variation in water uptake is less pronounced and hence barley for steeping is often screened to remove grains much smaller than this so that more even modification is achieved. The larger the grain size, the slower the rate of uptake increases.
Protein content	Mealiness and steeliness have an effect on water uptake steelier grains will have a lower rate of water uptake. Lower protein endosperm (tendency towards mealiness) enhances water uptake.
Grain viability	Once germination starts the rate of water uptake increases significantly.
Variety and Crop Year	Varieties that are loose husked or tend to split in wet seasons tend to take up water more rapidly.

Kernel Growth

A proper steep moisture should be found and maintained by crop year and variety. Unnecessary steep moisture manipulation can effect viscosity and cause other problems to arise. The principal concern and goal during steeping is to hydrate the kernel, as evenly as possible, all the way to the centre of the endosperm. Steeping time can be manipulated to control hydration; allowing control of progression toward germination *in the steep tanks.* This is especially helpful in controlling proper modification of "problem varieties." A given steep moisture can be attained by *either* slow or faster uptake of water in the early stages of steeping.

Turbidity (Beer Haze)

The appearance of cloudiness in beer is undesirable. Beer haze can be caused by several factors including the presence in wort of soluble polyphenols originating from malt. Amongst the potential methods to address this are: ensuring that the malt is well modified, use of alkaline or formaldehyde treated steeping waters or the use of anthocyanogen free barley.

Extract

The more fully grown or further developed green malt becomes, the more potential extract it uses up. Limiting overgrowing of green malt will increase extract readings, or at least will not lower them.

Lowering steep moistures can increase extract readings. Limiting the speed of modification or limiting germination time also has the potential to increase the extract available at the end of malting. Starting out slow in germination has shown promise also in saving extract.

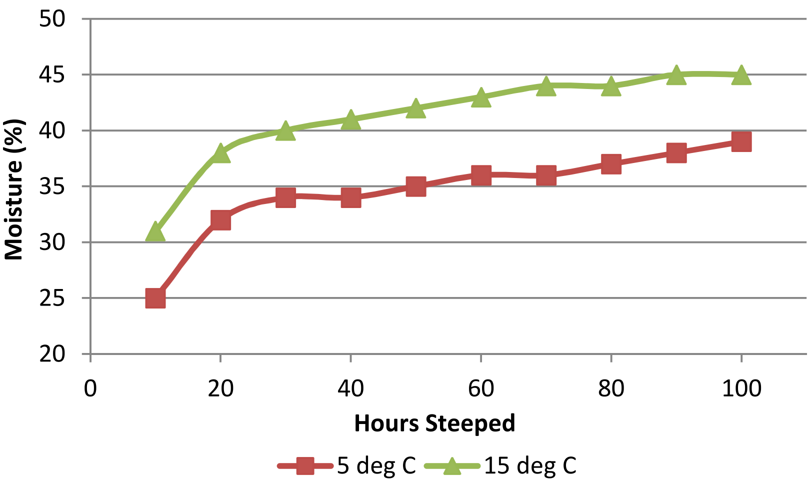
Overly skinned product will show a higher reading for extract by increasing the usable volume of the sample (less chaff and husk - more usable product). This is not a desirable scenario, since other areas, are adversely affected by skinned kernels.

Viscosity

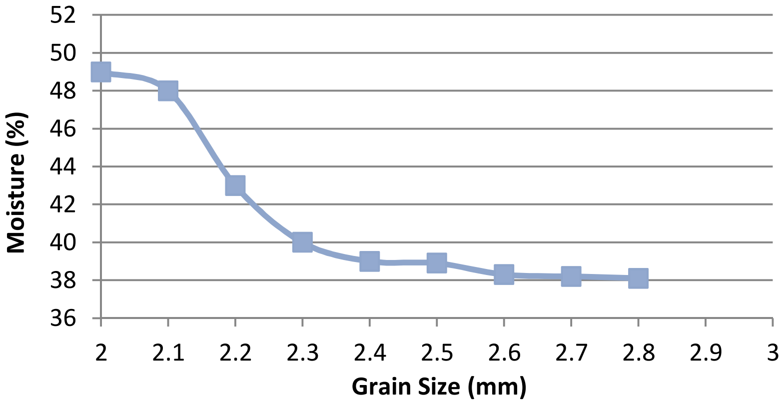
The viscosity (consistency/thickness) affects lautering time in the brewing process. The lower the viscosity reading is, the better the run off times. If viscosity readings are high, it is generally an indication of poor modification. An increase in modification, increase in steep moisture, and/or more time in germination can lower viscosity readings.

Factors Influencing Water Uptake

A moisture content of 45% - 47% is desired because this is the point at which rapid and even germination can be sustained. Achievement of this depends upon the rate and the quantity of water uptake by the grains. The following factors governing water uptake are critical to the process.



The effect of temperature on the rate of water uptake is shown above. The desired level of moisture is achieved after 100 hours of steeping with a water temperature of 15^oC while there is still some way to go using water at 5^oC. The higher the temperature, therefore, the faster the rate of uptake.



As shown in the Figure below, barley with a grain size of 2mm will achieve the desired moisture content within a single 48-hour immersion steep while larger grain cannot achieve the same rate of water uptake. The larger the grain size, therefore, the slower the uptake of the water. You will note, however, that although this is the case, the relationship between grain size and water uptake is not directly linear. A grain twice the size, will not absorb at half the rate. It is undesirable to have small grain size barley in a process batch as it has a much lower HWE potential than the larger grain. It is also undesirable to steep grains of mixed size in the same steep as the grains will not complete steeping with the same water content and therefore will not modify at the same rate, resulting in uneven modification of the finished malt.

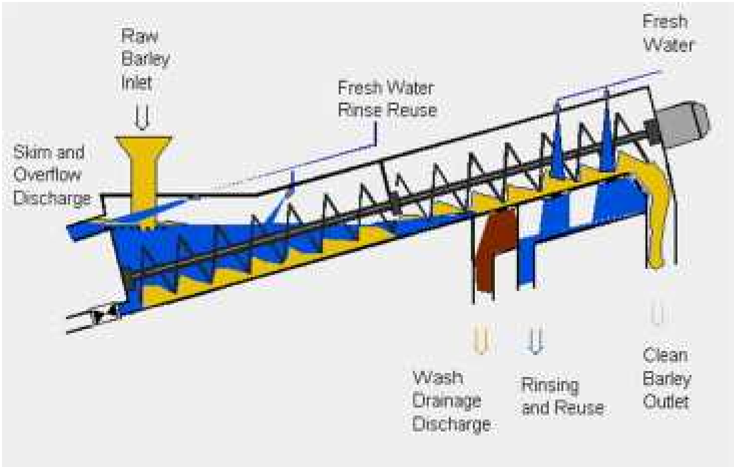
Summary

As the first of the three main malting functions: steeping, germination, and kilning, steeping is perhaps the most critical. As we will see in subsequent modules, problems that are introduced during steeping can cause problems that are difficult or even impossible to correct during germination and kilning. In addition these problems may resurface during brewing and result in effects such as reduced extract yield, and viscosity problems. For this reason, the deceptively simple steeping process takes on a critical importance to both the maltster and the brewmaster.

Other Technology

The purpose of washing the barley is to remove loose insoluble material and soluble material from the barley. Traditionally, barley washing is performed, by overflowing the steep tank, a process that is less than ideal. Less than 50% of the water that is consumed during steeping contributes to the moisture uptake of the barley – sometimes much less. A significant portion of the remaining water is used for washing.

The barley washer shown is in the simplest terms, an inclined screw conveyor with water. Barley is added to a float pool of water at the lower end of the auger. If the proper depth of water is maintained, some dirt and lightweight material will separate from the barley and float to the top of this pool. The barley settles to the bottom and is gently agitated and transferred up the conveyor by the auger. This motion helps to further clean the barley. The dirtiest water exits from the end of the barley washer. Clean fresh water enters from the top. Some of the cleanest water is recycled and reused at the lower end. Clean, partially wetted barley exits from the top end.



Barley Washer

The speed of the barley washer is equivalent to the normal conveyor speed. The barley washer is equipped with a reversible motor to facilitate cleaning.

Abrasion

The process of abrading the grain selectively damages the grain to effect quicker water and GA uptake. Abrasion of the grain may selectively damage the grain at the distal tip. This is due to the oscillation of the grain through the air. Abrasion damages the semi-permeable pericarp, permitting quicker and more extensive water and GA uptake and distribution. The grain therefore, modifies more rapidly and completely than would normally be achieved. Abrading the grain in combination with exogenously applied GA can accelerate malting by one to two days and in so doing reduce malting losses. The process was used by some malting companies in the late 20th century.

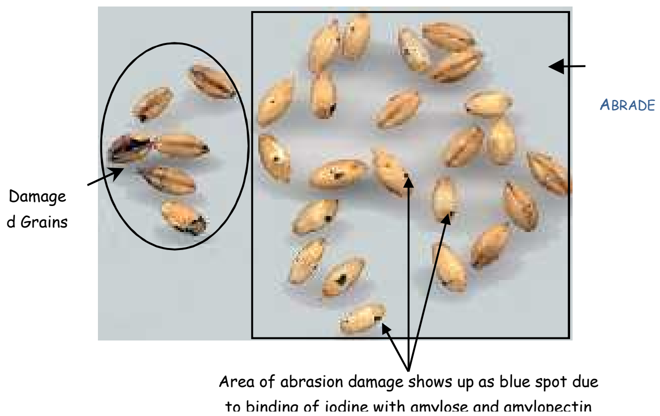


Figure 5. Abraded and damaged barley shown by staining with an iodine solution.

BARLEY GERMINATION – THE PHYSIOLOGICAL AND BIOCHEMICAL CHANGES.

Grain Hydration

The process of steeping determines final malt quality. The purpose of steeping (soaking of the grain in tanks) is to initiate grain growth through hydration. Hydration of the grain facilitates even endosperm modification. Steep water must be of potable quality and free of taints. If not, the impurities may be passed on through the malt to the final beer, affecting its quality and stability.

Why does grain hydration initiate germination? Before hydration the barley grain lies in a state of suspended animation, its growth has been halted in the field through desiccation. On re-hydration of the embryo, aleurone and endosperm, the revived aqueous condition provides a suitable environment in which the enzymes can regain functional activity.

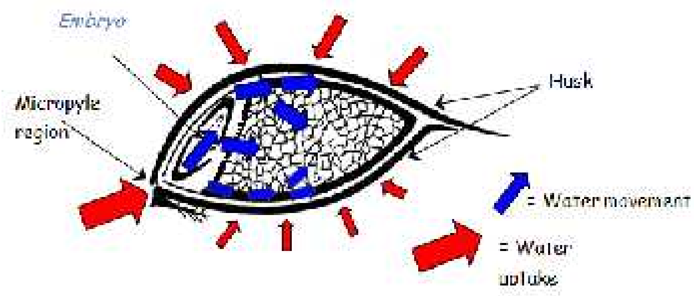


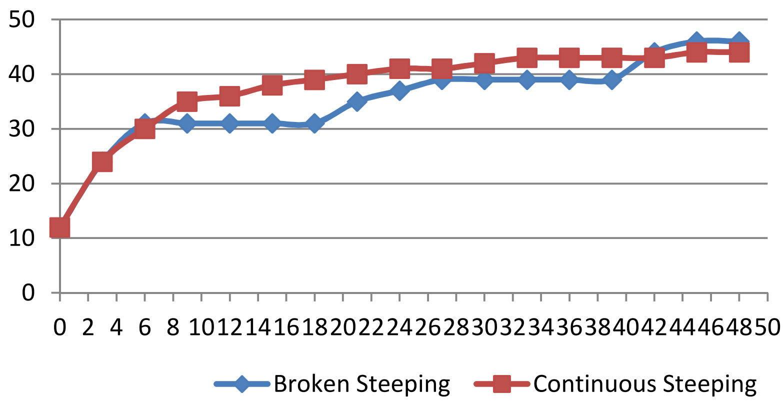
Figure 1. Water uptake in barley.

During steeping, the husk rapidly absorbs water via capillary action. However, although this water will penetrate through the cuticular layers of the pericarp and testa, transport of salts is a problem. If the husk dries out during malting, the embryo withdraws moisture from the endosperm to survive, and as a result restricts endosperm modification, generating poor quality malt.

Water enters through the micropyle region and passes into the embryo. From the embryo, water migrates to the endosperm through the scutellum, vascular tissue and finally via the aleurone layer. The rate of endosperm hydration is slower than that of the embryo, which has consistently higher moisture content than the endosperm. Grain hydration follows a proximal to distal pattern. Transfer of moisture from the embryo to the endosperm is most efficient on the dorsal side due to a greater proportion of vascular tissue, whilst the ventral furrow hinders the migration of water. Barley has no internal capillary action; therefore, the grain must be fully immersed in water for complete grain hydration. If total grain hydration does not occur modification will be incomplete, generating brewhouse problems.

During malting the barley grain swells by a third, replacing the water lost as it dried in the field, prior to storage. Water uptake occurs rapidly at first and slows as steeping proceeds. A critical grain moisture level of around 44% must be achieved. Below 44% moisture there is insufficient water to support the grain during germination and modification may be incomplete. Above 47% moisture the endosperm can become over-modified as the grains "bolt" through germination, and can create poor quality malt.

Traditionally, barley was continuously immersed under water for a period of up to three days in order to achieve the desired moisture content. The rapid depletion of oxygen in this process plus the accumulation of carbon dioxide (CO_2) allowed little growth to take place. Multiple steeping, in which each immersion is followed by an air rest, is now standard practice. In this process, germination can be enhanced and higher moisture achieved than with a single immersion. The duration of the air rest is dictated by the volume of air available to keep the grain cool and prevent CO_2 build up in the steep. The effects of continuous and multiple (broken) steeping are shown in below:



Endosperm Modification Progression

The most important function of the embryo during germination is the production and release of the plant hormone Gibberellic acid (GA) – this is one hormone of the gibberellin family. It is this plant hormone that stimulates the aleurone layer to synthesise and deliver the majority of the hydrolytic, endosperm-degrading enzymes, e.g. α-amylase.

Gibberellins are synthesised in the embryo. Production of gibberellins is induced within the first two days of embryo growth, during steeping, when internal embryo reserves have been depleted. The gibberellins are then transported to the aleurone through the vascular tissue of the grain, aided by the proximal-distal flow of water during grain hydration. After reaching the aleurone, the gibberellins stimulate the production and release of the modifying enzymes.

The pattern of endosperm modification is determined by:

1. The localised development of the vascular tissue.
2. The ventral furrow.
3. Degree of enzymatic contribution from the scutellum.
4. Mealiness or steeliness of the endosperm.
5. Temperature of germination.

The vascular tissue is developed to a greater extent on the dorsal side of the grain. Therefore, water and gibberellin distribution throughout the aleurone layer is greatest on the dorsal side of the grain. The hydrolytic enzymes are consequently released into the endosperm quicker and in greater concentration, than from the ventral side of the grain where the vascular tissue is defined to a lesser extent. This profile of aleurone stimulation and response results in an asymmetrical pattern of endosperm modification when viewed in a time course manner (Figure 3).

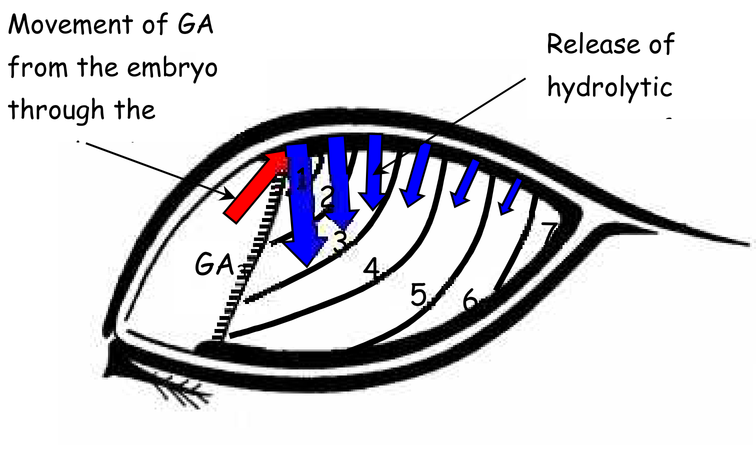


Figure 3. Asymmetric grain modification. Area of greatest modification (1) through to the least modified (7).

The ventral furrow that runs along the lower side of the grain impedes water and gibberellin distribution. This causes slower and reduced enzyme release and therefore, diminished endosperm modification in the ventral grain region.

The scutellar epithelial cells are stimulated to produce approximately 10% of total grain α-amylase (dependent on variety). As such, this additional input of α-amylase may affect the distribution of endosperm modification, reinforcing the proximal-distal pattern of grain modification in relation to starch degradation only.

Within the endosperm, areas of localised steeliness will hinder the distribution of water and impede enzyme dispersal. In these regions of the starchy endosperm, under-modification will occur. The opposite is true for grains with localised areas of increased mealiness, creating regions of over-modified endosperm.

Increasing germination temperature facilitates quicker enzyme dispersal and therefore, improved modification. However, excessive temperatures may dehydrate the grain and restrict modification.

Enzymes and Substrates Involved in Germination

On stimulation with gibberellic acid, the aleurone layer synthesises (*de novo*) and releases a wide range of hydrolytic endosperm degrading enzymes, including:

- α-amylase
- Limit dextrinase
- Endoprotease

The aleurone also releases the following enzymes, but it is unclear as to whether they are produced *de novo* or that they are already present in an inactive form and then activated within the aleurone layer:

- Endo-β1,3:1,4 glucanase
- Endo-β1,3 glucanase
- Pentosanases
- Phytase

The starchy endosperm does not synthesise but already contains the enzymes (as zymogens):

- β-amylase
- Carboxypeptidases

Once the production of the specific enzymes has commenced, synthesis continues through the normal period of germination and the concentrations of these enzymes steadily grow.

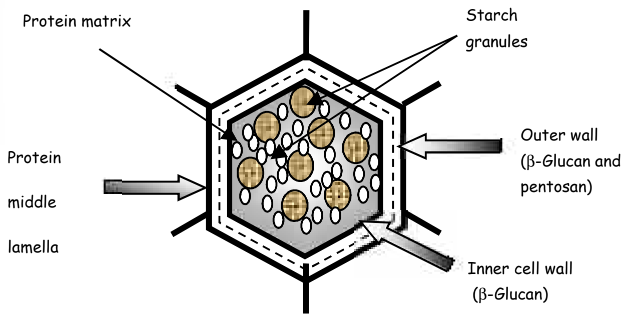
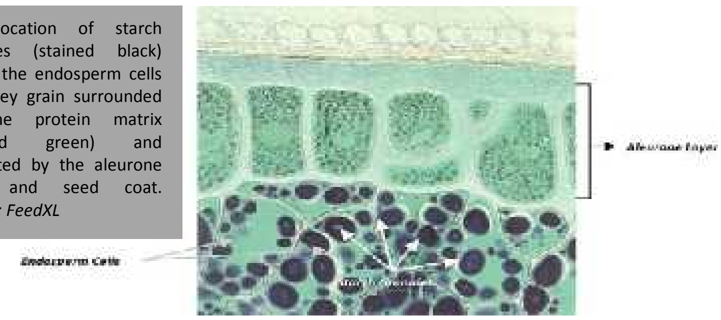


Figure 4. Endosperm cell structure

The location of starch granules (stained black) within the endosperm cells of barley grain surrounded by the protein matrix (stained green) and protected by the aleurone layer and seed coat. *Source: FeedXL*



The abundance of enzymes noted above is necessary for the release and conversion of the endosperm starch. In sequence, the outer cell walls must be degraded (by proteases) before carboxypeptidases, glucanases and pentosanases can attack the inner cell walls. Only after sufficient cell wall degradation can the proteases hydrolyse the storage protein matrix to expose the starch granules. The α- and β-amylases can then liquefy and saccharify the starch, respectively. This allows transport of the sugars, along with the amino acids derived from the protein matrix, through the scutellum to the embryo. The scutellum epithelial cells elongate to aid absorption of the nutrients into the embryo.

-Glucans and Pentosans

The walls of the endosperm cells comprise a mixture of hemicelluloses and gums. Hemicelluloses and gums are mixtures of polysaccharides with similar chemical structures. The relatively insoluble hemicelluloses are alkali extractable and are degraded to gums (warm water-soluble) probably through proteolysis. The hemicelluloses are less soluble due to their increased molecular weights and/or their increased degree of internal cross-linking.

The major components of the hemicellulose and gum fractions of the barley cell wall are:

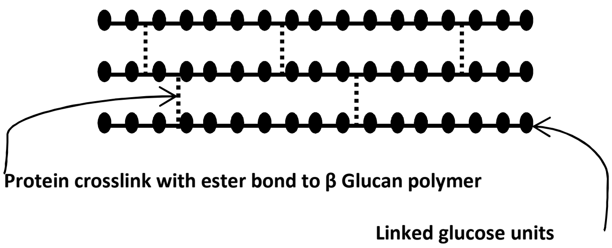
- β-D-Glucan (70-75%)
- Pentosans (20-23%) e.g. arabinoxylan.

Approximately 5% of the cell wall is made up of protein as a middle lamella, but the β-glucans and pentosans are the most important in brewing.

β glucan is a linear polymer of glucose comprising 70% β 1-4 links and 30% β 1-3 links.

70% of cell wall material is β Glucan. (Note that approx. 5% of the cell wall is protein as a middle lamella)

2 step breakdown of β Glucan:



1) β Glucan solubilase (a carboxypeptidase) breaks ester bonds to release linear polymers (solubilises β Glucan).
2) Endo 1-3, 1-4 β Glucanase hydrolyses β 1-4 links adjacent to β 1-3 links to release sugars which contribute to extract.

β Glucan solubilase is more heat stable than Endo 1-3, 1-4 β Glucanase – this can cause long chains of β Glucan to be released but not broken down. These long chain molecules result in viscous worts which are a problem in the mash house because they:

- Retard wort separation
- Produce wet/sticky spent grains
- Induce beer haze formation
- Reduce beer filtration rate

Endosperm Protein

The protein embedded within the endosperm cells forms a dense matrix surrounding A and B-Type starch granules. This protein matrix must first be hydrolysed during malting, to facilitate enzymatic starch degradation during mashing. Additionally, protein degradation provides the **Free Amino Nitrogen (FAN)** for grain embryo and yeast nutrition. If sufficient proteolysis does not occur during malting, a loss of potential extract will ensue in the brewhouse, along with other associated problems.

The proteins contained within the endosperm matrix are defined by their solubility characteristics.

- **Albumins** and **Globulins**: dissolve in water or dilute salt solutions.

- **Hordeins** and **Glutelins**: dissolve in alkaline or hot alcohol solutions, in association with reducing agents.

The less soluble storage proteins, hordeins and glutelins predominate in the endosperm matrix. Hordein and glutelin contain large amounts of the amino acids proline and glutamine. Notably, these protein fractions contain disulphide bonds. These bonds have the ability to be broken and reform creating different molecules. This formation of new bonds is thought to play a role in the production of viscous worts that are difficult to separate during mashing. As grain **Total Nitrogen (TN)** increases during grain development hordein becomes incorporated into the storage protein matrix in a disproportionate fashion.

Grains with high TN tend to have steely endosperms, whilst mealy endosperms will contain less TN. As described below, it is the quality of the packing of the mealy or steely endosperm that most influences proteolysis and grain modification, not enzyme concentration.

(a) Mealy and Steely Grains

Barley starch granules are located in the endosperm cells of the grain. This starch, however, is embedded within a dense protein matrix.

The distribution and density of this protein matrix differs with barley variety and growth conditions. Excess fertiliser applied in the field can result in barley with a high protein content, mostly concentrated in the endosperm protein matrix. In grains with a dense protein matrix there are less "water-free" or air filled spaces than in a grain incorporating lower protein levels.

- Grains with a high proportion of air filled spaces are known as mealy

- Grains with few air filled spaces, are known as steely.

Mealy grains allow rapid water penetration and uniform hydration of the endosperm. This results in quicker and more uniform modification, producing superior quality malt. Steely grains hinder endosperm hydration and enzyme distribution, giving uneven modification and poor quality malt.

A Farinator is a hand-held device, usually made of stainless steel, which may be used to slice open sets of 50 grains to reveal the steeliness or mealiness of the endosperm.

Grain size also affects grain hydration. Large grains proportionately take up water slower than smaller grains. The small grains will therefore "bolt" through germination. The malt produced will be non-homogeneous, with proportions of over and under-modified grains generating brewhouse problems.

(b) Proteolysis of Endosperm Protein

The enzymes responsible for proteolysis include:

- Endoproteases
- Exoproteases
- Carboxypeptidases

During germination, the GA stimulated aleurone layer synthesises and releases at least five endoproteases into the endosperm. These sulphydryl endoproteases attack internal protein bonds, whilst the exoproteases cleave bonds at the terminal chain ends. The endoproteases hydrolyse the large protein molecules, releasing smaller polypeptides upon which the exoproteases act to produce smaller peptides and amino acids.

The acid carboxypeptidases are located within the endosperm and their concentration increases throughout steeping and germination. Carboxypeptidases cleave single amino acids from the carboxyl end (COOH) of peptides, primarily during malting, but also to some extent during mashing.

This enzymatic action during germination results in the transformation of the insoluble nitrogen, much of which goes into solution on mashing and is recognised as the **Total Soluble Nitrogen (TSN)**. As germination progresses the level of TSN increases before declining, as a proportion is consumed for continued plant growth. The ratio of the TSN: TN obtained from the malt is used as a measure of modification. Typically during malting 40% of grain TN is solubilised by the endoproteases and carboxypeptidases.

The endo- and exoproteases are easily de-activated by heat and are easily denatured and inactivated during kilning. The carboxypeptidases are more heat stable and survive kilning to continue with subdued activity during mashing. As such, sufficient proteolysis must occur during germination.

If adequate proteolysis does not take place the consequences can be drastic, including:

- Reduced extract.
- Reduced wort α-amino nitrogen.
- Decreased colloidal stability.

Reduced extract potentials are created when the protein matrix is not satisfactorily degraded to expose the starch granules for hydrolysis.

If hydrolysis does not occur during malting, there will be a deficit of necessary enzymes during mashing to cleave and release amino acids. This FAN is essential for yeast growth and if deficient will cause problematic fermentations. If the protein is not broken down or solubilised, the large protein molecules will undoubtedly contribute to the formation of haze (colloidal instability) and related problems.

Excessive proteolysis can lead to:

- Increased malt colour formation.
- Destruction of essential foam forming polypeptides.

KEYPOINT: The combined action of proteolysis and β-D-glucan degradation renders the malt friable or "readily crushable"; this is due to the breakdown of the rigid cell walls and protein matrix. The friability of malt is often used as an indication of the extent of modification.

STARCH

During the malting process, degradation of the endosperm starch is limited to preserve extract potential. Approximately 10% of the barley starch is hydrolysed to provide nutrition for the embryo. The majority of this degraded starch is the small B-Type granules that degrade more rapidly than the larger A-Type, due to their increased surface area to volume ratio.

Although this degradation of the small starch granules contributes towards malting loss, it is somewhat fortuitous, as the small starch granules have higher gelatinisation temperatures than the large starch granules. During mashing ungelatinised starch will generate viscous worts that are difficult to separate, whilst also contributing to carbohydrate haze formation.

There are four major starch-degrading enzymes present in germinating barley.

- α-amylase
- β-amylase
- Limit dextrinase
- α-glucosidase

Barley contains no α-amylase prior to germination and its synthesis and release from the aleurone layer is dependent upon GA stimulation during steeping. β-Amylase is present in barley within the endosperm and exists bound to the proteins of the endosperm matrix. This latent β-amylase is activated on release from the matrix by proteases / carboxypeptidases.

α-Amylase slowly attacks ungelatinised starch during germination, but β-amylase cannot. α-Amylase breaks the starch down to smaller polymers (liquefaction), whilst the β -amylase acts at the reducing ends of the starch molecule to produce maltose units (saccharification). This combined action is most effective during mashing and will be dealt with in greater detail later on in the course.

Limit dextrinase, existing in both bound and free forms, degrades branched dextrin (partially degraded starch granules) to glucose. α-Glucosidase degrades maltose to glucose providing immediate metabolic substrates for the embryo. Limit dextrinase and α-glucosidase are easily de-activated by heat and rarely survive kilning to be of benefit in the mash. α-Amylase and β-amylase are to some extent easily de-activated by heat, with a proportion lost during kilning. β-Amylase is affected by heat more than α-Amylase.

Gibberellic acid in Malting

(a) Discovery of Gibberellic Acid

The discovery of the gibberellins, a group of naturally occurring plant growth regulators, dates from work of Kurosawa in the 1920's. He was studying the 'bakanae' disease of rice and showed that excessive elongation of the stems was due to an infection with the fungus *Gibberella fujikuroi*. In 1939, the active compound was isolated and given the name 'gibberellin A'. It was not until 1954 that further progress was made when the pure compound was isolated and characterised. By the 1990's over 80 gibberellins had been identified, over half of which were found in developing seeds. In barley the key gibberellin has been shown to be GA_1. The first application of exogenous gibberellic acid to malting took place in 1959 (Sandegren and Beling).

(b) Use of Gibberellic Acid in Malting

There is no legislative restriction on the use of gibberellic acid (GA) in malting although customers who wish to preserve the image of malt as a substance entirely produced by a natural process may choose to prohibit its use. This is particularly the case for the Scotch Whisky industry which, because of the long periods of storage of raw spirit (which are fundamental to the process of whisky production) has to anticipate future restrictive legislation or changes that may occur in consumer sensitivities and preferences.

Where the customer approves its use, GA application can offer a number of opportunities including:

- reduction or breaking of dormancy;
- accelerated malt production;
- enhanced enzyme production;
- reduced malting loss via embryo substitution.

The response to GA application is both dose and variety dependent. Typically in the maltings GA is applied in aqueous solution at a rate of up to 0.4 mg/kg of original barley. The preferred method of application is at the transfer from steep to germination box where a solution of GA is applied as a spray to the grain in conveyor. When using this method it is important to synchronise the spray and conveyor rates to ensure that there is an even application of GA across the whole of the batch in transfer if individual grains are to show even growth rates. The rate of uptake of GA by the grain will be dependent on:

- The surface moisture of the grain with better levels of uptake achieved by applications made to dry-cast than wet-cast grains.

- Temperature and maturity of the grain with improved uptake on well chitted and warmer grains.

- The concentration of the aqueous GA solution applied – if this is too dilute much of the solution will flow to waste, as the grain is unable to adsorb the relatively high quantities of liquid involved.

GA has also been applied in steeping and during early germination. Generally applications in steeping are less efficient because of the volume of steep water which must be treated and the fact that the grains are at a more immature stage. It is possible to improve the efficiency if in-steep grain development is encouraged but the more mature grains that result are more prone to physical damage on subsequent transfer to the germination vessel.

Similarly, for treatment of grain in the germination box, it is difficult to achieve an even application of GA across the depth of the grain bed. In those situations where the design of plant necessitates GA application in the germination box the usual approach is to incorporate a spray bar on the grain turner. This allows the application to be made at the instant of turning when the bed is most open and the chance of penetration to the lower grain is at an optimum.

The responsive of barley to GA can be enhanced by physical treatments. At the experimental stage, these physical treatments have included 'squeezing' steeped barley between mill rollers with the aim of disrupting the internal endosperm structure and enhancing hydration and physical transport pathways within the grain. However, the only technique to be commercially adopted was that of abrasion developed by Palmer in 1969.

In this technique, barley from store (at a nominal 11-12% moisture is passed through an abrading machine where the grains rub or are 'abraded' against wire brushes or abrasive surfaces lining the machine. Subsequently the grain is processed in the normal manner. Commercial operations showed that abraded barley required a considerably reduced steeping time for satisfactory malting. This is in Table 1 where there is an increase in the rate of water uptake that allowed a reduction in the overall steeping time.

All steeps were used to make malts of the same specification and it is obvious from the table that abraded barley was cast at a lower moisture content than their un-abraded controls. This reflects the fact that abraded barley inherently required less water for successful modification.

Maltings	Barley	Steeping Programme (h)	Total Time (h)	% Cast Moisture
1	Control	6w 8d 8w 6d 5w 11d	44	45
	Abraded	5w 7d 4w 8d 2w 8d	34	43
2	Control	8w 8d 8w 8d 2w 8d	46	46
	Abraded	5w 10d 6w 8d 5w 8d	42	43
3	Control	8w 10d 14w 14w	46	44.5
	Abraded	6w 10d 10w 10w	36	43.5

Table 1. Showing reduced steeping time to achieve acceptable cast moistures when using abraded barley at three different malt plants. Cast moistures are mean of 10 batches. Steep temperatures were the same for each control/abraded pair.

d = dry, w = wet

In his original hypothesis, Palmer attributes this phenomenon to the fact that the abrasion process scarifies the pericarp so allowing GA to enter the underlying aleurone. This in turn induces new areas of enzymatic modification of the endosperm remote from the usual localised influence of the embryo and this presumably reduces the dependency on hydration and transport mechanisms.

Although commercially proven, abrasion has only had a limited commercial acceptability and its use has been largely limited to brewer/maltsters. Possible reasons for the failure of maltsters to adopt the process include:

- ***Appearance*** – malt made from abraded barley can have a poor appearance and be prone to breakage.
- ***Unevenness*** – abrasion can introduce greater variability into the in-process behaviour of individual barley grains resulting in more heterogeneous malts.
- ***Customer limitations on GA usage*** – the abrasion process is most effective when used in combination with GA treatment. Where customer preference limits GA usage the normal benefits do not accrue.
- ***Loss of malt biomass*** – abrasion removes some material from the grain that leads to loss of malt revenue.

(c) Action of Gibberellic Acid on the Grain

The addition of GA to malting grain increases the endogenous gibberellin levels and enhances the grain's metabolism and endosperm modification. The production of enzymes that catalyse modification are enhanced more than embryo growth and so, with GA treatment, it is possible to malt the grain (in other words modify the endosperm) with smaller malting losses. A typical example of the impact of GA on the **Diastatic Unit** (a measure of α-amylase activity) and **Diastatic Power** (a measure of α- and β-amylase activity) and also the dose response effect is illustrated in Table 2.

Table 2. Impact of GA addition at differing levels on DU and DP enzyme activities (determined by IOB Methods) in barley

GA level ppm	DP (IOB)	DU (IOB)
0	33	97
0.1	38	102
0.2	39	105
0.5	44	117
1	47	128

There is now overwhelming evidence that the increase in activity of α -amylase is a consequence of *de novo* synthesis and the GA/ α -amylase system has formed the basis of several research investigations – many of which have used de-embryonated grains or isolated aleurone layers.

The incubation of isolated barley aleurone layers in GA solution has shown these to begin to secrete α -amylase after about 8 hours and that this release continues linearly over the next 16 hours (Figure 6). As also shown in Figure 6 **abscisic acid (ABA)**, the plant growth regulator is inhibitory to α -amylase production.

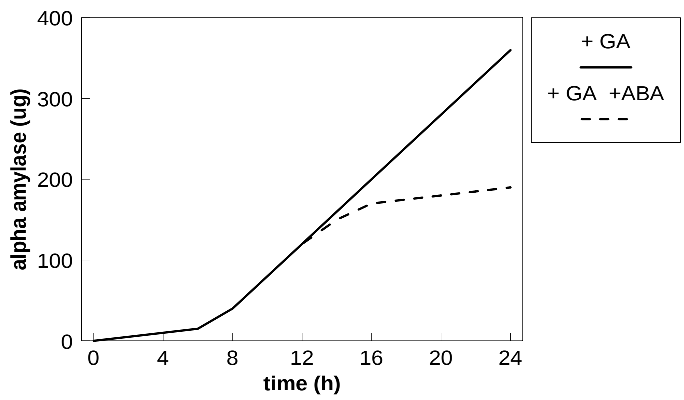


Figure 6. Time course of α -amylase synthesis and release by aleurone layers of barley variety Himalaya incubated in GA_3 and following application ABA at 10 hours.

(d) Alternatives to Gibberellic Acid

There are no real alternatives to the action of GA and practical attempts to approach the effect of GA on untreated malts revolve around methods that increase the metabolism of the grain. Typically, these will include steeping to high moisture content (>48%), extended germination and manipulation of temperature regimes to maximise the desired enzyme activities but generally this approach leads to high malting loss.

An alternative approach is to target the use of specific barley varieties which show greater propensity to produce the malts required (e.g. in the UK the 1980's variety Torrent had enhanced DP levels). This obviously demands the availability of several varieties with differing characteristics. In the past the extent of this variation between varieties has been limited by an all too consuming interest in extract yield.

This means that varieties exhibiting other favourable properties but slightly lower extracts have frequently been rejected as unsuitable at an early stage of the breeding cycle. This attitude is changing as options for the use of additives and processing aids are shunned or prohibited. However, the success of this approach will be entirely dependent on the market since farmers will not grow crops for which they receive uncompetitive returns.

GERMINATION

Introduction

At the end of steeping, the grain moves into the second phase of growth, signalled by chitting. As the grain strives for further growth, its oxygen requirements to facilitate increased respiration jump dramatically. This demand for oxygen cannot be met in the steep tank. If the chitting grain is left submerged in the steep, it takes up too much water and effectively drowns. The grain is therefore moved to germination chambers where its physical demands can be met more easily.

There are various types of germination chambers in use around the world, but they all operate around similar principles:

- Controlling grain temperature.
- Maintaining at least 40% grain moisture.
- Turning and mixing of the grain.
- Supplying sufficient oxygen to the grain.

The grain can be transferred or “cast” between the steeping tank and germination chamber as a slurry or dry. The grain is then spread out to form an even bed, typically between 1m and 1.5m in depth.

Throughout germination, it is essential that the grain bed is kept moist. If the grain is allowed to dehydrate, modification will be restricted. If the grain dehydrates, hydrolytic enzymes will be unable to progress throughout the endosperm, resulting in an under modified malt of poor quality that will cause serious brewhouse problems. The germinating barley is aerated with cool air, saturated with moisture to 100% relative humidity. Although the circulating air is at 100% humidity as it enters the grain bed, it is warmed as it removes the heat generated by grain respiration. This warming of the air decreases its relative humidity and is sufficient to effect some water removal and therefore mild dehydration of the grain, amounting to around 0.5%/day. Bed aeration serves several purposes. As well as helping to maintain bed hydration, circulating air replenishes the supply of oxygen for the grain and purges out any CO_2 that could stifle respiration. By maintaining air circulation, cooling of the grain bed is also accomplished.

Turning the Grain

Turners are initially used to lay down an even grain bed after transfer from the steeping vessel. The turners then run at regular intervals to augment aeration and cooling, by mixing the grain. As the grain germinates and the rootlets grow, they can become entangled. These clumps of grain trap heat as they respire and can generate microclimates within the bed. These are undesirable as they promote faster germination in localised areas of the grain bed, which could also promote microbial growth. If unchecked, the grain within this microclimate will malt quicker than the rest of the bed, attaining a more complete state of modification, generating non-homogeneous malt.

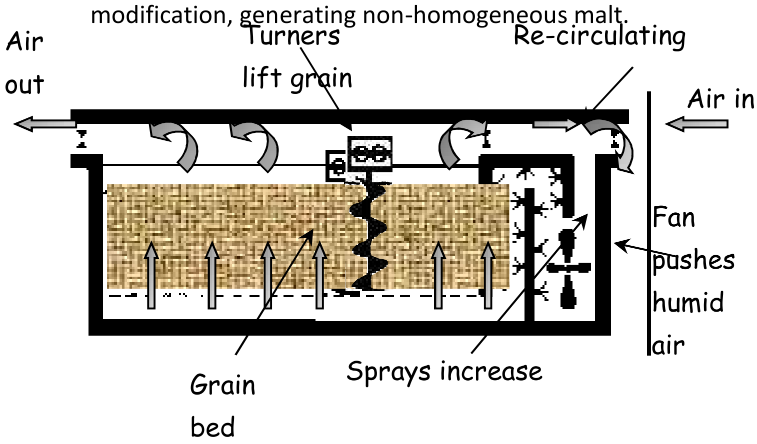


Figure 1 A schematic diagram of a Saladin Box.

Turning the grain bed using helical screws also lifts the bed to allow easier passage of the circulating air and hence more efficient cooling and CO_2 removal. Germination will typically last between 3-5 days, at temperatures between 15-20°C. As germination proceeds, respiration within the grain gains vigour, and by the end of the process the heat generated can result in the grain mass reaching temperatures of up to 22°C.

Boby Drum: In this type of drum the air conditioning unit, is situated at the end of the vessel. The air then moves up from the under-bed space, through the perforated plate floor and the grain bed. The drum can be rotated and this is done occasionally to prevent the matting together of roots and to loosen the grain bed to enhance cooling by the air stream. The drum also has a water supply feeding spray pipes inside the main drum body area for adjustment of moisture content. To empty the drum, the discharge ports are opened and the drum turned, allowing green malt to fall out into a discharge chute.

