Module 2

The Malting Process

Objectives of the Module

At the end of this module, you will be able to:

1. Outline the procedures for the intake of barley into maltings.
2. Understand the initial preparation of barley for malting.
3. Explain the objectives, importance and methods of steeping.
4. Describe the essential features of the germination process.
5. Demonstrate understanding of the process of modification.
6. Describe what happens during malt kilning and how malt quality is affected.
7. Understand the technological processes that comprise malt kilning.

Module Contents

This module covers the following:

1. Introduction to Malting
2. Barley Drying and Storage
3. Steeping
4. Germination
5. Kilning

IBD Notes References

The following sections in the IBD notes are applicable:

*Unit 1.2 – The Malting Process*

1.2.1 Barley Intake and Storage
1.2.2 Steeping
1.2.3 Germination
1.2.4 Kilning
1. INTRODUCTION TO MALTING

Malt and Malting

MALTED is a friable package of husk, starch, proteins, flavour precursors and nutrients along with a balanced supply of enzymes.

MALTING is the limited, uniform germination of barley under precisely controlled conditions.

Objectives of Malting

- Germinate the grain as a uniform mass in a reproducible controllable way
- Breakdown most of the starchy endosperm cell walls and matrix structure to give a friable malt
- Ensure that the right balanced amount of enzymes are produced for action in mashing
- Prevent over-modification, excessive starch loss, respiration loss and rootlet formation

Phases of Malting

1. Barley Intake and Storage – the raw barley is received, evaluated, often dried and then stored in optimal conditions until ready for the malting process.

2. Steeping – raise moisture from 12 - 45%. Even and vigorous onset of germination.

3. Germination – embryo grows, aleurone layer produces enzymes, pass into starchy endosperm breaking down cell wall and dissolving protein matrix.

4. Kilning – dry green malt from 45% moisture to below 6%. Arrests germination, produces friable, millable malt, permits rootlet removal, and provides a stable product. Should cause minimum enzyme destruction.
2. BARLEY DRYING AND STORAGE

Introduction

The first critical part of the maltings process is in fact the intake and storage of the barley. Barley is taken in from the harvest and clean, graded and dressed so that dried barley available for malting over the whole year. The process involves physical cleaning, storage, warm air drying & mechanical handling.

Barley Reception

The first stage is of course the reception of the barley.

The intake of barley from vehicles is at high discharge rates to minimise vehicle time - 100 to 200 t/h. This is the point of quality control before acceptance. Sampling and test procedures are as IOB, EBC, ASBC, MEBAK. This was reviewed in Module 1 – Barley. This is the point where there would be rejection if unacceptable. There should also be visual inspection during discharge. There will also be preliminary screening to remove large material and dust. There will then be transfer into intermediate storage.

The following diagram shows a typical barley intake system:

There are various types of barley screening material that can be used to remove:

- Under- & over-sized and broken grains
- Stones
- Awns
- Straw
- Other seeds
- Dust & light material
- Ergots

Note. Dust removal has safety benefits and can have equipment reliability benefits. Processing rate depends on the plant but can then be 30 to 60 t/h.
Barley Drying

To permit long term storage, barley must be dried generally to below 12% moisture. In some countries this may be how the barley is received (due to either drying on the farm or moisture content at harvest).

Storage conditions are a combination of moisture and temperature to prevent development of insects, mites and fungi. The above can cause damage to the grain by local heating, physical damage, contamination leading to depletion of germination (viability). Drying also 'Breaks dormancy' to permit malting of new season barley.

Barley is dried by a current of warm dry air. The temperature depends on moisture content. Drying can be batch-wise in malt kilns during a ‘Harvest shutdown’ whereas vertical dryers operate continuously. Barley flows down the tower and air passes across the grain via distributors. 2 stage and heat recovery reduce energy needs. Heating may be either direct or indirect. Direct, carries fire risk and possible quality problems. Typical flows are 25 t/h.