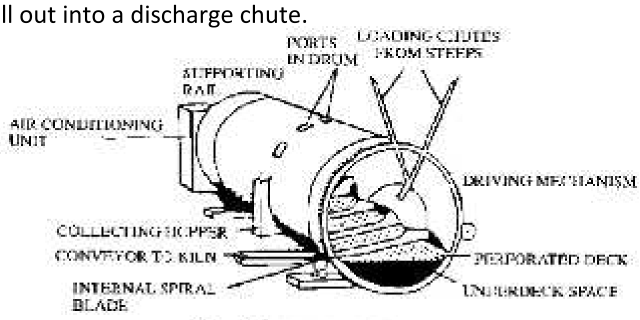


Figure 1. Boby Germination Drum

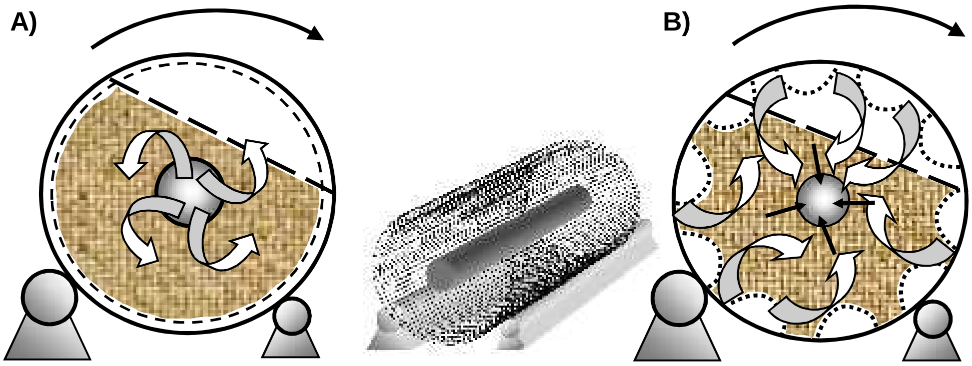


Figure 2 A) Schematic representation of a fully perforated drum. The drum rotates mixing the germinating grain whilst air emerges from the perforated central pipe. B) Schematic representations of a Galland drum. Air from perforated ducts, situated around the circumference of the drum, is exhausted through a central pipe.

The Wanderhaufen malting plant is a variation of the Saladin box plant. It is a semi-continuous process whereby each batch of germinating barley, referred to as a piece, is moved at intervals along the germination box thereby reducing the loading and unloading times and simplifying the conveying system. In Wanderhaufen maltings the steeped barley is cast into one end of a long rectangular open topped box with a plenum chamber below. A turner not only turns the grain but also moves it along the floor towards the kiln, this creates space on the floor for the next steep to be cast onto and green malt exiting the germination street is fed to the kiln. There is inevitably some mixing between one batch and the next so Wanderhaufen plants are best suited to maltings producing long runs on the same malt type.

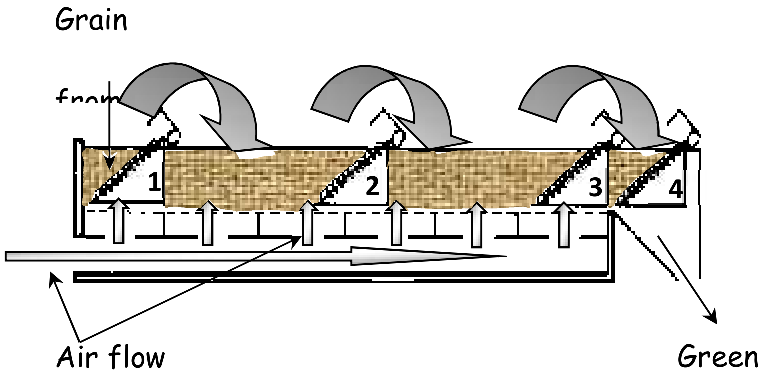
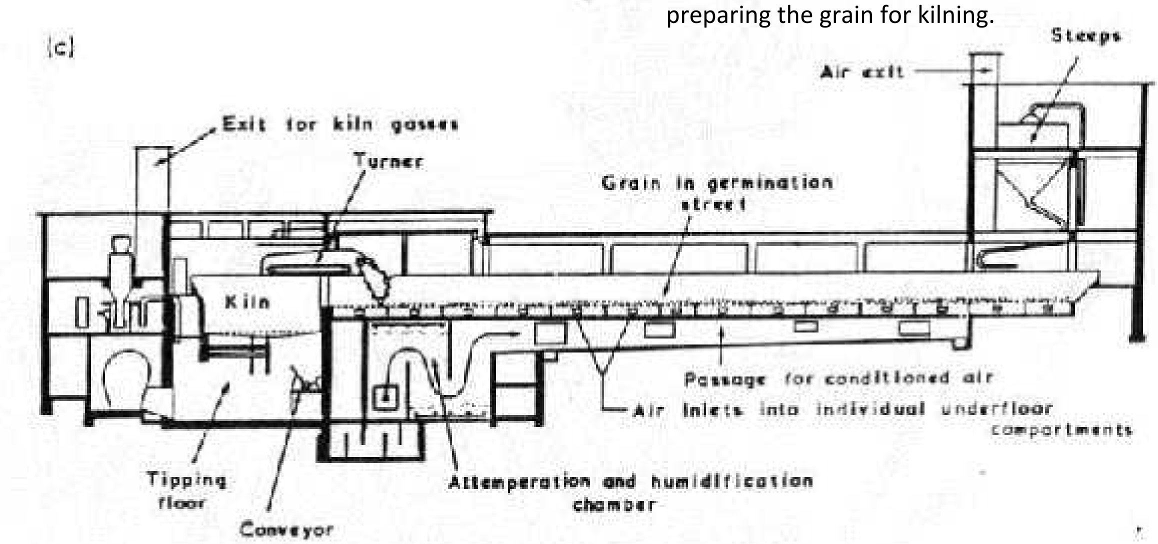


Figure 3 A schematic diagram of a Wanderhaufen system. The grain is moved along the "street" as the turners move from position 1 (steeped grain) to position 4 (fully modified grain).

Controlling the temperature of germination towards these latter stages can become difficult. If relying on cooling alone, temperature regulation could be lost altogether, forcing over modification of the grain and increasing malting losses. In order to prevent this and apply more accurate restraints, the grain is allowed to partially dehydrate. This manipulated desiccation of the grain is referred to as "withering". In combination, the air circulating through the grain bed can be enriched with CO_2, as it is re-circulated. These combined actions stifle grain respiration, growth and therefore grain modification, preparing the grain for kilning.



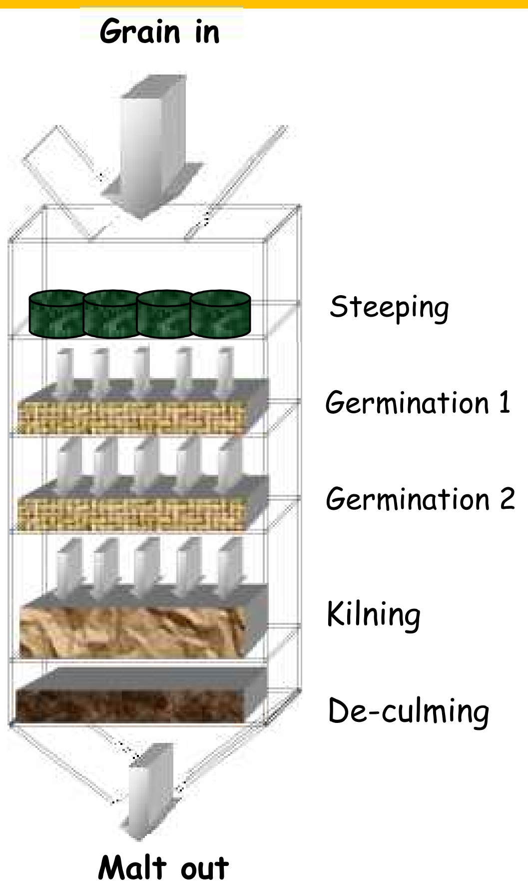


Figure 6. A schematic diagram of a Tower maltings. The grain progresses down through the tower, dropping through each floor with each process step. Usually only one germination floor is visited by a batch.

CONTROL PARAMETERS

(a) Moisture Control

Once the steeped grain has been cast samples are normally withdrawn and analysed by the laboratory for moisture content and growth counts. If the moisture content is too low the batch can be sprayed inside the vessel. It should be noted that this technique of moisture adjustment does not necessarily get the moisture into the centre of the endosperm where it is really needed and can also bring about excessive rootlet growth resulting in increased malting losses. Conversely, if the moisture content of the cast grain is excessively high the bed can be turned with the germination fan at maximum speed and air conditioning system off to remove some of the excess moisture. If either spraying or water removal is necessary then the steeping cycle is wrong and must be adjusted for subsequent batches.

Once the initial moisture content is at the correct level (44 - 47%) it is important that this moisture is maintained. Humidified air is therefore blown through the growing green malt. Even so, the grain moisture will fall by roughly 0.5% per day of germination due to the heat generated by the growing malt itself.

(b) Effect of Moisture on Modification

In general, malt modification is related to moisture content; i.e. increased moisture gives increased rate of modification. There is a limit to this since above 50% moisture the grain may be killed by drowning. It must be borne in mind that high green malt moisture also increases the rate of respiration, i.e. the grain grows vigorously using up valuable sugars, generating heat, CO_2 and rootlets resulting in increased malting loss and consequently less malt produced per tonne of barley steeped.

(c) Effects of Temperature on Germination

In general, malt modification is related to temperature, i.e. increase the temperature and the rate of modification increases.

(d) Effects of Temperature on Enzyme Development

A very complex network of biochemical reactions is involved in modification and the maltster must be aware that some of these reactions are significantly inhibited by increased temperature. Each enzyme has a specific optimum temperature for its activity and an increase in temperature will increase the activity of some enzymes and decrease the activity of others.

Two of the most significant groups of enzymes in the germination process are the proteases and amylases. Remember that proteases are enzymes that break down protein to soluble amino acids. The extent of this is measured by the SNR (soluble nitrogen ratio) in that a high level of protease activity results in a high SNR. Amylases are enzymes responsible for breaking down starch into sugar.

Both proteases and amylases are formed within the grain during germination. Their rates of development, however, are affected differently by temperature at the start of germination.

- high temperature start suppresses protease activity and
- low temperature start enhances protease activity

(e) Effect of Temperature on Rate of Modification

As both these enzyme systems are so important in malting, a compromise situation has to be found depending on the customer's malt specification. For example, a distiller requires high levels of soluble nitrogen in the wort, indicating that the protein matrix in the endosperm has been sufficiently broken down, whereas there is usually an excess of amylase. For this reason, moderate-low germination temperatures should be used to enhance protease activity.

(f) Air-on and Air-off Temperatures

In practice, the air-on temperature (air temperature below grain bed) is controlled. It is important, however, that the air-off temperature (air temperature above grain bed) is monitored and reacted to. When malting vigorous grain it is important to keep the growth under control. If the differential between below bed and above bed temperatures is too great then detrimental effects, such as moisture loss, uneven malt, increased malting loss, can occur.

Conversely, if the grain is slow to start, i.e. above bed and below bed temperature differential is too small; action must be taken immediately in order to encourage germination and modification rate. This temperature differential can be between 1.5^{o} and 4^{o}C depending on individual barley and malt requirements. Control of temperature is achieved by a combination of several factors.

(g) Control of Temperature

Fresh air at ambient temperature and humidity is drawn into the system by the germination fan. The air is fully humidified by passing through the spray chamber of the conditioning system. At most times of the year the temperature of this fully conditioned air is lower than required so a portion of exhaust air, which has passed through the grain bed and gained heat, is recirculated into the inlet air stream.

By altering the proportion of air re-circulation the air-on temperature can be closely controlled. The air-on temperature is pre-set at the control system and the amount of exhaust recirculation automatically adjusted by a feedback control system to a damper in the air duct.

(h) Effects of High Summer Temperatures

At certain times of the year, mid-late summer especially, the incoming ambient air is very warm. No exhaust air is recirculated back into the system and the air-on temperature can still be too high and out of control. Unfortunately, older malting plants were not originally intended to work throughout the summer months, as this was traditionally the "silent" or maintenance period.

Modern maltings may install refrigeration equipment in order that the germination temperature can be effectively controlled all year round. Passive cooling is achieved to some degree by evaporative cooling from the sprays in the germination air stream.

(i) Turning of grain

A third element used to prevent the germination temperature going out of control is to turn the bed.

At the end of germination, the modified barley, now termed "green malt" (un-kilned malt) has been manipulated to achieve the maltster's and brewer's specifications. These grain characteristics must now be fixed to avoid any deleterious changes that may occur before the brewery can take delivery of their malt. Kilning effectively serves two purposes:

1. To halt and capture the biological activity of the germinating grain at a point of optimum enzyme yield and endosperm modification.

2. To reduce the moisture content of the green malt to a level at which it can be safely stored to avoid deterioration and microbial infection.

THE PHYSICAL PROCESS OF KILNING

Kilning reduces the moisture content of the grain, which, at the end of germination is usually between 42% and 45%. A final grain moisture level of approximately 3 – 5% is achieved by the end of kilning. Kilning of the grain is also responsible for the characteristic colour and flavour of malt. This requires intense heating, which conflicts with the need to preserve essential enzymatic activity in the grain.

Enzymes are considerably more heat stable when the malt is dry. Kilning objectives can therefore be accomplished with a drying regime that first removes the majority of moisture at relatively subdued temperatures. Secondly, more intense heating is used to obtain final moisture removal, and colour/flavour production.

Kilning consumes some 75% of the total energy utilised in malting and must therefore be operated at maximum efficiency. This would dictate that the warm air (used to dry the grain) leaves the kiln satisfying its maximum moisture carrying capacity. This may not always be accomplished or even desired.

Kilns can be similar in design to germination chambers and in fact some maltings utilise vessels in which the two process steps are carried out in the one vessel - Germination and Kilning Vessels (GKVs).

Within the kiln, the green malt is loaded onto one or more perforated floors, through which heated air can be driven (by fan) upwards through the grain bed to effect drying. If there is more than one floor, the heated air from the lower level is rejuvenated with additional flow to heat the bed above, resulting in economic savings. In dedicated kilns, the bed is not usually turned, but in GKVs it may be. There are three stages incorporated in the drying process.

1. Free Drying (or pre-break).
2. Forced drying.
3. Curing (or the equilibrium phase).

(a) Free Drying

Initially, water can be easily removed from the moist grain using low temperatures (50 – 65°C) if combined with high volume airflow which reaches a Relative Humidity [RH] of >95% during drying in this phase. During free drying, water diffuses through the grain to its surface and is absorbed by the warm air passing through the bed. The action of water removal from the grain cools the malt (due to the latent heat of evaporation). Often the internal grain temperature will be 30°C lower than that of the air-on temperature. This removal of moisture at low temperatures ensures the maximal survival of enzymes, whilst encouraging the development of colour and flavour compounds.

KEYPOINT: In addition to the removal of water from the grain, kilning evaporates undesirable flavour volatiles that impart grainy or grassy aromas.

Caution is taken during free drying to prevent the occurrence of "drip back" or stewing of the grain, which prolongs and enhances colour/flavour production and enzyme destruction. Drip back occurs when the air-off reaches saturation (RH = 100%) which on cooling releases excess moisture. For instance, as the saturated air leaving the grain bed meets the colder interior of the kiln; the excess water condenses and drips back down into the malt. Stewing arises when the saturated air passing through the bed prevents evaporation and therefore cooling of the malt – in effect stewing it. Such conditions are avoided by increasing the water carrying capacity of the air by increasing its temperature and/or preferably flow volume.

Typically the "air-on" temperature is raised a few degrees each hour for the first 12 hours. Free drying produces malt with moistures in the region 15-20%.

The inherent nature of malt kilning, maintaining "air-off" relative humidity at above 95% makes it an inefficient and wasteful process.

Other inevitably sources of energy loss are:

- Imperfect fuel combustion;
- Losses associated with heating the kiln structure; or
- Heat losses directly to the atmosphere through limitations in the kiln structure.

KEYPOINT: Malt enzymes are damaged when moist malt is exposed to high temperatures. To protect the enzymes and also to minimise energy costs, drying starts with the air temperature at about 55°C and then raised at later stages. The design of the cycle varies according to the type of malt.

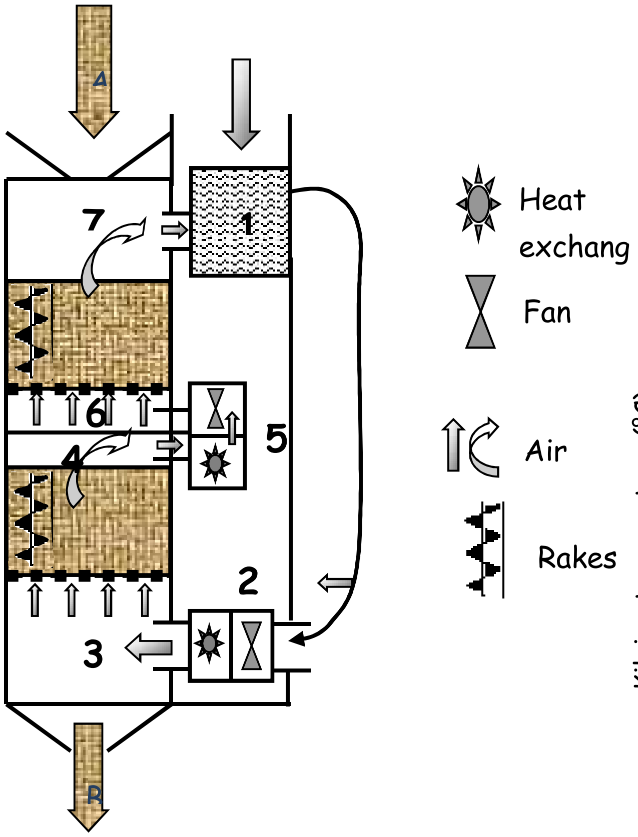


Figure 1. A schematic representation of a two-tier kiln. Ambient air is drawn in and passed to the primary heat exchanger (1). The heated air is drawn through to the secondary heat exchanger (2) and blown beneath the floor of the primary grain bed as the "air-on" (3). The "air-off" from the first grain bed (4) is drawn off and reheated, supplemented with additional air (5) and transferred to the secondary grain bed as "air-on" (6). The "air-off" from the secondary grain bed (7) is re-circulated to join the incoming ambient air at the primary heat exchanger.

A= Green malt in. B= Kilned malt out.

(b) Forced Drying

Grain surface moisture and that in the outermost layers is soon depleted during free drying. Moisture must then diffuse to the surface of the grain from the centre, an increasingly exhaustive process. As the grain dries it shrinks slightly reducing the internal distance that the residual moisture must diffuse before reaching the surface. However, the grain's total surface area is also diminished, restricting the rate of evaporation.

The efficiency of the process declines as a result of the change in grain size with the "air-off" exiting the kiln carrying less than maximum water levels. This point in the process is signalled when the "air-off" temperatures suddenly start to rise approaching the "air-on" temperature, termed "breakthrough" or the "breakpoint". Consequently, the "air-on" temperature and flow rate are suitably modified; the temperature is increased (70°C) and the airflow is reduced. Towards the end of this stage, declining airflow volumes becomes inefficient, and corrective measures are implemented, i.e. re-circulating the "air-off".

Re-circulation stages continue as grain moisture drops to 10-12%. Below 10% moisture only "bound" water remains. Bound water is associated with the macromolecules of the kernel (mainly attached to starch and β-glucans by hydrogen bonds).

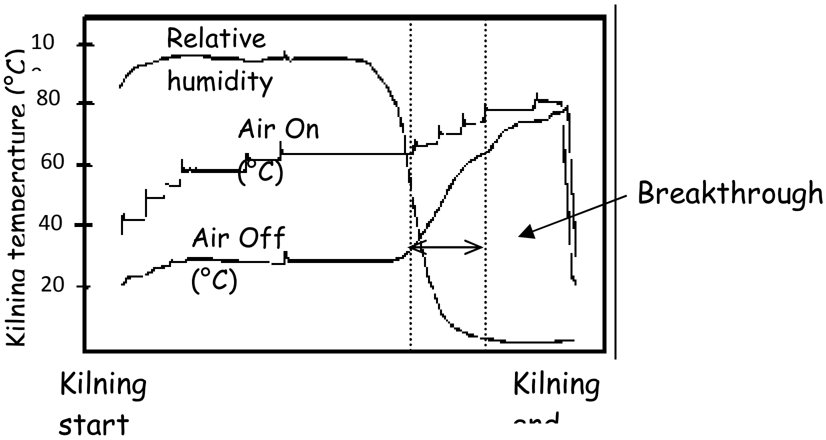


Figure 2. A graph showing the progression of kilning.

KEYPOINT: It is important to remember that, in kilning, different layers of the malt bed are at different stages of drying. The driest layer will be at the bottom of the bed and will have reached the forced-drying phase while the upper layers are still in the free drying phase. The break point (exhaust air at less than 100% RH) only comes when the whole malt bed has completed its forced drying phase. The drying front gradually moves up through the malt bed until the break is reached and the air-off temperature above the bed starts to rise.

(c) Curing

Curing is the final kilning stage, initiated as the grain moisture levels approach 5%. Depending on the malt type "air-on" temperatures range between 84°C (modern lager malts) and 100°C (classic ale malts) during curing. These temperature profiles are maintained for the last 2-4 hours of kilning, reducing moisture contents to approximately 3-4%. It is during curing that the desirable malty flavours and aromas are produced.

Once kilned, the malt is rapidly cooled wit with dry air and then often screened to remove rootlets before they can pick up moisture. The cool dry malt can be stored for long periods of time without degradation in quality.

Kiln Design and Technology

Older kilns tend to be square, whereas newer kilns are usually round. Nowadays, both incorporate heat recovery systems, having the capacity to recirculate air in the latter stages of kilning when the air from the grain bed still has drying capacity. They also have heat exchangers to recover energy, most important in the early stages of kilning when warm saturated air is being exhausted.

(a) Energy consumption

Kilning is the final process in the preparation of malt. It is a drying operation that is carried out at carefully controlled temperatures until the malt has reached the desired moisture content. If steeping is regarded as the most critical phase of malting in terms of achievement of malt modification, it is kilning which is the most critical phase in terms of operating efficiency and costs.

In malting plants where measures to improve energy utilisation have not been carried out, kilning can represent around 90% of the energy used. Even when extensive work has been carried out to produce the most cost effective kilns the energy requirement of this process will still represent some 80-90% of the total energy maltings use. Kilning is, therefore, important both in terms of product quality and commercial viability.

(b) Kilning Technology Today

Developments in technology over the last 20 years have been driven by the need to reduce operating costs and reduce environmental footprints. Developments in efficient heat recovery systems, highly efficient air heating systems and high tech process control have been the most recent technologies Maltster's have been incorporating into their Plants.

(c) Indirect and Direct Kiln Firing

In traditional kilning (and still used for some malts for distilling), kilns were directly fired, i.e. the products of combustion of the fuel pass up through the malt bed. This results in a high SO_2 content and low wort pH, (and is considered to have beneficial effects on whisky flavour).

With an indirect firing, the incoming air passes through a radiator containing hot air, water or oil from a heating system. The introduction of indirect firing in some cases reduced the efficiency of the kiln because of the losses associated with heat exchangers for warming the air'. Modern 'condensating' heating systems can be extremely efficient in and reach theoretical efficiencies of 100%, significantly higher than a typical high temperature hot water boiler of around 80%.

CONSIDERATIONS FOR ATTAINING OPTIMAL KILNING

While the mechanics of the kilning process are relatively simple and straightforward, some very complex chemical reactions take place during kilning. The scientific principles behind some of these reactions are not fully understood. In any case, operating experience has shown that using established practices provides consistent high quality results.

The three main variables that affect the kilning process include:

- Time
- Temperature
- Air flow

Successful kilning can be thought of as an exercise in the balance between time, temperature, and airflow.

Time

Kilning time has a major effect on finished malt analysis. This includes total kilning time as well as the time for each phase of the kilning process.

While the kiln has the capability of drying the malt in a period of 8 hours or less, experience has shown that to achieve reasonable colour and flavour characteristics, a minimum of 12 hours in the upper deck and 12 hours in the lower deck is required. If the grain is dried too fast, it may result in a lack of flavour development.

Temperature

Curing cycle temperature can be adjusted to meet the brewer's specifications. For example, if the brewer wants malt with a low colour, the maltster uses a lower curing temperature. Higher colour requires a higher curing temperature, but at the expense of enzymes, since more enzymes are destroyed at higher curing temperatures.

Airflow

Kiln cycle temperatures should be low enough to permit sufficient airflow to evenly dry the malt. It is sometimes necessary to reduce airflow to extend kilning time over 12 hours per deck. Excessive air flow volumes may cause problems with malt drying out too soon. Drying too fast during the free drying phase may result in not developing enough sugars to allow caramelization – if this is desired.

EFFECTS OF KILNING ON FINISHED MALT

Finish Malt Moisture

Finish malt moisture is dictated by kilning time and temperature. Therefore, a high or low off kiln moisture can be dealt with as follows.

High Moisture

Longer kilning hours, higher kilning temperatures, and/or more kiln air volume will reduce the moisture levels. Usually longer hours are used, but all three can be used together to achieve desired specified results. Time constraints will limit kiln hour availability. Care must be taken not to elevate temperatures too quickly, or enzyme activity and colour will be affected.

Low Moisture

Shortening kilning hours, reducing temperatures, and/or kilning air volume reduction will raise moisture readings. Moves should be slow, since high moisture is a greater problem than low moisture. If air is bypassed around the lower deck of a double deck kiln, increasing the volume or timing of this procedure can raise the finish malt moisture.

Kiln Design Considerations

Double deck kiln designs, in some climates, may contribute to lower than desired finish malt moistures. Total kiln hours, are dictated by the desired (specified) moisture of the malt on the upper kiln deck at the end of kilning cycles (drop moisture). If the kiln runs longer than required by the lower deck to reach optimum finish malt moisture (3.8% - 4.3%), a lower than desirable moisture will be attained. Some kilns are designed to allow passage of controlled volumes of kiln drying air around the lower kiln deck to assist with drying the upper kiln deck, while not over drying the lower deck. Although the results of bypassing this air are normally good, care must be taken not to impact enzyme and/or colour development in a negative manner. If the product transferred to the lower kiln deck is higher in moisture than desired, and all or most of the drying air prior to high heat (curing) is transferred around the lower deck, problems will occur. Typically, all drying air during the high heat (curing) phase of kilning is taken through the lower deck. If most air is taken around the lower deck during preceding cycles, the hot air (85-88°C) will be applied to the high moisture grain and destroy enzyme activity and accelerate colour development far above specifications.

Wort Colour

Wort colour is principally a product of kilning, and levels can be manipulated as follows.

Low Colour

Low colour problems can be eased, by having malt moisture elevated above approximately 15 percent when going to higher heats in the kilning cycles.

In theory, it is felt that avoiding as much beta amylase kill-off as possible during the first three quarters of the full kilning cycle will make more sugars available for caramelization. Limiting between bed temperatures and using longer hours and lower temperatures early in the kiln patterns on double deck kilns and dropping moisture on single deck kilns before higher heats (above 62°C.) could help produce colour.

NOTE: In fact, having a higher internal malt moisture when going to heats above 62°C will help develop colour. There is, however, a trade off, since this practice will also reduce beta amylase, thus lowering DP readings.

High Colour

Lowering the moisture of the malt entering the higher heat cycles (above 62°C.) should help to lower colour readings. A lower drop moisture on double deck kilns will result in a similar drop in colour. This reduction in moisture should be accomplished with longer time at lower heat settings to help avoid excessive DP losses.

Kilning Biochemistry

The skill of kilning is concerned with the preservation of enzyme activities. Inactivation of the enzymes is a result of denaturation (or protein coagulation). In addition to the denaturation of enzyme proteins, a proportion of the endosperm protein is also coagulated, and this will not dissolve in the wort. This removal of wort protein is beneficial, reducing the haze forming potential of the beer.

Which of the essential hydrolytic enzymes survive kilning to act during mashing? They are:

Most heat stable

Carboxypeptidase
α-Amylase
-Amylase
Proteases β
Endo β -1,3:1,4 glucanase
Endo β -1,3 glucanase

Least heat stable

KEYPOINT: If high enzyme activity is required in the finished malt then low temperatures (especially early in the kilning cycle) are used.

At the completion of kilning, we should have accomplished the following objectives:

- Enzymes are developed
- Protein is solubilized
- Starch is available for extraction
- Flavour and colour developed

(a) Diastatic Power (DP)

Proper kernel modification is a must for optimum DP values in the finished product. Most of the enzyme activity is released in germination; however, activity still exists in the kiln if temperatures are not allowed to climb too high. Much of the enzyme activity can be lost and D/P readings drastically reduced if high temperatures reach the grain too early, or when the internal kernel moisture is too high. Generally, we should not allow temperatures of above 62°C and malt moistures above 15% to exist at the same time for more than 30 minutes. A kiln temperature of over 90°C will also adversely affect DP levels.

NOTE: Raw barley with a low protein level can be expected to deliver lower enzyme activity. A higher protein barley will develop higher enzyme activity.

(b) Dimethylsulphide

Dimethylsulphide (DMS) characteristically imparts a "canned sweetcorn" aroma to beer. This is an important flavour note and can be desired in some beers, especially lagers.

DMS originates from the pre-cursor S-methylmethionine (SMM). During germination SMM is formed, in the developing grain from the amino acid methionine. On heating, in the kiln and during wort boiling, SMM is converted to DMS. Considerable amounts of DMS are driven off and lost during malt kilning but some remains and can be oxidised to dimethyl sulphoxide (DMSO). Malt will often contain all three compounds, SMM, DMS, and DMSO. Increasing kilning temperatures means that more SMM is converted to DMS and driven off – but the increased temperature causes increased malt colour.

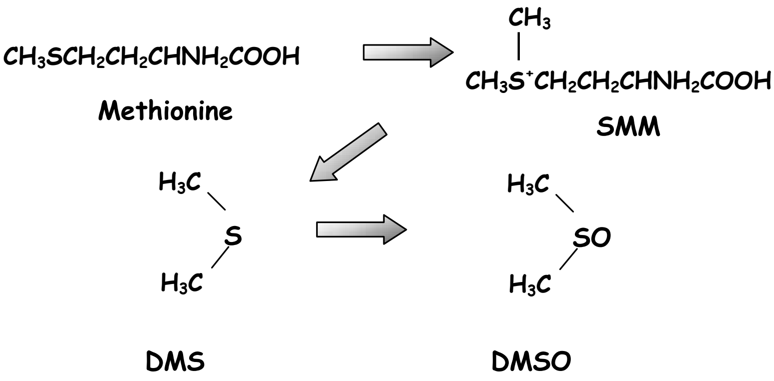


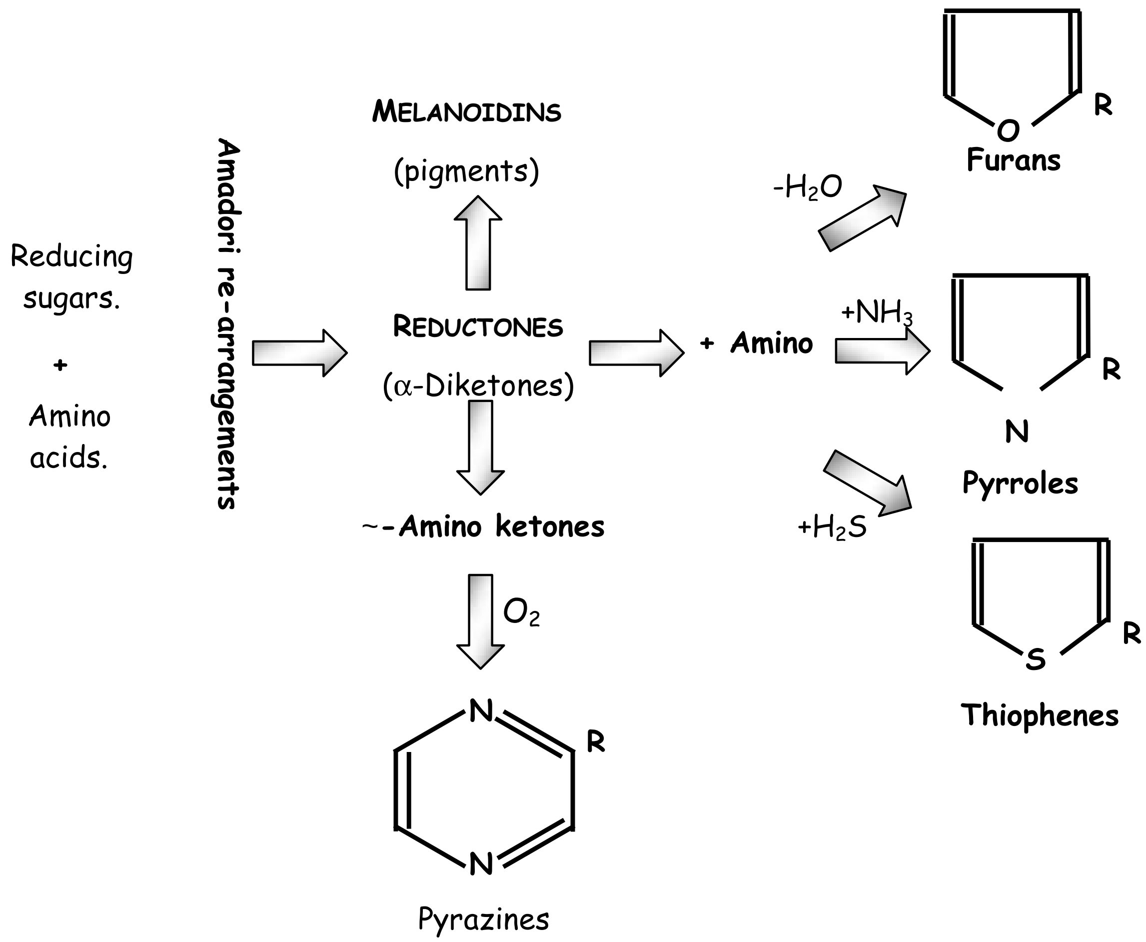
Figure 4. *Formation* of Dimethylsulphide (DMS) from methionine.

To minimize DMS in the finished beer, we need to minimize the formation of DMS and SMM in the malt. DMS and SMM production can be controlled somewhat by barley selection and by controlling the malting cycle. Higher curing temperatures help to control DMS levels in the malt. Also, barley varieties with higher total protein fractions tend to produce more SMM during malting. Also, the amount of SMM produced is related to the degree of germination and modification, so longer germination times and more modification lead to more SMM. SMM can be controlled during malting by curing at 180ºF (82ºC) or greater

(c) The Maillard Reaction

Some of the most important chemical reactions occurring throughout malting are the production of melanoidins. Melanoidins give the malt its characteristic flavour and colour. Melanoidins are produced from the interaction of reducing sugars with amino acids (from the malt) via the Maillard reaction. The intensities of these reactions are dependent on both moisture and heat. Ale malts require high curing temperatures at the end of kilning unlike distilling or lager malts.

KEYPOINT: α-Diketones and melanoidins are thought to limit beer oxidation and prevent the production of colloidal instability.



- Valine + Fructose → Malt flavour
- Glycine + Glucose → Dark colour
- Glycine + Maltose → Malty aroma & very dark colour

Figure 3. The Maillard reaction.

(d) Nitrosodimethylamine (NDMA)

Nitrosoamines are carcinogenic compounds generated during malting formed by the reaction of amines and nitrogen oxides. Malt specifications often restrict levels to stating that no more than 5 ppb NDMA can be present within the malt. NDMA is created through the interaction of the precursor hordenine (almost exclusively found in the rootlets) and nitrous oxides (NO_x) during kilning. The nitrous oxides are a result of the oxidation of nitrogen in the air fuels are combusted.

To combat NDMA production many maltings now use indirect kilning. In these kilns, air is heated using heat exchangers to prevent the NO_x containing flue gases, from the burning fuel, entering the kiln and making contact with the malt. Alternatively SO_2 or elemental sulphur can be added to the burners in the kiln when heating air used for drying the malt. When fuel containing SO_x (e.g. SO_2 and SO_3) is burnt, the problem of NDMA production is averted as the nitrosylation reaction does not occur under acid conditions.

However, two problems still remain. The first is that even when indirectly kilning, high NO_x levels can be present the air in some locations die to industrial processes and emissions from vehicles. This will provide opportunity for NDMA production. Secondly, the reaction of SO_3 and H_2O produces H_2SO_4. This sulphuric acid can corrode the malting plant.

To summarise, reductions in NDMA formation in modern malts have been achieved by a number of initiatives.

- Utilising indirect heating systems
- Utilising low NOx burners
- Burning sulphur in the early stages of kilning

(e) Peated Malt

Just to complete the description of how malt characteristics develop during kilning a short description of peated malt is included. There are a few specialist beers that may use peated malt but in general it is reserved for use in the whisky industry to produce whiskies with distinctive smoky or phenolic flavours.

An additional peat fire is burned under controlled conditions in order to maximise the production of peat “reek”. The main air fan draws the peat smoke into the kiln. Peat reek contains high levels of phenolic compounds such as phenol, cresol, eugenol and guaiacol. Also present are many nitrogenous compounds such as pyridines, some of which have very strong flavours. The amount of peat reek absorbed by malt and the amount present in the final whisky is found by measuring its phenol content.

The peat used has to have a moisture content of 50 - 60% and contain high levels of decomposed organic matter. If the peat is too wet, burning the required amount will not be possible and if too dry the fire will be too hot and the flavour components will be lost.

Approximately 100-200kg of peat per tonne of finished heavily peated malt.

Burning peat has an effect on the drying rate. The time taken to reach the break-point is extended due to the water vapour produced when peat is burned. Peating is most efficient using deep malt beds and when there is a continuous peating cycle from start of kilning to several hours after the break-point has been reached. Malt takes up phenols from peat smoke most readily at malt moisture in excess of 20%. Below this level the rate of uptake slows down. The longer malt of high moisture content is exposed to peat smoke then the higher the phenol content.

PREPARATION AND STORAGE OF FINISHED MALT

The malt storage process begins when malt is returned from the malt house to the malt silos after kilning. This process provides for the cleaning, sampling, aging, storage, blending, and shipping of malt and malt by-products after the malt house processes have been completed.

Malt has been dried during kilning to somewhere typically between 4% and 5% during kilning; this low moisture content means it is brittle and easily damaged by poor mechanical handling. Higher moisture levels and there is danger of mould infection as well as increased transportation costs (more water, less available extract) whereas lower malt moisture levels have higher extracts, tend to have higher colours (due to extended kilning) but an increased risk of damage. Equipment must therefore be chosen carefully and the malt handled in as gentle a manner as possible. It must not be allowed to come into contact with damp equipment or moist air, nor be allowed to become cracked, crushed or de-husked in advance of the milling process. Additionally, the malt silo is a hazardous place, and consideration must be given to good hygiene and housekeeping with respect to dust avoidance.

The process of moving malt, either into or out of silo, is usually achieved by some form of conveyor, having replaced manual handling in most medium and large sized brewing or distilling operations. Many forms of conveying systems are available, and are used according to the various needs of the materials being moved. Generally speaking, a conveyor can be classified as either mechanical or pneumatic and both types can commonly be used for malt handling. Chain conveyors are used for the horizontal transportation of malt over longer distances, and can also overcome a slight angle of inclination minor differences in height levels. Screw conveyors are used when malt has to be transported over relatively short distances, but can be used horizontally, vertically or at any angle of inclination.

Most malt storage silos are constructed from steel but they can be made from concrete. Silos have smooth walls with hopper bottoms to ensure easy grain withdrawal. Malt is stored at low moisture levels to discourage the growth of pests such as insects, moulds, fungi and bacteria, and also to prevent alteration to the biochemical structure of malt/adjunct prior to use due to an increase in moisture level).

Kiln Malt Cleaning

Kiln Malt Cleaning is the first major step after the finished malt piece comes back from the malt house. The primary purpose of this cleaning is to remove the sprout (rootlet) from the kernel- a process referred to as de-culming. The Kiln malt is cleaned with a malt cleaner, which is a screen grader similar to the barley cleaner (see section 4).

Malt Quality

The malt lab performs a minimum of two checks for malt quality. The first check occurs when the malt comes back from the malt house as kiln malt. Each piece is tested and assigned its analytical values from lab results. The second quality check of the malt is performed after blending the malt prior to loading the customer specification.

Bin Storage and Aging

After the malt is weighed, it is transferred to bins for storage and aging. Normally, multiple production batches are stored in a full-sized bin. Each bin is assigned a blend sheet that contains the quality of the malt in that bin. The malt is then aged for a minimum number of days, as assigned by customer specification. Typical storage is for a minimum of 21 days.

MALT STORAGE PLANT AND PROCESSES

Malt has been dried during kilning to somewhere typically between 4% and 5% during kilning; this low moisture content means it is brittle and easily damaged by poor mechanical handling. Higher moisture levels and there is danger of mould infection as well as increased transportation costs (more water, less available extract) whereas lower malt moisture levels have higher extracts, tend to have higher colours (due to extended kilning) but an increased risk of damage. Equipment must therefore be chosen carefully and the malt handled in as gentle a manner as possible. It must not be allowed to come into contact with damp equipment or moist air, nor be allowed to become cracked, crushed or de-husked in advance of the milling process. Additionally,

the malt silo and mill tower is a hazardous place, and consideration must be given to good hygiene and housekeeping with respect to dust avoidance. When considering a new brewhouse project, or an upgrade of an existing one to add bulk malt handling, there is a lot of equipment than needs to be considered.

The process of moving malt, either into or out of silo, is usually achieved by some form of conveyor, having replaced manual handling in most medium and large sized brewing or distilling operations. Many forms of conveying

systems are available, and are used according to the various needs of the materials being moved. Generally speaking, a conveyor can be classified as either mechanical or pneumatic and both types will commonly be used for malt handling. A typical intake system might comprise of a discharge ‘pit’ or hopper into which the malt is ‘tipped’ during offloading from the bulk transport. Some form of vertical elevator, such as a bucket elevator, would be used to raise the malt to the top of the silos and then conveyor would transport it horizontally towards the silo. Chain conveyors are used for the horizontal transportation of malt over longer distances, and can also overcome a slight angle of inclination minor differences in height levels. Screw conveyors are used when malt has to be transported over relatively short distances, but can be used horizontally, vertically or at any angle of inclination. Discharge from conveyor is by gravity into the top of the silo.

Most malt storage silos are constructed from steel but they can be made from concrete. Silos have smooth walls with hopper bottoms to ensure easy grain withdrawal. Malt and also cereal adjuncts are stored at their delivery moisture levels to discourage the growth of pests such as insects, moulds, fungi and bacteria, and also to prevent alteration to the biochemical structure of malt/adjunct prior to use due to an increase in moisture level).

Screening/Grading and Dressing

Prior to dispatch from the maltings the malt is screened and dressed. To ensure uniformity of milling, it is necessary to have a reasonable consistency in the size of corns. To obtain such consistency, bulks of malt are often graded. The malt is carried by pneumatic or mechanical means past magnetic separators to rotating, cylindrical, oscillating or flat-bed screens. Not only are corns of unwanted size rejected (these are sold for animal feed wherever possible), but foreign matter such as straw, stones, string, sacking and metal particles are removed.

Dressing

The malt dresser was usually a cylindrical screen revolving inside a wooden casing that has detachable doors on either side for easy access. The last part of the screen consists of a mesh large enough to let malt pass through to a small hopper feeding the weigher or the mill. Any foreign matter such as pieces of wood, metal, or stone, which are too large to pass through this mesh, is carried forward to the end of the screen where it is rejected via a spout into a bag. When the culms were separated from the malt during screening, circular brushes revolved against the exterior of the screens thereby ensuring that the apertures were kept clear.

Dust Removal

Dust is a dangerous substance because of the risk of explosion and also irritation to the lungs. It is now covered by COSHH (Control of Substances Hazardous to Health Act UK) regulations and it is extremely important that dust is not allowed to accumulate. If a film of dust appears, measures must be taken to eliminate the source of dust and vacuum any deposits – the presence of dust would indicate a failure in the dust extraction system or leak in the plant.

An electrically driven fan sucks the dust through metal ducts or pipes from various points such as the elevator, dresser and weighing machine. There are several ways of dealing with the dust collected; it may be blown into a cyclone from which it drops down into a bagging point. In some installations dust is blown into sleeves mounted inside a metal unit, on a frame that can be vibrated at the end of the grinding or malt intake operation to shake off the dust. The dust then falls into a container at the bottom. A regular system of emptying the dust sacks or containers is necessary to allow the plant to work at maximum efficiency, and a periodical examination must be made of the pipe ducts to and from the fan to avoid build up and blockage by dust.

Even if there is good housekeeping, it may not be possible to completely eliminate the risk of explosions in hoppers and conveying equipment. For this reason, explosion vents are provided to allow an explosion to pass harmlessly into the atmosphere without damage to equipment and people. For hazards associated with dust, see section 13.

MALT EVALUATION AND DISPATCH

Blending

After aging is completed, the malt varieties are blended to specification. Blending is accomplished by mixing malt from various combinations of bins. By adjusting slide gates at the bin discharge (either automatically or by manual adjustment) the grain flow rate can be adjusted to provide the desired ratios of varieties.

Shipping Malt Cleaning

After blending, the shipping malt is often cleaned again through further malt cleaning. This cleaning removes any sprouts not taken out during kiln malt cleaning. Thin kernels, husk, hull, and broken kernels are also removed. Malt is transferred to a pre-delivery storage bin, from which it is loaded directly for delivery.

Shipping Malt Sample
Prior to loading the rail cars, a shipping malt sample is taken and checked by the lab for malt quality.

Malt Dispatch
Road trucks, shipping containers or rail cars are loaded with malt. Once filled, the bulk units are closed and sealed with metal seals to discourage tampering.

Speciality malts, or malt for small brewing operations, are also bagged and available for delivery in batches as small as 25kg.

Malt Analysis and Specification.
It is essential that all malt leaving the malthouse is accompanied by a laboratory analysis and delivery certificate.

- Brewers and distillers purchase malt against a specification. A certificate of analysis / compliance to specification is normally required as part of the purchasing contract.
- Each malt delivery must contain a batch number (or blend ratio, when multiple batches have been loaded) that is traceable back through the malting process to the barley used for steeping. This in turn must be traceable back to the barley store and associated delivery data (such barley delivery date, barley variety – see section 4). This process allows full product traceability from bottle (of beer or whisky) back to the barley used to produce the malt.

Samples are collected either from a specialised sampling device, which automatically takes a small, continuous sample of malt from a conveyor during transfer to a delivery bin or malt truck, or can be sampled directly from the delivery truck/railcar by use of a sampling spear.

Delivery bins, holding malt for a number of bulk deliveries, are often analysed in advance of loading and delivery so that the completed laboratory analysis and delivery certificate can accompany the delivery to the brewery or distillery.

For detailed information on malt specifications, refer to section 10.4 malt Specifications.

Speciality Malt Production.

TYPES OF SPECIALITY MALTS

Thanks to the skilful manipulation of the malting and kilning regimes, the maltster is able to produce a diverse and vast array of malt types. The brewer can utilise this extensive malt family to craft beers with a multitude of qualities to satisfy the ever challenging consumer. The assorted malts range from lightly coloured white malts through to charred black and chocolate malts, each imparting their own unique colourful and aromatic qualities to beer. In addition, not only barley can be malted; the range of malts available can be extended by use of malted wheat, oats, rye and sorghum.

The primary factor influencing the colour and flavour of the malt produced are the temperature and extent of kilning to which the green malt is subjected. However, we cannot forget the biological nature of the grain and the purpose for which it is intended (to provide extract and the diastatic power required to yield this extract). The highest coloured malts contain little, if any residual enzyme activity after kilning, and it is essential to bear this in mind when setting your grist recipes.

KEYPOINT: The colour of malt is measured in EBC units. Wort is produced from a laboratory extract of malt and the colour determined by a spectrophotometric method.

Table 1: Comparative ranges in the composition of barley and malt.

	Barley	Brewers	High-diastatic
Kernel weight (mg)	32-36	29-32	29-32
Starch (%)	55-60	50-55	50-55
Sugars (%)	0.5-1.0	8.0-10.0	8.0-10.0
Total nitrogen (%)	1.6-2.3	1.6-2.3	1.6-2.3
Soluble nitrogen % of total)	10-12	35-45	40-50
Diastatic Power	50-60	100-150	150-250
alpha-Amylase	Trace	35-45	55-65
Proteolytic acitivity (arbitrary units)	Trace	15-20	20-25

White Malts

The palest of the malts produced is the white malt (attaining a colour of 2 EBC units). Lightly kilned, with an air on temperature not exceeding 70°C, white malts retain a large proportion of their enzyme activity. The lack of real heat treatment restrains the development of flavour compounds producing malt with a neutral, slightly sweet taste. Often the grassy, aldehydic aromas will remain along with sulphidic and DMS tastes due to the lack of heat to drive them off during kilning.

Wheat Malts

Wheat malts differ from their sibling barley malts due to physical composition. Wheat has no husk, and as such hydrates quicker during steeping than barley to generate higher extract values. The contrasting chemical composition of wheat also gives the malt an altered characteristic. Wheat contains more protein than barley, which gives the resulting beer a fuller mouth-feel and enhanced head stability. Wheat malt is notoriously difficult to produce, is often undermodified with reduced friability and can generate viscous worts. Compared to barley malt, wheat malts produce turbid, physically unstable beers. Wheat malts tend to have a colour of approximately 2 EBC units.

Lager/Pils Malt

The very pale Pilsner malts tend to be made from plump, two-rowed barley with Total Nitrogen (TN) contents of 1.52-1.84%. The barley is steeped to achieve moisture content of 43%, which after a long, cool germination period (below 17°C) produces fully modified malt. This green malt is dried quickly at cool temperatures (around 55°C), with rapid airflow to around 8% moisture before final curing at 70-85°C. These malts are characteristically very pale with no trace of caramel or melanoidin colour formation, and have weak aromas.

The UK lager malt has evolved into a very pale, well-modified malt produced from two-rowed barley with moderate TN contents of 1.65-1.8%. These malts are lightly kilned to produce characteristics that closely match the European Pilsners. Historically lager malts were undermodified, but this is no longer true and the light curing to which they are subject permits considerable enzyme survival, generating high extract yields - often more than the pale ale malts.

Kilning "air-on" temperatures are in the range 55-70°C and curing around 85°C, which is adequate to effect removal of most of the green, grassy aromas produced from oxidised lipids, but insufficient to break down the DMS precursor (SMM). This is acceptable in lager malts and is often specified. However, a stand of at least 30 minutes is required during wort boiling to ensure DMS control. Malt moisture levels are typically 4-6%, colours ≤ 3 EBC units, and TSN values between 0.5-0.7% giving a lightly coloured malt with a malty, biscuit-like flavour.

Pale Ale and Mild Malts

The pale and mild ale malts are typically used when producing traditional British top fermented beers and cask conditioned ales. The pale ale malts are produced using the best two-rowed barley, with low nitrogen contents ideally 1.5% TN. This lower protein content helps achieve the required good clarification and physical stability of these beers.

- If slightly less well modified malts are used head retention is favoured.
- Under-modified malts generate poor extract recoveries, hinder wort filtration and instability.
- Over-modified malts give wort separation problems, lend a thin character to the beer, and produce weak head retention.
- Losses can also be incurred as over-modified malts break up easily when handled.

Finished pale ale malts have high extract values and moderate TSN values, commonly 0.5-0.7%, with TSN: TN ratios around 40%. Colours range from 4-6.5 EBC units. Kilning regimes are sufficient to drive off any grassy notes and remove the DMS precursors to produce a characteristically malty, biscuit flavour with toffee and caramel notes provided from the increased Maillard reaction products.

The mild malts are prepared in a very similar manner to the pale ale malts. They are subjected to higher curing temperatures of between 110-140°C. This provides these mild malts with rich nutty, toffee and caramel flavour characteristics.

Table 2. Representative IOB standard analysis values for a sample of typical UK floor-malts.

Analyses	Best Pale Ale	Mild Ale	Standard	Lager
HWE (l°/kg @ 20°C)	307	296-304.9	301-306.2	307
Moisture Content (%)	1.7-3.0	1.5-3.2	1.8-3.6	1.8-3.9
Colour (EBC units)	4-5	6-7	5-7	2-3
CWE (%)	18-20	17-19	18-20	18-19
Diastatic Power (°L)	35	33-48	39-47	63
TN (%)	1.35-1.5	1.44-1.65	1.46-1.7	1.6-1.75
TSN (%)	0.49-0.54	0.5-0.63	0.55-0.65	0.66-0.68

Vienna Malts

Vienna type lager malts or Wiener malz are much darker than their UK counterpart lager malts, attaining colours of between 5-10 EBC units. These tend to be mid-range values of the Pilsner and Münchener (Munich) type malts. Vienna malts are used as part of the grist in the production of dark, European golden lagers. Two rowed barley, that have higher than average protein contents, are commonly used to achieve increased colour. The malts tend to be well, but not over-modified, and production often encapsulates raised germination temperatures on the final day.

Kilning initiates with a slow re-circulation of air to promote the development of the soluble sugars and amino acids that take part in the Maillard reaction generating the flavoured melanoidin pigments. Paradoxically, compared to the Carapils® malts, endosperm liquefaction must not occur during kilning. Once hand-dry, the kilning regime is ramped up and curing set at around 90°C to impart the dark colour and strong nutty, toffee flavour, whilst limiting the enzyme content of the malt.

Speciality Malts

The following, malts are classified as special malts, produced through high temperature kilning regimes. Such kilning regimes destroy the majority of the enzymatic activity of the grain, but consequentially release additional colour and flavour. If green malt is subjected to these high drying temperatures prior to final curing the grain is not so much kilned but "stewed" producing caramelised malts.

(a) Munich Malt

Munich malts (Münchener Malz) have characteristically high melanoidin contents producing dark, aroma-rich malts (strong nutty flavours) and are typically used for brewing strong, full-bodied dark lagers. The barley used has high nitrogen values, moisture contents greater than 45% and are permitted a long, warm germination period. Today single deck kilns are used to kiln the green malt, where it is held in warm re-circulating air for an extended duration, which slows evaporation and further effect endosperm modification. This allows the accumulation of reducing sugars and amino acids for colour and flavour formation.

These highly coloured (15-30 EBC units) and flavoured malts (mainly imparted by pyrazines) have slow conversion times and reduced extract yields, combined with reduced fermentability due to their poor enzymatic content. However, due the high buffering capacity and reducing power of the resulting wort, derived from the high melanoidin content, beers with good stability are produced.

(b) Crystal and Carapils® (Caramel) Malts

Carapils® and crystal malts are distinctly different from the rest of the malt family due to the physical and structural change that the endosperm starch undergoes. With Carapils® malt, warm air is circulated around the wetted grain encouraging the degradation of the starch and proteins into sugars and amino acids. Once the majority of the conversion is complete, the grain is heated to generate colour and a glazed appearance, with flavours typically noted as "sweet biscuit" and full, but little caramelised flavour. A process that effectively liquefies, mashes and re-crystallises the starch produces Crystal malts.

Crystal malt (hence the name) are the only malts that truly undergo complete biochemical transformation of the starch to sugar. The green malt is deliberately held wet

Crystal malts are currently prepared using fully modified (not over-modified) green malt that is steeped to effect re-wetting, up to 50% moisture, and loaded into a roasting drum. Initially the drum is fired directly at about 50°C to remove any surface moisture from the grain. After this the drum is closed to prevent excess evaporation before the temperature is steadily raised to 65-70°C via external heating (Carapils® malts are dried at lower temperatures, in the range of 55-60°C). This generates the maximum yield of reducing sugars, completely replacing the endosperm with a clear sweet liquid. When this grain is squeezed sugary liquid comes out. At this point the temperature is increased (suddenly or incrementally) to 100°C in order to dry the grain and re-crystallise the sugars. The final curing temperature can be as high as 120-160°C for more highly coloured products.

On slicing the crystal malt grains open at least 90% should appear hard and glassy, as opposed to the Carapils® malt which remains floury and mealy. With both malt types, changing the initial moisture content of the grain and kilning regimes will alter the characteristics of the product.

Crystal malt grains are smooth, round and swollen whilst evenly coloured and bright. Final colour values attained are around 15-35 EBC units (Carapils®) and 10-40 EBC units (Crystal). However, some British caramel malts achieve colours in excess of 300 EBC units with values around 140 EBC units the most popular.

- Crystal malts when added to the grist bill give beer a characteristic flavour with greater body and enhanced haze and flavour stability.

- The crystal malts provide ruby red colours and rich, sweet, full caramel flavours.

- Caution must be taken when using grists comprised of more than 8-12% crystal malt. At this ratio astringent notes can be produced.

- Caramel malts impart more palate fullness, and head formation/retention to the beer.

- A slight red hue is imparted to beer when using caramel malts, in association with light flavours whilst also contributing body.

- As progressively darker malts are produced the flavours they impart develop and become increasingly toffee-like and malty, providing aromatic, luscious honey-like notes.

- Extracts for both malt types are in the range 260-285 l°/kg with moistures between 3-7.5%.

KEYPOINT: Roasted malts start their life in the same manner as any other malt. Initial drying is at relatively low temperatures, but the later conventional drying is superseded with extremely high air temperatures effected through the roasting drum, at the expense of total enzyme destruction.

(c) Amber Malt

Open coke-fired kilning was used at one time to produce amber malts. This no longer occurs and roasting drums are now utilised, hence the finished malt no longer has a smoky flavour. It is normal for finished malt (pale ale or more commonly mild ale) to be directly heated within the roasting drum with temperatures reaching between 49°C and 170°C. These malts are amber coloured, impart a pleasant, dry, biscuit-like flavour with toffee undertones. Amber malts are used to produce special ales with golden, ruby red hues and dry palates. Extract values are typically 270-285 l°/kg, colour 35-85 EBC units and low moistures around 3.5%.

(d) Chocolate and Black Roasted Malts

Chocolate and black roasted malts are very dark coloured products that have no enzyme capacity. They have quite distinct characters, which are different to any of the coloured malts already discussed. Plump barley with a modest nitrogen content (1.5-1.7%) is used and is less modified than typical lager malt.

The kilning temperature is gradually increased to final curing temperatures of 215-225°C. The colour of the grain is frequently checked throughout production and when the required degree is obtained heating is stopped and the roasting process halted by quenching the grains with water. This causes the grain to swell. In total around 15% of grain dry weight is lost during the process as dust and fumes.

Depending upon the quality of product the malt will be chocolate brown to black, the husk should appear shiny and polished, and when the endosperm is cut open it should be floury, mealy and friable not steely or charred.

- Pale chocolate malts attain colours of about 500-600 EBC units.

- Standard chocolate malts have between 900-1100 EBC units colour units.

- Black malts achieve colours in the range 1,150-1,300 EBC units.

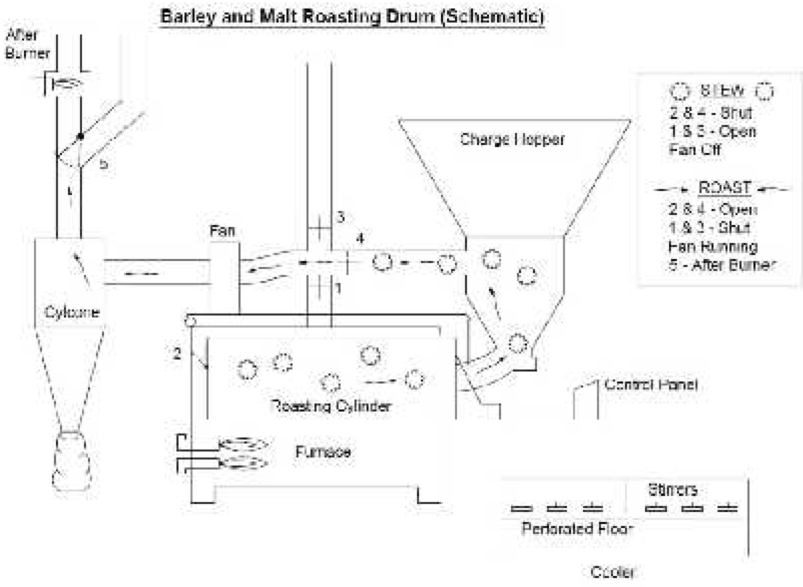
- HWE for both are in the range 255-275 l°/kg and moistures approximately 3-3.5%.

Chocolate malts impart a coffee caramel, burnt flavour mainly provided by pyrroles and pyrazines from the Maillard reaction and black malts impart an acrid sharp taste. Chocolate and black malts are used in sweet stouts and dark beers, whilst in small quantities they can be added to cask conditioned beers to provide a deeper colour in combination with a fuller flavour with a final hang or bite. Typically addition rates are 1.5-3% of the total grist.

(e) Roasted Barley

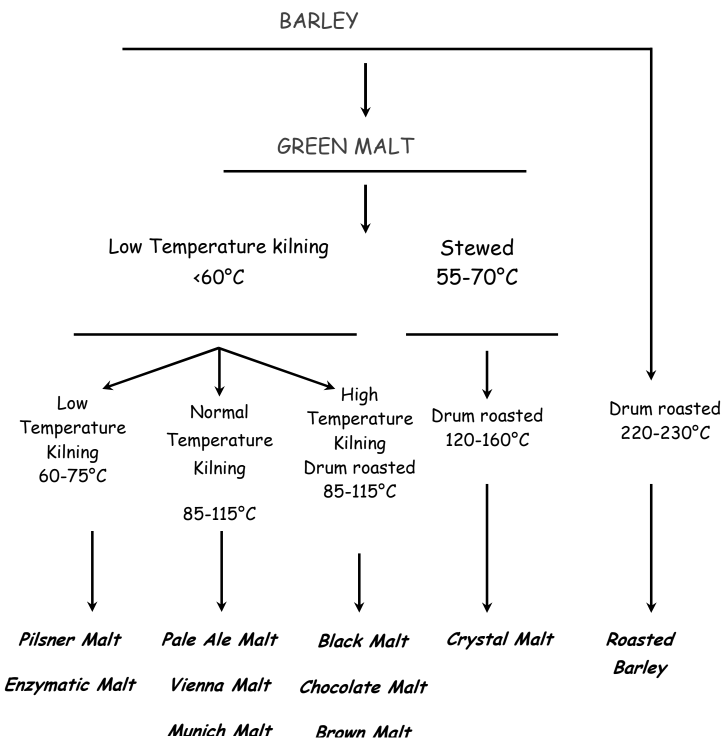
To produce roasted barley, grain at approximately 2-16% moisture is directly fired in a roasting drum for around 2.5 hours. The malting quality of the grain is irrelevant. Over the first 2 hours the temperature within the drum is raised from 80°C to 230°C. This effects very rapid colour formation that needs to be frequently monitored by inspecting the grain every 2-3 minutes. The heat applied to the grain in the final stages is reduced to 215°C. At this temperature roasting is halted and water is used to cool the grain and prevent combustion (a massive risk in roast houses).

The grains typically appear reddish, shiny and black whilst swollen to almost double the size, consequently approximately 50% will be split. Roast barley has a very different flavour than the roasted malts and is described as sharp, dry, acidic, astringent and burnt whilst providing no sweetness. Roast barley achieves colours in the range 1200-1400 EBC units with extracts around 260-275 l°/kg and moistures of 3-3.5%. Roasted barley is mainly used to produce stouts.



(Source: Probat)

Figure 1. A schematic representation of malt production.



Barley and hence the malt are derived from living materials and so are subject to the variations that can occur as a result of genetic and environmental conditions. This means that no two batches of malt are identical. Malt analysis provides guidance on the effectiveness of the malting process and suitability of the malt for brewing.

PRODUCT CONSISTENCY

The people who use our malt expect and deserve a consistently high quality product.

The key factors in maintaining consistent quality are the establishment of, and the measurement for comparison to, a set of process and product **specifications**.

There are a number of measurements that are taken during the process and at the completion of the process which indicate whether the process is in control and whether the malt is of the right quality.

Examples of the most important of these measurements are given below.

The principle of controlling quality is based on setting specifications for each of these measurements, measuring the process and taking corrective action if the product or process is 'out of specification'.

Having said that, there are some factors to be taken into consideration:-

- All measuring instruments have a degree of tolerance.
- The raw materials used in the malting process are naturally grown and therefore cannot be expected always to behave in exactly the same way.
- Errors can be made in sampling, especially when a small sample is taken from a large batch as it may not be representative of the whole.

Therefore it is usual to give specifications a 'range' to reflect the normal expected variation in values.

Notes.
Write down the specifications for a raw material, product and a process that you are familiar with.

METHODS FOR RECORDING, REPORTING AND THE INTERPRETATION OF DATA.

(a) Sampling Schedules.
A sampling schedule is a plan specifying where, how and how frequently samples of the product in process and at the end of process are taken.

A routine sampling schedule is required so that:-

- Key measurements are taken without exception and the whole of the process is covered. It is too late if the first warning of a quality problem comes from the customer.
- The quality picture can be seen from statistically presented data. A very useful quality control method is to look at historical trends. Using this method, current results are compared to those obtained in previous months/years. A sampling schedule makes sure that there are enough data to make these comparisons.
- The work of the people who are sampling and measuring can be organised effectively.

An example of a sampling schedule is detailed in the table below:-

Stage.	Frequency.	Notes.
Raw materials (Barley)	Each delivery.	Frequency depends on supplier reliability and performance.
Barley storage operations.	Each batch / silo	
Steeping Operations	Each batch	Process control to monitor water uptake and the steeping process
Germination	Each batch	Process control to monitor the germination process
Kilning.	Each Batch	Process control to monitor the kilning process
Kilned malt	Each Batch	To monitor post-kiln analysis, potential for blending
Malt for dispatch	Each Silo	To confirm conformance to specification and therefore suitability for delivery
Delivery sample	Each delivery.	Analysis of conformance to customer specification

(b) Collation and presentation of data.

It is likely that there will be a large number of results from a sampling schedule like the one illustrated, especially in a large plant. The results must then be presented in a way that highlights the information as effectively as possible.

There are two main ways of presenting data so that problems are highlighted and action can be taken:-

- Defect highlighting.
- Control charts.

An illustration of how defects can be highlighted is given below:-

Sample Number	Result for malt moisture (Specification = 3.0 to 5.0)
1	4.1
2	4.1
3	3.9
4	4.0
5	4.1
6	3.9
7	4.1
8	**5.1**
9	4.2
10	4.3

It can be seen very quickly that sample number 8 is out of specification.

This type of presentation is useful, if for example, a simple decision is required as to whether the malt is passed as suitable for delivery.

It does not however, assist in analysing results so that some clue as to the cause of the problem result can be discovered.

- It would be useful to know the average moisture of these malts. If that was high, then an adjustment to the process upstream could be made.

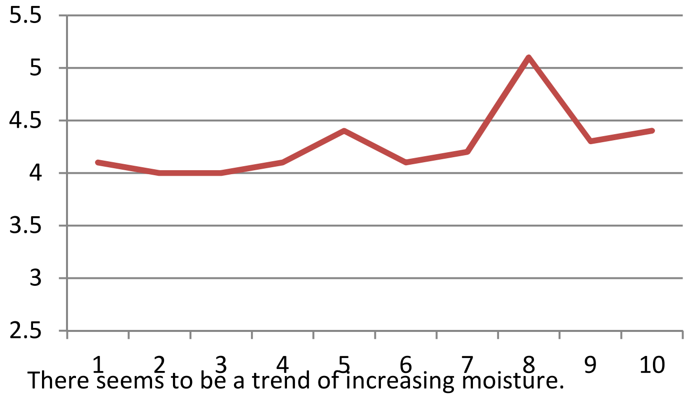
- It would be useful to know the range or spread of moisture of these malts. If the range is very wide, then the process may be out of control and action may be required to resolve the situation.

In order to resolve these problems, statistical analysis in the form of **control charts** is required. Pictures in the form of graphs have much more impact than simple tables.

Control charts can be in different formats and can show:-

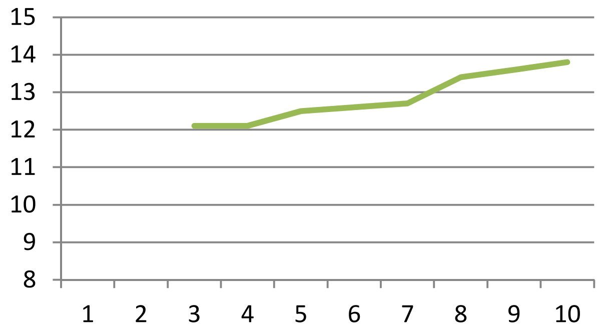
- Individual results plotted on a graph. The specifications can be drawn in as well.
- Average results or 'rolling' average results plotted on a graph.
- The range of results obtained.
- The cumulative effect of deviation from the target and the effect of any action taken.

This is a graph plotting the malt moistures that were shown above as individual results:-



There seems to be a trend of increasing moisture.

The next graph was prepared by plotting a three point moving average of the same moisture results. The first point is an average of moistures 1, 2 & 3 the second point is an average of moistures 2, 3 & 4 and so on.



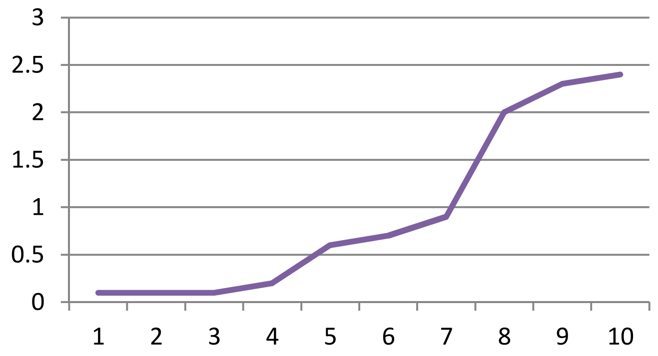
This method of presenting data evens out the highs and lows and illustrates the rising trend very well. From this graph, it can be seen that the moistures have been increasing steadily and that, unless something is done about it, they will likely continue to increase.

The next graph below is called a 'cumulative sum' or 'cusum'. It is designed to exaggerate very graphically, how a trend is going and the effect of any action taken to correct a problem. It is plotted by taking as a starting point the target value which would normally be the middle of the specification.

(For our malt moistures, the middle of the specification would be 4.0.)

The next step is to calculate the difference between the target value and the actual moisture. Then the differences are added up cumulatively as follows.

Sample number	Result	difference from target of 4.0	Cumulative sum
1	4.1	0.1	0.1
2	4	0	0.1
3	4	0	0.1
4	4.1	0.1	0.2
5	4.4	0.4	0.6
6	4.1	0.1	0.7
7	4.2	0.2	0.9
8	**5.1**	1.1	2
9	4.3	0.3	2.3
10	4.4	0.1	2.4



The ideal situation for a cusum graph is for it to run along the zero line because that indicates that there is zero deviation from the target. The graph above shows that moistures were in control until sample number 5 and from then on they were too high.

Many malt houses enter the results of analyses into computer databases. This gives a number of benefits:-

- Recording data is quick and easy.
- It means that cumbersome paper records are not required.
- Defects can be highlighted automatically.
- Records can be easily accessed from a number of points on a network.
- The sort of graphs discussed above can be generated automatically.

PRODUCT AND PROCESS SPECIFICATIONS

Action to be taken when parameters are out of specification:-

There are two points to consider when confronted with an out of specification result:-

- Firstly, what to do with the current problem.
- Secondly, what to do to prevent things going wrong in the future.

When handling any problem, it is best to start with some form of investigation and not to jump to conclusions. The sorts of questions to ask are:-

- Is it real? Are the results correct?
- What is the extent of the problem? Are other batches affected?
- When did it happen? Where did it happen? What else was going on at the time?
- What are the possible causes? What are the likely causes?
- What can be done about it?

This is an example of the action that could be taken to resolve the out of specification high moisture discussed earlier in this section. (That is the 5.1 moisture of sample 8.)

Investigation and action:-

Are the results correct?	Recheck the analysis. -The result is correct
What is the extent of the problem?	Check other malt moistures. -There are no other defects.
When did it happen?	Check the cusum graph. - Moisture started to increase at sample 5.
What else was happening at the time?	Check process activities that could affect malt moisture at the time that sample 5 was kilned - An air-on temperature during curing was below specification.
What are the possible or likely causes?	It is likely that the curing temperature is causing the high moistures.
What can be done about it?	For the current problem:- Blend the batch with a lower moisture malt. The malt is acceptable and blending will not cause any further problems. For the future:- Increase the temperature of the air during curing Investigate the cause of the low air temperature

LABORATORY ANALYSIS

There are three main systems of analysis currently in use:

- The Institute of Brewing analysis (The Institute of Brewing and Distilling).
  IOB – Recommended Methods of Analysis of Barley, Malt and Adjuncts (used in the United Kingdom).
  These methods are no longer maintained, but have been incorporated into the EBC analyses.

- European Brewery Convention analysis.
  EBC – used in Continental Europe and by many British breweries.

- American Society of Brewing Chemists analysis.
  ASBC – mainly used in North America.

Malt Analysis

A large number of often very detailed analyses are carried out on brewing and distilling malts and for a wide variety of reasons. The most commonly used analyses are briefly outlined below:

(a) Hot Water Extract (HWE)

This is probably the most important of all malt analyses. It gives a measure of likely yield in the brewhouse. As such, it reflects the extent to which the endosperm is solubilised during germination of the barley and also the portion that is released by the enzymes during mashing. The higher the value, then potentially the more alcohol that can be derived by the brewer or distiller per unit of malt and the more valuable the malt (especially if other parameters are met).

This method is described briefly – two samples of malt (approximately 100g each) are milled in the laboratory using a Miag mill, one finely (0.2 mm mill setting), the other coarsely (0.7 mm mill setting) and then mixed with hot water. The modified endosperm dissolves in the water and the husk and unmodified starch/ protein is left in the spent grains. This process mimics what occurs in a brewery or distillery mash process.

The **specific gravity (SG)** of the resulting wort is found and a calculation is carried out that determines what percentage of the malt has dissolved. This value may also be as expressed in L^{o}/ kg (i.e. how many litres of wort at SG 1.001 a kilogram of a malt will give at 20^{o}C). The difference between the fine grind and coarse grind extracts gives an indication of how well modified the malt is i.e. the smaller the difference then the higher the degree of modification.

The fine grind/ coarse grind difference indicates the **modification of the malt**. A "steely" or vitreous malt, one suitable only for a mash cycle that includes a protein rest, will have an F/C difference of 1.8 – 2.2%, while a mealy and well-modified malt eminently suited to infusion mashing will have a F/C difference of 0.5 – 1.0%.

(b) Cold Water Extract (CWE)

An alternative measure of modification, although becoming less popular, is CWE. The CWE is the amount of extract that is soluble in cold water (20°C), and this value has a loose relationship to the F/C difference as an indicator of malt modification. A CWE of 19 – 23% indicates the malt is acceptable for infusion mashing; lower values indicate the need for low-temperature mash rests.

(c) Total and Soluble Nitrogen (Protein)

As proteins are made of nitrogen-based compounds such as amino acids, maltsters use protein and nitrogen values interchangeably, where each 1% of nitrogen equals 6.25% of protein. Whether the analysis sheet provides total protein or **Total Nitrogen (TN)**, the figure represents all the nitrogenous matter in the malt, including insoluble forms.

The reference method for TN analysis is Leco combustion, which replaced Kjeldahl digestion and distillation. The Leco method is used to calibrate Near Infra-Red Reflectance (NIR) spectrometry as a simpler and quicker method for routine samples, especially at intake.

For all-malt beers, malt protein values exceeding 12% (1.9% TN) indicate that the beer may be prone to haze formation or present mash run-off problems. European lager and British ale malts usually contain around 11% protein (1.75% TN). One of the major reasons brewers prefer these malts for all-malt beers is because their protein levels are adequate for head-formation, body, and healthy fermentation – yet low enough to present less chill haze potential than high-protein North American malts.

When adjuncts are used, malts containing more than 10% protein are required to achieve acceptable head, body, and yeast nutrition.

Total Soluble Nitrogen (TSN) is also referred to as the amount of protein or nitrogen in soluble form, expressed as a percentage of malt weight. In whichever terms it is expressed, the soluble protein or TSN parameters are used to calculate the soluble nitrogen ratio.

KEYPOINT: The Soluble Nitrogen Ratio (SNR) can also be expressed as the Kolbach Index. SNR is calculated by dividing the soluble nitrogen (or protein) value by the percent total nitrogen (or protein).

The SNR is an important indicator of **malt modification**. The higher the number, the more highly modified the malt. Malts destined for infusion mashing should have an SNR of 36 – 42%, or up to 45% for light-bodied beer. If the wort has an SNR value greater than 45%, the beer will tend to be thin in body and mouthfeel. For traditional lager malts, 30 – 33% indicates under-modification, and 37 – 40% indicates over-modification. More modern malt specifications may show these figures a little higher for lager malts.

(d) Moisture

A weighed portion of the malt is milled, dried off in an oven and then re-weighed. The loss in weight can be attributed to the water driven off in the oven and the results are expressed as a %.

The lower the moisture content the higher the extract in the malt. The moisture content of malt should never exceed 6%; otherwise there is a risk of mould infection that can lead to processing and flavour problems. Malt with moisture in excess of 6% is described as **slack**; the moisture content generally reflects the quality of the malting itself, a high moisture content may indicate a poorly malted or kilned grain. Remember that moisture is driven off during kilning; this means that malts with a higher colour tend to have a lower moisture content.

(e) Diastatic Power (DP)

Diastatic power expresses the strength of starch-reducing enzymes α and β amylase in the malt and is measured in °Lintner (sometimes referred to as IOB units). Diastatic power, considered together with mealiness of the grain, indicates how well malt will respond to mashing. The DP may be as low as 35 – 40 for well-converted, low-protein British ale malt, about 100 for European lager malt, and 125 or greater for high-protein American two-row malt. Six-row malts can have DP as high as 160. The latter malts have more protein, and thus more enzymes to reduce their own starch as well as adjunct starch, while the British malts have enough enzyme activity to convert their own reserves under normal infusion mash conditions.

In the analysis, malt enzymes are extracted with water at 40°c. A standard starch solution is hydrolysed by the malt enzyme extract and the amount of sugars formed is estimated using iodine. The result is calculated as grams of maltose produced by 100 grams of malt.

KEYPOINT: The EBC unit of measurement for diastatic power is °WK (Windisch-Kolbach units). The value of °WK can be converted to °Lintner by the formula DP °Lintner = (°WK + 16) / 3.5.

(f) Dextrinising Units (DU)

While DP gives a measure for all amylases present in the malt, DU specifies the activity of α-amylase. A range of 35 – 50 DU is acceptable, depending on the malt type and the mash program. Munich malt may be less than 10, and pale malts may be as low as 25.

(g) Colour

Colour is a major determinant of beer quality and type and is derived either entirely from raw materials and processing or from the addition of caramel. There is no connection between colour and alcoholic strength of the beer. The recommended method for determining colour is to measure absorbance at 430 nm, which is multiplied by 25 (and any dilution factor), to give EBC colour units. Alternatively, the beer can be compared by eye against standard coloured discs.

In the United States, colour is expressed in terms of the Standard Research Method (SRM) values set by the ASBC or in °Lovibond, an older method of visual measurement upon which SRM is based (the two measurements are essentially equivalent).

The formula °EBC = (°L X 2.65) - 1.2 gives a reasonably accurate conversion to °Lovibond values.

(h) Friability

A physical measure of how well malt is modified can be made by assessing how friable the malt is. This analysis, which is carried out using the **friabilimeter,** measures what percentage of the malt can be milled under gentle conditions. Normal range = 85 – 95%.

(i) Homogeneity

Dead grains do not malt and can lead to processing problems in the brewery or distillery. The homogeneity analysis that is also carried out using the friabilimeter measures how many dead (or very poorly modified) grains are present in the finished malt. Minimum results of 96% (i.e. fewer than 4% dead or unmodified corns) are normally specified.

(j) Dimethyl Sulphide (DMS)

Brewers are divided in their preference for the character of DMS in beer – some say it contributes to lager qualities but others prefer low levels. All the DMS in beer originates from the germinating embryo of malting barley. This precursor known as DMS-P or SMM (S-methylmethionine) is more concentrated in a well-modified malt due to a greater embryonic development. SMM and dimethyl sulphoxide (DMSO) are converted to DMS during kilning and wort boiling. More intensive kilning, and longer kettle boiling, can drive off DMS.

There is more SMM in lager malt than ale malt because ale malts are more intensely kilned and SMM is driven off; consequently there may be more DMS in finished lager malts. Brewers not wanting DMS should ensure that they use malt with a low SMM value and to use a long and vigorous boil to drive the DMS off.

(k) Fermentable Extract (FE)

The HWE described above measures all the components of the malt that are soluble in water. Many of these components are not sugars and cannot be fermented by yeast into alcohol.

Brewers and distillers are obviously interested to know how much fermentable extract is present and so the wort produced for the HWE test is mixed with yeast and allowed to ferment. By measuring the SG of the liquid after fermentation, it is possible to calculate what percentage of the malt is fermentable.

Normal range of results for FE is 66 – 67%

$$Fermentability = \frac{FE \times 100}{HWE}$$

Normal range of Fermentability = 86 – 87.5%

(l) Predicted Spirit Yield (PSY)

It is possible to predict the distillery spirit yield from the laboratory data described above.

In a malt distillery, this can be done using the obtained values of the malt soluble extract (SE7), the % fermentability and a fixed factor:

PSY (lpa/t, dwb) = fermentability (%) x SE7 (dwb) x 6.06

(Where lpa/t = litres of pure alcohol per tonne, and dwb = dry weight basis).

In a grain distillery, the calculation is a little more complicated due to the use of both malt and wheat (or maize). The first step is to calculate separately the PSY of the malt and the PSY of the other cereal. Then it is an easy matter to calculate the PSY of the particular mash recipe in use at the time. For instance, in a distillery using 10% malt with a PSY of 420 lpa/t and 90% wheat with a PSY of 370 lpa/t, the calculation and result is:

420 x (10/100) + 370 x (90/100) =375 lpa/t

MALT SPECIFICATIONS

Malt Types and Products

Two general types of malts are produced commercially – brewers and distillers malts (see Table 1). Brewers malts are made from plumper, heavier kernels with a friable starch mass. They are steeped and germinated at moisture contents ranging from 43 – 46%; the final temperature used in drying malts is in the range of 71 – 82^{o}C. These malts are dried to 4% moisture. The final curing temperature reduces the enzyme activity of the malt, darkens the malt and hence the wort made from it and also increases the flavour and aroma compounds.

Distillers (or high diastatic) malts are made from smaller barley kernels that are higher in protein and enzyme content. This barley is steeped and malted at a higher moisture content (45 – 49%) and dried at lower temperatures (49 – 60^{o}C) to a higher final moisture content than the brewers' type malt.