The graph below shows typical drying temperatures dependent on moisture:

Types of Store

The process of physical storage and this may be done in several types of stores:

- Vertical bins – concrete or metal
- Horizontal flat stores
- Bag stores
**Risks in Storage**

There are potential risks in storage as the following may occur:

- Spontaneous heating and fire/explosion
- Loss of grain vigour
- Mould and fungi growth
- Mycotoxin formation
- Insect and mite growth
- Rodent, bird and vermin attack

**Loss of Viability**

- There is a clear relationship between moisture content and temperature for optimal storage
- If you need to store for long periods (>12 months), dry below 13% moisture and store below 15°C
- Risk when warm storing/conditioning to break dormancy

**Barley Storage**

Storage must be secure against vermin and weather. They are ventilated by a stream of cool dry air evenly distributed 10m³/h/t for silos, 20m³/h/t for flat stores. There is temperature monitoring to detect ‘hot spots’. At end of season, stores must be cleaned and fumigated. Debris should be burned to prevent infestation.

The following graph shows the relationship between temperature and moisture content:

![Graph showing relationship between temperature and moisture content]

**Insect Growth and Attack**

- Main controlling factor is temperature
- Below 15°C insects alive but do not reproduce
- Above 15°C insects start to reproduce actively
- Cause hot spots and migrate outwards thus seriously damaging the grain as they can also provide a further potential for infestation growth.
**Insect Infestations**

These are typical insect infestations that may be seen:

- Rust Red Flour Beetle
- Saw Tooth Grain Beetle
- Foreign Grain Beetle
- Rust Red Grain Beetle
- Rice/Maize Weevil
- Grain Weevil
- Hairy Fungus Beetle
- Plaster Beetle
- Lesser Grain Beetle

**Weevils – Typical Insect Infestation Pattern**

- Weevils Mate
- Females use long snout to lay eggs inside grain – up to 400 eggs
- Hole is plugged
- Larvae spends life in grain until the adult eats its way out
- Life cycle is completed in 35-40 days
- One pair of rice weevils can produce 150 000 000 offspring in 6 months

**Mite Attack**

- These are tiny 8-legged creatures
- Can multiply at low temperatures (5°C) and low moisture (12%)
- Normally found in bulk grain stored with bales of straw or which have not moved for many months
- Can multiply quickly (2500 X per month)
- Can leave an irritant compound on the grain which causes an allergic reaction in farm animals

**Use of Controlling Agents**

Apart from general good practice (housekeeping, intake procedures, state of incoming malt, drying and storage, etc.) there are various agents that may be used:

1. Fumigant. A gas may be introduced into the air spaces between the grains. A lethal does is maintained to kill insects. For this to be effective you need gas tight silos. At the end you blow-off gas to ensure there are no residues left. This does not provide lasting protection. A typical fumigant used is Phosphine under the trade name of Phostoxin. Usually this is done either on intake of the grain, on transfer from one silo to another, or if grain is stored for long periods the whole silo block may be fumigated

2. Protectant. Here you spray on insecticide. This is long lasting and the residue decays during storage. It has to be approved. A standard trade name used is Actellic.

**Practical Insect Control**

In vertical silos transfer grain and add Phostoxin tablets - Phosphine gas is produced which kills the insects. Seal the silos for several weeks. This is more difficult in large flat stores. Isolate the infected area and seal off with polythene sheeting. Inject Phostoxin tablets and leave and evaluate as before.
**Fungal Infestation**

Main risk at normal storage temperature is high moisture.

Types of fungi:

Field: *Aspergillus, Alternaria, Cladosporium, Penicilli, Fusaria, Helminthosporia*

Storage: *Aspergillus spp., Penicillia spp.*

Storage fungi growth often occurs in damp areas, e.g. leaks and condensation. Fungi can cause loss of grain viability and formation of mycotoxins.

**Conveying**

Vertical conveying is almost always by bucket elevator. Safety measures are vital to prevent fire/explosions. Correct explosion venting, fault sensors, and interlocking with rest of the plant are essential. Bucket elevators are generally run externally. If internal, then vents from explosion hatches must be <3m. Maximum vertical speed is 1.5 m/s.