Biochemical Changes during Malting

Two important changes occur during malting. Firstly, the barley activates its own enzyme systems to release the energy reserves stored in the endosperm to germinate and grow in the field. Secondly, during the malting process the enzymes breakdown the endosperm releasing nutrients essential for yeast growth (fermentation).

Both outcomes are important to the brewer to ensure that they obtain the best results from the raw materials. It is therefore necessary to use a series of tests to measure the changes that occur during the malting process and to give some indication of the expected brewing performance of the malt.

Barley and hence the malt are derived from living materials and so are subject to the variations that can occur as a result of genetic and environmental conditions. This means that no two batches of malt are alike. Malt analysis provides guidance on the effectiveness of the malting process and suitability of the malt for brewing.

Malt is tested in accordance with the Institute of Brewing (**IOB**), European Brewery Convention (**EBC**) and the American Society of Brewing Chemists (**ASBC**) methods of analyses (see above). However, malt specifications are not always the most reliable indicator on how well the malt will perform in the brewery, and maltsters, brewers and distillers are continually looking for better predictions of the brewing performance of malt.

(a) Barley Variety

Each variety has its own characteristics; its genetic make-up determines whether it has qualities that are important to brewing. Some varieties produce better brewing and distilling malts than others.

Table 1. Comparative ranges in the composition of barley and malt.

		Malt	
Measurement	**Barley**	**Brewers**	**Distillers**
Kernel weight (mg)	32 – 36	29 – 32	29 – 32
Starch (%)	55 – 60	50 – 55	50 – 55
Sugars (%)	0.5 – 1.0	8.0 – 10.0	8.0 – 10.0
Total nitrogen (%)	1.6 – 2.3	1.6 – 2.3	1.6 – 2.3
Soluble nitrogen (% of total)	10 – 12	35 – 45	40 – 50
Diastatic Power	50 – 60	100 – 150	150 – 250
α-Amylase	Trace	35 – 45	55 – 65
Proteolytic activity (arbitrary units)	Trace	15 – 20	20 - 25

The following characteristics will vary according to the barley variety:

- Percentage of nitrogen (protein) in the grain.
- Proportion of small to large starch granules.
- β-glucanase levels.
- Homogeneity of corn size.
- Ability to produce the necessary enzymes.

These factors are also influenced by environmental conditions, e.g. weather, soil type and fertiliser. The barley variety is also important not only because of its brewing characteristics, but because of special characters it gives to the finished beers.

(b) Extract Yield

The extract yield is a measure of the amount of sugar potentially recoverable from the grain during the brewing process. There are a number of recognised methods for measuring extract potential. Briefly, the % extract is measured by preparing a dilute mash in distilled water with very finely ground grist. After a set stand time at a particular temperature the solids are separated by filtration and the gravity of the extract is measured using a specific gravity bottle. The two standard methods are the IOB and the EBC methods:

- In the IOB method the mash stands for 60 minutes at 65°C. The extract is expressed as **L°/ kg**.

- The EBC method there are two mash stands at 45°C and 70°C. The extract is expressed as **% sugar** (sucrose) over the total weight of malt.

(c) Modification

This is probably the most important measurement the brewer has to gauge and this measurement demonstrates how well the maltster has done his job! Modification gives an indication of how evenly the cell structure has broken down in the endosperm during the malting process. The degree of modification can be measured in a number of ways:

- Soluble nitrogen/ total nitrogen expressed as a % (**Kolbach index**) that measures how much of the nitrogen wall structure has been broken down. The higher the value, the greater the modification of the protein matrix surrounding the cells in the endosperm.

- Difference in extract between a coarse and fine grind. When malt is ground the cells are crushed up and the extract can be recovered for analysis. In brewing, it is necessary to have a relatively coarse grind so that the residues can form a filter bed for wort separation. The difference in extract between the coarse and fine grind shows how much of the structure of the endosperm has broken down. The smaller the difference, the better the modification.

- Friability. This is the amount of energy needed to grind the malt. As the endosperm structure is broken down, the grain becomes easier to mill. The friability meter (Friabilimeter) measures the amount of energy required to mill the grain – the lower the energy then the better the modification. It also measures the homogeneity or evenness of the modification.

- Cold water extract measures the amount of sugars broken down and released during the malting process – a greater value for the cold water extract means a higher modification

It is important to use malt that has been correctly modified. Under-modified malts will give brewhouse problems, for example, poor extract recovery and hinder wort filtration. With over-modified grains the extract is easier to recover but some of the extract will have been lost to growth. Over-modified malts also give wort separation problems, lend a thin character to the beer, and produce weak head retention; losses can also be incurred as over-modified malts break-up easily when handled. If slightly less well-modified malts are used head retention is favoured.

(d) Visual/ Sensory Evaluation

Lot analysis specifications are really best for making comparisons between lots and between products. You can draw your own conclusion by putting the malt through a few simple tests.

Malt needs vary depending on the style of beer to be brewed and the mashing profile to be used. Experienced brewers can often tell just by looking at and handling the malt how it will perform in the mash. Take some time to compare samples of different malts to give you a reference point. Any sample should include a handful of at least 50 kernels for a reasonable analysis. The main rules of thumb are that the majority of the kernels should be of similar size, modification, and colour for good milling and mashing, and should show no visible signs of disease (that is, discoloured or seriously misshapen kernels). The plumper and larger the kernel, the better! In base malt, the ends should not be vitreous, or glassy. You should be able to easily crush the malt with your fingers. Chewing the malt will also tell you about its friability, or softness, as well as its flavour and aromatics.

If you are very concerned about degree of modification, you could also cut into a handful of malt to expose the acrospire, the embryonic barley plant inside the husk. The length of the acrospire should be three-quarters or greater of the kernel in well-modified malt. Well-modified malt will also float in water.

Contribution of Malt to Wort Quality

Malt supplies the sugars required for alcohol production and the main nutrients for satisfactory yeast growth. The typical components supplied by the malt for yeast fermentation include:

- Simple sugars for fermentation.
- Amino acids (also called free amino nitrogen) for yeast growth.
- Mineral ions to enable enzyme function (especially zinc and copper).
- Vitamins for healthy yeast growth.
- Some lipid material (fatty acids and sterols) for yeast cell wall production and function – although the yeast manufactures most of these compounds itself using oxygen from the wort.

Generally, in an all-malt wort, the malt supplies all the necessary nutrients to meet the needs of the yeast. High adjunct worts may have to be supplemented by the addition of yeast food because they contribute little soluble nitrogen to the wort. Malt also contributes to the appearance and taste of the beer because:

- Most of the colour of the beer comes from the crushed malt or is developed during the brewing process from reactions between malt compounds.
- The colour compounds also give beer a characteristic flavour from 'light biscuity' for a lager to a strong burnt acrid taste from black and roasted barley.
- The mouth feel and texture of the beer mostly comes from the residual unfermented sugars (dextrins) derived from the malt.
- The pH of wort and beer is regulated through the interaction of malt components and ions in the brewing liquor.
- Beer foam is made up from hydrophobic proteins that originate from malt.
- Other proteins derived from malt cause non-biological haze. Non-biological hazes are composed of colloidal particles that give beer a cloudy appearance. Most non-biological hazes are comprised of particles brought about from the interaction of protein and polyphenols, derived from the malt, to produce protein-polyphenol complexes. Carbohydrate hazes consist of ungelatinised starch, pentosans, and β-glucan. These "invisible" hazes are produced due to the incomplete degradation of the carbohydrates during malting and mashing.

Malt also has an effect on beer flavour due to the action of certain flavour active compounds, including:

- Dimethyl sulphide (H_2S) is derived from malt and it has a flavour of 'uncooked sweet corn' and is often associated with lagers. Off-flavours can develop from H_2S, present in beer as a metabolic by-product of yeast fermentation, or from the degradation of the amino acids methionine and cysteine. Compounds such as methyl mercaptan (CH_3SH) and disulphides, (dimethyl disulphide $CH_3S\text{-}SCH_3$) are produced during fermentation imparting cooked cabbage, sulphidic characters.
- The amino acids, derived from malt, are converted by yeast to flavour active compounds especially if they are in excess concentrations. This excess of flavour compounds can produce beer with an undesirable taste or unbalanced taste.
- Various stale flavours are encountered during brewing that originate from a variety of sources. The most important staling compounds are aldehydes, formed from unsaturated fatty acids, which are derived from malt and hops. Linoleic acid is oxidised during malting and mashing to produce various "off-flavoured" compounds in particular trans-2-nonenal. Trans-2-nonenal is detectable at concentrations as low as 0.1 ppb and imparts a papery, cardboard taste to the beer. It is usual for the aldehydes, produced from oxidation of the unsaturated fatty acids during malting and mashing, to be evaporated off during wort boiling. The oxygenated fatty acids remain and have the capacity to produce stale flavours later in the process.

Specifications for Brewing and Distilling Malts

The essential property of any brewing or distilling malt is its extract potential. This is indicated by the **Hot Water Extract (HWE)** parameter, which determines how much sugar is available for alcohol production. Friability and homogeneity values, based on a physical crushing technique, are an indication of how well the maltster has modified the malt. The **Soluble Nitrogen Ratio (SNR)** or **Kolbach Index** both measure the degree of modification based on the amount of protein breakdown during malting. Lager malt does not have to be so well modified as an ale (or distilling) malt – as the "head" on a glass of lager depends essentially on the protein content.

Yields in both distilling and brewing are important. Distillers are interested in how much spirit can be obtained from the malt, hence the requirement for **Fermentability**, **Fermentable Extract (FE)** and **Predicted Spirit Yield (PSY)** specifications, whereas yields in Breweries are measured in terms of extract before fermentation.

Brewers are particularly concerned about the final colour of their beers and specify malt colour in order to control this characteristic. Lager beers, being very pale use malt with low colour values – compared with the higher colour values for ale malt that produces very much darker beers. The maltster controls the development of malt colour during kilning.

Some brewers and grain distillers make use of other cereals as well as malt and so require a high enzyme malt to assist in the conversion of the non-malted cereals during mashing. A minimum ?-amylase activity (also known as **Dextrinising Units**) and **Diastatic Power (DP)** are specified to achieve this. Diastatic power is the measurement of the combined activities of the α- and β-amylase enzymes. These enzymes are heat sensitive and so can also be used as a means of confirming that the kilning regime has not been too severe.

Individual customers also specify certain flavour characteristics in their malt. Some distillers have requirements for peat smoke flavour and the distilling malts are peated to varying degrees. Some lager beers are identifiable by particular flavours and odours, so lager malts may often have a DMS specification. The maltster is able to achieve this wide range of flavour characteristics by adjusting the germination and kilning processes.

Table 2. Shows a list of analytical parameters used in specifications for ale and lager malts.

Analytical Parameter	Abbreviation	Ale Malt	Lager Malt
Moisture (%)		3.0 – 4.0	5.0 – 6.0
Hot Water Extract (%)	HWE	76.5	75
Fine Coarse Difference (%)	F/C Diff	1.5	1.5 – 2.0
Fermentability (%)		-	-
Predicted Spirit Yield (litres of alcohol/ tonne)	PSY	-	-
Total Nitrogen (%)	TN	1.5 – 1.6	1.75
Soluble Nitrogen Ratio (%)	SNR	38 – 44	34 – 40
Kolbach Index		-	38 – 42
Phenols (ppm)		-	-
Dimethyl Sulphide (ppm)	DMS		8
Colour (EBC units)		4.0 - 6.0	2.0 – 3.0
Viscosity (cP)			1.57
alpha-Amylase	DU		30
Diastatic Power (°L)	DP	50	75
Friability (%)		90	80
Homogeneity (%)		96	96

Table 3. *Typical list of analytical parameters used in specifications for distilling malts.*

Analytical Parameter	Abbreviation	Typical Distilling Malt	Range (Dist. Malt only)
Moisture (%)		5.0	4.5 – 5.0
Hot Water Extract (%)	HWE	76.5	76 - 78
Fine Coarse Difference (%)	F/C Diff	1.5	1.0 – 2.0
Fermentability (%)		86.8	86.5 – 87.5
Predicted Spirit Yield (litres of alcohol/ tonne)	PSY	402	400 - 416
Total Nitrogen (%)	TN	1.65	1.5 – 1.7
Soluble Nitrogen Ratio (%)	SNR	38 .6	37 - 40
Phenols (ppm)		4	0 - 80
Colour (EBC units)		2.3	2 - 3
NDMA (ppb)		<1.0	< 1.0
α-Amylase	DU	36	35 - 40
Diastatic Power (°L)	DP	88	80 - 90
Friability (%)		96	>95
Homogeneity (%)		98	>98

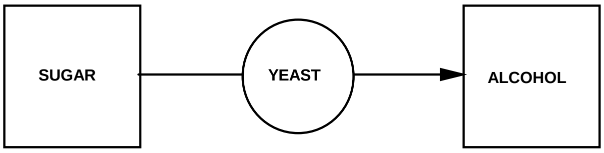
The consistent achievement of these specifications depends on the maltster's expertise in the selection of barley variety and quality, correct drying and storage, and complete control of timing, temperature and moisture throughout all stages of the malting process. The role of the maltings laboratory (and effective reporting systems) in producing reliable quality assurance information in order that this end is achieved cannot be under-estimated.

A Definition of Beer:-

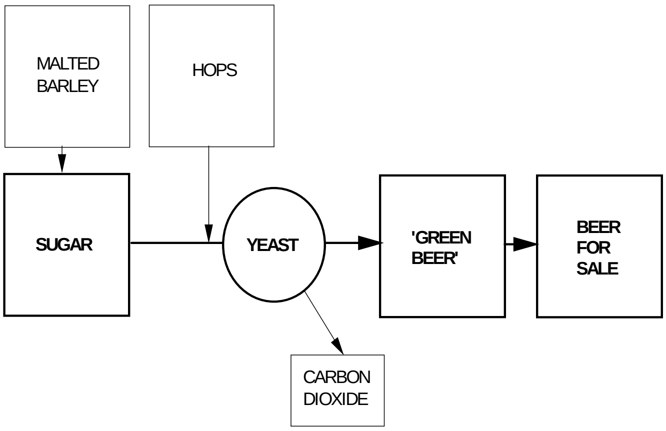
In its basic sense, beer is an alcoholic beverage produced by the fermentation of sugars derived from malted barley and flavoured with hops.

There are some minor differences where malt is supplemented with adjuncts or where the hops are replaced by other flavours, but this definition would be recognised by the majority of people round the world.

The manufacture of all alcoholic beverages utilises the ability of yeast to ferment sugar into alcohol.



The full process also involves preparing the immature or green beer for consumption.



BEER TYPES

Different types of beer.
Different areas around the world have developed their own types of beer. The variations have come about through a combination of the materials available for its manufacture and the tastes of the consumers.

Lager is by far the biggest proportion of beer sold. Its delicate flavour comes from:-

- The use of a malt that is relatively undermodified and lightly kilned.
- A relatively low bitterness.
- The use of a bottom fermenting yeast.
- Cold maturation.

Ales come from:-

- The use of a well modified malt and specialty malts which is sometimes highly coloured.
- They use of a top fermenting yeast.

Ales come in various forms, bitters, pale ales and mild beers.

Wheat beers are beers produced from the use of a proportion of malted wheat, often around 50%, replacing some of the "malted barley.

Stouts are very dark in colour and richly flavoured from the use of highly coloured malts or roasted barley.

Low alcohol / alcohol-free beers are produced by several different processes and their definition varies in different countries.
Usually alcohol-free means less than 0.05% (vol/vol) alcohol and low alcohol means less than 0.5% (vol/vol) alcohol (less than 1.2% in UK).

- Often produced by removing alcohol from standard strength beers (for example, by evaporation or reverse osmosis methods).
- Can be produced by a very limited fermentation process, by making a very low fermentable wort.
- Not to be confused with malt drinks, which are essentially unfermented wort.

Low-carbohydrate beers are brewed by producing wort that is more fermentable than in “standard beers” by several techniques, but usually by adding additional enzymes to convert more of the non-fermentable sugars into fermentable sugars. These enzymes may be produced from unboiled wort and added to conventional wort, or from commercial suppliers derived from fungal and/or bacterial sources and added during wort production or during fermentation. The overall objective by making the wort more fermentable than standard (or “super-attenuated”) is to brew products that have lower carbohydrate content in the finished beer.

ADJUNCTS AND COLOURED MALTS.

Adjuncts are solid or liquid brewing raw materials that are used to supplement the malt in the grist.

They are used for a number of reasons:-

- To change the character of the beer by altering its colour or flavour.
- To improve the quality of the beer for example its head stability, its fermentability or its haze potential.
- To increase the capacity of the brewhouse by the addition of liquid adjuncts to the wort boiling vessel (copper/kettle).
- To reduce production costs.

Categories of Adjunct.

There are four major categories of brewing adjunct:-

- Malted cereals that are used in the grist along with the malt.
- Processed cereals that are also used in the grist.
- Unprocessed cereals that require additional processing in the brewhouse.
- Sugars or syrups that are added to the wort kettle or later in the process.

Coloured malt.

Coloured malts are used to increase beer colour, to modify flavour and because of their nature they produce a more stable beer. During the extra kilning or roasting used for coloured malts, the enzymes will have been destroyed.

Crystal malt is produced by a different kilning procedure. The germinated malt with a high moisture content is heated in a roasting drum to saccharification temperature of around 65^{o}C and is 'stewed' before lightly roasting and drying. This produces a high colour and a distinctive toffee flavour. Crystal malt is used in ale brewing to provide a rich red colour and a distinctive flavour.

Carapils and Munich malt are similar to crystal malt but they have a lower colour and a more delicate flavour from using undermodified malt followed by less kilning. Carapils and Munich malt are used to colour and flavour lagers.

Amber malt and Brown Malt are produced by roasting the malt in a drum to give it a slightly higher colour and biscuity flavour.

Black malt and Chocolate malt are produced by roasting finished malt in a drum at higher temperatures. Both malts have a very high colour and a dry bitter flavour. They are used in stouts to give a very dark and highly flavoured beer, but are also used at low inclusion rates to introduce flavours and limited colour to paler beers.

Roasted Barley is used to contribute colour and its distinctive burned coffee flavour to stouts.

Wheat.

Wheat is a cereal like barley and it can be malted in the same way. It does however, have different characteristics, for example it has no husk after threshing and its starch is less protected. The flavour it produces is different and the nature of its protein is different from barley protein which improves head stability but it will not clarify on the addition of finings.

Malted Wheat is used as the main carbohydrate source in Munich Weissbier. It contributes to the beer's distinctive appearance, colour flavour and outstanding head stability.

Torrefied Wheat is produced by heating the unmalted grain to rupture the internal structure and release the starch so that it is accessible when mashed in the brewhouse, in a similar process to popping corn. Torrefied wheat is used at up to 10% to improve the beer's head stability and (because it is cheaper than malt) to save costs. It brings some bisuity flavour but not to the same degree as malt

Wheat Flour. is produced by milling wheat, the process releases and separates starch from the embryo and the protein that is present at high levels. It is used at up to 10% to improve the beer's head stability, to reduce protein levels in the grist and to save costs because it is much cheaper than malt.

Maize.

Maize is a common crop grown in warm and temperate climates. It is a lower-cost source of carbohydrate. The starch is readily accessible but it must be 'gelatinised' at high temperature before it can be converted into fermentable sugar. Maize is used at up to 20% of the grist in lager to reduce malty flavours and produce a clean delicate flavoured beer.

Maize grits are produced by milling the maize and at the same time removing the germ which contains protein and oil. Maize grits must be cooked in the brewhouse to gelatinise the starch. Maize grits are cheaper than malt and can reduce costs.

Maize flakes are produced by processing grits through hot rollers which gelatinises the starch and makes it accessible to enzyme action.

Rice.

Rice is a very common crop and a major source of carbohydrate. Rice is used in brewing for the same reasons and in the same way that maize grits are used though usually it is milled in the brewhouse before being cooked.

Sugar.
Sugar can be grown naturally as in the case of sugar cane or beet. It can also be produced from starch, usually from maize. The method of production will dictate the type of sugar - sucrose from cane sugar, glucose or maltose from starch. A range of fermentabilities and flavours are available.

Sucrose is mostly used in liquid form, it is highly fermentable and is usually added to the boiling vessel (wort kettle). It is used to supplement the malt where malt processing plant (storage, mills, mash tuns etc.) is a limiting factor. Sucrose can be added to the beer after fermentation as 'primings' to provide sugar to encourage conditioning or increase sweetness.

Invert is produced by hydrolysing sucrose and it can be liquid or solid. It is added to the wort kettle and is used for the same reasons as sucrose although it has a more distinctive flavour.

Glucose is produced from starch and is used in liquid form in the same way that sucrose is used. Its fermentation characteristics are very similar to sucrose.

Maltose and Maltotriose etc. are produced from starch and are used in liquid form in the same way that sucrose is used. Their fermentation characteristics depend on the sugar type so that they can be used to modify the fermentability of the wort and therefore the character or alcohol content of the beer.

Lactose is produced from milk whey and is used to contribute a milk character to milk stout. It is added to the wort kettle.

Caramel is extremely dark and has a burned toffee flavour. It is produced from sugars and is used to contribute colour and flavour to beers like stouts and dark milds.

Un-malted cereal adjuncts are typically used in the brewery or distillery in one of three ways.

Cereal cooker – in a cereal cooker the adjuncts generally contain starch in their unrefined forms, such as grits, flour, dry grain or starches. These adjuncts need to be gelatinised (to allow the starch molecule to be enzymatically converted to fermentable sugars) and liquefied to allow solubilisation and pumping to the main malt mash in a second vessel where the malt enzymes can now be used to modify the starch from the adjunct and create fermentable sugar.

Not all cereal starches gelatinise at the same temperature. Barley starch gelatinises at around 61 – 62°C, whereas rice and maize starch gelatinise at temperatures between 70 – 80°C. If the adjuncts are not pre-gelatinised they must be cooked in a separate vessel before addition to the main mash.

Mash tun – if the starch gelatinisation temperature is lower than the malt conversion (or saccharification) temperature required, or when the adjunct has been pre-gelatinised by flaking (using steam or infrared heating), torrefication (expanding by heating), or pre-refining (syrups), then the adjunct can be added directly to the malt in the single mashing vessel.

Brew kettle – sugars are typically added directly to wort kettle where they are readily dissolved and sterilised.

As well as un-malted cereals such as corn, rice, and wheat being used by brewers as adjuncts, the use of un-malted barley is also common as it gives a rich and grainy flavour to the beer (as well as being typically cheaper than the malted equivalent). It will help improve foam retention at the detriment to physical stability due to the higher level of nitrogen and proteins.

MALT HANDLING IN THE BREWERY

Raw Material Intake
The responsibilities of the brewer start as soon as their raw materials are delivered. It is important to routinely check the raw material consignment to ensure that what the brewery has ordered has been delivered.

(a) Sampling
When the consignment of material arrives at the brewery, the delivery vehicle is weighed in and then again before it leaves the brewery; this is to measure and record the quantity delivered. At this point the materials are randomly sampled and checked for quality and specification. For example, malt will be checked for moisture content – the brewer wants to pay for extract not water.

The sampling of malt can be carried out using spears. These are hollow spikes that are pushed into the grain bed and when withdrawn retrieve a sample of the grain. Many designs are available to the brewer, but to avoid bias results samples must be taken from randomly defined points throughout the grain bed. The main priority for the brewer is to obtain a homogeneous batch of malt; this helps avoid production problems. For example, a delivery of malt may be composed of two different batches. This batch may contain 95% Malt A and 5% Malt B, but if malt B is not high quality (i.e. it is undermodified or has a high β-glucan content) this 5% may cause production problems.

These problems include:

- Poor extract recovery
- Sticky spent grains
- Viscous wort
- Poor wort separation
- Potential carbohydrate haze
- Poor clarification performance

KEYPOINT: The most important issue for malt, whether during production in the maltings or during processing in the brewery is HOMOGENEITY. Non homogeneous malt with some undermodification in a fraction can cause problems such as viscous worts, hazes and reduced extract recovery.

Sampling is therefore very important. In modern times a more refined method of sampling is by use of a trickle filter or diverter system. This equipment either continuously takes small samples of material as it is conveyed to the grain store or diverts the occasional sample into a collection chamber as the conveyor transports the cereal. These systems give a more representative cross section of the delivery for analysis, and consequently a more accurate prediction of brewhouse performance. The majority of breweries unload their malt into a delivery bay from where the malt will be transported to a storage silo, by pneumatic methods or conveyor belt.

(b) Storage

We are already familiar with the concerns of barley storage and these are no different for cereals entering the brewery. The different types of materials (grains, flakes, grits, flours, starches and syrups) are all stored separately until required for processing. Most storage silos are constructed from stainless steel but they can be made from concrete. Silos have smooth walls with hopper bottoms to ensure easy grain withdrawal. The malt and cereal adjuncts are stored at their delivery moisture levels to:

- Discourage the growth of pests such as insects, moulds, fungi and bacteria.
- Prevent alteration to the biochemical structure of malt/adjunct prior to use (for example increasing in moisture or “turning slack” and losing enzyme activity).

Storage and handling of syrups is unique. Syrups are stored in insulated tanks and held at elevated temperatures (glucose syrups 45°C and sucrose/invert syrups 25°C). Warm storage is essential to prevent the syrup from crystallising, whilst the viscosity of the syrup will hinder, if not halt, transfer between vessels. Microbial infection can be avoided by ensuring that glucose syrups contain at least 80% solids and sucrose syrups 67% solids. It is extremely important to avoid condensation within the vessel which can drip onto the liquid surface and dilute locally the syrup. Maintaining the syrups at such solids loadings or concentrations produces osmotic pressures within the syrup at which few microbial contaminants can survive. The use of sterile air filters will also help maintain sterility. Of course all storage silos should be cleaned at regular intervals to prevent the build up of soil and contaminants.

KEYPOINT: Hand evaluation of the materials appearance and odour should never be overlooked; it is a quick and easy method of material analysis.

Malt and adjuncts should be delivered and stored in sufficient quantities to defend against unforeseen shortages that could halt production. However, storage should not be excessive – providing for only a few days’ requirements. Otherwise capital becomes unnecessarily tied up in expensive material and storage capacity.

(c) Screening/Grading and Dressing

Prior to despatch from the maltings the malt is screened and dressed. To ensure uniformity of milling, it is necessary to have a reasonable consistency in the size of corns. To obtain such consistency, bulks of malt are often graded. The malt is carried by pneumatic or mechanical means past magnetic separators to rotating, cylindrical, oscillating or flat-bed screens. Not only are corns of unwanted size rejected (these are sold for animal feed wherever possible), but foreign matter such as straw, stones, string, sacking and metal particles are removed.

Magnets

It is essential that pieces of metal that may be in the malt should be removed before they reach the mill, because such metal can cause a spark and start a fire or explosion. Separation is effected by placing permanent magnets either in the malt chute to the dressing machine or across the feed to the mill.

Malt should flow over the magnet in a thin layer and at the same rate as it is being ground, thus allowing the magnet to extract any metal that may be in the malt.

Dressing

The malt dresser was usually a cylindrical screen revolving inside a wooden casing that has detachable doors on either side for easy access. The last part of the screen consists of a mesh large enough to let malt pass through to a small hopper feeding the weigher or the mill. Any foreign matter such as pieces of wood, metal, or stone, which are too large to pass through this mesh, is carried forward to the end of the screen where it is rejected via a spout into a bag. When the culms were separated from the malt during screening, circular brushes revolved against the exterior of the screens thereby ensuring that the apertures were kept clear.

In modern installations there is a separator/dresser to remove foreign material based on size, and in addition a de-stoner that separates material according to density. In this way small stones of the same size as the malt grains can be removed and it has been found that the amount of stones can vary considerably according to the source of the barley. Stones can damage mill rolls and can also create sparks in the mill.

MILLING OBJECTIVES AND CONSIDERATIONS

Malt contains all of the essential ingredients for beer production, all the brewer must do is open up the malt and add water, yeast, hops and energy. The first step is to mill the malt and adjuncts to produce the **grist** (cereal flour). From the flour grist we **extract** the sugars, proteins and other nutrients essential for yeast fermentation.

There are two main objectives of milling malt and cereals for brewing:

1. Particle size reduction
2. Particle size control

During milling, the malt grain is crushed so that the highest possible yield of soluble nutrients can be extracted during mashing. This physical degradation of the malt into an array of small particles is called **comminution**. The greater the degree of comminution (i.e. the finer the flour produced) the larger the surface area available for enzymatic attack – this means there will be a better extract efficiency. As a comparison it takes longer for a sugar lump to dissolve in your coffee than a spoonful of granulated sugar.

Friability

The action of comminution is influenced by malt **friability**. What is friability? The friability (extent of modification) of malt is a measure of the amount of energy required to "crush" the grain.

During malting of barley the endosperm is modified to differing extents with particular areas prone to under-modification (high nitrogen, steely areas) and over-modification (the low nitrogen, mealy areas). The internal structure of well-modified malts fully degraded by diastatic malt enzymes are said to be friable – they are easily crushable and therefore require only a small input of mechanical energy (**milling**) to break them up. In the case of poorly modified malt, the internal structure of the grain remains fairly intact (they are less friable) and requires a high input of energy via milling to comminute the grain.

Milling of well-modified malts yields grist with a large proportion of fine flours and small grits, whilst under-modified malts produce coarser grist. This is because the endosperm cell walls that survive in an under-modified grain bind the particles together giving coarse grits. Therefore, inhomogeneous batches of malt subject to the same milling operation (i.e. the same mill setting) will breakup into different sized particles – this is dependant upon the extent of modification.

If milling is excessive the grist produced will be too fine for Lautering (but may be suitable for **Mash Filters**). Extremely fine grist will theoretically yield maximal extract but hinder the separation of wort to the extent that wort filtration can be halted (a "set mash"). Wort filtration (**lautering**) is affected by particle size because very small particles reduce the porosity of the filter bed, which can become compressed. This causes process down time, and various quality issues associated with extended processing.

There is therefore a trade-off between extract yield and process efficiency.

Large grist particles
Fast filtration = Reduced extract recovery

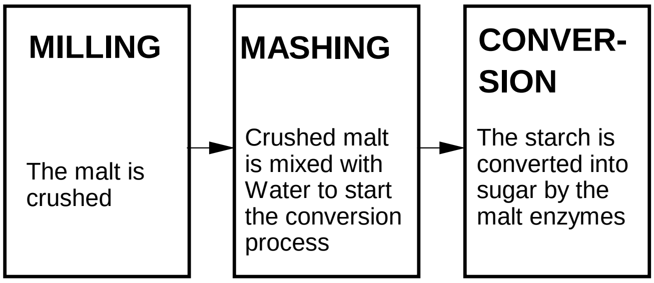
Small grist particles
Slow filtration = Increased extract recovery

MASH CONVERSION.

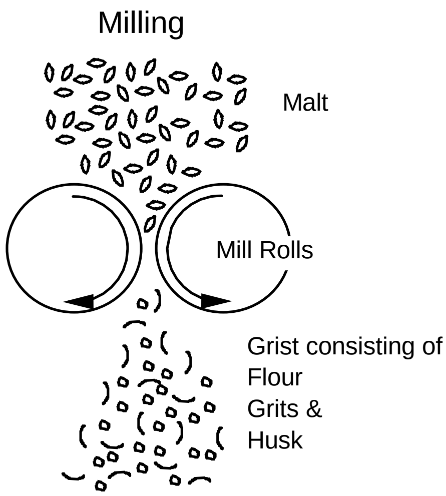
Mashing is the process where the crushed malt or grist is mixed with water under specified conditions so that enzymic action can take place to convert the starch into fermentable sugar and in certain cases break down proteins into more soluble forms.

Milling, Mashing and Conversion:-

Beer production starts in the brewhouse where the malt is processed to release fermentable sugars.



First the malt is milled to grind the starch into flour while protecting the malt husk because undamaged husk is required later.

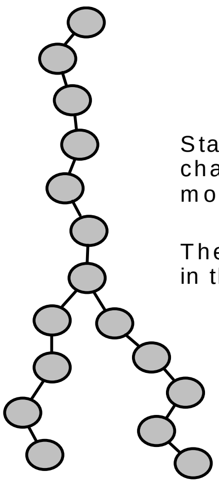


Then the milled malt or grist is mashed in with water under controlled conditions. This process brings the enzymes present in the malt into action and they convert the malt starch into sugar.

Condition	Low	Optimum	High
Temperature.	Low temperatures do not affect the enzymes much, but the starch must be gelatinised first. Gelatinisation temperature for malt starch is 65°C.	65°C	High temperatures inactivate enzymes including a and ß amylases. 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 virtually complete after 30 minutes. A longer time will not increase the yield of sugar but may make it more fermentable.

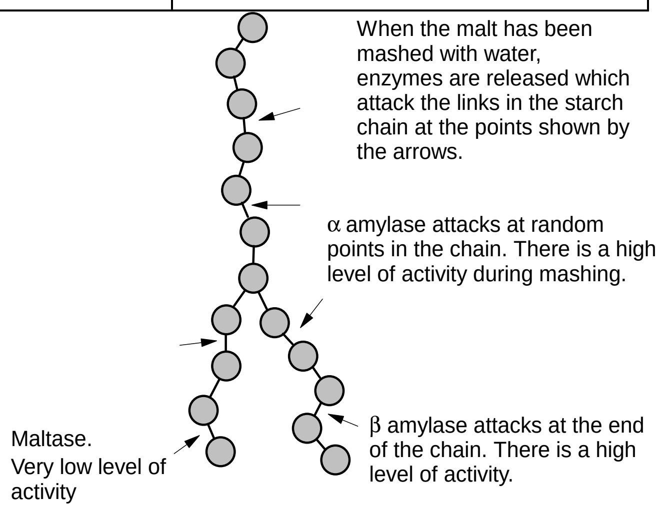
The production of fermentable sugars from starch is a complex biochemical reaction starting with 'gelatinisation' of the starch by heat. This is where the spiral configuration of the starch molecule is unwound so the enzymes can attack.

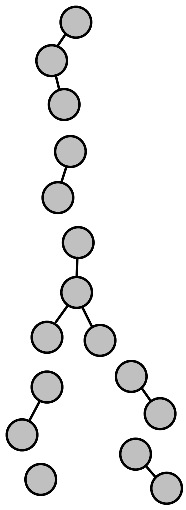
Conversion follows and the diagrams below illustrate how the enzymes in the malt attack the long chains of sugar units that make up the starch molecule and convert them into fermentable wort:-



Starch consists of a long chain of sugar (glucose) molecules linked together.

There are some branches in the chain.

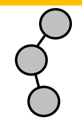




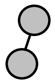
The result of the enzyme attack is shown here.

These units are **sugars** and they dissolve in the water used in the mash. The liquid is called 'wort'.

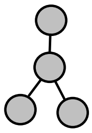
Most of these sugars are fermentable but some are not.



This sugar is called malto-triose. It will ferment slowly.



This sugar is called maltose and it ferments quickly.



This sugar is a dextrin and it will not ferment.

This sugar is called glucose and it ferments very quickly.

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 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 illustrated in the table below:-

The most important enzymes are the amylases. They convert the remaining unmodified starch granules in the mash into fermentable sugars. Fundamentally, however, the two amylases have distinct temperature optima:

Enzyme	Optimal Temperature (°C)	Inactivation Temperature (°C)
α-Amylase	70 – 75	75 – 80
β-amylase	63 – 65	68 – 70

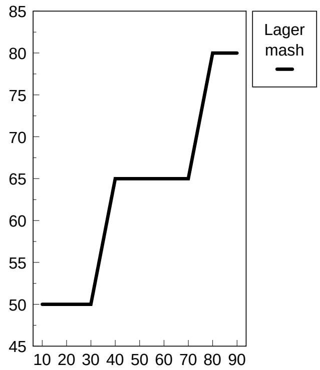
<u>Proteolysis</u> is the term used to describe enzymic action that breaks down proteins into simpler soluble forms. The action of proteolytic enzymes is very similar to that of the starch breakdown enzymes except that their optimum temperature is slightly lower at 50°C.

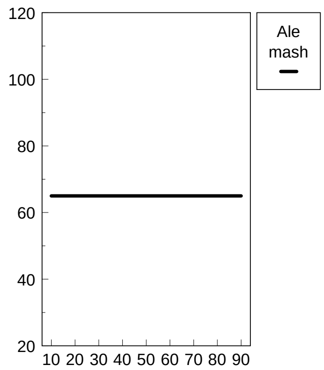
- It becomes necessary for proteolysis to take place during mashing when the malt is undermodified and the proteins surrounding the starch granules have not been completely broken down during malting.

- Mashes with undermodified malt, for example lager malt, will allow for this by having a low temperature stand for the proteolytic enzymes to work, followed by a 'saccharification' stand for the starch enzymes to work.

- Mashes with well modified malt only need a saccharification stand.

These principles are illustrated in the charts below:-





The temperature rise to 80°C in the lager mash is to improve filterability in the wort separation system.

Starch Test

The colour reaction between iodine and large-chain glucose (dextrins and starch) is used to detect their presence in wort. Aside from producing a wort of desired fermentability it is the goal of mashing to reduce the maximum length of dextrins in the sweet wort to less than 9 glucose molecules for unbranched and less than 60 for branches chains. At this point they don't show a reaction with iodine anymore and the wort or mash is said to be iodine negative and mash conversion is complete.

In an incomplete conversion dextrins are carried over, and the beer may develop a so called "starch haze". Despite its name in most cases this haze is not caused by starch but by long dextrins which become less soluble and precipitate in the presence of alcohol. Those dextrins give a red to purple colour reaction with iodine

MEASUREMENT AND CONTROL OF EXTRACT RECOVERY AND YIELD.

Measurement and control of extract yield and efficiency

Malt is an expensive raw material and achieving good extract levels is therefore very important. Extract yield is a measure of the effectiveness of the brewhouse in its use of malt and adjuncts. That is how much of the available material in malt and adjunct has been converted into useful extract for the production of beer.

Extract is calculated as follows:-

Total amount of dissolved material in the wort divided by the total weight of raw materials used.

IoB Method:

$$\frac{\text{Volume collected X specific gravity}}{\text{Weight of malt + adjuncts}} = \text{litre degrees / kg}$$

Example - 10,000 **litres** of wort at a S.G. of 60° are collected from 2000 kilograms of malt. The extract is:-

$$\frac{10{,}000 \text{ X } 60}{2{,}000} = \textbf{300 litre degrees / kg.}$$

300 litre degrees of extract was obtained from every kilogram of malt used.

Or in degrees Plato and EBC extract units-

Example - 10,000 **kgs** of wort at a S.G. of 15° Plato are collected from 2000 kilograms of malt. The extract is:-

$$\frac{10{,}000 \text{ X } 15}{2{,}000} = \textbf{75\%.}$$

75 % of the weight of the malt has been converted to extract.

Both of these calculations are based upon the total weight of raw material being used, and represent the brewhouse yield. Malt is an expensive raw material and achieving good extract levels is therefore very important.

INTRODUCTION - THE MAJOR CEREALS, SOURCES OF ENZYMES AND YEAST USED IN DISTILLING

It is not possible to cover, in these notes, all of the starch-containing cereals or other sources of starch that are used worldwide for the production of spirits. Instead, the basic principles of spirit manufactured by fermenting cereal extracts are described using the raw materials maize, wheat and rye, barley and malted barley, and microbial enzymes. The latter are used in distilling for the conversion of cereal starch to fermentable sugars when they are not converted by the enzymes from malted barley. This list is not meant to be exclusive; other cereals and other sources of starch are used, for instance rice, sorghum and potatoes.

Cereals are used for three reasons:

- as a source of carbohydrate for fermentation,
- for their contribution to the flavour of the distilled spirits and
- in the case of barley only, as a source of enzymes for the conversion of starch to fermentable sugars after the barley has been malted.

All cereals selected for distilling must be:

- undamaged and disease free
- uncontaminated with other cereals, weed seeds or any other detritus
- have the correct dry matter content (neither too much nor too little water) and
- contain an appropriate amount of starch

The seeds of cereals convert sugar from the growing plant into starch, which is the carbohydrate stored in the seed as a food reserve for the future regeneration of the plant. Cereals are grown commercially for their seeds, which we call the 'grains', since the starch and protein in the grains are important sources of food for both human consumption and animal feed. However, to make potable spirit this starch must be converted back to fermentable sugar, since starch itself is not fermentable by yeast. Much of this section deals with the manner in which distillers produce fermentable sugars from the starch and extract them so that they can be fermented by yeast.

There are three principal means of obtaining fermentable extract from cereals:

- Exclusively from malted barley using the endogenous enzymes of the malt
- From a mixture of unmalted cereal and malted barley again using the endogenous enzymes from the malt
- From unmalted cereal using exogenous bacterial or fungal enzymes

In the latter case the enzymes are bought in from specialist suppliers and can therefore be regarded as a separate raw material.

The fermentation of the sugars obtained by mashing is carried out by yeast, which represents the third major raw material purchased by the distiller. Pure cultured yeast can be provided by specialist suppliers or surplus yeast can be purchased from brewers. Cultured yeast can either be used on its own or admixed with brewers yeast. The latter is never used on its own since it cannot provide as high a spirit yield as the various forms of cultured yeast which are now available.