There are various different types of horizontal conveyors that may be used:

1. Worm or Screw conveyor. Some minor grain damage. Can operate at 12° from horizontal. High energy requirements. In long machines, intermediate bearings mean discontinuity in screw length and potential point of grain damage. Critical loading is 40% of trough capacity.

2. Chain and Flight Conveyor. May also be known as a drag or Redler conveyor. ‘Tee’ shaped flights are attached to a chain and impart movement to whole mass of grain with little slippage. Low grain damage. Low energy requirements. Can operate at up to 20° from horizontal. Damage occurs if run at low loads. Noisy unless plastic components used in critical components. Maximum speed 0.3 to 0.4 m/s

**Explosions**

Cereal dusts are explosive. Primary explosion ignited by friction, spark, flame etc., disturbs dust and causes devastating secondary explosion. Dust removal is important by product aspiration. Good housekeeping around the plant is vital in reducing the potential secondary explosions. Pressure waves must be vented by adequate venting according to prescribed practice. Explosion suppression relies on detection and release of extinguisher ahead of flame front.
Raw Materials – The Malting Process

3. STEEPING

This is considered the most crucial phase for the maltster as it sets up the correct conditions for the germination and kilning of the malt.

Objectives are:

- Uniform and complete endosperm hydration
- Even onset of germination
- Cleaning of the grain

**Water Uptake Sequence**

Water enters the husk & pericarp – the Testa actually inhibits/prevents water uptake. The water enters via micropyle. Firstly the embryo moisture increases and then the aleurone layer begins to hydrate. Finally the endosperm hydrates slowly from the embryo end.

The following factors will affect the water uptake:

- Variety
- Steep water temperature
- Grain size - thin corns take up water quicker
- Grain nitrogen and steeliness
- Grain vigour, water sensitivity and maturity
- Husk intactness
- Crop year
- Steep cycle

The water for steeping should be clean, potable, free of pathogens and free of organic matter and heavy metals and chlorine. Chalky, slightly alkaline waters are best. The moisture content is to be raised from 12% to 45% in about 48h at a temperature of about 16°C. This requires water volume of 0.8 to 1.2 cubic metres/tonne/wetting.

Water temperature is critical - between 12 and 20°C (normally around 16°C). Warmer increases water up-take.

Usage

- Conical steep ± 0.8m3/t
- Flat bottom steep ± 1.4m3/t
- Spray steep
- Grain absorbs ± 0.94m3/t (12% → 45%)

90% of maltings water is used in steeping.

Steeping activates the grain, increases the moisture and metabolic activity. The process needs Oxygen needs and produces CO₂ and heat.

**Steep Cycles**

Historically just one long immersion of grain in water was the standard but this is no longer the case. Now days normally 3 wet periods and 3 dry periods are used. Moisture content at end of first wet should be not more than 32%. Aeration in wet periods is usually at 1.5 cubic metre/tonne and ventilation in dry periods at 100 cubic metre/tonne.
Raw Materials – The Malting Process

Metabolism must start and grain should be chitted (i.e. rootlets have started to appear) on leaving the vessel.

Air rests are used so that the grain does not ‘suffocate’. It allows carbon dioxide to be removed and replaced with air and hence oxygen. Temperature control is critical during this process so the grain bed does not cool down due to evaporative cooling.

The following schematic shows typical steep cycles:

Conical Vessel

<table>
<thead>
<tr>
<th>12</th>
<th>7</th>
<th>12</th>
<th>7</th>
<th>5</th>
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<tr>
<td>C</td>
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</table>

Flat bottomed vessel

<table>
<thead>
<tr>
<th>10</th>
<th>7</th>
<th>10</th>
<th>6</th>
<th>5</th>
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<td>A</td>
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<td>A</td>
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</tr>
</tbody>
</table>

Under water period

Air rest period

'A' Aeration period

'C' Carbon dioxide extraction

Note. High vigour barleys may need only 2 under water periods.

This graph further shows the effect of air rests on water uptake:
The Steep Process

**Steep In**

There are various methods for grain transfer. Methods for grain transfer-in:

- Dry steeping – dust sprays on
- Wet steeping

Need to ensure standard steep in time is achieved – extended steep times will affect final malt quality so delays in steep in will effect this.

The following picture shows a typical steep in:

![Typical Steep In Process](image)

**Wet Stands**

Water is pumped in to cover the grain. An overflow removes floaters in 1st wet stand and cleans the grain. This water usually foams to drain. The time to cover the grain is important. Air rousing is used. A typical cycle would be on for approximately 15 seconds and 45 seconds off. This keeps the water aerobic, promotes washing of the grain and ensures even hydrostatic pressure by turning the grain. Aeration is usually at 15 m$^3$ per ton per hour submerged

**Dry Stands**

Water is drained out and fans are used to remove CO$_2$.

Typical values would be:

- 1st Air rest - 80 m$^3$/t
- 2nd Air rest 200 to 300 m$^3$/t

Air flow is downward in conical steeps and upwards in flat-bottom steeps.
Raw Materials – The Malting Process

This graph shows what typically happens to oxygen levels in the steep:

![Graph showing oxygen levels in the steep with peaks and troughs.]

**Steep Tank Design**

There are basically two types of steep tank design – conical and flat-bottom. Each have their pros and cons:

**Cylindroconical**
- Bed depth <7m
- 20 to 60t
- Good for rousing
- Best for 1st steep

**Flat bottom**
- Bed 1.5 to 1.8m
- 60 to 400t /piece
- Good CO₂ removal
- Good bed depth
- Best for 2nd steep

Diagrams of the various steep tank designs follow:
Flat Bottom Steeps

Advantages:
- Excellent air flow
- Even temperature control
- Easy to dry-cast

Disadvantages:
- Expensive
- Difficult to clean
- High water usage
Conical Steeps

External View

Internal View
Advantages:

- Cheap
- Easy to clean
- Low water consumption

Disadvantages:

- Poor air flow
- Difficult to dry-cast

Steep variables

The following may cause the maltster to change the steep programme:

- Grain size
- Barley TN levels
- Barley growth conditions
  - Dry, warm weather in ripening $\rightarrow$ slow uptake
  - Impacts on the protein content
- Water sensitivity
- Dormancy
- Required cast out moisture (which in turn has many implications on final malt quality)
Raw Materials – The Malting Process

Steep parameters

The following may be adjusted to achieve the end state specifications:

- Number of wet stands
  - Traditionally 1 long wet stand
  - 3 Wet stands vs 2 Wet stands (or even one wet stand??)
- Steep parameters may be changed to take account of the type of barley being used. These include:
  - Number of stands
  - Water temperature
  - Steep water temperature
  - Immersion time and length of air rests

Washing of barley

Some maltsters use various additives in the steep water including:

- Alkali – Caustic - removes polyphenols and suppresses mould growth
  - Acid – Nitric – as an antimicrobial
  - Disinfectants such as Formaldehyde and Aluminium sulphate (not normally permitted by most brewers)

Other Additives

There are other additives that may be used.

1. **Gibberellic Acid** – Normally found naturally in malt but can be obtained from fungi. Added in steep or on transfer to germination at 0.025-0.25ppm. Permitted by some brewers but not Distillers or follows of the Rheinheitsgebot.

   Effects:
   - Increases enzyme levels
   - Faster malting
   - More rapid enzyme development
   - Overcomes immaturity
   - Can end up with too much SN and colour
   - Very cost effective

2. **Formaldehyde** – removes polyphenols

3. **Potassium bromate** – inhibits growth of rootlets and hence reduces malting loss
   - Now banned by all customers but legally allowed by some countries
   - Used at 25-100 ppm
   - Reduces proteolysis during malting
   - Reduces SN and colour
   - Reduces rootlet formation
Steeping Effect on Quality

High cast moisture leads to:

- Better endosperm modification
- Increased friability
- High SNR
- High colour
- High malting losses due to rapid germination
- Possible extract loss due to over modification
- Increased enzyme activity

Therefore the maltster can use the steep out conditions to influence the final quality of the malt.