Grain based spirits

Scotch whisky – By legal definition Scotch whisky must be produced in Scotland from natural water in a mash of either exclusively malted barley (Malt Whisky) or a mash of un-malted cereal and malted barley (Grain Whisky). The enzymes of malted barley convert the cereal starch to sugars (wort) which are then fermented by yeast, with no temperature control.

In Malt Whisky and some Grain Whisky distilleries the wort is first separated from spent grains or may be fermented in the presence of the cereal residues (most Grain Whisky).

Any un-malted cereal may be used in Scotch Grain Whisky but the two cereals presently used are wheat or maize. The fermented wort (wash) is distilled in a batch process using pot stills (Malt Whisky) or continuously in column stills (Grain Whisky) to an alcohol concentration of less than 94.8%. The new-make spirit (NMS) is then reduced to an alcoholic strength of between 60% and 70% and matured in oak casks, not exceeding 700 litres in capacity, for a minimum period of 3 years.

However, malt whisky from a single distillery (Single Malt) or blended malt whiskies from a range of distilleries (Vatted Malt Whisky) are usually matured for 8 to 15 years. Grain Whisky is nearly always blended with Malt Whisky (Blended Scotch Whisky) of the same or older age (usually 5 to 8 years). Finally, Scotch Whisky must be bottled in Scotland at a minimum strength of 40% alcohol by volume (%ABV).

Other whiskeys – Malt and grain whiskey is distilled in many other countries, but not always with a strict legal definition. American whiskey can have both a Federal legal definition as well as a regional designation, e.g. Kentucky Bourbon must be a distillate of a fermented mash which contained not less than 70% corn (maize) and must have been matured in charred new oak containers for not less than 2 years in the state of Kentucky.

Similarly Tennessee whiskey is distilled from a fermented mash that contained about 80% corn, 10% rye and 10% malted barley.

Other North American whiskeys may have the designation of the principal un-malted cereal used, such as Corn

Whiskey (Bourbon), which usually has a grist composition of approximately 70% corn, 15% rye and 15% malted barley.

Rye Whiskey on the other hand must contain at least 51% rye with the rest of the grist consisting of corn (ca. 39%) and malted barley (ca. 10%).

Key types of American whiskies listed in the US Code of Federal Regulations:

- Rye whiskey, mash contains at least 51% rye.
- Rye malt whiskey, mash contains at least 51% malted rye.
- Malt whiskey, mash contains at least 51% malted barley.
- Wheat whiskey, mask contains at least 51% wheat.
- Bourbon whiskey, mash contains at least 51% corn.
- Corn whiskey, mash contains at least 80% corn.

The main processing difference for non-Scotch whiskey is that bacterial or fungal enzymes (i.e. non endogenous enzymes) may be used to convert the cereal starch to fermentable sugars. Fermentation of the cereal extract (beer) is similar to Scottish practice, except that temperature control is commonly used.

Both pot and column stills are used to distil the wash/beer although column continuous distillation is the commoner practice.
In some countries there may also be no stipulation on length of maturation; e.g. some Japanese whiskey has been made by the blending of matured Malt Whiskey with a grain new-make spirit. Irish whiskey is traditionally made from a mixed grist of malted and un-malted barley and is triple distilled in large pot-stills.

Grain neutral spirit - Neutral spirit is essentially an odourless and tasteless spirit distilled from a fermented mash of 100% cereal grain. The minimum alcoholic strength in the UK is 96% ABV but may vary in other countries. The common factor is that neutral spirit must be free from congeners which would impart a distinctive odour or taste. Such spirits can then be used as the base for potable spirits by the addition of flavourings, e.g. vodka, gin, and many liqueurs.

Mash Conversion

This recipe is used around the world for making malt whiskies. 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.

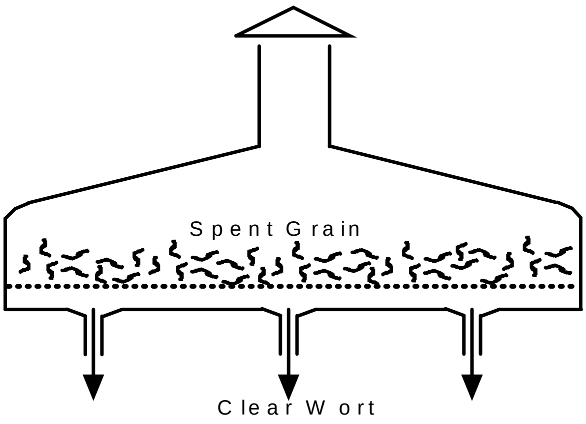
Mashing requires the following equipment:

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 and
- 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; an alternative and much shorter name used in Scotland is '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.



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.

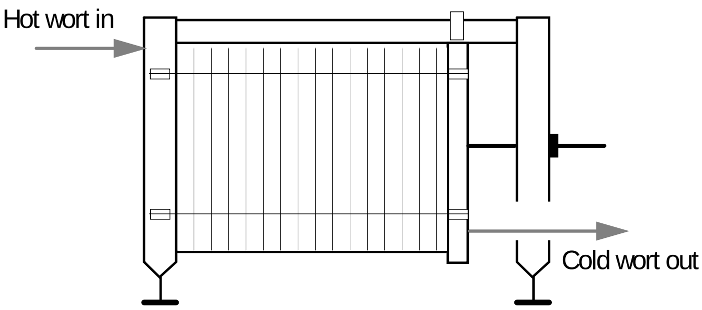
The temperature of the mash in the mashing vessel must be:

- warm enough to gelatinise the remaining malt starch,
- cool enough to preserve the activity of the enzymes and
- 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. Un-yeasted fresh wort can become heavily infected with *Lactobacilli* in a matter of an hour or so.

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.

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, batches of which may be around 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.

The Process 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 and
- other materials that 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, and
- optimal conversion of the carbohydrate to fermentable sugars.

When present, protein-degrading enzymes (proteases) can produce smaller molecules such as amino acids which have a beneficial effect on 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 surrounding the starch is being broken down.

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^{0}C. 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:

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

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

The Principles and Purpose of Wort Separation

In some grain distilleries the entire mash, including residues from the wheat or maize and malt is carried forward to the fermenter (to achieve higher alcohol yields), but in some the wort is separated from the spent grains in a mash tun or on filters of various types.

However, in every malt distillery, wort **is always** separated from the spent malt grains.

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 extracted 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**:**

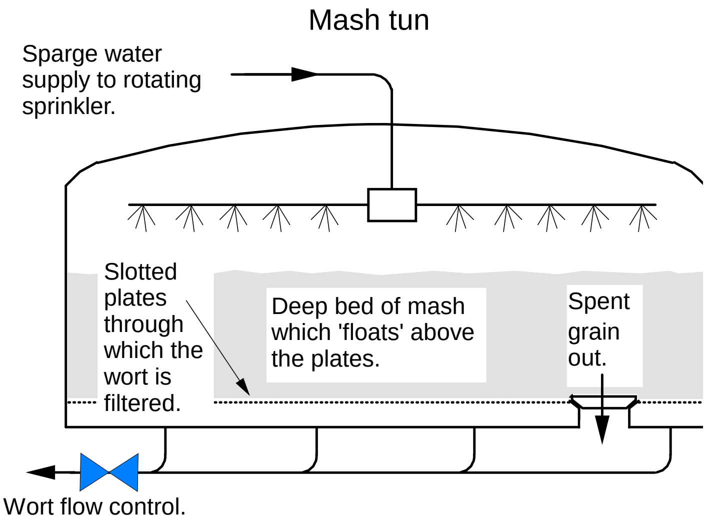
- The traditional mash tun.
- The lauter mash tun.
- the semi-lauter mash tun
- the mash filter

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

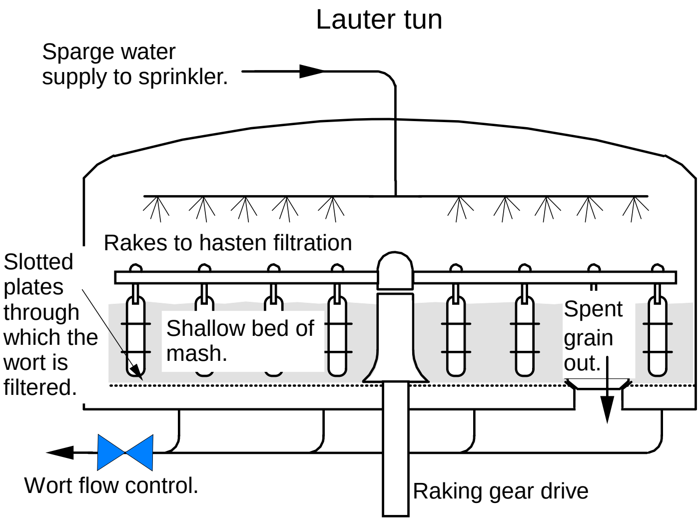
Strong wort (called the **first water**) is run off slowly because of its high concentration and because the mash bed must not settle on to the plates too quickly. When the first water is fully drained, a second water at a higher temperature is added through the mashing machine at a temperature of 75 -77^{0}C and mixed into the drained mash. This second water is again allowed to drain off, before a 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 rakes 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.

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.

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

Preparation of wort from unmalted source of starch (80-85%) and (15 - 20%) malted barley

In this type of mash bill, the saccharification enzymes come from malted barley. Therefore the process is similar to that described for the 100% malt mash, 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, the starch granules in malted barley are partly broken down in the malting process, they gelatinise at a relatively low temperature of about 64°C. Starch granules in maize and wheat on the other hand gelatinise at higher temperatures , can be heavily encased in protein, and are enclosed in un-degraded cell walls so require cooking.

Cereal cooking process

The purpose of cooking is to gelatinise the starch granules in cereals that are not malted. Maize and wheat are the main unmalted cereals used by distillers.

Gelatinised starch is accessible for saccharification by enzymes, but ungelatinised starch is not. The gelatinisation 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.
- 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 gelatinisation and
- the addition of backset (stillage from the beer column of the continuous still) to the water, reducing the water usage rate.

Mashing and Mash Conversion (Saccharification) by Malt

If malted barley is being used as a source of enzymes to convert the gelatinised starch to sugars. it also provides its share of the total starch needed. As in 100% malt whisky production, the malt must be milled to expose the enzymes and allow them to disperse in 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 as oligosaccharides to be converted to sugar in the early stages of fermentation. Without this secondary conversion, the alcohol yield would be about 15% lower.

MALT AND MALT ENZYMES

Malt and its Uses

The distiller buying malt from a malting company must agree a specification because of the potentially variable nature of malt.

A basic specification for distilling malt is:

1. moisture of less than 5% (to preserve the enzyme content)
2. the predicted spirit yield that can be calculated from how much material can be extracted from the grain (soluble extract) and how much of the material extracted can be fermented by yeast (fermentabilty), both of which are laboratory measurements,
3. diastatic enzyme levels (i.e. the enzymes which break down starch); alpha and beta-amylase are the two main diastatic enzymes involved in the breakdown of starch to fermentable sugars.
4. the malt should be easy to process through the stages of milling and mashing and there are various tests, such as friability, which can be used to specify malt modification and ease of processing.

Malt is important to both mashing and fermentation, particularly as a source of yeast nutrients and yeast growth factors (such as vitamins and minerals) and as a source of enzymes responsible for starch conversion to fermentable sugars. The husk of malted barley is also important as a filter medium during wort separation.

Use of Green Malt

Some grain distillers choose to use green malt (freshly produced malt that has not been stabilised by kilning), for its high enzyme content. Some think that green malt makes a significant contribution to grain nms (new make spirit) flavour.

Green malt must be used very soon after it is produced because it continues to metabolise, generating heat and stimulating undesirable microbial growth.
Compared to dried malt, green malt has very limited storage time and must be used as quickly as possible. This requires very precise logistics.

In distilleries using green malt, the milling is done in a wet hammer mill. The objective of the milling is to expose the enzymes needed to effect conversion. Milled green malt has the consistency of a thin porridge, no particles being greater than a quarter of a corn in size. Obviously, all green malt has to be kept cool and used as quickly as possible, for it would deteriorate rapidly in storage.

Key Malt Analytical Parameters

Key analytical parameters for malt distilling malt and examples of typical values are:

(a) Moisture < 5%

In the last 20 years, the moisture content has been raised from 4 to 5% or slightly higher for two main reasons. Firstly, gentler kilning helps preserve the activities of the more heat-sensitive enzymes, which can continue to work during the mashing and fermentation, releasing more fermentable carbohydrate. Second, there is a saving in energy. Malt is hygroscopic (attracts water) and there may be a moisture pickup of up to 0.5% between maltings and distillery. So, if the malt is required to be 5% moisture, the off-kiln moisture should be 4.5%.

Where there are adjacent maltings and distillery, it can be dried to 5%. Malt with moisture content of 6% or more is difficult to mill, and there is the possibility that ‘green-malt’ sensory notes may enter the spirit from lightly kilned malt. However, grain distilling malt moisture content can be up to 6%, the lighter kilning preserving enzymes.

(b) Friability: 85 - 95% of corns friable

And

(c) Homogeneity: 98% of corns homogeneous

The Friabilimeter is a laboratory instrument in which a weighed amount of malt is subjected to pressure of a roller pressing it against a rotating perforated drum. The more friable the malt due to modification, the more passes through the drum.

This analysis is commonly used in malting as a check on the endosperm's modification of the malt, to determine the homogeneity of the modification and to measure the percentage of corns that have not grown. It is widely used in the plant as well as in the laboratory.

The information obtained from the Friabilimeter, while a useful early indicator of the quality of malting, must be taken as complementary to other laboratory results. In recent years, there have been problems with calibrating these instruments, and results should be treated with caution, as they are also variety and operator dependent.

(d) Soluble Extract (SE): > 80% of malt materials made soluble

The units used to describe SE are 'litre°/kilogram' or '% extract' (%). The two units are related by a factor. Both units are in use, depending on distiller's preference.

The SE2 figure is the maximum extract that is obtainable from the malt, as milling at this 0.2mm setting (fine grind) mechanically breaks up any residual cell wall material, releasing the starch granules. This figure varies little with the degree of modification of the malt. Milling at the 0.7mm setting (coarse grind) (SE7) releases only the starch granules that have been made available because of matrix breakdown during malting, so it is a measure of the degree of modification of the malt. The fine/coarse difference is normally about 1%. Some distillers prefer to use a coarse SE figure obtained by milling the malt sample with a mill gap setting of 1.0mm, but the vast majority use 0.2 and 0.7mm SE's.

The SE7 figure was chosen when the Miag laboratory mill became standard because its values were closest to the distillery's mash tun extract (mte), when the traditional mash tun was the norm. In the last about 30 years, there has been a gradual change in Scottish malt distilleries to lauter-type mash tuns, which have higher extraction efficiency. These tuns can achieve SE2 levels of extract, but the SE7 figure that is the most reliable figure for predicting spirit yield.

(e) Fermentability: >88% of the extract obtained is fermentable

This laboratory test is used to determine the percentage of the SE7 that is fermentable, and allows calculation of the Fermentable Extract (FE7).

The method of determining wort's Fermentability is by conducting a laboratory fermentation, and calculating it using the laboratory Original Gravity (OG) and Final Gravity (FG). Malt fermentabilities are normally up to in the range 86-90%. It should be noted that this laboratory test, based on IGB laboratory wort, is not suitable for malts that have high sulphur content or those that are highly modified to achieve high TSN values.

(f) Fermentable Extract: >70%

The % fermentability value multiplied by the SE7 value gives a figure for fermentable extract obtainable from the malt.
The fermentable extract value is used to calculate a predicted spirit yield from the malt.

(g) Predicted Spirit Yield (PSY)

It is possible to predict the distillery spirit yield from the laboratory data described above.
In a malt distillery, this can be done using the obtained values of the malt soluble extract (SE7), the % fermentability and a fixed factor:

PSY (lpa/t, dwb) = fermentability (%) x SE7 (dwb) x 6.06

(Where lpa/t = litres of pure alcohol per tonne, and dwb = dry weight basis).

In a grain distillery, the calculation is a little more complicated due to the use of both malt and wheat (or maize). The first step is to calculate separately the PSY of the malt and the PSY of the other cereal. Then it is an easy matter to calculate the PSY of the particular mash recipe in use at the time.

For instance, in a distillery using 10% malt with a PSY of 420 lpa/t and 90% wheat with a PSY of 370 lpa/t, the calculation and result is:

420 x (10/100) + 370 x (90/100) =375 lpa/t

(h) Total Soluble Nitrogen (TSN) and Free amino-nitrogen (FAN)

Free α-amino nitrogen in the wort is required for the yeast growth that occurs at the start of fermentation. If wort is deficient in this respect, the performance of the yeast fermentation will be affected. FAN measurement gives a direct analysis for this parameter. TSN measurement is a measure of protein modification, and may be expressed as a ratio to the total nitrogen – soluble nitrogen ratio (SNR). It is unlikely that there will be a shortage of FAN in malt whisky production. Some distillers specify high TSN values, which tend to depress laboratory fermentability values. Grain distillery wort can be FAN-deficient particularly if the proportion of malt in the mash is lower than 9% (w/w).

(i) Malt enzyme levels

Sometimes it is necessary to measure the enzyme levels in malt. Two measures are used: dextrinising units (DU) which give an indication of the content of alpha-amylase in the malt. This enzyme is the first enzyme to act on starch granules, breaking the starch down into fragments called dextrins. Secondly, diastatic power (DP) power which gives an indication of the content of

beta-amylase in the malt. This second enzyme produces the major fermentable sugar, maltose, from the solubilised starch and large dextrins. Typical values for dried malt are:

Dextrinising Units (DU)	>100 units
Diastatic Power (DP)	>200 units

The secondary enzymes, limit dextrinase and alpha glucosidase (sometimes called maltase) play a part in secondary conversion in the wash back and are not routinely measured in malt.

Health and Safety (H&S), also known as Occupational Safety and Health (OSH) is a cross-disciplinary area concerned with protecting the safety, health and welfare of people engaged in work or employment. The goals of occupational safety and health programs include fostering a safe and healthy work environment. OSH may also protect co-workers, family members, employers, customers, and many others who might be affected by the workplace environment.

This section will illustrate typical H&S legislation by referring to **UK legislation**.

IT IS IMPORTANT THAT CANDIDATES ARE FAMILIAR WITH UP TO DATE H&S LEGISLATION IN THEIR OWN COUNTRY.

MALTING PLANT SAFETY CONSIDERATIONS

The Evolution of Carbon Dioxide from Steeping & Germination

Malting barley respires at a very low level even when in storage. During the steeping process which initiates germination, the respiration rate is accelerated and significant amounts of carbon dioxide (CO_2) are generated. During the dry phases of steeping, carbon dioxide will be removed from the steeping vessels by extraction fans.

Once steeping is completed and the process moves to the germination phase the green malt gives off even greater amounts of CO_2, requiring higher levels of ventilation of the grain.

The Hazards Associated with Carbon Dioxide

Carbon dioxide is a toxic gas which is odourless and colourless. It is significantly heavier than air and many fatalities from asphyxiation have resulted from entry into pits, tanks, sumps or cellars where CO_2 has accumulated and displaced the oxygen.
Note: When the carbon dioxide concentration increases above 10%, unconsciousness will occur in under one minute and unless prompt action is taken, further exposure will eventually result in death.

The Monitoring & Checking of Atmospheres, including Exposure Limits.

Monitoring Equipment

Many different types of monitoring equipment are available from various suppliers, detectors can be fixed or portable.

Fixed detectors; are permanently installed in a chosen location to provide continuous monitoring of plant and equipment.

Portable detectors; usually refers to a small, handheld device that can be used for testing an atmosphere in a confined space before entry, for tracing leaks or to give an early warning of the presence of gas, flammable gas or vapour when work is being carried out in a hazardous area.

Whichever type of detection is in use, people must be trained in the use of the detector and how to respond to any alarm situation.

Regular maintenance and calibration of the carbon dioxide monitors and alarm system are essential, as well as the maintenance of mechanical ventilation systems

Exposure Limits - CO_2

UK Exposure limits:
Workplace Exposure Limits (WEL) are found in the HSE publication Occupational Exposure Limits EH40.
Short Term Exposure (15mins) 1.5% (15000ppm)
Long Term Exposure based on 8 Hour Time Weighed Average (TWA) 0.5% (5000ppm)

Note: Detectors are generally set to alarm well below (often at one-tenth) of the Workplace Exposure Limit (WEL).

Note: These UK exposure limits are given as an example, please check with your relevant responsible organisation.

Safe Working Practices for Malting Plant Operations

In general terms and under normal operating conditions, if plant, equipment and Local Exhaust Ventilation (LEV) systems are well maintained, fixed/portable detection systems calibrated and maintained, staff trained and aware of the potential for CO_2 generation then the risk to the individual will be managed to an acceptably low level.

However hazards may arise due to abnormal conditions, i.e. breakdowns, spillages, failure of extraction systems or alarm situations. This is when people are most at risk as often they focus on resolving the abnormal condition rather than considering the effect the abnormal condition may have had on the work environment.

When dealing with these conditions consideration must be given to the following;

a) What product am I dealing with, (barley, green malt etc.)
b) Will CO_2 be generated or be present in the area
c) Do I need to, or how can I ventilate and move fresh air through the area
d) If I ventilate the area using mobile equipment, where will it go
e) Does the area need evacuation

Once these questions have been answered then a safe system of work can be established to deal with the abnormal incident.

Note: There are other considerations outside of CO_2 issues, such as isolations, permits to work etc. that would need to be addressed when dealing with the abnormal condition.

Some situations are well known to be potentially hazardous, for example Confined Spaces such as elevator pits. Not only can these be difficult to access and restrict movement when inside them, but they can have accumulation of CO_2 due to potential respiration of barley or green malt deposits spilt in them, and as already stated CO_2 being heavier than air will deposit itself in the bottom of the pit displacing oxygen and could cause asphyxiation of anyone entering the space without adequate protection.

Confined Spaces require special precautions before entry can be made;

a) Entry into a Confined Space should be controlled by a Permit to Work
b) Atmosphere testing using a portable detector should take place and the results recorded, this will determine if there is an issue with CO_2 or any other gas.
c) Depending upon the results of the atmosphere testing the confined space may need ventilation before entry can be attempted.
d) Once ventilation has been carried out the atmosphere should be retested to ensure it is safe to enter, (if still unsafe to enter further ventilation should take place, if this is not possible then appropriate breathing apparatus should be used for entry for which individuals must be trained).
e) Assuming the atmosphere test is acceptable entry into the confined space can be made, once all the requirements of the permit are met.
f) Continuous atmospheric monitoring of the confined space should be carried out using a portable detector carried by the entry person.
g) Entry requirements and rescue procedures should be in place and documented, these should either be included or referred to on the permit to work.

Note: Confined Space entry is only to be undertaken by persons who are trained, physically & mentally fit and under a Confined Space Permit or similar written authority. Likewise CO_2 is not the only issue to consider when planning safe entry into a confined space.

Note: These UK regulations are given as an example, please check with your relevant responsible organisation.

MALT AND BARLEY STORAGE PLANT SAFETY CONSIDERATIONS

1. The Hazards Associated with Dust.

Dust creates a number of potential hazards from ill health to the possibility of a major explosion.

Ill Health

Exposure to high levels of grain dust can lead to serious and irreversible respiratory damage, it can also result in short term conditions such as 'Grain Fever' where the individual can suffer from fever, chills, dry cough, malaise, dyspnea (shortness of

breath) and headaches, these develop between 4 -12hrs after exposure with the symptoms lasting for about a day. Grain dust is classed by the UK HSE Occupational Exposure Limits EH40 as a sensitiser.

Nuisance levels of dust can cause irritation of the mucus membranes and eyes, as well as skin irritation and rashes.

Likewise inhalation of dust from poorly stored grains, eg damp mouldy conditions, can also lead to ill health with conditions such as 'Farmers Lung' (Aspergillus Fumigatus) or 'Maltsters Lung' (Aspergillus Clavatus), although with improved storage conditions and handling of grain, cases of these conditions are rare.

The UK maximum exposure limit (MEL) for grain dust.

The HSE guidance on the new maximum exposure limit (MEL) for grain dust came into effect on the 1 January 1992 (HSE Agricultural Information Sheet no. 3). It applies to all dust, including contaminants, arising from harvesting, drying, handling, and storage or processing of barley, wheat, oats, maize or rye. The MEL is an average of 10 mg/m3 of total respirable dust in the air over an 8 hour period. This is a maximum and not a target. Dust levels must be reduced as far below the MEL as reasonably practicable. Higher concentrations can be permitted if exposure times are shorter, but the maximum dust level should never exceed 30 mg/m3 measured over a 10 minute period.

Note: These UK regulations are given as an example, please check with your relevant responsible organisation.

Organisations should carry out individual and background monitoring of dust as part of a Control of Substances Hazardous to Health (**COSHH**) assessments, to ensure individuals are not exposed to high levels of dust and to satisfy themselves that the LEV systems control effectively the dust in the working environment.

2. Explosive Atmospheres in the Workplace.

An explosive atmosphere can be created where sufficient density of dusts are suspended in the air in a contained area e.g. a plant building or elevator and exceed the Lower Explosive Limit (LEL), (for barley dust 40-50 g/m3 and malt dust 60 g/m3) and an ignition source is introduced, eg a spark, naked flame. After the initial explosion a secondary explosion will generally take place propagating through unprotected equipment or through the building via dust clouds raised by the initial explosion. The potential results of this kind of event are major plant damage and potentially serious injury or the death of employees.

To protect workers from the risked posed by potentially explosive atmospheres the EU Explosive Atmospheres Directive (ATEX 137 Workplace Directive 99/92/EC) has been adopted in the UK as the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR 2002).

This requires organisations to carry out risk assessment to identify hazardous areas and to classify them into zones based on the frequency and persistence of the potentially explosive atmosphere.

Hazardous Area Zones and Equipment Categories.

Zones

As described above hazardous places are classified in terms of zones on the basis of the frequency and duration of the occurrence of an explosive atmosphere.

Zone 20 (highest risk)

A place in which an explosive atmosphere in the form of a cloud of combustible dust in the air is present continuously, or for frequent long periods, i.e. reverse jet filters, cyclones

Zone 21

A place in which an explosive atmosphere is likely to occur in normal operation occasionally, i.e. dust hoppers.

Zone 22

A place in which an explosive atmosphere is not likely to occur in normal operation but if it does, will persist for a short period only, i.e. elevators handling whole grain

Notes:

1. "Normal operation" means the situation when installations are used within their design parameters.
2. Also layers, deposits and heaps of combustible dust must be considered as another source which can form an explosive atmosphere.

ATEX SIGNS

Installation Signage

Equipment Marking

Note: These EU regulations are given as an example, please check with your relevant responsible organisation.

Equipment

Special precautions need to be taken in hazardous areas to prevent equipment from being a source of ignition, for example belt alignment, rotation/under-speed sensors, bearing temperature monitors, plastic buckets etc. In situations where an explosive atmosphere has a high likelihood of occurring, reliance is placed on using equipment with a low probability of creating a source of ignition. Equipment is categorised (1, 2 or 3) depending on the level of zone where it is intended to be used.

Therefore equipment selection depends upon the following;

The Zone Rating
Zone 20 – not less than category 1
Zone 21 – not less than category 1 or 2
Zone 22 – category 1, 2 or 3

Equipment must be suitable for use in dust so therefore;

Equipment is typically marked as follows: – **CE-EX- II- 1- D**

CE = conformity mark
EX = specific marking of explosion rating
II = Equipment group for surface industries (I = mines)
1 = category marking appropriate for zone (1,2 or 3)
D = suitable for use in dust (G = gas)

***Other Sources of Ignition include*;**

Hot Work:- Welding, Disk Cutting, Grinding, Oxyacetylene Cutting etc.
Friction Sparks, Misaligned Elevators, Overheated Bearings, Static Electricity, Fire and Tramp Metals etc.

Note: These EU regulations are given as an example, please check with your relevant responsible organisation.

3. Safe Working Practices for Malt Storage Plant Operations

The increased friability of malt gives the potential to generate dust during each movement cycle, therefore minimising the frequency and distance of travel should be considered. Additionally conveyors, elevators etc. should normally be kept under negative pressure by LEV systems, to prevent dust being released into the atmosphere.

Local Exhaust Ventilation (LEV) Systems (Dust Extraction, Aspiration Systems)

LEV systems are engineering controls that help to prevent people being exposed to contaminants in the work-place; they can be used to remove dust particles or vapours. A simple LEV system works by having a suction fan pulling air down a single or series of pre-sized ducts that originate at the point the dust is being created, this then carries the dust to a capture unit leaving the workplace atmosphere clear.

LEV systems should be regularly serviced and maintained. The documents relating to its performance capabilities, from either commissioning information or supplier's specification should be held for the lifespan of the equipment, so that subsequent monitoring and testing can confirm the system is working to its design capability. Periodic examination and test by a competent person should take place at least every 14 months and the records should be held for 5 years.

Respiratory Protection Equipment (RPE)

Respiratory Protective Equipment falls into two main categories, either air purifying or air supplying.

Air purifying respirators use disposable filters to capture the dust allowing the wearer to breathe in clean air; these can be full face masks or half masks. It is essential that the correct type of cartridge filter is used for the environment the individual is working in and that the filters are changed at the recommended periods.

Additionally Disposable Masks can be used, they are easy to use and offer protection for short term applications. Both types require the filter or mask to be offering at least P3 protection.

Full face masks can also be supplied as battery powered masks that filter the contaminants out via disposable filters and force clean air into the mask (or hood). These are particularly useful in very dusty atmospheres.

Air supplying respirators are generally used in more hazardous environments like chemicals, smoke etc. and they would include airline systems and self-contained breathing apparatus (SCBA). Anybody using this type of equipment must be fully trained and competent.

All RPE should be comfortable, fit the wearer and meet the requirements for protection from the contaminant. Face-Fit testing should be carried out to ensure this criteria is met, in fact is it a legal requirement if the RPE is used as a control measure.

The UK COSHH Approved Code of Practice says that "Employers should ensure that the selected face piece is of the right size and can correctly fit each wearer. For a tight-fitting face piece, the initial selection should include fit testing to ensure the wearer has the correct device. Also, employers must ensure that whoever carries out the fit testing is competent to do so."

Health Surveillance

The UK Control of Substances Hazardous to Health Regulations 2002 (COSHH) require health surveillance to be mandatory where risk assessment has shown individuals are likely to be exposed to harmful substances.

The purpose of health surveillance is to, protect the health of employees by early detection of adverse changes or disease, collect data for detecting or evaluating health hazards and evaluate control measures.

Generally organisations have in place annual employee health surveillance which is carried out by occupational health specialists and these checks would include lung-function tests and examinations for skin conditions.

House Keeping& Hygiene

Robust housekeeping programs are essential in maintaining a clean and safe plant. The systematic removal of dust deposits will eliminate the potential source of fuel and in the event of an explosion help to prevent the propagation of a secondary explosion.

Likewise the regular removal of dust from the workplace will provide clean and healthy environment for employees to work in.

SAFETY - POTENTIAL HAZARDS WHEN WORKING WITH CHEMICALS.

Chemicals, such as detergents (designed to dissolve organic matter) and sterilants (designed to kill organisms) may be hazardous materials for people to handle.

In the most countries, under Control of Substances Hazardous to Health (C.O.S.H.H.) legislation, manufacturers are required to issue technical information on any cleaning materials they supply. This information covers recommended usage concentrations and actions to be taken in case of accidents.

An analysis of the risks indicates the following methods of reducing the hazards:-

- If a detergent or sterilant is considered too hazardous then choose an alternative which is safer.

- Isolate people from the hazard, for example in CIP (Cleaning in Place) systems, detergents and sterilants are kept in automatically topped up tanks and away from the staff. They are also stored in suitably sized bunds and kept away from other materials that would react together.

- Implement control measures like 'safe systems of work' that when followed, eliminate risks to the staff. An example would be a 'permit to work' procedure for the maintenance of CIP equipment.

- Ensure that people in the proximity of detergents and sterilants use protective equipment especially eye protection (goggles), gloves, boots and overalls.

- Install safety showers in areas where risks are highest like detergent and sterilant delivery points.

- Inform people who work with detergents and sterilants of the potential hazards.

Safety Requirements of Cleaning Chemicals and Materials

Cleaning of tanks and vessels sometimes require the use of chemicals which are strong acids and strong bases.

Sometimes, oxidising compounds are used. Safety precautions, as required by local Occupational Health and Safety legislations, have to be considered when using these chemicals.

Components of these chemicals may have short or long-term effect on the health of the employees. Some components can affect the health of the consumer at parts per million levels.

The safety of the environment has to be considered as well, which means that the products used have to comply with environmental legislation with respect to handling of spillage.

Every material used must be accompanied by **Material Safety Data Sheet (MSDS).**

An **MSDS** should disclose the following:

- manufacturer's details
- product identification
- composition information on ingredient
- hazards identification
- safety first measures
- fire fighting measures
- accidental release measures
- handling and storage
- exposure control and personal protection
- physical and chemical properties
- stability and reactivity
- toxicological information
- ecological information.

The MSDS is meant to give enough data about the product that assist the user to make an informed technical decision. A user will only know about this safety information if the information provided is read and the supplier is questioned to get clarity.
There is still a culture of not going through the MSDS document before the product is used.

Hazards Identification - European hazard symbols

These **hazard symbols for chemicals** are defined in Annex II of Directive 67/548/EEC.

National Legislation and Public Organizations

Occupational safety and health practice vary among nations with different approaches to legislation, regulation, enforcement, and incentives for compliance.

IS IMPORTANT THAT CANDIDATES ARE FAMILIAR WITH UP TO DATE H&S LEGISLATION IN THEIR OWN COUNTRY

European Union

In the European Union, member states have enforcing authorities to ensure that the basic legal requirements relating to occupational health and safety are met.

United Kingdom

In the UK, health and safety legislation is drawn up and enforced by the Health and Safety Executive and local authorities (the local council) under the **Health and Safety at Work Act 1974**. Increasingly in the UK the regulatory trend is away from prescriptive rules, and towards risk assessment. Recent major changes to the laws governing asbestos and fire safety management embrace the concept of risk assessment. www.hse.gov.uk

United States

In the United States, the Occupational Safety and Health Act of 1970 created both the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA).[40] OSHA, in the U.S. Department of Labor, is responsible for developing and enforcing workplace safety and health regulations. NIOSH, in the U.S. Department of Health and Human Services, is focused on research, information, education, and training in occupational safety and health. www.osha.gov www.cdc.gov/NIOSH/

Canada

In Canada, workers are covered by provincial or federal labour codes depending on the sector in which they work. Workers covered by federal legislation (including those in mining, transportation, and federal employment) are covered by the Canada Labour Code; all other workers are covered by the health and safety legislation of the province they work in. The Canadian Centre for Occupational Health and Safety (CCOHS), an agency of the Government of Canada, was created in 1978 by an Act of Parliament. The act was based on the belief that all Canadians had "...a fundamental right to a healthy and safe working environment." CCOHS is mandated to promote safe and healthy workplaces to help prevent work-related injuries and illnesses.
www.ccohs.ca

South Africa

In South Africa the Department of Labour is responsible for occupational health and safety inspection and enforcement in commerce and industry apart from mining and energy production, where the Department of Minerals and Energy is responsible.

The main statutory legislation on Health and Safety in the jurisdiction of the Department of Labour is Act No. 85 of 1993: Occupational Health and Safety Act as amended by Occupational Health and Safety Amendment Act, No. 181 of 1993.

QUALITY MANAGEMENT

*Candidates should have an understanding of the fundamental principles of Quality Management and be familiar with the methodology of **at least one quality system** appropriate to their region/country of operation.*

The Key Features of a Quality Management System are:-

- To understand precisely what is to be achieved.
  This means having **specifications** to meet and it means having **procedures** to follow.
  This also means that the procedures and specifications will have to be **documented**.

- To **monitor** actual performance against what is to be achieved.
  This means keeping records of performance and it means **auditing**.

- To correct things when they go wrong.
  This means having a system of initiating **corrective action**.

- To **review** the overall quality management system and to plan for **improvement**.

(a) Specifications.
Process and product specifications must detail all those parameters that are required to be measured, including flavour, and they must identify an ideal value together with an acceptable range for each parameter.

(b) Procedures.
Documented procedures are there to explain what has to be done and when and how it should be done. Procedures can cover a wide range of topics:-

- An explanation of the organisation and responsibilities.
- Procedures to be followed in the case of non-conformances.
- Procedures on how the processes are managed.
- Instructions on how to operate the plant.
- Procedures to be followed when auditing.

(c) Documentation.
Quality management systems rely on documents to ensure that procedures are followed. The theory is that 'if it isn't written down, it isn't done'.

It is important that documents are 'controlled' so that people are confident that the document they are working to is current and valid.

(d) Monitoring.
Quality performance is monitored on a regular basis and the results can be presented in a way that highlights problems.

(e) Auditing.
The purpose of auditing is to check that the quality system is being followed.
Audits are concluded with a report back which usually identifies areas for improvement.
Auditing procedures have the advantage that they can be conducted internally.
Audits do not necessarily have to cover the whole quality system, often following a trail of evidence will reveal how rigorously procedures are being followed.

(f) Corrective Action.
Action must be taken to put things right and how this is done is usually covered by a procedure.

The procedure will ensure that the following areas are covered:-

- Detail of the problem.
- Nominating the person responsible for taking the action.
- When the corrective action will be completed.
- A review of the result of the corrective action taken.

(g) Review.
An overview is required so that it can be confirmed that, for example:-

- Corrective actions are being followed (implemented) in time.
- Audits are taking place as specified.
- The maltings' quality is meeting requirements.

The procedure for a review is specified and documented in the same way as all other procedures.

(h) Improvement.
It may be that an overall improvement in quality is required, many world class manufacturers have a 'zero defect' policy.
In this case a plan to achieve the required improvements is necessary. The quality management system will contain all the specification and monitoring procedures to enable an improvement plan to be implemented.

Control of Quality

The control of quality through a 'Quality System' gives the following advantages over a 'Final Inspection' approach:-

- The use of documented procedures and specifications ensures that everybody knows what they are supposed to be doing.

- The responsibility for quality sits with the people who are operating the plant and making the malt.
- Quality problems will be identified as soon as they occur rather than much later when the process is over.
- Maintenance of accurate records makes it easier to track back and investigate raw materials or processes so that 'due diligence' in manufacturing can be proved.

A good quality system includes:

- Motivated and well trained workforce
- Well maintained plant
- Adequate capacity for peak demand
- Good plant cleanliness and house keeping
- Sufficient time for operations, cleaning and maintenance
- Good relationships between suppliers and customers.

Typical Quality Management Systems include:

- ISO 9000 - Quality Management
- ISO 14000 - Environmental Management
- GMP - Good Manufacturing Practice
- GLP - Good Laboratory Practice
- NAMAS - National Accreditation of Measurement and Sampling
- HACCP - Hazard Analysis Critical Control Points.

Total Quality Management (TQM)

TQM is a system of continuous improvement that is centred on the needs of the customer. Pioneered by Dr Edwards Deming, TQM is a long-term approach to ensuring quality. Key components are employee investment, problem solving teams and statistical methods. The principles of TQM are as follows:

1. Quality can and must be managed.
2. Everyone has a customer and is a supplier.
3. Processes, not people, are the problem.
4. Every employee is responsible for quality.
5. Problems must be prevented, not just fixed.
6. Quality must be measured.
7. Quality improvements must be continuous.
8. The quality standard is defect free.
9. Goals are based on requirements, not negotiated.
10. Life cycle costs, not front end costs.
11. Management must be involved and lead.
12. Plan and organise for quality improvement.

Making TQM work requires not only the commitment of the entire organisation, but also an understanding of quality management, and the willingness toward change. The central focus of TQM is identifying the customer, the customer needs and requirements, and then setting out a plan toward meeting those requirements. In order to do this effectively, the organisation must have a good quality management system, statistical process control, and teamwork. Implementing TQM must start with top management and flow downward throughout the organisation. A good quality control system involves co-operation between all the major departments and embraces a variety of quality assurance techniques.

Notes.

Give details of a quality management system that you are aware of.

ROLES AND RESPONSIBILITIES AND BENEFITS

Individual Actions on Product and Service Quality

Quality is the responsibility of everyone working within an organisation. However, the following actions are required of a quality system:

- It is the responsibility of top management to formulate the Company's quality policy and to ensure commitment at all levels to comply with the Quality System and to improve its effectiveness.

- Communication to all members of staff so that all understand it and are involved with its implementation.

- All staff members responsibilities and level of authority should be defined and understood.

- A management representative should be appointed as Quality Systems Manager, responsible for:
  - managing the requirements of the quality standard,
  - issuing amendments to manuals,
  - arranging audits,
  - checking suppliers,
  - taking minutes of quality meetings,
  - investigating problems and initiating corrective actions,
  - following up corrective actions,
  - handling complaints.

The Control of Documents

All Quality Systems require control of documentation. It is necessary to identify Controlled documents (i.e. updated) and Uncontrolled documents.

- Examples of Controlled documents include:
  - Quality Policy
  - Quality Manual
  - Procedures
  - Work Instructions
  - Specifications
  - HACCP systems
  - Codes of Practice

- Controlled documents must be:
  - approved before issue
  - reviewed and updated
  - changes identified
  - up-to-date
  - legible

- external documents also controlled
- obsolete documents removed.