Abrasion

This is a method that was proposed but I am not sure is used any longer.

The objective was 2-way modification and hence a significant reduction in the time required to achieve the necessary modification. It has to be used in conjunction with exogenous GA to give a normal modification pattern. Testa/pericarp is impervious to water/GA so therefore it is scratched and can then get GA into non-embryo end. You do get 2-way modification with this method BUT some husk is removed due to damage (with obvious disadvantages in the brewing process). Commercial abraders work at 10 t/hr. I do not know of its use these days due to reluctance to use exogenous GA and the difficulty with getting homogeneity.
4. GERMINATION

Objectives of Germination

- Produce maximum balanced enzyme levels
- Hydrolyse cell walls and protein matrix
- Minimise extract loss
- Produce correct kilning characteristics
- Meet customers specifications
- Meet production schedules
- Make hygienic malt

The key aspect is to produce a batch of malt where *every* grain is identical and meets the requirements of the customer.

Input:

- Steeped barley at 45% moisture showing signs of germination.

Output:

- Green malt modified with enzymes fully developed.

Process:

- Holding under conditions of controlled temperature, humidity and oxygen, to encourage development of enzymes through the corn and breakdown of cell walls.

The physiology in germination was discussed in detail in Module 1 but the basic steps are:

- Water is taken up
- Sugars within the embryo are used up
- The embryo produces the plant hormones gibberellins
- These stimulate the scutellum & aleurone to produce enzymes
- Enzymes pass into the endosperm and digest
  - Cell walls
  - Protein matrix
  - Small starch granules
  - Large starch granules

Processes in germination:

- Box loading (may include application of GA)
- Germination
  - Levelling
  - Air flow
  - Humidification (including spraying)
  - Temperature control
- Withering
- Box unloading
Design of Germination Vessel

There are many different types of batch germination systems but the all follow the same basic principles:

- Grain bed of 0.5-1.5m
- Sits on a perforated deck
- Cool, humidified air blown through the bed, removes carbon dioxide and heat and adds oxygen for grain respiration
- Air conditioning in room to help maintain a consistent temperature
- Grain turned every 8-12 hours
  - Breaks up rootlets
  - Loosens bed
  - Breaks up temperature gradients
- The process must be hygienic and hence cleaning is of vital importance

Germination Systems

There historically have been many types of germination systems used including the following:

A. Floor Maltings

The traditional malting method was by merely spreading the grain in a very thin bed on a wooden floor. The bed depth is 75mm to 100mm and a maximum of 100 tonnes per piece. This is very rarely used these days due to the amount of floor space involved and amount of manual work as well as difficulties in ensuring homogeneity.
B. Boby Drum

A Boby drum is a drum in which the germination and potentially kilning can be done.

During germination the grain sits on a perforated bed and is turned by means of the whole drum rotating. Very gentle but limited to 30 tonnes/drum. Not seen much these days as the power requirements and difficulty in getting economies of scale.
C. Wanderhaufen Street

Literally means ‘moving bed’ in German. In this system there are up to seven individual batches on the Street at any one time – one a day being placed on. Each batch moves day by day along the bed until when it is at the far end (at the end of seven days) it is ready for kilning. One of the problems with this system is the inability/difficulty to change germination variables, particularly time.

1. The germination street
2. Bed support
3. Germinating grains
4. Half day section
5. Turner (old type – with bucket scoops)
6. Section being cleaned
7. Steep
8. Discharge screw conveyor
9. Fan
10. Ventilation duct
### D. Tower Malting

This is similar to the circular germination system but takes it one stage further by having steeping, germination and kilning in a vertical structure where the grain is fed between each stage by gravity.

### E. Saladin Box

This is one of the most popular germination systems done batch by batch. Saladin box has turners, vertical slowly rotating screws on a travelling carriage. These are used for turning to avoid matting of the grain and for 'Stripping' at the end of germination. Air is supplied from underfloor space via humidification sprays and refrigeration. Air recirculation saves refrigeration energy and is necessary to achieve temperatures in N. European winters.

Stripping is by a removable end wall using turners as a ‘pusher’. Floor plates are manually lifted for cleaning. Bed depth of 1.4m and a maximum size of 225 tons.
F. Circular Germination Vessel

This is one of the most widely used germination systems as very large batch sizes can be used with a large central giracleur for turning and possibly humidification of the grain. The current trend is to have circular vessels, either with fixed floor or rotating floors. Construction costs are less especially in sized >150 tonnes and design is compatible with towers. Turners, are mounted on a bridge between edge and centre which either rotates or is fixed depending on floor type. Central column is used for services and grain movement. Floors can be made to lift to enable access for cleaning and underfloor are designed for hygiene. CIP sprays can be incorporated.
Circular Vessel – Fixed Floor

Turner and loading/unloading screw, rotate around central pillar on circumferential rail.

Steeped barley

Refrigeration coil
Humidification sprays

Green malt

Circular Vessel – Fixed Floor

Steeped barley

Rotating floor supported on rails on central pillar and vessel circumference.

Turner and loading/unloading screw, on a fixed bridge between vessel edge and central pillar.

Refrigeration coil
Humidification sprays

Green malt
Germination Process Variables

There are several variables that may be used to control the germination process and produce the quality of malt required by the customer and these are mainly a combination of Time v Temperature v Moisture

- Time may be fixed by process schedules
- Moisture may be controlled by humidification levels or spraying when turning
- Temperature may be controlled by amount of recirculated air or the introduction of chilled air

Air flow in Germination

Continuous air flow needed to:

- Remove Carbon dioxide
- Supply fresh oxygen for barley germination
- Maintain grain bed temperature

Air flow control – 0.15 to 0.2m3/s/tonne. This is done by dampers (old technology) or variable speed drives – energy savers.

Air source can be:

- Fresh air – has low humidity and may have extreme temperature fluctuations
- Return air – has constant humidity and temperature but high carbon dioxide

The air flow obviously regulates temperature but we still see temperature gradients throughout the bed:
**Humidification**

Maintaining the moisture in the grain at or close to steep out moisture is critical for even germination. The air entering the grain bed needs to approach 100% relative humidity (RH) to prevent drying out the bed. Relative humidity is a term used to describe the amount of water vapour that exists in a gaseous mixture of air and water vapour.

**Spraying Grain Bed**

This may be done to raise grain moisture if steep out moisture is low, or, air humidification is not sufficient. It may cause uneven hydration from the top of the bed versus bottom of the bed. It tends to lead to increased moisture in the embryo. This is an acknowledgement of inadequate steeping and should not be a standard practice but ‘last resort method’.

**Temperature Control**

Air on temperature is controlled by humidification sprays, or refrigeration. Air-off temperature is influenced by air on temperature, air flow rates through the bed and the rate of germination. $\Delta T$ should be less than 2°C - this is the difference between air-on & air-off temperatures.

**Malt Turners**

Loosen the bed to prevent matting of rootlets which in turn may lead to poor air flow, temperature hot spots, and, over-modification of the grain.

Start Time can be set by:
1. Time - Every 4 hours
2. When the air-off temperature rises

Note the circulation produced by the turners.
**Raw Materials – The Malting Process**

**Withering**

This is the process of allowing the grain to begin drying in the last few hours of germination by stopping humidification. This may be done by switching off the humidification sprays and I used to reduce the moisture at the end of germination and hence kilning costs.