- Document control is usually achieved by:
  - issuing on coloured paper or including colour logo
  - no photocopying
  - uniquely identified
  - pages numbered (e.g. Page 1 of 10)

  - maintaining distribution list of holders
  - ensuring documents are not issued without authorisation
  - only being available to staff who need to use them
  - limiting number of copies issued.

- Document change is controlled by:
  - approval of changes before issue
  - issue of an amendment sheet so that changes are identified
  - keeping a master list of document numbers to ensure all staff use up-to-date copies
  - retrieval of obsolete copies as replacements issued
  - archiving one copy.

The Maintenance of Conformity

Adherence to a well-established quality system will ensure that conformity of product quality and company operation is maintained.

However, all quality standards strive for improvement and this is often best achieved by regular management reviews of the quality system and appropriate communication to all staff, especially for changes to systems and Regulations.

Regular Quality Review meetings should:

- review the Quality Policy and Quality System at defined intervals (at least annually)
- be additional to departmental or section quality meetings
- be chaired by senior management
- include QA staff, production managers, auditors, purchasing staff
- review the operation of the quality system
- ensure the policy and system are suitable and effective
- recommend changes
- record actions and responsibilities
- meeting agenda should include:
  - audits (internal and external)
  - process performance
  - complaints
  - preventative and corrective actions
  - changes
  - training needs
  - supplier performance
  - future developments.

Benefits

The control of quality through a 'Quality System' gives the following advantages over a 'Final Inspection' approach:-

- The use of documented procedures and specifications ensures that everybody knows what they are supposed to be doing.
- The responsibility for quality sits with the people who are operating the plant and making the malt.
- Quality problems will be identified as soon as they occur rather than much later when the process is over.

Maintenance of accurate records makes it easier to track back and investigate raw materials or processes so that 'due diligence' in manufacturing can be proved.

HAZARD ANALYSIS AND CRITICAL CONTROL POINTS (HACCP)

When applied to the food and beverage industries, a HACCP procedure involves the systematic analysis of production and handling processes from the purchasing of the raw materials through to the end use of the product by the consumer. A HACCP audit seeks to identify the source and severity of potential hazards that may threaten the safety or integrity of the product. It involves the identification of **critical control points (CCPs)**, i.e. locations, stages, operations or raw materials that if not properly controlled, provide a threat to product acceptability and consumer safety.

(A) Role in Food and Beverage Production

One of the main difficulties faced by the food and beverage industry in controlling the hygiene status of products is the time taken for conventional laboratory methods to produce useful results.

Understanding the source of contamination and the way in which different microorganisms respond to processing and storage conditions enables prediction of their behaviour and the design of the processes and products to eliminate them or prevent them from growing. This concept forms the basis of HACCP approach to the control of microbiological hazards.

A properly designed and operated HACCP system is essential to food handlers or processors intent on ensuring the safety of their operation in the food supply chain.

(B) Hazard Analysis

Consideration of HACCPs is essential for maintenance of high quality standards. Hazard analysis is equally applicable to non-microbiological problems, e.g. the prevention of glass fragments in malt is an engineering problem. Therefore, the panel assessing hazards must be composed of all relevant specialists. A multidisciplinary team that covers all aspects of the production should carry out the HACCP programme.

Briefly, hazard analysis comprises the following steps:

1. Prepare a flow diagram of the process, identifying the hazards associated with each stage.

2. Specify the control or preventative measures at each stage.

3. Identify the CCPs for these hazards.

4. Establish critical limits for each CCP.

5. Establish corrective action to be taken when monitoring indicates a fault at a CCP.

6. Establish record keeping for HACCP; for documentation, and verification that HACCP analysis is effective.

KEYPOINT: Different food processes are vulnerable to different hazards. There is no single hazard analysis that covers all cases, but the general principles of HACCP will still apply.

If a safety hazard is identified that results from inadequate or, in some cases, no control measures in place at a CCP, then as far as the legislation is concerned food safety is lacking and the situation must be rectified.

When considering quality hazards, however, a more-defined risk assessment can prove very useful indeed. A popular method of assessment is a dual risk assessment based on the risk of the hazard occurring with control measures in place at a specified process step compared with the probability of that hazard getting through to the final product with subsequent control measures in place.

A score is given in each case based on a scale of 1 to 5:

1. Minimal or no risk
2. Possible risk
3. Likely risk
4. Very likely risk
5. Definite risk

For example, it could be considered a 'likely (3)' risk of weevils gaining access to the barley in the silo block. However, the risk of the insects being carried through to the final pack is 'possible (2)'. The final risk assessment is given as 3/2.

The scores help to prioritise action. This is especially useful when action requires capital expenditure, or significant changes in procedures or process. Priority issues can be addressed first and should be addressed in the current financial year. Other issues can take a back seat, although a clear action plan must be documented and held with the HACCP plan.

(C) Practical Application

In practical terms, this involves the following procedures:

1. Define the process. The process must be accurately and sequentially defined from start to finish, and this is often done in the form of a flow diagram.

2. Identify all hazards and list the control measures. Obvious sources of hazards are as follows:
   - ***Processing stages****:* *time, temperature, recontamination.*
   - ***Product shelf life:*** *packaging, storage, and temperature.*
   - ***Raw materials:*** *micro-organisms, trace contaminants such as pesticides and heavy metals.*

3. Assess the risk of hazard occurring. Once the potential hazards have been identified the associated risk of each should be quantified, usually into high, medium and low categories.

4. Identify CCPs and prepare a 'decision tree' for action. Control of hazards is exercised at CCPs. These can be locations, procedures, practices or processes, such as maintaining staff hygiene standards, correct operation of thermal processes, control of product storage temperatures etc.

5. Establish critical limits for each CCP. Once CCPs have been identified, the means of testing to ensure that the control is adequate must be established for each. This assessment may include microbiological, chemical, physical, sensory or administrative procedures.

6. Establish monitoring procedures for each CCP. Once established, all controls must be implemented and the CCPs monitored to ensure that adequate control is being maintained. Monitoring should be on a continuous basis.

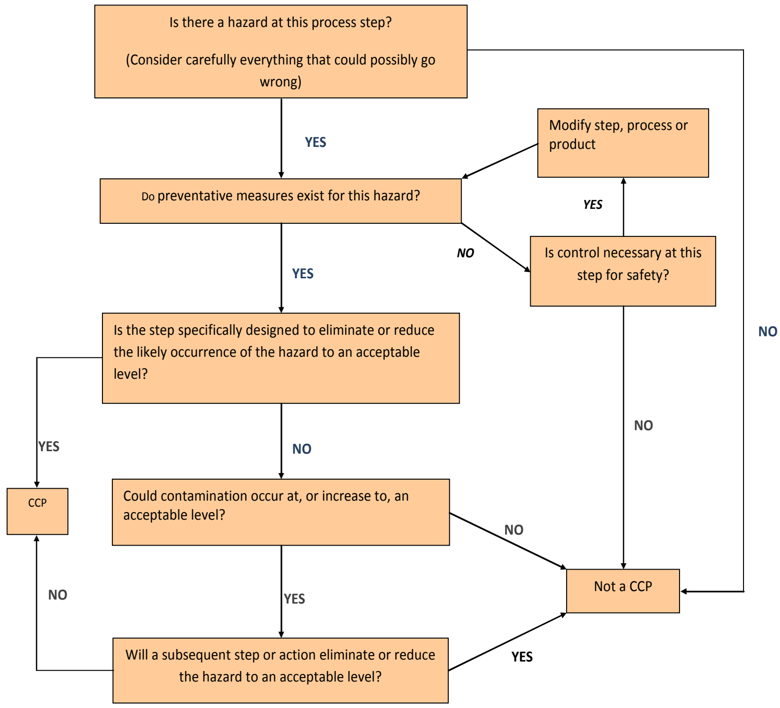
7. Establish corrective action for each CCP. Procedures must be written detailing the course of action to be taken when the CCP is found to be 'out of control'. These procedures detail the steps to be taken to bring the CCP back into control.

8. Establish record keeping and documentation.

9. Establish and audit procedure for verification. More detailed tests should be used periodically to ensure the effectiveness of the HACCP system in relation to the stated protocols and any hazards not included in the initial hazard analysis.

10. Review the HACCP system each time there is any change to the process. Any changes in the production or handling processes that may affect the HACCP system must be identified and

appropriate modifications to the HACCP system implemented.



An example of a critical control point decision tree.

An example of the implementation of HACCP for malt is described on the Maltsters Association of Great Britain (MAGB) website.

MALT RELATED FOOD SAFETY

Potential contaminants from outside the malting plant – field mycotoxins, agrochemicals, heavy metals

Field Mycotoxins

Field mycotoxins originate from moulds which infect the growing barley. The most important of these moulds are Fusarium species, especially graminearum and culmorum, plus Microdochium species. The compounds are toxic and can cause a range of diseases and can even be fatal in high doses. The most prevalent and toxic compounds are subject to legal maximum limits (ML) in the European Union, and information is being collected on more compounds to inform potential future regulation and limits.

The field mycotoxins of most relevance to barley are deoxynivalenol (DON), zearalenone (ZEA), nivalenol (NIV), T-2 and HT-2. DON has a maximum limit of 1250µg/kg in barley intended for human consumption (ie entering the malting supply chain). There is a higher figure given as a guideline for barley intended for animal feed. ZEA, being more toxic, has a ML of 100µg/kg. NIV is not regulated itself, but as it co-occurs with the more toxic DON it is regulated by implication. T-2 and HT-2 co-occur with each other, and are usually discussed with regard to the total concentration of both mycotoxins. There is no ML set in law, but a guideline from the European Commission has requested food processors to monitor levels in grain and to investigate the agronomic and storage history of any samples which exceed 200µg/kg (different figures are set for wheat and oats). Once sufficient data have been collected by this surveillance, a review will be undertaken to develop controls if necessary.

Fusarium infection is subject to various risk factors, but there is no statistical model to predict particularly high risk practices for barley whereas there is such a model for eat. The factors are believed to be similar, so the advice growers is the same and includes

- Choose fusarium resistant varieties
- Do not follow a previous crop of maize
- Deep ploughing is better than low or no tillage
- Apply full fungicide programme
- Monitor rainfall during flowering
- Analyse before delivery if concerned

It is the grower’s responsibility to ensure that the grain is legal before delivery to a malting plant.

That said, the requirements of due diligence impose on the maltster the need to operate a regime for sampling and analysis as an assurance that grain is not taken into a maltings that has a mycotoxin level above ML. Accordingly, a programme of random sampling is undertaken, with greater frequency immediately after harvest until a picture can be seen of a generally safe crop. Test kits are available to allow analysis during the normal intake analysis time period. These are not as accurate as full laboratory analysis – which takes some hours to conduct. A back-up survey is therefore undertaken to confirm the findings of the rapid tests.

If a sample is found to have a mycotoxin above the ML, a repeat test will be carried out. If confirmed, then (in the UK) the Food Standards Agency must be informed, and steps taken to try to remove the grain from the food chain. If the result is from a rapid test at intake, this is straightforward by rejecting the load which will likely then become animal feed. If the result is from grain which is in store, then isolation can be difficult.

Over the next few years, the European Food Safety Authority (EFSA) wishes to collect information on the prevalence and levels of several other mycotoxins, including Alternaria toxins, sterigmatocystin, diacetoxyscirpenol (DAS), plus ergot and masked mycotoxins.

Masked mycotoxins are those held in a form that does not show on conventional analysis – often a glycosylated form of the original chemical compound such as DON. Analysing these forms is a longer, more costly process, but it will be necessary to ensure that their level entering the food chain is safe and does not require specific legislation to control it.

Ergot is a contaminant of grain that has been recognised for hundreds of years. It is generally considered a physical contaminant that has chemical toxicity. It is a fungus that produces a fruiting body that occupies the space of a grain on than ear of barley (or other cereal) – see picture 1.

Picture 1

Picture 2

The fruiting bodies, or sclerotia, are a similar size or slightly larger than the replaced corn – see Picture 2. The strain of ergot that contaminates barley is *Claviceps purpurea*.

Ergot contains hallucinogenic amines, which are the toxins of interest and concern to the food industry. Control of contamination is currently by rejection of any load of grain that contains just one sclerotium. It is possible, at some cost, to clean sclerotia from grain by passing the grain over a photocell which activates rejection of black material..

There is little information available of the level of the toxic amines that are transferred to the grain by the presence and physical degradation of the ergot bodies. This is a further area of work that EFSA are pursuing, again through malt producers and other cereal processors.

Agrochemicals

Cultivation of commercial crops requires the application of agrochemicals for various reasons – even if the crop is grown to organic standards, although this specialised market is not covered in this section.

These chemicals include agents to control diseases such as fungal infection, to control insect infestation, fertilisers, growth regulators, desiccants and herbicides.

Any chemical used in agriculture within the European Union has to be licensed for use, and this will only happen after extensive trials and submission of an evidence pack to the European Commission for approval. Once approved, chemical usage must be in accordance with label conditions for concentration, application rates, time of application (especially if there needs to be a period between application and harvest). The accepted safe maximum of an agrochemical is called the Maximum Residue Level or MRL.

In the UK, further approval is needed for agrochemicals to be used on malting barley or hops. Obvious needs for such additional approval are that a herbicide does not persist into the malting process and prevent germination of the barley, or that a fungicide persists into the brewery and stops fermentation by yeast. Taste taints are also important to avoid. The British Beer and Pub Association (BBPA, the trade association for brewers) organises assessments and publishes a list of acceptable agrochemicals.

Approval of chemicals is the first stage in control of contamination – the next is their use on farm. A high degree of trust is vested in growers in the expectation that they follow Good Agricultural Practice (GAP). There are farm assurance schemes (in the UK, for example, Red Tractor or Scottish Quality Cereals) which arrange audits of registered farmers to ensure that their practices meet agreed and published standards. Sourcing barley from accredited growers is an assurance that GAP has been operated. Due diligence still requires that malt producers check by survey the absence – or acceptable presence – of agrochemicals.

Individual companies carry out surveys, and a co-ordinated survey is carried out by MAGB members to provide a comprehensive picture of any one crop year.

In general, certain chemical residues may be found in barley samples, but at levels consistent with GAP, and which are safe for processing further into foodstuffs.

Heavy Metals

Heavy metals, also sometimes referred to as potentially Toxic Elements (PTEs) in particular lead and to a lesser extent cadmium, can be taken up by the growing plant from the soil, or can be deposited on to the grain from traffic fumes and other pollution in the air. Lead in food can accumulate in the body and cause harmful effects. Governments across the world have therefore tried to reduce the amounts of these metals in foodstuffs. The increasing use of lead-free petrol has resulted in a decline in contamination of foodstuffs, which allowed the legal limit to be lowered from 2 mg/kg to the current limit of 0.2 mg/kg from April 2002.

Limits are set by assessment of toxicity and the dietary intake of consumers, either by the CONTAM panel of the European Commission or the Joint FAO/WHO Expert Committee on Food Additives (JECFA). The dietary limits are expressed as 'tolerable daily intake (TDI) or an equivalent monthly or weekly figure. Recent consideration of the physiological effects of lead has moved EFSA to removing any recommended tolerable intake.

In the UK, the Malting Industry has monitored its raw materials for lead and cadmium over several years. The results confirm that levels of these heavy metals in UK malting barleys are well below the current legal limit and have been declining over the past five years, due largely to the reduction of lead emissions from vehicles. Levels are now often below the detection limit for lead.

Cadmium is present in soils to a greater or lesser extent, and it is possible that levels occurring naturally may be higher than desirable for food quality cereals. Monitoring work must be undertaken to assess such a possibility. Cadmium is present in phosphate fertilisers as a natural contaminant, and there is discussion about removal of cadmium (an expensive process) to reduce the levels introduced from this source. Different sources of phosphate fertilisers contain varying amounts of cadmium, so this represents a potential means of control as well.

Other heavy metals which are monitored include arsenic, copper, mercury, and zinc. Not all of these metals will have a maximum level (ML) set in regulation, but there is a presumption under food safety law that safe levels must be adhered to.

Again, a due diligence survey is the best means of monitoring heavy metal concentrations in barley and in malt. Some result area available on the MAGB website.

Potential contaminants from within the malting plant – storage mycotoxins, NDMA/ATNC, ethyl carbamate

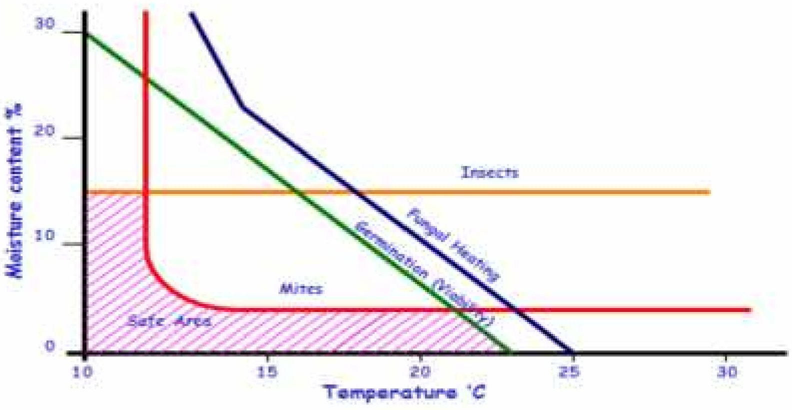
Storage Mycotoxins

These mycotoxins originate during storage of the grain from fungal growth, and include ochratoxin A (OTA) and a range of aflatoxins. In temperate climates, aflatoxins may not be a problem in cereals storage and may therefore not need monitoring.
OTA is produced by Penicillium verrucosum and Aspergillus species, aflatoxins by Aspergillus species.

The growth of these species during grain storage is dependent on the moisture content and temperature of the grain, and it is practical to control this growth by ensuring that grain enters storage at appropriate moisture and that it is cooled promptly to a suitable temperature.

Once grain is safely in store, monitoring of temperature must continue by a matrix of thermometers throughout the bulk. This will show whether heating is occurring through, for example, insect infestation or water contamination leading to germination. Once an area of the bulk starts to heat, moisture rises from this area and can condense on other grain, leading to further mould growth, insect or mite proliferation and possible grain germination – a bulk can quickly be spoilt from a quality viewpoint because of reduced Germinative Energy (GE) and from a food safety angle because of contamination with mycotoxin. A composite chart showing the safe zones of moisture and temperature for insects, mould, mites and germination is shown below.

Temperatures should be checked in store at least every week until they reach the safe zone, at which time the frequency may be reduced to fortnightly.



Protection against insect infestation can also be achieved by dosing an approved storage insecticide onto the grain on its way into store.

Should raised temperatures be observed in the bulk grain during storage, there are few options for remedial action. Moving the grain to steep or to an empty silo are possibilities – but at the risk in the latter case of spreading the infestation. Fumigation with an insecticide – typically phosphine – may be carried out on the static bulk, at some cost but with no problems of chemical residue.

NDMA/ATNC

This potential contaminate was identified around 1980 when analytical techniques improved to be able to identify lower levels of the compound nitrosodimethylamine – NDMA.

A survey of beers showed that malt from certain maltings was responsible for higher levels of NDMA in the finished product, and a rapid conclusion as to the common factor between these maltings was that they operated direct-fired gas kilns. Then the task of understanding the chemistry started.

We are now able to benefit from those studies to understand that the nitrosylation of amines in the malt, particularly in the rootlets of the growing grain, was caused by oxides of nitrogen in the gases which passed over the grain in the kiln – styled NOx, as the important two gases are NO and NO2.

The maltings that did not produce high NDMA malt were fired indirectly, or fired by oil or even coal. The difference from the change of fuel was the pH on the surface of the grain – more acid when the fuel contained sulphur which burned to produce SO2 and created sulphurous acid in the flue gases. The change for indirect-fired kilns was that the flue gases did not pass through the grain, but instead the drying air passed through a heat exchanger and was heated by (typically) a thermal fluid – steam, hot water or thermal oil which itself had been heated in a boiler by the flue gases from the flame.

The initial reaction for maltings with gas-fired kilns was to inject SO_2 into the flue gas stream, or to burn sticks of sulphur to achieve the same effect, mostly followed as capital investment plans allowed by a change to indirect firing.

Ethyl Carbamate

Some barley varieties produce high levels of cyanogenic glucosides, commonly known as glycosidic nitriles and abbreviated to GN, when malted. The use of these varieties in the distilling industry, under certain conditions, can produce significant levels of a potentially carcinogenic compound – ethyl carbamate, often abbreviated to EC.

The propensity for barley to produce GN is genetically determined, and for many years plant breeders have been developing barley verities which produce only low levels of GN. More recently, in response to the continuous improvement demanded by distillers, only nil-GN producers will be considered by the MAGB/IBD Malting Barley Committee for approval for malting and distilling.

In the future, as the essential combination of nil-GN, good agronomic yields and high quality of malting/distilling performance is bred into varieties, it can be expected that all barley malted for distilling will be GN free.
A typical specification for GN in malt is <0.5g/tonne.

References:

MAGB Implementation of HACCP for barley and malt.
http://www.assuredukmalt.com/The%20MAGB%20HACCP%20Protocol%20%20Version%203.0.pdf

BBPA list of approved pesticides for barley.
http://www.ukmalt.com/sites/default/files/files/TECH-456%20BARLEY%20Feb%202012.pdf

Red Tractor http://assurance.**redtractor**.org.uk

Scottish Quality Cereals http://www.sqcrops.co.uk

MAGB survey of agrochemicals http://www.ukmalt.com/node/78

MAGB survey of Heavy Metals http://www.ukmalt.com/heavy-metals

Plant Cleaning; cleaning in place (CIP), pest control and general cleaning.

TYPES OF SYSTEMS AND CLEANING CYCLES.

There are essentially two types of plant cleaning available, Manual Cleaning and Automatic Cleaning. For the purpose of this learning material assume all automatic cleaning systems are of CIP type even if they have to be manually activated. Automatic cleaning / CIP has been adopted into the malting industry from the brewing and distilling industries and is suitable for a number of specific types of cleaning duties. As you might expect the brewing and distilling sector use a large number of enclosed systems such as pipes, tanks, vats etc. As these elements are usually subject to filling with fluid it makes them particularly suited to automatic / CIP cleaning. Likewise, the malting industry has some similar areas suitable for the automated cleaning. Such areas include:-

- Steep tanks
- Germination vessels
- Conveying equipment/pipework associated with both the above.

Automatic / CIP cleaning in such systems has the following benefits:-

- Reduced downtime for cleaning procedures.
- No requirement to dismantle for cleaning.
- Cleaning can be programmed to begin at set stages rather than wait for manual intervention.
- Workers are not subject to any dangerous effects from cleaning materials during the cleaning process.
- Workers are not entering confined spaces.
- If the CIP system is suitable for task then the task will be repeated to a very similar standard during each use.
- Chemical use can be optimised and evenly applied.
- Running costs are lower due to negligible manpower required.

Disadvantages include:-

- High capital outlay.
- If not correctly set up, may fail to clean evenly or to a high enough standard.
- Has a degree of burden for the plants engineering department to maintain the extra equipment.

Manual cleaning on the other hand can be used to clean all areas of a malting plant. A plant cleaning operative may be tasked with cleaning any of the areas an automatic system might as well as areas not suitable for automated cleaning. Typical areas not suited to automated cleaning include:-

- Kilns.
- Storage facilities
- Dry product handling machinery
- General cleaning (eg: vacuuming floors, cleaning walls, cleaning railings etc)

Manual cleaning has the following benefits:-

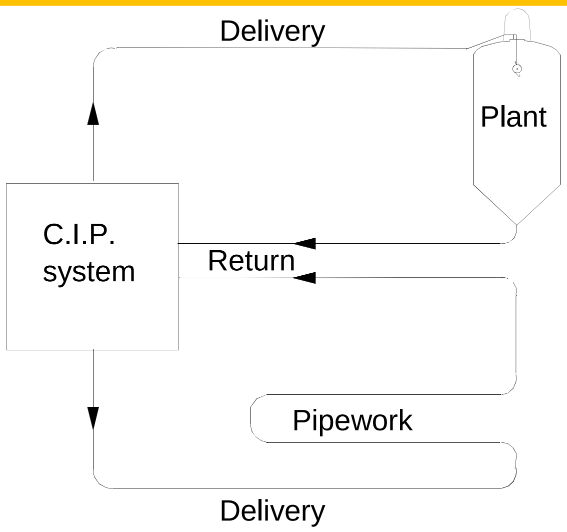
- No significant capital outlay.
- Adaptable to changing cleaning requirements.
- Can clean dry areas.
- Plant is observed more closely and issues can be brought to light early.

Disadvantages include:-

- Standard of cleaning is determined by the individual and subject to variation.
- Running costs are higher than automatic cleaning due to the salary overheads in addition to the cleaning materials.
- Workers may be subject to any dangerous effects from cleaning materials during the cleaning process.
- Workers may be entering confined spaces.
- Cleaning can take longer to complete.

Cleaning in place has replaced older methods where plant was dismantled for manual cleaning. Modern plants do not have the manpower or time for manual cleaning operations and they need the higher standards that an effective CIP system can deliver.

CIP is the circulation of detergents, water rinses and sterilants through fixed plant without dismantling. In order to achieve this, plant has to be fitted with spray balls/heads and pipework has to be linked into a ‘ring’ main.



The detailed features of a CIP system to be considered are:-

- The CIP could be a ‘recovery’ or a ‘total loss’ system.
- The CIP programme or sequence of cleaning elements.
- Plant CIP choice of spray head.
- Flow rates, delivery and return.
- Choice of cleaning/sterilising materials (se Section 16).
- Automation and monitoring.
- Running costs.

Choice of System - Recovery or Total Loss.

A **recovery** CIP system consists of tanks where supplies of detergent and sterilant are held at the required concentration for use. Cleaning fluids are delivered from the tanks and returned to them. Detergent and sterilant strength is maintained in the tank.

A **total loss** system doses concentrated detergent or sterilant into the delivery line and although they are re-circulated, at the end of the clean the cleaning fluids are run to waste.

CIP Cleaning and Sterilising Programmes.

The standard programme is:-

- A **rinse** to remove as much soil as possible and to flush this to drain. The time taken for these rinses will depend on the plant and how easy it is to clean.
- A **detergent recirculation** to clean the plant. The time of recirculation will depend on the level of soil in the plant, but times of **30 to 60 minutes** are common. As the plant may contain rinse water, the first delivery may be run to drain so as not to dilute the tank.
- A **rinse to remove traces of detergent**. As the plant may contain detergent, the first delivery may be returned to the tank to save detergent.
- A **sterilization** to destroy any remaining micro-organisms. The time of sterilization will depend on the level of microbiological contamination in the plant, but times of **10 to 20** minutes are common. Micro-organisms are destroyed by contact so that actual circulation of the sterilant is not necessary.
- A **final rinse** if it is decided that no sterilant should remain in the plant. This is similar to the initial rinse although the water that is used must be uncontaminated. If it is considered, however, that residual traces of the sterilant will not harm the product, the final rinse may be omitted. Water from the final rinse can be collected and used as an initial rinse when the next vessel is cleaned. The benefits of a final rinse recovery being a reduction in water use, a reduction in effluent and a more effective pre-rinse.

Comparison of Recovery versus Total Loss Systems

The benefits and problems associated with ‘Recovery’ and ‘Total Loss’ systems are detained in the table below:-

Recovery System	Total Loss System
Capital costs are higher because of the need for large tanks	Lower capital cost
Running costs are lower because all chemicals are recovered	Higher running costs
Simple to operate.	Complex control system relying on detergent/sterilant strength sensors.

Plant Cleaning

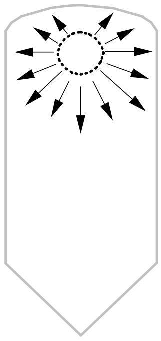
Spray heads for plant CIP.

There are two main types of spray head, the fixed spray ball and the rotating spray head.

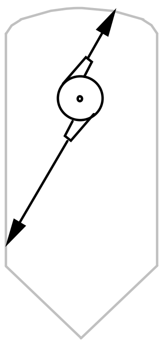
Fixed spray ball.
This uses large volumes of cleaning liquid at low pressure.

It relies on the cleaning liquid flowing over the surface of the plant, therefore the whole surface must be covered. Positioning of the head must ensure full coverage.

Tank fitted with low pressure fixed spray head (spray ball)



Tank fitted with high pressure rotating spray head



Burst rinsing is effective because the liquid finds new routes to flow down with each burst.

The large volume of cleaning liquid used means that attention needs to be paid to plant drainage/scavenge. The base of a poorly drained plant is not cleaned because the cleaning liquid does not flow over the surface at sufficient speed.

Spray balls are relatively cheap and they are easy to maintain although they can block up especially if the cleaning liquid is unfiltered.

Rotating spray head.
This is a mechanically driven head that rotates to direct a high-pressure jet to the plant surface, usually in a pattern to ensure that the entire surface is jetted. This principle means that it takes a specific time to complete the pattern and cover all surfaces.

The mechanical force is a powerful aid to the cleaning process and the system can use colder and or less aggressive detergent than the fixed head.

Rotating spray heads are relatively expensive and are made up of moving parts, therefore there is wear and tear during use.

Rotating spray heads are often fitted with rotation detectors because a stationary head will only clean a small section of the plant.

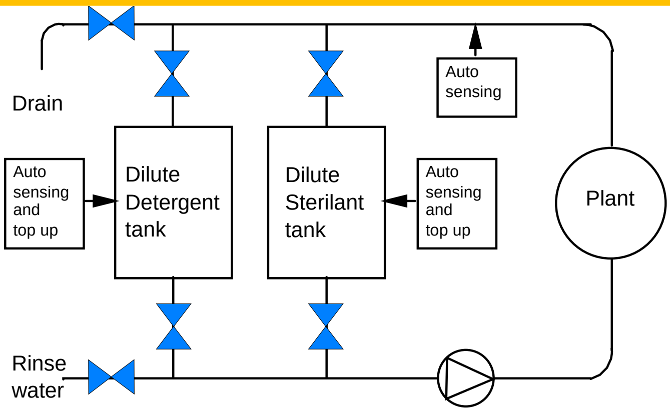
Automation and monitoring.

Complex CIP systems are ideally controlled automatically, the advantages being:-

- A programme can be designed and set when the plant is commissioned to maximise cleaning and this will be consistently adhered to.
- Detergent and sterilant strengths can be optimised.
- A cleaning cycle can run unsupervised.
- Automated recording of cycle times, detergent strengths and temperatures by the monitoring equipment is available.
- Cleaning can be held up if a problem is detected.
- Sensors can detect detergent/sterilant strength on the return line and direct the return to tank or drain saving chemical costs.

In the CIP system illustrated below, the following items are automatically controlled:-

- Inlet and outlet valves of detergent/sterilant tanks.
- Delivery pump.
- Rinse water and drain valves.
- Detergent/sterilant strength detection and tank top up from bulk supplies.
- Detergent/sterilant strength detection on the return line.



Plant Design - Hygiene Considerations.

Effective cleaning is the result of a combination of four factors:-

- **Time**. How long is the cleaning agent/detergent in contact with the plant?
- **Temperature**. How hot is the cleaning agent/detergent?
- **Chemical activity**. How strong/effective is the cleaning agent/detergent?
- **Physical activity**. How vigorously is the cleaning agent/detergent applied to the plant?

If one of these factors is reduced, for example if the plant has to be cleaned quickly, then another factor must be increased to compensate, for example hot instead of cold detergent could be used.

GENERAL SITE PEST CONTROL PRINCIPLES

Overview

The objective of Site Pest Control should be to prevent, as far as practicable, the introduction of pests onto the site and to reduce the conditions that may encourage their presence.

The presence of pests should be regarded as unacceptable. The risks posed by pests include:

- Physical damage to product leading to possible quality loss and financial loss.
- Increased food safety risk due to mycotoxin build up in infested grain.
- Damage to property.
- The spread of disease.
- Adverse customer opinion and loss of reputation.

The types of pests that are related to the malting industry are as below:

- Rats
- Mice
- Birds especially pigeons
- Weevils, beetles, mites

In the United Kingdom, malt plants are registered as food producers with their local authority and come under the EU Food Hygiene Regulations in which are laid down general hygiene requirements for all food business operators stating that;

- The layout, design and construction of food premises are to permit good food hygiene practices including protection against contamination and in particular, pest control.

- There should be adequate procedures in place to control pests.

A site pest control system should be a pre-requisite of the company HACCP (Hazard Analysis and Critical Control Points) system and is a requirement to comply with Good Manufacturing Practice and a number of standards including the Feed Material Assurance Scheme FEMAS.

Good practice for pest control:
The company shall develop and implement a pest control program using a trained specialist that has been approved in accordance with national legislation. The programme shall ensure that all products, processes and other sensitive areas are suitably protected from pest activity. The company shall ensure that all storage, processing, packaging and dispatch areas are protected against the ingress of pests. Waste materials shall be regularly cleared away so as to avoid attracting pests. Records of all treatments and inspections shall be kept. The program can be developed and operated in-house or sub-contracted. If an employee carries out the pest control it must be in accordance with legislation and DEFRA guidance.

It follows that pest management should be carried out with due diligence and be properly documented. Pest control companies should be a member of a recognised trade association or body. In the UK these would be the British Pest Control Association or National Pest Technicians Association.

Effective site pest control requires an integrated approach involving appropriate site controls and support from a suitable pest contractor.

The objective is the maintenance of pest free conditions in all areas of the site. A systematic approach should be taken to pest control and pest prevention involving exclusion, restriction and destruction.

Exclusion
Refers to the methods used to prevent pests entry onto site or into a building. This will include vigilance at intake

Restriction
Refers to the methods used in creating unfavourable conditions for pests to harbour and breed.

Destruction
Refers to the physical and chemical methods used to control pests.

Most buildings provide 3 main attractions for pests:

- **Food and water** – Most pests require very small amounts of food, an adult mouse for example can survive on as little as 3 grams a day. It follows that cleaning is a key requirement of pest control as is removal of water sources.
- **Warmth** – A few degrees increase in temperature may be sufficient to encourage infestation particularly in winter months. With most species of pests an increase in temperature corresponds to an increase in breeding frequency and numbers.
- **Shelter** – All buildings provide a degree of shelter or harbourage whether old or new, if they include areas allowing internal movement of pests such as wall cavities, service ducts, panelling and suspended ceilings for example.

A Typical Pest Control Service Contract:
This will contain the following.

Premises Risk Assessment.
The number and type of routine visits will be based on risk assessment. This will consider the past history of the site. Is there documented evidence that rodents have been active in the last two years?

The site's potential for infestation. Does the layout, construction, manufacturing process, hygiene practices or product lend the site liable to infestation? Are there water courses, railways, amenity sites nearby? Is the site situated within or adjacent to a high risk area?

What is the status of neighbouring properties? Are the activities of adjacent properties or businesses liable to attract pests into the vicinity?

The key points of a Pest Control Contract are as below:

1) Responsibility must be allocated to a senior manager.

2) Suppliers Health, Safety and Environmental Policy and Risk Assessments in relation to the tasks to be undertaken. The Insurance documents of the Supplier should also be available at all times. The supplier must also provide a Waste Carriers Licence for approved disposal of pests and pesticides.

3) The contract will identify terms and conditions including costs, frequency of visits, key contact details, reporting mechanism and contract length.

4) The contractor will provide proof of a Trade Body Membership Certificate and Contractor Qualification. Proof of contractor operator training must be regularly checked.

5) Details of out of hour contacts are to be available with contractor and malt producer.

6) Adequate measures must be taken to prevent pests from entering buildings.

7) Appropriate measures of insect control, such as fly screens, electronic fly killers, rodent baits etc. must be provided, properly placed and maintained.

8) A reputable pest control contractor must be employed unless the company has equivalent expertise and resources. In the case of a company-based pest control service, the operation must be managed by an appropriately experienced supervisor.

9) The contractor must be provided with a contract specification which requires the contractor to report to the responsible manager before and following visits to the premises. An exit meeting should take place within an agreed time schedule to review findings of the visit.

10) The contractor must provide the company with a written report of any pest control activities undertaken on the premises and must provide, where needed, written recommendations of action required to solve pest related problems.

11) All instances, as seen by any employee, of pests within buildings or, in the case of rodents, within the site perimeter must be immediately reported to the responsible manager.

12) Hygiene auditing must encompass routine surveillance of buildings and perimeter for pests.

13) A manual must be available which will contain all the relevant information of the pest control programme, including a site plan with the location of all pests traps where necessary.

14) Pesticides and chemicals when used must be industry approved and have the relevant documentation including COSHH data sheets. Usages of pesticides are to be kept.

Pest Diseases:

a) Weil's Disease

Weil's disease is an infection that humans can catch from animals, including domestic animals like dogs. Perhaps most commonly however, the disease is spread by rats. Rats carry and excrete an organism called *Leptospira ictero-haemorrhagiae* in their urine. Between 50 and 60% of all rats carry this organism. If humans are infected with this organism, it can make them very ill and even result in death. As many as 10% of all cases of human infection have resulted in death.

Previously, Weil's disease only infected people such as sewage or abattoir workers, although there have also been incidents of farm workers and miners contracting the disease. New research shows that people who perform water activities, such as cavers and potholers, are also at risk. Rats commonly live near water and other areas where they can find food, such as farms, stables and riverbanks. The organism that causes the disease in humans cannot live for very long in dry conditions, but it can survive for some length in wet or damp areas. Salt water will kill off the organism.

The organism that causes Weil's disease enters the body through cuts, blisters or abrasions in the skin. It can also enter via the lining of the nose or through the throat or alimentary tract. The disease begins with a fever, followed by muscular aches and pains. Loss of appetite and vomiting follow. The incubation period is 7 to 13 days.

b) Rat-bite Fever

Fatal in 10 percent of untreated cases. Usually contracted from rats, but infection can also occur from mice. The bacterium causing this disease enters the body through bites, as its name suggests, or from urine contaminating either food or pre-existing skin wounds.

c) Salmonella:

Mice and rats are both frequent carriers. Spreads to humans by contact with mouse droppings, especially through consumption of contaminated food. Causes serious, sometimes fatal gastroenteritis. Household pets are also frequently infected with Salmonella by this means and often die as a result.

d) Pigeon Droppings:

Often referred to as 'rats with wings', feral pigeons have become just as much of a problem in towns and cities as their furry, four-legged counterparts.

Descendants of rock doves, originally cliff dwelling birds, the feral pigeon has adapted well to living alongside humans and is an integral feature of town centres. It is still unknown how big a health risk pigeons pose to humans, with many experts believing the chance of infection to be slight.

An undisputed and particularly visual pigeon problem however is mess. Combined pigeon deposits can weigh up to several tons and can cost businesses a significant sum per year to clear up. Droppings not only cause buildings to look unsightly, but can cause long term damage to buildings.

a) Fresh pigeon droppings, whilst unpleasant, pose no risk to health. It is dried droppings that can potentially spread infection
b) Spores from the dried droppings can be inhaled as dust and carried on the wind. It can cause a flu like illness in healthy people, but poses more serious problems to those with low immunity

Pest Proofing:

Mice and Rats

- Close all doors
- Block all spaces between doors and floor
- Ensure all electrical conduit are fixed and enclosed.
- All grain spillages must be cleaned and removed
- Check brickwork and buildings for any gaps and holes.
- All drains and water discharge areas are covered.

Pigeons/Birds

- All doors and entrances must be kept shut
- All grain spillages must be cleaned and removed.
- All windows are to be kept shut.
- Cover openings of grain with netting.
- Use imitation birds of prey to scare other birds away from the premises.