**Germination Conditions and Quality**

Long germination time leads to:

- Increased endosperm breakdown
- Increased β-glucan removal
- Higher friability
- Higher then lower extracts
- Increased SN
- Increased FAN
- Increased colour
- Increased DP
- Increased malting loss

Therefore, generally, short germination times have the opposite effects. Again all these statements must be considered in terms of the starting conditions at the end of steeping.
5. KILNING

Most energy intensive process in malting using 50-70% of the total energy.

Objectives of Kilning

- Arrest enzyme activity and hence chemical changes within the malt
- Produce product which is stable and can be stored by moisture removal
- Permit removal of rootlets
- Form flavour positive compounds
- Remove flavour negative compounds
- Produce colour
- Give a product that may be milled

Input:

- A uniform high quality piece of green malt with desired levels of modification having been achieved on conclusion of the germination period with moisture levels of between 42 and 44% inclusive of rootlets.

Output:

- A dry uniformly kilned malt piece with a moisture of not greater than 4.5% moisture is produced conforming to specifications, for immediate deculming (dry rootlet/fines removal) and transfer to silo for storage and later blending after a storage period during which enzyme stability and moisture equilibrium occurs.

Process purpose

- To halt germination by reducing moisture levels through a gentle drying process through controlled drying, by passing heated air though the grain bed in preparation for storage.

Kilning and Malt Quality

Kilning has a significant effect on malt quality:

- Moisture is reduced for safe storage and maintenance of product quality.
- Biochemical processes stopped
- Colour is produced (by Maillard reactions)
- Flavours produced (by Maillard reactions)
- Enzymes preserved
- SMM is converted to DMS and driven off
- Rootlets (Culms) are dried to allow for removal in deculming.
- Malt quality can be enhanced or destroyed in kilning.

Colour Formation

Dependent on:

- Kilning and final curing temperatures
- Length of curing phase
- Level of modification going to kiln
- Stewing effects
Formed by reaction of reducing sugars and amino acids to form reductones. These can then:

- Polymerise to form melanoidins (colour)
- Combine with amino acid to form aminoketones which then further transform to pyrazines (flavour)

**Di-Methyl Sulphide (DMS)**

Important flavour compound in beer – imparts sweetcorn/cooked vegetable flavour.

Formation and destruction:

- S-Methyl Methionine (SMM) broken down to DMS in kiln
- DMS volatile lost in kiln exhaust
- SMM converted to DMS during boiling
- DMS volatilised during wort boiling
- DMSO (di-methyl sulphoxide) can be formed during kilning and reduced by yeast to DMS in beer

**Drying Theory**

Air will absorb moisture up to the saturation point. The amount of moisture at saturation will depend on temperature and the volume of air passes through the grain bed. Heating of air has a dramatic reduction on saturation and a similar dramatic increase in the ability to absorb moisture from material being dried. If the “air off” has an R/H above 90-95% then no cooling will be imparted to the top of grain bed, the grain bed heats up and “stewing” of the bed will occur as will deterioration in malt quality. As air passes through a grain bed, the temperature is reduced due to loss of latent heat.

The following steps occur during kilning:

- Free moisture reduction occurs from 46% to 25% (60 % of total moisture content)
- Intermediate moisture reduction occurs from 25% to 12%
- Bound moisture reduction from 12% to 5%

Moisture is initially loosely held by grain and easily released into air-stream. The rate of drying is virtually constant over time – this is known as the ‘Constant Rate Period’. The rate of drying depends on the rate of air-flow and the temperature of the heated air. Air-flow is the controlling factor.

When the bound moisture falls below 13% it is held tightly in cell structure. Temperature increases mobility of moisture through cells to grain surface. The rate of removal gradually falls with time – known as the ‘Falling rate period’. Air-flow no longer the controlling factor. Transition from free drying is termed the ‘Break point’ and occurs when there is a drop in the RH of the air off and an increase in the air off temperature.

When the ‘Front’ reaches the surface of the bed, the air off temperature rises and the humidity falls. This is known as the ‘Break Point’ and its accurate detection is vital in efficient control of the process. Typical breaks occur after approximately 12 hours in a 24 hour cycle kiln. Post-break exhaust air is unsaturated and capable of further drying.