Insects/Mites

- Clean all spillages.
- Remove any dead pests.
- Ensure maltings is free from laying dust

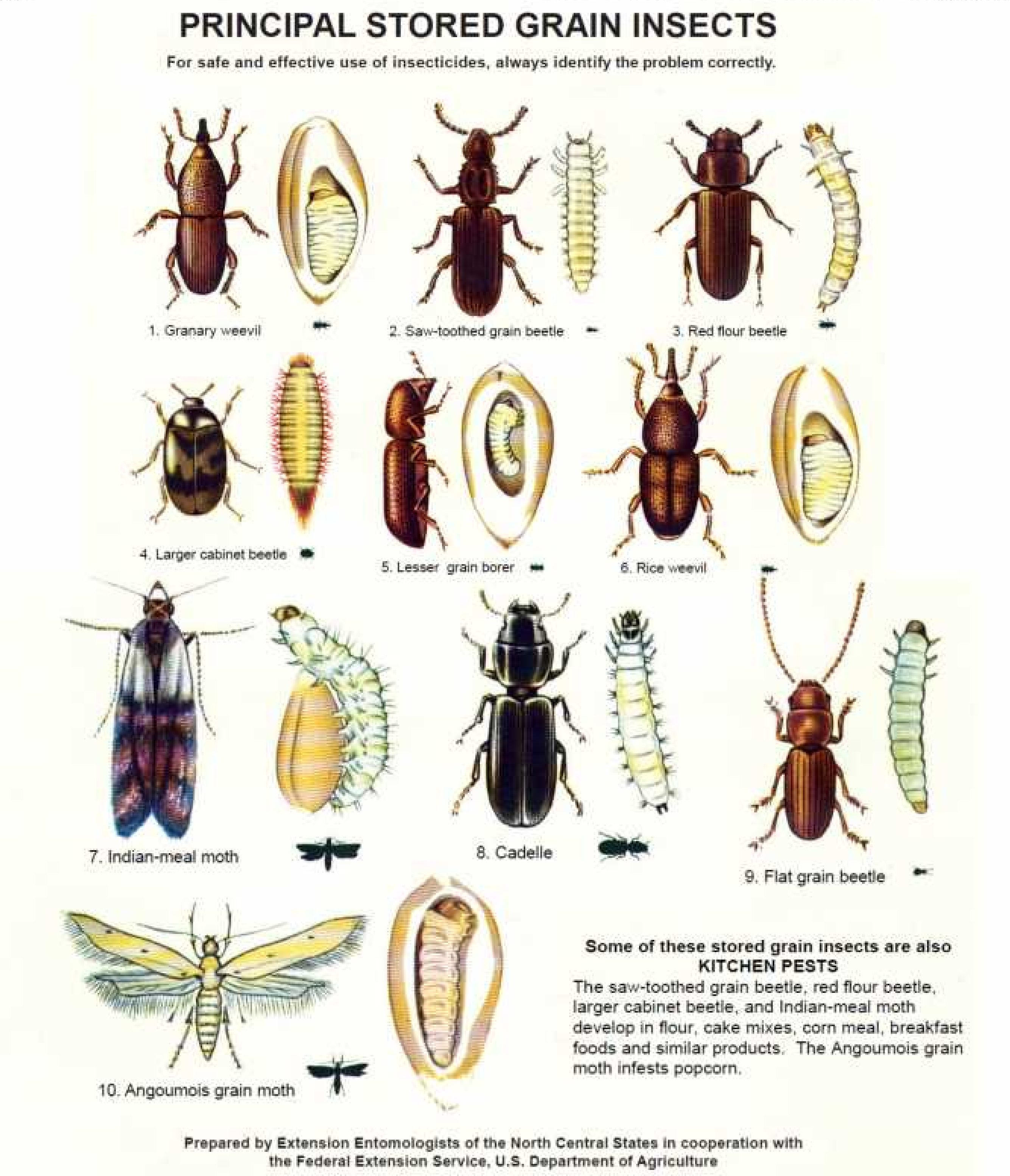
Insect Detection and Control (material adapted from Purdue University Extension)

1. GRANARY or GRAIN WEEVIL, Sitophilus granarius. This weevil, along with the closely related rice weevil, is among the most destructive of all stored grain insects. The larvae develop inside kernels of whole grain in storage, thus making an infestation difficult to remove in the milling process. The granary weevil is largely a pest of stored wheat, corn, and barley, especially in elevators, mills, and bulk storages. The adult cannot fly, and field infestations do not occur.

2. SAW-TOOTHED GRAIN BEETLE, Oryzaephilus surinamensis. Along with flour beetles, the saw-toothed grain beetle is one of the most common insects in stored grain and cereal products. The larvae develop in flour, cereal products, and many other dried foods. For this reason, it is a common pest not only in grain bins, but also in elevators, mills, processing plants, warehouses, and kitchens. In grain bins, it feeds on broken kernels and grain residues.

3. RED FLOUR BEETLE, Tribolium castaneum. This beetle is similar to the saw-toothed grain beetle in habits and types of products infested. It is a serious pest in flour mills and wherever cereal products and other dried foods are processed or stored. Like the confused flour beetle (not pictured), the red flour beetle may impart a bad odor that affects the taste of infested products.

4. LARGER CABINET BEETLE, Trogoderma inclusum. Representing a group also referred to as Trogoderma, the larger cabinet beetle is a scavenger that feeds on cereal products and dried animal matter. The fuzzy, slow-moving larvae — similar to the larvae of carpet, hide, and larder beetles — often are found crawling about on or near the



5. LESSER GRAIN BORER, Rhyzopertha dominica. This pest is most common and destructive in warm climates but can spread to any area in transported grain. It is a problem of grain only and not cereal products. The larvae develop inside the kernels of whole grain. The adults also damage grain by boring into the kernels and leaving them covered with powder from the chewed material.

6. **RICE WEEVIL, *Sitophilus oryzae* .** The rice weevil is similar to the granary weevil in both appearance and habits. The name is misleading, however, because it infests other grains besides rice. Adults can fly and, in warm climates, can cause widespread damage to corn, wheat, and other grains before harvest.

7. INDIANMEAL MOTH, *Plodia interpunctella.* Common to both stored grain and cereal products, Indianmeal moth larvae cause damage in corn meal, packaged foods, bagged grain, and grain in storage. Attack is confined to surface layers of stored shelled corn and small grains. In the case of stored ear corn, however, feeding occurs anywhere because the moths crawl among the ears to lay their eggs. Larval feeding is characterized by a webbing of the material infested. The mature larvae then often leave the material and crawl about in search of a place to pupate.

8. CADELLE, *Tenebroides mauritanicus.* Both the adult and larvae are large and easy to see. Both stages feed mainly on the germ of stored grains, but may also attack milled cereal products. The larvae leave stored grain in the fall and burrow into woodwork, such as wooden bins or boxcars, to hibernate. They may also burrow into packaged cereal products, thus providing an entrance for other cereal pests.

9. FLAT GRAIN BEETLE, *Cryptolestes pusillus.* This is a tiny beetle that feeds primarily on the germ of stored grains, especially wheat. It is readily attracted to high-moisture grain. In fact, under high-moisture conditions, the flat grain beetle may also develop in many cereal products, but is not a common pest in kitchens.

Direct-feeding damage by insects reduces grain weight, nutritional value, and germination of stored grain. Infestations also cause contamination, odour, mould, and heat-damage problems that reduce the quality of the grain and may make it unfit for processing into food for humans or animals. Commercial grain buyers may refuse to accept delivery of insect contaminated grain, or may pay a reduced price.

Kinds of Stored Grain Insects

Several species of insects may infest grain in storage. The principal pests that cause damage are the adult and larval stages of beetles, and the larval stage of moths. All may be a problem by their presence, either alive or dead, in grain that is to be processed for food.

Stored-grain insects are known as "internal feeders" if they feed within the kernels, otherwise they are referred to as "external feeders." The granary weevil, rice weevil, lesser grain borer, and larvae of the Angoumois grain moth are internal feeders.

External feeders (or "bran bugs") that feed on grain dusts, cracked kernels, and grain debris without entering the kernel, include Indianmeal moth, sawtoothed grain beetle, red and confused flour beetles, flat grain beetle, and cadelle. Other species, such as the foreign grain beetle and hairy fungus beetle, feed on moulds or fungi growing on grain stored at excessive moisture levels.

Preventative Measures Before Binning

Grain Bin Clean-up: Newly harvested grain may become infested when it comes in contact with previously infested grain in combines, truck beds, wagons, other grain-handling equipment, augers, bucket lifts, grain dumps, or grain already in the bin. Insects may also crawl or fly into grain bins from nearby accumulations of old contaminated grain, livestock feeds, bags, litter, or any other cereal products. Insect infestations can be prevented with good management practices. Where appropriate, the following guidelines should be used two or more weeks before grain is placed in bins:

1) Brush, sweep out and/or vacuum the combine, truck beds, transport wagons, grain dumps, augers, and elevator buckets to remove insect-infested grain and debris.

2) In empty bins, thoroughly sweep or brush down walls, ceilings, ledges, rafters, braces, and handling equipment, and remove debris from bins.

3) Remove all debris from fans, exhausts, and aeration ducts (also from beneath slotted floors, when possible).

4) Remove all debris from the storage site and dispose of it properly according to local / national guidelines (this debris usually contains insect eggs, larvae, pupae, and/or adults, all ready to infest the new grain).

5) Remove all debris and vegetation growing within ten feet of the bins (preferably the whole storage area).

6) Examine area to determine if rodent bait stations are required, and use if needed. Be sure to follow all label directions.

7) Spray cleaned area around bins with a residual herbicide to remove all undesirable weedy plants.

8) Inside bins, spray wall surfaces, ledges, braces, rafters, and floors with an approved insecticides to the point of runoff. Outside, spray the bases and walls up to 15 feet above the bases, plus the soil around the bins.

Preventative Measures During Binning

A grain protectant may be applied to grain that will be in storage for one or more years. Grain protectants are insecticides registered for application to whole grain to protect against insect infestations while the grain is in storage. Grain protectants kill insects as they crawl about or feed on treated grain and/or grain fragments. These formulations are generally applied to grain as it is being augured, loaded, or turned into storage facilities. **Do not** apply grain protectants before high temperature drying because extreme heat will result in rapid volatilization and reduced residual qualities of the pesticide. Grain protectants applied to 13% moisture grain will have a greater residual life than grain at 15% or greater moisture. Grain protectants, when applied according to approved use, can be sold or fed immediately after application.

Preventative Measures After Binning

Top-Dress: Some grain protectants may be applied as a surface treatment ("top-dress" or "cap off") to the grain mass already in storage to control "surface feeders" such as the Indianmeal moth larva. Remove any webbing that may already exist (produced by the larvae) before applying the top-dress treatment. Raking the product into the top few inches of levelled off grain will increase the likelihood that the larvae will be controlled.

No-Pest Strips: Approved insecticide impregnated strips may be hung in the open space of the grain bin during the spring, summer, and fall months to control flying insects such as the adult Indianmeal moth

Control Measures After Binning

Any time the grain is at or above 12°c, it should be in-spected every two weeks for insect activity. Stored grain pests are generally inactive at temperatures below 12°c. Even if insects appear active only on the surface of the grain, use a grain probe or other sampling device and determine the extent of infestation within the grain mass. Insects collected should be identified before chemical treatment is considered. Knowing what insect species is infesting stored grain can provide important information on the grain condition and what should be done about it.

The most common stored grain insect pests may be grouped by their feeding habits. Listed below are appropriate management strategies for these groups.

Internal Feeders

Weevils and Lesser Grain Borer

The only options with infested grain is to sell for animal feed at a discounted rate, or fumigate it. All fumigants are classified as restricted use products. Fumigants are **extremely hazardous** for the user and must be applied by a certified and licensed commercial fumigator. Fumigants for use in farm storage bins are registered as either "liquid under pressure" or "solid formulations." Regardless of the formulation, fumigants become effective when they change to a gas form, and settle down through the grain mass.

The grain bin should be air-tight and all openings sealed before fumigation. Best conditions for treatment are a calm day with grain temperatures at or above 18°c. Success depends on the concentration of the fumigant, grain temperature, and length of time the fumigant is in the bin. The minimum exposure period is generally 72 hours. After fumigation, the grain must be aerated for at least 48 hours, or until the gas concentration level is below that listed for that fumigant. All labelling information regarding safety in handling and proper application techniques must be followed when making application. Specific safety equipment such as the use or availability of self-contained breathing apparatus and specialized instruments to measure gas concentrations are now required.

Remember that although a successful fumigation does drastically reduce the insect pest population, it offers no re-sidual effect. The grain becomes immediately susceptible to reinfestation once the gas is evacuated (approx. 72 hrs).

External Feeders

There are several management options available for control of "bran bugs" other than fumigating. Management decisions will vary depending on the insect species and numbers present, the storage facilities, and how quickly you want to move the grain.

Indianmeal Moth

The caterpillar (larva) is a surface feeder and stays in the top 3-6 inches of the grain mass feeding on fines while creating a webbing. For control refer to PREVENTIVE MEASURES AFTER BINNING.

Foreign Grain Beetle and Hairy Fungus Beetle

These beetles are fungus feeders and are present in the grain mass because of mouldy grain. Correcting aeration and/or moisture problems on the surface or within the grain mass and removing the out-of-condition grain will control this problem. Pulling grain out the centre of the bin (collection of fines), cleaning the remainder of the grain mass as it is being moved, and conditioning (drying and cooling) the grain will provide a bin unsuitable for these mould feeders.

Sawtoothed Grain Beetle, Red and Confused Flour Beetles, Flat Grain Beetle, and Cadelle

These secondary feeders infest bins because of the availability of grain dusts, cracked kernels, and grain debris. These pests can be distributed and feeding throughout the grain mass or localized because of a collection of fines, such as in the core of the bin where fines collect at binning. They will also feed on the dusts and damaged kernels created by internal feeders; if this is the case then the only control option is fumigation.

A grain bin of whole undamaged kernels is the key to preventing the secondary feeders. This may require running the grain through a cleaner or aspirator while moving the grain from one bin to another. This will not only remove the fines, but dead and live insects as well. Applying a grain protectant) while moving this grain would be a sound management practice. Refer to PREVENTIVE MEASURES BEFORE BINNING for proper preparation of the grain bin.

Continued Stored Grain Pest Management
All grain producers having grain in on-farm storage need to maintain a good management program that includes proper grain-handling, regular grain inspections, and pest control. Correct management `actions' taken as grain first goes into on-farm storage and then throughout the storage period will minimize the chance of problems that necessitate expensive `reactions'.

Grain has a limited storage life. If most of this life is used up during the autumn (fall) and winter, the grain may not make it through the following summer. There are basic management practices, however, that can prolong this storage life. Attention to these practices should help insure successful grain storage the year around.

Proper condition and moisture of grain for storage
Grain stores best if it is dry, cool and clean. Grain must be dry to hold it through the summer months. Cooling can sometimes replace drying, as when moist grain is held through the winter. And grain that is clean will better resist mold growth and insect infestation even if stored at 1-2 percent higher moisture content than will grain that is `dirty' (i.e., containing a lot of broken kernels, chaff and foreign material).

Aeration to maintain grain in storage
To maximize storage life and prevent moisture migration and buildup, grain should be held at near-average outdoor temperatures. The technique now used almost exclusively to control and maintain these desired grain temperatures is aeration, which merely mechanical ventilation of grain in storage.

Why Aeration Is Necessary In On-Farm Bulk Grain Storage
In large storage bins the grain bulk or mass is so large that it fails to cool uniformly enough to avoid storage problems as outdoor temperatures change with the seasons. The unequal temperature in the grain mass then causes air current to circulate from warm to cold grain.

Since warm air holds more moisture than cold, the air moving up through the warm grain centre picks up a full load of moisture, depositing some as it moves through the cold grain in the top layer. This causes moisture build up, molding and crusting. These minute `convection currents' in the grain cause moisture migration and accumulation that can only be prevented by reducing temperature difference in the grain bulk.

Uniform temperatures can be maintained in aerated grain storage if the aeration system has been well designed and is properly operated.

(material adapted from Purdue University Extension)

GENERAL PLANT CLEANING

Plant cleaning can be split into either wet or dry cleaning.

In wet areas cleaning is usually undertaken by the following means:

Abrasion cleaning
In manual cleaning, the normal steps of cleaning are followed *i.e.* pre-rinsing by removing as much loose dirt as possible followed by use of detergent at the correct concentration and scrubbers. The scrubbing material should not scratch the surface being cleaned. Therefore scrubbers or steel wools should be avoided. The surface that has been cleaned should be rinsed thoroughly with potable water.

High Pressure Cleaning
High pressure cleaning combines high pressure, high temperature and detergent. This cleaning technique allows effective cleaning of surfaces that are difficult to access, *e.g.* top of pipes and ceilings. Cleaning at high pressure (high hydraulics) and high temperature will minimise the detergent usage. The use of a high pressure gun at appropriate pressure will ensure that even stubborn soil is removed.

Foam Cleaning
In foam cleaning, the working solution is diluted with air. Strong detergent solutions can be used. Because of dilution with air, small quantities of water are used. The generated foam adheres to dirt, emulsifying and loosening it. The foam is removed by rinsing with water. An advantage of using foam as opposed to just a cleaning agent is that it improves the surface contact time of the cleaning agent with the surface being cleaned.

In dry areas cleaning is usually undertaken by the following means:

Brush
Brushes may be used in many areas of the malting plant to sweep up debris, spilled grains or even dust. It should be noted that using brushes to sweep dust can result in the dust being redistributed to atmosphere. This contributes to the health and safety of personnel from both the possible inhalation of the dust to the increased explosion risk form having airborne dust. Not to mention that airborne dust will eventually resettle.

Vacuum
Particularly suited to dusty areas, the vacuum removes the dust safely to a dust vessel or such. A malting plant will typically have a fixed vacuum system installed whereby there is a centralised vacuum cyclone unit providing the suction and a network of fixed pipes to each floor. Portable vacuums may also be employed but are limited to their capacity and portability. Vacuum systems can use a

number of different attachments for cleaning areas of the plant in the same way a modern household vacuum does. All vacuum components should be anti-static and where possible earthed to avoid electrical discharge during cleaning.

Legionella

Legionellosis is the collective name given to the pneumonia-like illness caused by legionella bacteria. This includes the most serious legionnaires' disease, as well as the similar but less serious conditions of Pontiac fever and Lochgoilhead fever. Legionnaires' disease is a potentially fatal form of pneumonia and everyone is susceptible to infection. However, some people are at higher risk, including:

- people over 45 years of age
- smokers and heavy drinkers
- people suffering from chronic respiratory or kidney disease
- anyone with an impaired immune system

The bacterium *Legionella pneumophila* and related bacteria are common in natural water sources such as rivers, lakes and reservoirs, but usually in low numbers. They may also be found in purpose-built water systems such as cooling towers, evaporative condensers and whirlpool spas.
Where does it come from?

Legionella bacteria are widespread in natural water systems, e.g. rivers and ponds. However, the conditions are rarely right for people to catch the disease from these sources. Outbreaks of the illness occur from exposure to legionella growing in purpose-built systems where water is maintained at a temperature high enough to encourage growth, e.g. cooling towers, evaporative condensers, spa pools, and hot water systems used in all sorts of premises (work and domestic).

How do people get it? People can catch legionnaires' disease by inhaling small droplets of water, suspended in the air, containing the bacteria. Certain conditions increase the risk from legionella, including:

- water temperature between 20–45^{o}C, which is suitable for growth
- creating and spreading breathable droplets of water, e.g. aerosol created by a cooling tower, or water outlets
- stored and/or re-circulated water
- a source of nutrients for the organism e.g. presence of sludge, scale or fouling

Ref:- http://www.hse.gov.uk/legionnaires/what-is.htm

Within a malting plant there a number of places that could be susceptible to legionnaires disease developing. Examples are:-

- Any hot or cold water storage vessel
- Shower systems
- Humidification systems
- Cooling towers

Prevention

Perform a risk assessment of any areas that could be subject to contamination and act upon it. Prevent water temperatures for stored water dwelling within the range 20-45^{o}C Ensure all water storage is clean and devoid of contaminants. Above 60^{o}C the bacteria are killed. Therefore use temperature as a means of killing the bacteria. Treat water where temperature treatment is impractical to kill the bacteria or limit its growth.

MALTING PLANT MAINTENANCE – APPROACHES AND TASKS.

Maintenance is the management of activities that contribute to optimum levels of availability and performance of plant.

The **AIMS** of maintenance are:

- To sustain the functionality of plant
- To minimise downtime
- To provide a safe environment for personnel operating/cleaning/maintaining the plant
- To protect product quality
- To prove due diligence, for example for consumer safety
- To ensure legal requirements are met, for example environmental compliance
- To protect the value of plant

There are four approaches to maintenance.

1. No maintenance.
This is when no checking and no maintenance take place at all.

This applies to certain items like electrical components that as and when they fail are discarded and replaced. This approach will only be appropriate in some circumstances.

2. Breakdown maintenance.
This is when equipment is only attended to if it breaks down.

With this system, there is a big risk of lost production because breakdowns often occur at the worst time.

It may be applicable if duplicate plant is installed; otherwise a big stock holding of spares is needed. Breakdown maintenance can also be known as **Corrective** maintenance.

3. Preventative maintenance.
This is where plant is maintained to a plan whether or not it shows signs of wear.

Usually several similar components are replaced at the same time, for example pump glands or wear strips on conveyors.

Planned maintenance can vary from a weekly inspection and oil top, through two or three day mini-overhauls, up to a complete line or major item annual overhaul.

The concept is that unforeseen breakdowns are much less likely to occur.
Preventative maintenance can also be known as **Planned** maintenance or **Planned Preventative** maintenance.

4. Predictive maintenance.
This is where plant condition is monitored and a prediction is made about when it is likely to break down. A maintenance programme is developed based on the information gathered.

This is called 'Condition Monitoring' and specifically it is a maintenance process where the condition of equipment is monitored for early signs of impending failure. Equipment can be monitored using sophisticated instrumentation such as vibration analysis, oil analysis, laser alignment of shafts in rotating equipment and thermal imaging. More traditionally, temperature, over voltage or current and liquid level has been monitored to warn of problems. Equally monitoring can be manual often using the human senses. Where instrumentation is used (automatic monitoring) actual limits can be imposed to trigger maintenance activity, generally through a computerised maintenance management system.

Predictive maintenance can also be known as **Condition Based** maintenance. A further variation can be **Risk Based** maintenance where maintenance tasks are arranged to reflect the risk of failure based on predicted plant life and plant history.

Comments

a) Whatever maintenance system is employed all activities must be carried out safely and meet all legal requirements. To meet these requirements a system of 'safe working practices' should be employed to ensure that Health and Safety is treated as a priority at all times. A system of safe working practices would include items such as:

- Some form of permit to work.
- Use of the correct personal protective equipment.
- Interlocked guarding systems.
- Training
- System reviews

b) Most maintenance systems now employ computers for recording information, issuing work and storing plant history. This also enables automatic electronic spares ordering and easily obtainable financial information about maintenance.

c) The cost of engineering maintenance needs to be controlled so annual budgets and regular reviews (normally monthly) of expenditure are a pre-requisite for control purposes. The normal costs for day-to-day maintenance activities are usually referred to as revenue items whereas the purchases of new plant like a barley screen or boiler are capital items.

The advantages and disadvantages of the various maintenance systems are detailed in the table below:

System	Advantages.	Disadvantages.
No maintenance.	Easy to set up. Appropriate in some circumstances	Risk of plant unavailability at key times. High cost of replacement parts.
Breakdown maintenance.	No unnecessary work on the plant.	Risk of plant unavailability at key times. High cost of spares.
Preventative Maintenance.	Work done on the plant at a convenient time. Less likelihood of breakdowns.	Expensive. Plant may be worked on unnecessarily.
Predictive maintenance.	Most effective use of engineering resources. Work done on the plant at a convenient time. Less likelihood of breakdowns.	Complex information system needs to be maintained.

TYPES OF TASKS ASSOCIATED WITH ENGINEERING MAINTENANCE.

Whether the conditions are breakdown, planned, preventative or associated with an overhaul the majority of engineering maintenance tasks can be linked to the following headings:
Mechanical
Lubrication
Electrical
Software/hardware
Calibration
Inspection
Condition monitoring
Cleaning of plant
Health and Safety
Recording and updating information

Notes.
Specify important pieces of mechanical and electrical plant that you are familiar with. What method of maintenance is employed to ensure that these pieces of plant or equipment perform as required?
Describe in detail a variety of maintenance tasks that are performed under the headings shown above.
How much does engineering maintenance cost on an annual basis. How is the budget controlled?
Find out the costs of major capital plant items.
Describe how health and safety and other legal requirements are met under the engineering maintenance banner

PERFORMANCE IMPROVEMENTS.

Poor plant performance and plant failure in one form or another has a major impact on business performance; consequently systems that improve plant reliability are becoming widely implemented.

Three process improvement initiatives are:-

- Reliability Centred Maintenance (RCM) where teams of key personnel for example maintenance engineers and plant operators decide on how the plant can fail, the consequences of failure and finally the most appropriate maintenance procedures that will reduce the incidence of failure.

- Total Productive Maintenance (TPM) where the plant technicians/operators are trained to pay strict attention to detail, to take great pride in their equipment and to tolerate zero plant defects.

- Workplace Organisation (5S) where technicians/operators focus on achieving and maintaining visual order and cleanliness. 5S aims to remove unneeded items and organise the workplace so that it is easy for the operatives to carry out their tasks and maintain a clean and orderly environment.

In more detail:

Reliability Centred Maintenance (RCM)

The principles which define and characterise RCM are:
- a focus on the preservation of system function;
- the identification of specific failure modes to define loss of function or functional failure;
- the prioritisation of the importance of the failure modes, because not all functions or functional failures are equal;
- the identification of effective and applicable maintenance tasks for the appropriate failure modes. (Applicable means that the task will prevent, mitigate, detect the onset of, or discover, the failure mode. Effective means that among competing candidates the selected maintenance task is the most cost effective option).

These principles, in turn, are implemented in a seven-step process:

1. The objectives of maintenance with respect to any particular item/asset are defined by the functions of the asset and its associated desired performance standards.
2. Functional failure (the inability of an item/asset to meet a desired standard of performance) is identified. This can only be identified after the functions and performance standards of the asset have been defined.
3. Failure modes (which are reasonably likely to cause loss of each function) are identified.
4. Failure effects (describing what will happen if any of the failure modes occur) are documented.
5. Failure consequences are quantified to identify the criticality of failure. (RCM not only recognizes the importance of the failure consequences but also classifies these into four groups: Hidden failure;

Safety and environmental; Operational and Non-operational.)

6. Functions, functional failures, failure modes and criticality analysed to identify opportunities for improving performance and/or safety.
7. Preventive tasks are established. These may be one of three main types: scheduled on-condition tasks (which employ condition-based or predictive maintenance); scheduled restoration; and scheduled discard tasks.
8.

Although one of the prime objectives of RCM is to reduce the total costs associated with system failure and downtime, evaluating the returns from an RCM program solely by measuring its impact on costs hides many other less tangible benefits.

Typically these additional benefits fall into the following areas:
(1) improving system availability;
(2) optimising spare parts inventory;
(3) identifying component failure significance;
(4) identifying hidden failure modes;
(5) discovering significant, and previously unknown, failure scenarios;
(6) providing training opportunities for system engineers and operations personnel;
(7) identifying areas for potential design enhancement;
(8) providing a detailed review, and improvement where necessary, of plant documentation.

Total Productive Maintenance (TPM)

TPM aims to establish good maintenance practice through the pursuit of "the five goals of TPM":

(1) Improve equipment effectiveness: examine the effectiveness of facilities by identifying and examining all losses which occur - downtime losses, speed losses and defect losses.

(2) Achieve autonomous maintenance: allow the people who operate equipment to take responsibility for, at least some, of the maintenance tasks. This can be at:

- The repair level (where staff carry out instructions as a response to a problem);
- The prevention level (where staff take pro-active action to prevent foreseen problems); and the
- Improvement level (where staff not only take corrective action but also propose improvements to prevent recurrence).

(3) Plan maintenance: have a systematic approach to all maintenance activities. This involves the identification of the nature and level of preventive maintenance required for each piece of equipment, the creation of standards for condition-based maintenance, and the setting of respective responsibilities for operating and maintenance staff. The respective roles of "operating" and "maintenance" staff are seen as being distinct. Maintenance staff is seen as developing preventive actions and general breakdown services, whereas operating staff take on the "ownership" of the facilities and their general care. Maintenance staff typically move to a more facilitating and supporting role where they are responsible for the training of operators, problem diagnosis, and devising and assessing maintenance practice.

(4) Train all staff in relevant maintenance skills: the defined responsibilities of operating and maintenance staff require that each has all the necessary skills to carry out these roles. TPM places a heavy emphasis on appropriate and continuous training.

(5) Achieve early equipment management: the aim is to move towards zero maintenance through "maintenance prevention" (MP). MP involves considering failure causes and the maintainability of equipment during its design stage, its manufacture, its installation, and its commissioning. As part of the overall process, TPM attempts to track all potential maintenance problems back to their root cause so that they can be eliminated at the earliest point in the overall design, manufacture and deployment process.

TPM works to eliminate losses:

- Downtime from breakdown and changeover times
- Speed losses (when equipment fails to operate at its optimum speed)
- Idling and minor stoppages due to the abnormal operation of sensors, blockage of work on chutes, etc.
- Process defects due to scrap and quality defects to be repaired
- Reduced yield in the period from machine start-up to stable production.

Workplace Organistion (5S)

5S can be broken down into 4 activities and one conviction to continue with the 4 activities. 5S originated in Japan and there are many translations of the Japanese words for 5S – a common set is listed below:

- "Sein" - Sort
- "Seiton" - Set in order
- "Seiso" - Shine
- "Seiketsu" - Standardise
- "Shitsuke" - Sustain

Sort

The aim of Sort is to remove from the workplace items that are not needed, such as tools, materials and parts, and to identify what items are needed to perform the operations at each of the workstations.

Set in order

Set in order is the part of the 5S technique that arranges materials, components and tools in such a way that the operatives can easily access them. An example of this is a shadow board, where each tool has its own place and can be easily located. Additionally, if an empty place exists on the board the missing tool can easily be identified.

Shine

For Shine, the workplace needs to be kept clean so that it is safe for the operators to carry out their tasks and move around their workstation. This also benefits productivity as the easier it is for the operatives to move around the quicker it is for them to carry out their tasks.

Standardise

Formalise the Sort, Set in order and Shine activities to standardise their practice so that all involved can achieve the same results. Application of this will ensure that the workplace is clean and organised.

Sustain

The sustain activity will ensure that 5S is ingrained in the organisation culture. Sustain aims to keep the workforce focussed on carrying out 5S activities on a regular basis, usually daily. Performance is measured to maintain consistency and ensure that all involved are informed of their progress.

The direct changes resulting from carrying out 5S are workplace tidiness and orderliness; these have a beneficial effect on a large number of other factors which improve efficiency. These range from reduced time searching for tools, reduced changeover time, reduced inventory to reduced cycle time.

All three methods rely on detailed records and analysis and 'problem solving' in a teamworking environment. These methods also depend on the teams being supported by senior management.

High initial set-up costs ultimately enable the achievement significantly improved and sustainable plant reliability.

Comments:

There are a number of performance improvement initiatives that are similar to RCM, TPM and 5S. The majority of them focus on improving plant performances by combining a number of simultaneous initiatives and typically include the following:

- 'Organisational Changes'.
- Computerised systems for maintenance, measuring plant breakdowns and performance.
- Predictive maintenance techniques.
- Cleaning-inspection-lubricate.
- Teamworking.
- Improvement analysis (various techniques).
- Defining roles, responsibilities and accountabilities.
- Training and education.

Notes.

Describe the typical features of a performance improvement initiative you are familiar with.

Describe your role and responsibilities, who you consult and who you inform.

TYPES OF FUEL IN THE MALTING INDUSTRY

Overview:

This topic will provide information of alternatives for the provision of fuels utilised in the malting industry. Fuel is a major contribution to the cost of the malting process and is linked to efficiencies, but also food safety of the final product. The process areas requiring a high load of fuel consumption are kilning of malt and barley drying.

1. Choice of fuels available:

a. Tradition - Kilns were traditionally heated by direct burning of fuels such as wood, anthracite, peat, oil or gas.

b. Gas - Natural gas is the cleanest burning fossil fuel. Coal and oil, the other fossil fuels, are more chemically complicated than natural gas, and when combusted, they release a variety of potentially harmful chemicals into the air. Burning methane releases only carbon dioxide and water. Since natural gas is mostly methane, the combustion of natural gas releases fewer by products than other fossil fuels. Water of combustion formed during the process of burning gas will reduce the drying effect slightly.

c. Direct heating methods via a burner unit: Nitrogen Oxides (NOx) formed in the flames (esp. Natural Gas) will produce NDMA (n-nitrosodimethylamine) with certain proteins in the malt. To counteract the formation of NDMA, sulphur would be burnt during the early stages of the kilning process, reducing the pH level on the grain surface. Oil and coal have sufficient sulphur content to prevent NDMA formation.

d. To minimise the formation of NDMA, low NOx burners provide controlled combustion temperatures at temperatures below 1250°C and therefore will reduce the formation of NOx products.

Direct combustion is probably the cheapest in capital cost terms.
It should be remembered that there is a major fire risk since cereal matter may be in direct contact with flames from the fuel.

e. Low sulphur gas oil, fuel oil. – This fuel medium would be used in conjunction with a direct fired burner, but due to the nature of the product, the maintenance of the burner unit is higher than gas as oil is viscous and more difficult to handle. Importantly the maltings would need a storage vessel to hold the oil before use and this area would need to be bunded to contain the product in case of spillage. An advantage of utilising this product is that it already contains a low percentage of Sulphur and this would provide controls for NDMA formation. Heavy fuel oil is also used, again requiring good burner maintenance and on-site storage for the fuel.

f. Indirect Heating:

- Indirect heating provides a physical barrier between flame and drying air.
- Heat can be transferred from a boiler by pressurised water, thermal fluid or steam. This has the advantage of a remote heating plant.
- Specially designed heaters, e.g. Air Frohlich ‘Anox’ or Flucorrex ‘Varinox’ contain combustion in tubes with kilning air flowing over the tubes.
- Water of combustion does not affect the drying.
- No additional NOx is formed in the kilning air.
- Conducive to high degree of heat recovery with flue gas cooled to <50°C and efficiencies >100% of Net Calorific Value.

2. Fuel cost control:

There are a number of factors to take into consideration when trying to control the fuel costs in a maltings. Importantly the business must have resource to provide a purchasing strategy for fuel purchasing. There a number of ways to purchase fuel including spot, forward buying and hedging. There are no perfect methods for purchasing fuel, but expertise is key to ensure it is undertaken correctly.

Below are a number of considerations to be undertaken to control the cost of fuel use.

1. Housekeeping
   - Ensure no leaks in the drying units where hot air can escape.
   - Kiln bed is evenly compacted & flat, this will enable the warm air to pass through the bed of malt with even distribution.
   - Kiln is stripped & loaded as quickly as possible. If the kilns cool down due to a slow process, it will require more fuel to re heat the drying unit.

2. Insulation: the kilns must be insulated, so that the heat will be contained within the building. also the

kilns must contain no leaks, so all holes in the fabric should be filled and doors correctly sealed.

3. Process control: The system will ensure the correct sequence of kilning is followed and fuel costs are finely managed by correct use of heat, recirculation and reuse of warm air.

4. Moisture of final malt: It is essential that the correct moisture is attained, but no lower, as energy may be wasted by lowering the moisture beyond the necessary requirements.

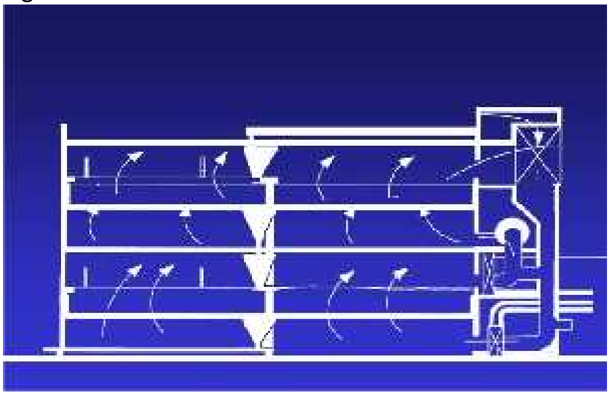
5. Air recirculation (post-break): warm air with low moisture content can be used to lower the amount of fuel required.

6. Glass tube heat exchanger: The exhaust air from the kiln passes on one side of a set of glass tubes, with ambient air flow on the other side being pre-heated. The process is particularly efficient as it gains the latent heat of condensation from the exhaust air in the period before the break point and for some time after it.

7. Run around coils: A fuel medium in a contained unit is warmed up by air leaving the exhaust of the kilns. The heated fuel medium is then pumped into a heat exchange unit where the ambient air passes over prior to being forced through the kiln bed. The cooled fuel medium is then warmed up again by the exhaust air from the kilning process.

8. Multiple kilns linked: Kilns are linked together and fuel use is reduced due to the exhausted heat from the kilns is recirced between the units. The temperature exchanged between the kilns is controlled by the air off temperature and the moisture content in the exhaust air.
   Double deck kilns: An example of linked kilns is a double deck kiln. The diagram below (figure 1) illustrates the movement of dry air from the lower kiln bed into early stages of the batch in the top layer.

Fig.1



3. <u>Combined heat and power systems, CHP Technology</u>

A CHP plant consists essentially of an electrical generator combined with equipment for recovering and using the heat produced by that generator. The generator may be a prime mover such as a gas turbine or a reciprocating engine. Alternatively, it may consist of a steam turbine generating power from high-pressure steam produced in a boiler. In some cases, a CHP scheme may be a combination of prime mover(s), boiler(s) and steam turbine(s) as shown in the image below.

CHP plant can be broadly placed into three categories:

<u>Packaged CHP</u> :
Packaged CHP are designed and supplied as complete units that can easily be connect to a building's electrical and heating systems. Typically these units range in size from generating 50 kW to over 1 MW generating capacity. They are usually provided with an integrated remote monitoring and control system.

What are the advantages?

- Simple to integrate into site utilities
- Fit and forget system
- Lower training requirements

What technologies are used?
Packaged CHP typically use well known technologies, current development favours reciprocating internal combustion engines.
Other technologies with development potential are fuel cells, and micro gas turbines.

<u>Custom built CHP</u> :
Custom CHP systems are designed and built to meet the specific requirements of the site. These systems are usually integrated into the site's utilities and services. Typically these schemes range in size from generating 1 MW to 100s of MW generating capacity.

What are the advantages?

- Custom designed for customers' requirements
- More flexible than packaged systems
- Typically more efficient than packaged systems
- Typically longer service intervals than packaged systems

What technologies are used?
Custom CHP systems typically use well known technologies, current development favours open and combined cycle turbine systems due to their high reliability and lower costs at high generating capacities.

<u>Renewables CHP</u>, designed to utilise can renewable fuels or feedstocks.
The key benefit of CHP generation is that much of the heat which would otherwise be wasted from power only generation is recovered for additional uses, thereby reducing overall fuel consumption and atmospheric emissions of greenhouse and polluting gases. Renewable CHP generation reduces further still the carbon intensity of

power generation through the use of carbon neutral, renewable fuels.

Many of the technical aspects of Renewables CHP are the same as conventional fossil fuel fired CHP.

The two type GC 357 N5 CHP plants equipped with MTU Series 400 engines deliver around one megawatt of thermal and approx. 700 kilowatts of electrical energy

Further potential Energy plants for the malting industry

Anaerobic Digestion

Anaerobic digestion (AD) is the accelerated decomposition of biodegradable material in the absence of oxygen by anaerobic bacteria known as anaerobes. This process can be carried out in purpose built vessels known as anaerobic digesters for the purpose of producing a medium calorific value gaseous fuel known as biogas. AD also produces a stabilised nutrient rich solid by-product known as digestate which, depending on the digester feedstock, can be used as a soil improver and fertiliser.

Anerobic Digestion is suitable for the conversion of wet biomass material into biogas. Typical digester feedstocks include sewage sludge, industrial effluent and malt waste eg pellets and screenings. Solid biomass which is high in lignin, such as wood and straw, is resistant to anaerobes and is therefore not suitable as feedstock for digesters.

Biogas is suitable for use in boilers, gas engines and gas turbines and it is common practise to utilise biogas in CHP units for simultaneous generation of heat and power. The heat generated by the CHP units is primarily utilised for digester heating with surplus heat available for secondary uses such as greenhouse heating or for distribution to other users via a district heating network.

WATER SOURCES, TREATMENT AND USES IN MALTING

The aims of steeping are to get barley to take up water to initiate germination and to increase the moisture content substantially to achieve an appropriate level of endosperm hydration for adequate modification.

A modern maltings with batch sizes up to 400 tonnes can use a very large amount of water (circa 3.5 – 4.5 m3/T). A maltings needs a reliable supply of large volumes of uncontaminated water, steeping liquor, free of pathogenic organisms, chemical contaminants or substances able to taint the malt, and iron salts, which give the malt a dull, grey appearance caused by the colour given by the interaction of the ferric ions and the polyphenols in the husk.

The nature of the steep water can influence malt quality. Highly saline waters are unsuitable, but generally the small amounts of salts dissolved in potable waters have minimal or no detectable effects on steeping. Chalky, alkaline waters are said to limit microbial growth in steep, and washing with short exposure to half- or completely saturated limewater (water saturated with calcium hydroxide, slaked lime) was once common.

Malt producers may draw their water from boreholes or from domestic supplies. The latter is almost always the more expensive choice.

Water from boreholes also has inherent risks that need to be managed. Contamination either chemically or biologically is a real concern and equipment to deal with these risks needs to be adopted. Chemical contamination by ferric, magnesium ions, nitrates and nitrates can be removed by passing the water through a catalytic media for the ions and a reverse osmosis plant for the nitrates and nitrites if the levels are unacceptably high.

UV light is commonly used to sterilise the water. Pathogens such as clostridium, E Coli and various coliforms may be found in borehole water.

Addition of chemicals (chlorine in particular) is to be avoided if possible as it may lead to taints in the malt as well as additional costs.

Usually the appropriate government body must license a borehole for extraction rights, (Environment Agency or SEPA in the UK). Flow rates and total volumes extracted may be regulated.

It has long been recognized that by warming water and steeping at slightly higher temperatures the duration of steeping can be shortened.

However, there are physiological limits on how warm steep liquor can be before germination is reduced and, at even higher temperatures, grain is killed. Steep temperatures of up to 18 °C are not unknown, and the temperatures are closely controlled. To achieve this, the water is normally stored in large, insulated holding tanks warmed by heat exchangers. Sometimes, final temperatures are achieved by blending water from hot and cold sources. Another advantage of having a water-storage tank is that it can be filled at a moderate rate using small mains and pumps, but using gravity feed and large mains it can be used to fill steeping vessels very rapidly indeed, saving 'turn round' time and ensuring that all the grains in a batch are wetted at nearly the same time.

Violent aeration, or other agitation of the grain in water, is an excellent way of cleaning the surface of grain, dislodging dirt and microbes.

In addition, water may be used to transfer the grain and will certainly be used to wash down and clean the steeping vessels.

Various suggestions have been made to permit the re-use of steep water. The ideal would be to process effluent to achieve such a degree of purity that it could be reused in steeping. Many maltings already process their effluent to reach a standard that permits it to be discharged to water courses and therefore the additional investment in reverse osmosis plants to reach a potable standard may not be unjustified.

A project undertaken by French and British maltsters defined a process of ultrafiltration and reverse osmosis tht produced potable water that may be used as steepwater.
(see
http://www.ukmalt.com/sites/default/files/files/SWAN%20FINAL%20REPORT.pdf)

Ref: Malts and Malting - Dennis E. Briggs

SOURCES OF EFFLUENT AND ITS MEASUREMENT

Typical used steep water analysis

Sample	BOD mg/l	COD mg/l	Organic Nitrogen mg/l	pH	Suspended Solids mg/l
Steep 1	2800	3100	132	6.35	218
Steep 2	2250	2480	75	5.9	145
Steep 3	1900	2140	64	5.65	112
Steep 4	490	650	12	6.4	27.5
Composite	1860	2120	71		

Waste steep water is yellow-brown, readily putrescible, contains microbes (but few or no pathogens), suspended organic matter, colloidal materials and a range of low-molecular-weight substances: dissolved salts, hexose and pentose sugars, amino acids, organic acids (including phenolic acids) and phosphates dissolved from the surface layers of the grains and from the interiors of broken grains. The liquid is prone to froth. Initially it may contain floating grains and awns.

Steeping losses vary in the range 0.5-1.5% (dry basis) so a 200 t batch of barley may add 1-3 t solids to the effluent stream. The longer the grain is in contact with steep liquor the more material is extracted and the higher the 'strength' of the effluent.

Most maltsters that deal with their own effluent use aerobic primary treatments and, in a few cases, may treat the sludge that is produced anaerobically. However, anaerobic systems are frequently proposed, and are said to be cheaper.

Treatments begin by screening the effluent to remove floating grains, husk, rootlets and other debris. The sieves may be flat or cylindrical, or bands or discs. The solids are continually moved from the screens by wipers or brushes. Often the liquid is received in a holding or mixing buffer tank, from which it can be withdrawn steadily, so evening out the flow, and in which mixing occurs leading to a 'feed' of more uniform composition for the biological treatment system. Some primary settling may occur in this tank and so it must be de-sludged from time to time.

The common oxidative treatments used in maltings are either based on trickling filter beds (bacterial beds, percolating filters, fixed film reactors) or 'activated sludge' (suspended growth) systems.

Trickling beds have the effluent sprayed over a porous bed, often 2-3 m deep, of granular material circa 3.8 cm diameter such as gravel, broken rock, coke or blast-furnace slag. The beds are usually circular but may be rectangular in cross-section.

The liquid percolates downward over the solid surfaces and is in contact with an upward stream of air. The biology of such beds is extremely complicated but, in principle, a 'zoogleal' bacterial slime forms on the solid support and it is here that oxidation occurs; suspended material is retained and the bacteria accumulate.

Sometimes it is necessary to add ammonium salts and phosphates to the effluent to maintain the population of microbes.

Dislodged solids are carried away in the liquid stream and are collected in a separating tank. The bed must not be allowed to dry and the effluent must not be too concentrated, so some recirculation of treated effluent may be used.

The daily BOD load probably should not exceed 0.178 kg/m3 per day. Sometimes it is preferable to use at least two beds working in sequence, with facilities to alter the order of use.

Such beds may be more than 98% efficient in reducing the BOD; for example, in one case a filter with recirculation reduced the BOD value of an effluent from 1500 to 20 mg/l. Such trickling beds are low filtration-rate devices and are large. Overloading must be avoided since this can lead to 'ponding'.

There can also be difficulties with offending odours and flies breeding in the filter beds.

More compact, high-filtration rate devices have been used, for example as a preliminary treatment preceding activated sludge treatment. In these devices, a plastic material with a high surface area, used to support a film of microbes, is packed in a tower covering a relatively small ground area, and the effluent is sprayed in at the top. Such towers are able to tolerate higher BOD loads than trickling filters.

In other devices, rotating biological contactors, supporting a mass of biological slime, are partly submerged in the effluent to be treated.

The next objectives are to remove biologically oxidizable materials and the suspended solids remaining after screening. This is achieved by a combination of biological oxidative treatments and settling or precipitation. (In principle, anaerobic 'digestive' processes might be used instead.)

Under the aerobic conditions provided, microbes convert the dissolved susceptible organic materials into carbon dioxide, water and extra microbial mass, which accumulates and is recovered as sludge. The microbes tend to clump together and colloidal and particulate materials adhere to them so that they too are removed. The flow of liquid through settling tanks must be slow and steady so that solids can separate efficiently.

The disposal of sludge is potentially difficult and expensive. Sometimes it is accumulated in holding tanks and may be thickened to 4-5% solids by settling, and then is transported to be dumped or spread on fields as a soil conditioner and fertilizer. In contrast to some others, sludges from maltings do not contain significant residues of toxic heavy metals.

In large treatment plants, the sludge may be 'dewatered', often with the addition of lime, under vacuum, by pressure filtration or by heat to reduce the volume.

Perhaps the most satisfactory arrangement is to biologically digest the sludge anaerobically at 30-35 °C: the volume is substantially reduced (e.g. by 50%), the sludge is stabilized and swells less and carbon dioxide and methane is generated. This can be burned as a source of heat and may be used to keep the digester warm or to provide an energy source if the plant is large enough.

Ref: Malts and Malting - Dennis E. Briggs

SUSTAINABILITY AND CLIMATE CHANGE.

The malting, brewing and distilling industry, in common with other industries, impacts on the environment in many different ways. For example:

- As a user of energy.
- As a 'consumer' of water and other natural resources.
- As a source, both directly and indirectly, of atmospheric emissions, trade effluent and packaging waste.

Sustainable development

The challenge of sustainable development is to achieve economic, social and environmental objectives at the same time.

In the past economic activity and growth have often resulted in pollution and wasted resources. A damaged environment impairs quality of life and at worst may threaten long term economic growth, for example as a result of global climate change.

Climate change

Climate change is being caused by an increase in greenhouse gases in the atmosphere. These gases come from both natural and man-made sources, but the increase is the result of human activity, mainly the release of carbon dioxide from the use of fossil fuels such as coal, gas, oil, petrol and diesel.

All businesses and societies, to a greater or lesser extent, will feel the impact of climate change and the policies of governments around the world to address it. These may include:

- restrictions on emission levels
- restrictions on water use
- changes in agricultural growth patterns
- increases in energy prices
- changes in consumer habits

Sustainability guiding principles

Companies committing to minimising the total impact of their activities on the environment, to using natural resources wisely, to pursuing social progress and to playing leading roles in their economies adhere to certain guiding principles typified by the following:

- To comply with all relevant national and local legislation and regulations. To design, operate and maintain processes and plants to:
  - optimise the use of all resources (materials, water, energy etc) whilst ensuring that unavoidable wastes are recovered, reused or disposed of in an economically sustainable and environmentally responsible manner.
  - minimise the potential impact on the environment from site emissions to air, water and land.

- To regularly assess the environmental impacts of processes and plants and, based on the assessments, set annual objectives and targets for the continual improvement of environmental performance.

- To use and develop packaging and distribution systems for which packaging/product combinations will make fewer demands on non-renewable and renewable natural resources.

- To minimise the use of substances which may cause potential harm to the environment and ensure they are used and disposed of safely.

- To encourage a culture of awareness on sustainability issues amongst employees through management commitment, appropriate communications, training and other initiatives.

- To establish and maintain appropriate procedures and management systems to implement these principles through policy commitment.

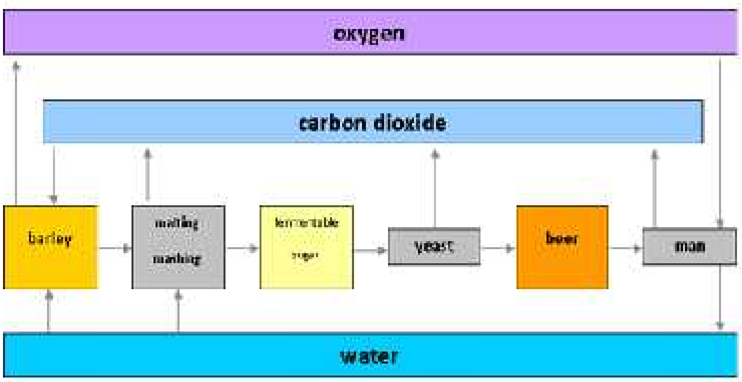
- To work with suppliers and other business partners in the supply chain to maintain high environmental standards.

The role of carbon dioxide – the carbon cycle

Carbon dioxide emission is seen as a key measure of environmental damage. During germination the barley respires, taking in oxygen and giving off carbon dioxide. The impression may erroneously be given that this malting process is a net generator of carbon dioxide as a result. In reality, carbon dioxide evolution through that route is simply part of the natural carbon cycle:

- The amount of carbon dioxide released during germination is only a small fraction of that absorbed by the growing barley crop through photosynthesis.
- Photosynthesis by the growing grain releases oxygen back into the atmosphere.
- Carbon dioxide is also released back into the atmosphere through human metabolism.

CO_2 PROCESS CYCLE



Principal sources of carbon dioxide emissions

The real source of carbon dioxide emissions in the malting industry is the combustion of fossil fuels – either at the malting plant itself or in the generation of the electricity supplied.

There is therefore a need for continuing improvement in the efficiency with which fossil fuels are used, whether through the use of electricity or through the combustion of fuel at the malt plant:

- Electricity, as compared with natural gas, gives rise to three times the quantity of carbon dioxide for the same amount of delivered energy.
- Whereas electricity provides only perhaps 25% of the energy requirements of the malting industry, the generation of electricity creates almost 50% of carbon dioxide emissions.
- Where available, natural gas generally provides perhaps 75% of the total energy requirement but creates only 50% of carbon dioxide emissions.

ENERGY CONSERVATION IN THE MALTING INDUSTRY

Overview

The cost of energy is the second largest cost of malt production. (Barley is the highest.)

Up to 90% of the fuel bill goes towards heating the air passing through the kiln.

Typical fuel consumption of a kiln is between 700 and 1000 kWh/T

Electricity takes a further 10% or so of the kiln consumption; the rest of the energy is used to heat up the air (natural gas or another energy source)

1. Principle energy consuming activities in a malthouse

The key items within a maltings that consume energy are listed below:

Barley driers – These will consume high levels of fuel in relation to drying barley from moistures of >15.0% to 12.0%. Also electricity consumption is high due to fan use to pull air through the drier units.

Steeping – All steep tanks will have a fan linked to the unit to enable air to be either pulled/pushed through the grain to remove CO2 build up. A number of steeps will also have an aeration system which will require a high volume of compressed air to move the grain whilst under water.

Germination – All germination units require air to pass through the bed and this is done via a large fan unit. These will be driven by a large motor/gearbox and consume high levels of electricity as they will normally operate for 24 hours/day. Other items of plant will be germination turner units and water spray units which will consume high levels of electricity, with some spray designs also using compressed air.

Kilning – This part of the process will consume high levels of fuel and electricity.

Examples of energy consumption of different types of kilns with various energy systems are listed below:

	Fuel kWh/tonne	Electricity kWh/tonne
Natural draught	1450	Nil
Pneumatic kiln	1015	80
Plus loader leveling	900	75
Plus recycle/reuse	800	75
Plus heat recovery	700	75
Plus fan speed control	650	65

Whilst the list of malting activities consumes the majority of energy within the process, there are a number of activities that need to be managed in line with Energy Conservation. These are listed below:

- Barley conveying and elevators.
- Barley cleaning plant.
- Barley/malt Dust extraction systems
- Green malt conveyors throughout the process
- Lights
- Compressed air
- Secure buildings
- Malt cleaning plant
- Motors to drive all moving equipment
- Refrigeration plants
- Air conditioning units

2. Typical energy reduction strategies

Process Control:

The operation of the maltings is controlled by plc (programmable logic controller) from barley intake to malt outloading. The basic units have a CPU (a computer processor) that is dedicated to run one program that monitors a series of different inputs and logically manipulates the outputs for the desired control. They are meant to be very flexible in how they can be programmed while also providing the advantages of high reliability (no program crashes or mechanical failures), compact and economical over traditional control systems.

Flat and evenly compacted kiln bed:

Utilisation of automated mechanical loading units enables the kiln to be loaded evenly, which will ensure that air passes through the bed of malt in an even manner. This will also provide energy savings, as kilns will operate effectively with a quick turn round time frame.

Kilning:

a) Rectangular Kilns:

This traditional design of vessel has been successfully employed for many years. These units have been successfully upgraded with automating existing vessels including stripper/loaders, modifying floors & heating systems.

b) Circular Kilns

The circular kiln has a number of advantages in terms of even air distribution & the ability to obtain a flat bed. These kilns achieve maximum efficiency by the use of modern technology. Heat recovery & recirculation, high performance insulation, variable speed fans and microprocessor control and monitoring ensure efficient reliable performance.

c) Double Deck Kilns

A number of new/upgraded maltings have double deck kilning technology bringing the benefits of maximum efficiency. By offset phasing of kiln batches, maximum reuse of heated air can be achieved, optimising energy use.

From a kilning perspective it is essential that no time is lost between unloading and loading the kilns. This will ensure that any residual heat in the kiln is utilised for the next batch to be kilned.

Key points of the Kilning cycle:

Recycling/ re-use of air

- the air-off after the break can be used to dry malt (it is not completely saturated)
- It can be recycled within the drying system
- It can be re-used in another kiln.

Heat exchangers

- When saturated air is passed over a cool surface, the water vapour leaves its heat on that surface
- heat can then be recovered through heat exchangers.

Variable fan speed control:

Variable Speed Drive (VSD), also known as Inverters or Variable Speed Drives, is the term that describes the equipment used to regulate the rotational speed and hence torque of an electric motor. In reality VSDs are electronic devices that can be attached to a motor to fluctuate its speed through a control mechanism, such temperature or pressure.

A VSD can reduce energy consumption of a motor by as much as 60%.Even a small reduction in the rotational speed can give significant savings in the energy consumed by a motor.

Utilisation of a VSD normally provides a very good payback in relation to capital employed.

Location of VSD in the maltings:

- CO_2 extraction fans during steeping
- Germination fan motors
- Kiln fan motors

Efficiency motors:

Energy-efficient motors, also called premium or high-efficiency motors, are 2 to 8% more efficient than standard motors.

Energy-efficient motors owe their higher performance to key design improvements and more accurate manufacturing tolerances. Lengthening the core and using lower-electrical-loss steel, thinner stator laminations, and more copper in the windings reduce electrical losses. Improved bearings and a smaller, more aerodynamic cooling fan further increase efficiency.

Benefits of purchasing are that energy-efficient motors generally have longer insulation and bearing lives, lower heat output, and less vibration. In addition, these motors are often more tolerant of overload conditions and phase imbalance. This results in low failure rates, which has prompted most manufacturers to offer longer warranties for their energy-efficient lines.

Purchasing an energy-efficient motor can dramatically cut energy costs. For example, purchasing the energy-efficient version of a 25 horsepower, 1800-rpm, totally enclosed, fan-cooled 460-volt motor that runs 16 hours per day at 75% load will save £500 per year over a standard motor at an electrical rate of £0.07 per kilowatt hour. With a cost premium of £325, the simple payback is less than eight months.

Systems:

Malting businesses are now considering the standard below for managing Energy within the business.

ISO 50001 (full name: ISO 50001:2011, *Energy management systems – Requirements with guidance for use*) is a specification created by the International Organization for Standardization (ISO) for an energy management system. The standard specifies the requirements for establishing, implementing, maintaining and improving an energy management system, whose purpose is to enable an organization to follow a systematic approach in achieving continual improvement of energy performance, including energy efficiency, energy security, energy use and consumption. The standard aims to help organizations continually reduce their energy use, and therefore their energy costs and their greenhouse gas emissions.

Management:

A malting business may appoint a full time manager to oversee use of energy. The individual would be responsible for implementing an Energy Management Strategy that would include monitoring and targets. For a business to reduce energy consumption it needs to understand the mains areas of use and this can be done by comprehensively metering the whole process and then measure before and after any improvements that may be made. The Energy Manager would also ensure that periodic audits are undertaken, so that areas of improvement may be proposed.

Moisture of malt:
Energy can be lost by drying malt to levels below the specification moisture level. Training and awareness is essential, so that the moisture required is understood and that it is evaluated in line with air off temperatures within the kiln.

Combined Heat and Power:

Cogeneration (also **combined heat and power**, **CHP**) is the use of a heat engine to simultaneously generate both electricity and useful heat.

See Section **17.1 Types of fuel in the malting industry**

3. Principle water consuming activities:

The keys area for water consumption within the malting industry is in the steeping process.

Steeping:

The table below highlights the types of steep systems that may be used and typical water use of each type of vessel.

	Simple Conical Steep	Ventilated Conical Steep	Flat Bottomed Steep
Max. Water usage/ Effluent production	4.5 m3/mt => Low effluent	4.5 m3/mt => Low effluent	6.0 m3/mt => High effluent
Vessel size	Up to 30 mt	Up to 60 mt	200-600 mt
Hygiene	Good	Difficult	Very difficult
Construction costs	High	Very high	Lower
Installation costs	Lower	Higher	Much higher

Traditional Steep cycles tend to be 3 waters.

In some steep systems, there is a 'pumpover '; the grain is transferred from one tank to another and mixed at the same time.
The grain can also be mixed if steep tanks are arranged one above the other; the grain can be dropped from one to another during an air break.

Germination:

Green malt that is transferred into the Germination process will normally have a moisture content between 43 – 46% moisture. During normal malting conditions, grain may dry out by > 0.5% each day it is germination. The germination unit will be humidified during this stage by passing moisture through the bed of malt which is introduced into the air stream below the bed of malt.

Types of units in the Germination are

- Sprays
- Compressed air and water
- Spinning Discs

Hygiene:

High levels of water are used during wash down of malting plants with High Pressure Hoses.

4. Typical water conservation strategies.

Metering:

Measure and monitor use of water and implement a plan to reduce consumption. Set targets, then measure and review on frequent basis.

Steep Programmes:

Selection of barleys for processing is key. Use of 2 water steeping cycles to reduce normal water consumption by 25% is maximised.

Reuse of water:

Technology to clean up the discharged effluent and bring the product up to potable water standard is under consideration; the product could then be blended with water and then be utilized in both the steeping process and used for cleaning the plant with high pressure water systems.

Bore hole:

Review the malting plant and utilise professional assistance to identify potential locations to extract bore hole water for the process, whilst this may not reduce consumption, it will assist in providing a resource at little cost.

Steeping plant:

Lowering of the steep tank overflows to allow full and robust steeping and overflows while reducing the amount of water required.

Barley Washer:

A barley washer can be used as a pre steep vessel and can be utilised to clean the barley and significantly raise the moisture content of the steeped barley. It consists of two pairs of washing screws each with a high throughput capacity per hour. The machine separates any floating barley as well as cleaning and pre-moistening the barley as it transfers to the steeping vessel.

This process step gives optimal hygiene levels which improve the effectiveness of the steeping process.

Ecosteep

- Developed by Buhler and various Dutch universities.
- The system reduces water consumption of the plant compared to other FBSTs by over 30%.
- The system has eliminated the clearance area below the floor, which requires the use of lots of water and is very difficult to clean.
- It also produces a more uniform malt quality by using only a low depth of malted grain material during the production cycle.
- Air and water for the process are controlled carefully by being fed through uniformly configured nozzles

Photograph of an Ecosteep unit.

Rainwater:

It has been considered to collect rainwater and utilise the product for wash down water and flush down water for sanitary units.

WASTE STORAGE AND SEGREGATION

The malting industry gives rise to various waste streams and co products; these are in general generated during normal malting activities,(barley intake drying and storage, malt production, storage, blending and dispatch), but can also arise during maintenance and project activities. Barley screenings, barley dust/husks, malt culms, malt dressings and dust (co-products) are normally sold either individually or combined and pelleted for ease of storage and transport. When combining barley screenings, or large substance (straw, un-thrashed ears, peas & beans etc.) produced by barley dressers with culm and dust for pelleting, it is sometimes necessary to mill prior to pelleting. However sometimes due to location or circumstances some of these products are disposed of as waste. Malting also produces waste water from process and cleaning activities. General cleaning, leaking equipment and breakdowns can produce wet and dry barley and malt waste. Along with the normal malting process; projects, maintenance, laboratory, office and canteen activity can give rise to both hazardous and controlled waste of various descriptions. It is essential to have good waste management processes in place for the sake of the environment, and both cost management and legal compliance.

Best practice dictates that, where possible:

- wastes are stored as close as possible to the point of generation
- waste storage areas are clearly marked
- skips are specified appropriate for the duty
- skips are stored on hardstanding areas
- wastes are segregated wherever possible to maximise the opportunity to reuse or recycle.

From time to time “special” wastes may arise which have particular storage requirements. Typical examples may include:

- Surplus cleaning chemicals (typically strong alkaline or acid products).
- Residual chemicals left in portable storage containers (thus prohibiting return of the containers to the supplier).
- Chemicals that have been identified as waste due to quality aspects (e.g. contaminated, out of specification or simply substances no longer used)
- Flammable wastes
- Wastes sensitive to heat or light.

In such cases, some or all of the techniques listed below may be applied to minimise potential environmental impacts:

- the storage area is covered
- the storage area is fully enclosed (to contain spillage)
- there is protection against flood or fire-water ingress
- there is an air extraction system
- drainage liquids are contained, treated and tested prior to release
- there is fire protection

When considering temporary waste storage areas, factors considered when assessing a storage risk assessment would normally include:

- compatible containers are used for the substances being stored and that these containers are of robust construction to ensure that spills and leaks do not occur
- adequate warning notices, barrier tape and signage are in place forbidding access to the storage area
- storage areas are not located adjacent to surface water drains and, where possible, these areas are located within bunded or kerbed areas
- individual containers are labelled to identify their contents and volume
- the period of storage is minimised so that all waste containers are removed from the area as soon as possible
- no other wastes are stored in the temporary area other than those that have been agreed.

Waste disposal and duty of care

Where waste disposal is controlled by taxation, levy or simply cost, systems to monitor waste are required. Information recorded would normally include:

- quantity
- nature
- origin (where relevant)
- destination
- mode of transport
- treatment method

Increasingly malting plants have service agreements with specialist, licensed waste disposal contractors for the provision of comprehensive waste disposal and management services, covering but not limited to:

- reducing the amount of waste produced
- making the most efficient use of waste
- selecting waste disposal options which minimise the risk of environmental pollution and harm to human health
- employing the hierarchy of waste reduction, **reuse**, **recycle**, **recover** and dispose.

The duty of care responsibility ensures that waste management is audited throughout the process including confirmation of the final location of the waste disposal or recycling.

The pressure on landfill

Landfilling is increasingly discouraged for a number of key reasons:

- Climate change caused by landfill gas from biodegradable waste.
- Loss of resources
  - Constraints on areas suitable for landfill sites
  - Loss of recyclable components of waste landfilled.

Many countries have introduced a landfill tax which is a form of tax that is applied to increase the cost of landfill. The tax is typically levied in units of currency per unit of weight or volume.

The reasons for landfill taxes can vary from country to country. They may include:

- a means of raising general revenues
- to generate funds for solid waste planning and inspection programmes
- for long-term mitigation of environmental impacts related to disposal
- a means of inhibiting disposal by raising the cost in comparison to preferable alternatives (in the same manner as an excise or “sin tax”).

Steps to implement waste management

Most companies will already be managing waste to some extent and have a level of awareness and competence on site. For effective waste management it is important that awareness and competence is generated at all levels appropriate to the degree of involvement with the waste management system. (i.e. putting the correct waste in the appropriate receptacle, or ensuring the correct duty of care paperwork is in place.)

1. **IDENTIFY AND MEASURE ALL WASTE STREAMS** – this could include

- Barley and malt dust and spillages from intake, out loading and the malting process
  - This could be further classified as wet or dry.
- Out puts from effluent pre or full treatment
  - Waste water
  - Thin corns, swimming’s and rootlets from effluent screening
  - Sludge, thickened and un thickened

- Office/Kitchen Waste/Laboratory
  - Paper
  - Card
  - Plastic
  - Glass
  - Food waste
  - Batteries
  - Printer cartridges
  - Waste electrical equipment
  - Waste chemicals from laboratory analysis and activities
- Maintenance Activities
  - Waste Oil & Grease
  - Oily rags
  - Empty Aerosol cans
  - Scrap Metal
  - Fluorescent tubes
  - Asbestos waste

2. **ADOPT THE WASTE MANAGEMENT CONCEPT - REDUCE, REUSE, RECYCLE**

In terms of environmental impact there is increasing pressure to improve the utilisation of materials, water, energy and minimise waste. The hierarchy of waste reduction applies:

- reuse
- recycle
- recover
- dispose

REDUCE

- Prevent spillages, repair, renew, replace equipment
- Reduce water usage, optimise effluent treatment
- Examine current practices and methods is there a nil or low waste option
- Specify/select minimal packaging
- Only print if necessary, then double sided, black and white

REUSE

- Spillages immediately returned to process where possible, alternatively combined with co-products for sale as feed, or sent for composting.

- Maximise screener/dresser outputs as co products
  - Check calibration and efficiency of equipment
  - Screenings sold as feed barley
  - Dust, rootlets, husks as bulk or pelleted to animal feed

- Explore biofuel, bio energy options available

RECYCLE

- Segregate waste streams (as identified above) and recycle where possible.
  - Provide clearly marked suitable receptacles, to keep waste secure, clean (dry), prevent contamination and bunded where appropriate.
  - Ensure hazardous wastes are kept separate from controlled wastes.
  - Ensure waste collection areas are secured to prevent unauthorised use, and provided with spill kits and clean up tools as appropriate.

- Where general waste (land fill) is removed from site, ensure utilisation of a waste management company that employs secondary sorting and segregation via a waste management centre

Increasingly governments and other regulating authorities are “encouraging” the recovery of waste unless it is technically or economically impossible to do so.

In considering options for waste management, many countries now encourage a process known as “Best Practical Environmental Option (BPEO) Assessment”. As the term suggests the assessment is designed to demonstrate that the chosen routes for recovery or disposal represent the best environmental option considering, but not limited to, the following:

- all avenues for recycling back into the process or reworked for another process
- composting
- animal feed
- landspreading where the malt plant:
    - can demonstrate that it represents a genuine agricultural benefit or ecological improvement
    - has identified the pollutants likely to present from a knowledge of the process, materials of construction, corrosive / erosion mechanisms, materials related to maintenance, for both normal and abnormal operation, validated as necessary by appropriate analytical techniques
    - has identified the ultimate fate of the substances in the soil

Qualifications

The General Certificate in Malting (GCM)

Examination Syllabus

This syllabus details the course of study necessary to prepare for examination in the **General Certificate in Malting**.

The specifications to which the respective examination papers are prepared are also shown.

Introduction.

The **General Certificate in Malting** gives international recognition of a basic, under-pinning knowledge and understanding in the principles of malting operations. The qualification is offered by both the Institute of Brewing and Distilling (IBD), as a stand-alone qualification, and the Maltsters' Association of Great Britain (MAGB) as part of their Certificate in Malting Competence (CMC) qualification.

The General Certificate in Malting has been designed for candidates who may have little or no formal academic or technical qualification and will often be employed as a senior operator or technician in a malthouse, or will be graduates or managers new to the malting business. The scope of these examinations will also enable those from smaller malting operations to obtain this recognised qualification, and are open to anybody with interest in malt production. They are a measure of basic knowledge (theoretical and practical) underpinning cereal growing, malt production and associated operations.

- The General Certificate in Malting can be an end in itself, or the start of professional development leading to further qualifications in malting.
- The General Certificate in Malting is accredited at Level 3 of the National Qualifications Framework in the UK (or equivalent internationally recognised standards).
- The General Certificate in Malting takes the form of one multiple choice paper of two hours.
- The General Certificate in Malting is a module forming part of the MAGB's Certificate of Malting Competence.

Candidates can register to sit the exam on-line instead of using the traditional paper format. Candidates sitting within malthouse or university centres will be encouraged to take the on-line version. The exam itself appears on the screen very much like the paper version and with the same number of questions, but there are various different ways of asking the questions which make the exam a more interesting experience. The marking is done electronically and candidates will received a detailed feedback on how each section of the syllabus has been answered.

The pass mark is set at 66% (40 correct answers from 60 questions) for all IBD General Certificate exams.

Candidates attaining 90% or more achieve a Distinction pass and between 80% and 89% achieve a Credit pass.

IBD	**Syllabus Section 1: Cereals; their uses for malting and beer/spirit production.**	mcgb

Ref.	Topics (No. of questions to be answered = **2**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
1.1	**Cereals and Food**	1. Cultivation of cereals for food. 2. Competition for land – food vs. energy.
1.2	**Types of Cereals**	1. Types of cereals. 2. Common cereals and growing regions. 3. Alternative cereals.
1.3	**Malted cereals**	1. Uses of malted cereals (including non-brewing/distilling uses) and malt co-products. 2. Malted cereals in Brewing. 3. Malted cereals and Distilled Spirits.

	Syllabus section 2: Malting; overview and requirements.	

Ref.	Topics (No. of questions to be answered =3)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
2.1	**Malting process overview**	1. The role of barley as a principal source of starch. 2. The special attributes of barley for malting. 3. The significant changes that occur when the barley grain is malted. 4. The principal constituents of malt.
2.2	**Types of malt plant**	1. Traditional methods of malting. 2. Different types of automated malting plant.
2.3	**Requirements for malting**	1. Costing – an awareness of the essential cost elements in the manufacture of malt. 2. Malting yield – control and measurement of 'malting loss'.

IBD	**Syllabus section 3: Barley growing and harvesting.**	mcgb

Ref.	**Topics** (No. of questions to be answered = **4**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
3.1	**Barley growing**	1. UK Barley growing regions. 2. Barley growth cycle. 3. Harvesting barley.
3.2	**Barley varieties**	1. Barley varieties and their uses. 2. Development and establishment of new barley varieties
3.3	**Barley breeding**	1. Plant breeding. 2. UK new variety development and approval process.
3.4	**Barley Purchasing**	1. Contracting and purchasing of barley.

IBD	**Syllabus section 4: Malting – Barley intake and storage.**	mcgb

Ref.	**Topics** (No. of questions to be answered = **5**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
4.1	**Barley evaluation at intake**	1. Sampling techniques. 2. Evaluation of barley at malthouse intake. 3. Laboratory and rapid methods of determining barley quality.
4.2	**Identification of common malting varieties**	1. Hand evaluation and inspection. 2. Morphological characteristics of barley
4.3	**Barley intake plant and processes.**	1. Different elements of barley intake plant. 2. Barley screening. 3. Operating principles of dust extraction plant. 4. Co-products.
4.4	**Barley storage.**	1. Storage requirements for barley 2. Drying of barley 3. Barley store housekeeping and pest control. 4. Use and control of pesticides. 5. Storage related food safety issues associated with un-malted cereals.

IBD	**Syllabus section 5: Malting – Steeping.**	mcgb

Ref.	Topics (No. of questions to be answered = **4**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
5.1	**Pre-germination tests for barley**	1. Predictive tests for germination and their interpretation. 2. Selection of barley for specific malts
5.2	**Steeping plant and process design**	1. Different types of barley steeping plant. 2. Barley washing. 3. Operating principles of steeping plant. 4. Steep programme design.
5.3	**Control of steeping**	1. Steep temperature control. 2. Importance of aeration and CO_2 extraction. 3. Process control parameters. 4. Factors affecting moisture uptake

	Syllabus section 6: Malting – Germination.	

Ref.	Topics (No. of questions to be answered = **4**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
6.1	**Modification – its meaning and control.**	1. Biochemical changes during germination. 2. Control of the degree of modification.
6.2	**Germination plant and process design**	1. Different types of germination plant. 2. Operating principles of germination plant. 3. Germination programme design. 4. Germination plant hygiene considerations.
6.3	**Control of germination**	1. Germination temperature control 2. Importance of air flow and air conditioning. 3. Process control parameters. 4. Use of additives in germination 5. Hand evaluation

Ref.	Topics (No. of questions to be answered = 4)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
7.1	**Kilning plant and process design**	1. Different types of kilning plant. 2. Operating principles of kilning, including the phases of the cycle. 3. Kilning programme design.
7.2	**Control of Kilning**	1. Planning kilning cycles for specific malts. 2. Importance of air flow, humidity and temperature control. 3. Understanding of the 'break point' 4. Process control parameters.
7.3	**Effects of kilning on finished malt**	1. Development of malt colour and flavour. 2. Control of finished malt specification – enzyme activity, NDMA, DMSP 3. Control of moisture levels, and effect on finished malt quality.
7.4	**Cooling off-kiln**	1. Control of cooling off-kiln.

IBD	**Syllabus section 8: Malt - Storage and Dispatch.**	mbgb

Ref.	**Topics** (No. of questions to be answered = **2**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
8.1	**Preparation and storage of finished malt**	1. Operating principles of deculming and screening plant.
8.2	**Malt storage plant and processes**	1. Storage requirements for malt 2. Different types of malt stores 3. Mechanical handling – conveyor and elevator types. 4. Malt silo housekeeping and pest control 5. Food safety issues associated with malted cereals
8.3	**Malt evaluation at dispatch**	1. Different types of outloading systems. 2. Dispatch quality checks.

	Syllabus section 9: Speciality Malt Production.	

Ref.	**Topics** (No. of questions to be answered = **3**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
9.1	**Types of speciality malts**	1. Different types of speciality malts, their characteristics and their production. 2. Raw materials for roasted malt production 3. Raw materials for 'other' speciality malts
9.2	**Plant and processes**	1. Principles and operation of malt roasting equipment. 2. Process Control parameters
9.3	**Uses of speciality malts**	1. Typical uses of roasted and 'other' speciality malts.

IBD	**Syllabus section 10: Malt Quality and Process Control.**	mcgb

Ref.	**Topics** (No. of questions to be answered = **5**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
		Key parameters examined in this section are: *Extract (fine and coarse), total and soluble nitrogen or protein, Free Amino Nitrogen (FAN), Diastatic Power (DP), α-Amylase (AA), β-Glucan (BG), screenings, colour, moisture, homogeneity and friability, steeliness, fermentability,* *Predicted Spirit Yield (PSY), Dimethyl Sulphide Precursors (DMSP).*
10.1	**Process Specifications**	1. Process adjustments to address the variable nature of the natural ingredients of malt. 2. The purpose of process specifications. 3. Effects of the malting process on the final product value of these key parameters.
10.2	**Process Control**	1. The principles of monitoring and adjustment to achieve product consistency. 2. Simple quality control procedures. 3. The concepts of tolerance and range for specification parameter values. 4. Typical specifications which differentiate malt types. 5. Typical process specification ranges, especially those requiring periodic adjustment to achieve product consistency [see Ref 10.1.above].
10.3	**Laboratory Analysis**	1. Principles of the analytical methods for the key parameters.
10.4	**Malt specifications**	1. Sampling of finished malt. 2. Finished malt specifications 3. Implications of blending of malt to achieve specification.

	Syllabus section 11: Beer Types; raw materials and sweet wort production.	

Ref.	**Topics** (No. of questions to be answered = **3**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
11.1	**Definition of beer and types of beer**	1. A generic, non-legalistic definition of beer in terms of its typical ingredients and methods of production. 2. Characteristics which differentiate lagers, ales and stouts.
11.2	**Barley and malt**	1. The brewer's key malt parameters of degree of modification, extract content, moisture content, extract, and colour. 2. The selection of malt for beer type and mash conversion method. 3. Pre-acceptance checks at malt intake.
11.3	**Adjuncts**	1. Reasons for the use of adjuncts. 2. Types of adjunct and their method of use. 3. Typical usage rate as proportion of the grist.
11.4	**Mash conversion**	1. The respective roles of the amylases and protease, the effect of temperature, pH and time on their activity. 2. Temperature and wort viscosity. 3. The influence of the ionic composition (hardness salts) of mashing water in the mash and on beer flavour. 4. The starch test.
11.5	**Grist composition and extract performance**	1. The extract yield of raw materials.

Ref.	Topics (No. of questions to be answered = **2**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
12.1	**Definition of potable spirits**	1. Definitions of the main spirits derived from cereals.
12.2	**Characteristics of potable spirits**	1. The range of spirit types and their respective styles and characters.
12.3	**Malt and its uses, including green malt and peated malt.**	1. The selection of malt for spirit type and mash conversion method. 2. Pre-acceptance checks at malt intake. 2. The importance of malt to mashing and fermentation, particularly for yeast nutrients, a source of enzymes and as a filter medium for wash. 3. The advantages and disadvantages of the use of green malt in grain whisky distilleries.

	Syllabus section 13: Safety in the Malt Plant.	

Ref.	**Topics** (No. of questions to be answered = **3**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
13.1	**Malting Plant Safety Considerations**	1. The evolution of carbon dioxide from steeping and germination 2. The hazards associated with carbon dioxide. 3. The monitoring / checking of atmospheres for safe working including a quantitative knowledge of exposure limits. 4. Safe working practices for malting plant operations.
13.2	**Malt and barley storage plant safety considerations**	1. The hazards associated with dust. 2. Explosive atmospheres in the workplace. 3. Safe working practices for malt storage plant operations.
13.3	**Chemical Safety**	1. The hazards associated with chemical cleaning and sterilizing agents. 2. Good practices for the storage of chemicals. 3. Use of personal protective equipment (PPE). 4. Procedures in case of accidental spillage or discharge of chemicals.

	Syllabus section 14: Quality Management.	

Ref.	Topics (No. of questions to be answered = 4)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
14.1	**Features of a quality system**	1. The key features of a quality system: - written specifications - written procedures - monitoring of performance - corrective actions - auditing - regular reviews for improvement
14.2	**Roles responsibilities and benefits**	1. The impact of individual actions on product and service quality. 2. The control of documentation. 3. The maintenance of conformity. 4. The business benefits of an effective quality management system.
14.3	**Product safety**	1. The control of product safety: - Hazard Analysis Critical Control Point (HACCP). 2. The importance of traceability for product recall.
14.4	**Malt Related Food Safety**	1. Potential contaminants from outside the malting plant – field mycotoxins, agrochemicals, heavy metals 2. Potential contaminants from within the malting plant – storage mycotoxins, NDMA/ATNC, ethyl carbamate.

IBD	Syllabus section 15: Plant Cleaning; cleaning in-place (CIP), pest control and general cleaning.	mcgb

Ref.	Topics (No. of questions to be answered = 3)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
15.1	**Types of Cleaning Systems**	1. Automatic vs Manual cleaning. 2. The general differences between single use and recovery systems – advantages and disadvantages. 3. The types of cleaning head used and reasons for their choice. 4. The operating principles and diagrammatic representation of CIP systems.
15.2	**Pest control**	1. General site pest control principles. 2. Insect detection and control.
15.3	**General plant cleaning**	1. Cleaning plant surfaces, walls and floors. 2. The constituents of foam cleaning agents. 3. The use of foaming systems, steam cleaning, chlorinated and high pressure water cleaning. 3. *Legionella* in cooling water and service water and the health risks associated with the micro-organism.

	Syllabus section 16: Engineering Maintenance.	

Ref.	Topics (No. of questions to be answered = 3)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
16.1	**Objectives and approaches**	1. The key business reasons for an effective maintenance system. 2. The features, advantages, disadvantages and applications of: - no maintenance - breakdown maintenance - preventive maintenance - predictive maintenance 3. The contribution of maintenance tasks to plant safety, reliability, quality, economics and environmental impact.
16.2	**Maintenance tasks**	1. Familiarity with key maintenance tasks: - mechanical - electrical - calibration - inspection - condition monitoring - cleaning of plant - health and safety 2. Maintenance planning and record keeping. 3. Autonomous maintenance.
16.3	**Systems for continuous improvement**	1. The key features of the following performance improvement systems - Reliability Centred Maintenance (RCM) - Total Productive Maintenance (TPM) - Workplace Organisation (5S)

IBD	**Syllabus section 17: Utilities; energy, water and effluent in malting.**	mcgb

Ref.	Topics (No. of questions to be answered = **3**)	**Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:**
17.1	**Types of fuels**	1. Choice of fuels available. 2. Fuel cost control. 3. Combined Heating and Power (CHP) systems.
17.2	**Water sources, treatment and uses in malting**	1. Characteristics and quality of an ideal malt house water supply 2. Sources of water for a malt house. 3. Differentiation and typical uses of water in malt production.
17.3	**Sources of effluent and its measurement**	1. The nature and characteristics of effluent from principal malt house operations. 2. The components of effluent quality: - volume - suspended solids (SS) - chemical oxygen demand (COD) - biological oxygen demand (BOD) - pH - temperature

Ref.	Topics (No. of questions to be answered = 3)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
18.1	**Sustainability and climate change**	1. The concept of a sustainable industry. 2. The role of carbon dioxide – the carbon cycle 3. Sources of carbon dioxide emissions.
18.2	**Conservation**	1. Principal energy consuming activities in a malthouse. 2. Typical energy reduction strategies. 3. Principal water consuming activities. 4. Typical water conservation strategies.
18.3	**Waste**	1. Principal waste generating activities in a malthouse. 2. Issues for waste disposal. 3. Strategies to minimize waste and encourage recycling.