After the ‘Break’ air-flow can be reduced to save energy. A good, clean, even break depends on good air distribution and even bed loading.
After the break, ALL of the malt bed is in the falling rate phase with water as bound moisture. Further drying depends on increased temperature to mobilise water molecules and air flow may be reduced to save energy. Enzymes are less temperature-sensitive at lower moisture levels, which enable the increase of kiln “air on” temperatures to remove bound moisture from the grain. Temperatures are raised to +/- 83°C (dependent on malt type required) to achieve desired colour, flavour and aroma development. This is called the curing phase with a minimum of 4 hours at this temperature.

The last phase of kilning is the “cooling” phase achieved by passing ambient air of <30°C through the grain bed. Exhaust air can be used either by a kiln in the pre-break phase or recirculated.

The following graph depicts this:
Enzyme Heat Stability

This table shows the stability of the enzymes which are still active at the end of germination. Significant amounts of enzymes are inactivated/denatured during the kilning process and one of the maltster’s skills is to try to minimise this.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Lethal Temperature</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>α- amylase</td>
<td>&gt;80°C</td>
<td>Most stable enzyme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activity increase during kilning</td>
</tr>
<tr>
<td>β- amylase</td>
<td>65-70°C</td>
<td>Very sensitive enzyme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Approx. 40% destroyed</td>
</tr>
<tr>
<td>β- glucanase</td>
<td>55-60°C</td>
<td>Most sensitive enzyme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Approx. 50% destroyed</td>
</tr>
<tr>
<td>β- glucan solubilase</td>
<td>70°C</td>
<td>Relatively stable</td>
</tr>
<tr>
<td>Endopeptidase</td>
<td>60-65°C</td>
<td>Fairly sensitive</td>
</tr>
<tr>
<td>Arboxyopeptidase</td>
<td>75°C</td>
<td>Relatively stable</td>
</tr>
<tr>
<td>Dipeptidase</td>
<td>55°C</td>
<td>Fairly sensitive</td>
</tr>
</tbody>
</table>
Processes in Kilning

1. Kiln loading

2. Kilning
   • (Stewing) during loading without prior to fan operation
   • Free drying: 100% fresh air at “air on” - 63°C.
   • Forced drying: Introduction of return air and increase in temperature possible as R/H decreases.
   • Curing: 100% return air and a minimum temperature held for 4 hours
   • Cooling: 100 % fresh air until desired temperature is achieved.

3. Kiln unloading:
   • From kiln though deculming (to remove rootlets and malt fines to storage silo)

As discussed – the process of kilning (just like wort boiling) is a significant energy user:

<table>
<thead>
<tr>
<th>Type of Plant</th>
<th>Electricity GJ/tonne</th>
<th>Fuel GJ/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional kiln</td>
<td>0.21</td>
<td>4.8</td>
</tr>
<tr>
<td>Manual re-circulation</td>
<td>0.38</td>
<td>3.9</td>
</tr>
<tr>
<td>Auto re-circulation &amp; air volume control</td>
<td>0.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Semi-continuous</td>
<td>0.08</td>
<td>1.8</td>
</tr>
</tbody>
</table>
1. Kiln Loading: Transfer from Germination. Transfer time – should be as quick as practically possible. Temperature during transfer should be maintained.

2. Grain Leveling: The main importance of a level bed is preferential air flow. There are various methods of leveling:
   - Malt thrower
   - Giracleur
   - Leveling screw (shown below)
   - Shovel!

This next picture shows a malt thrower:
Kiln Design

Traditionally they were rectangular boxes with a perforated floor and grain to between 1.5 and 2 m. Warm air is pushed (pressure kiln) or pulled (suction kiln) through the malt by fans. Continental double deck kilns transfer malt from upper to lower deck at break point. Leveling of malt on loading is vital to ensure an even air distribution and a ‘clean’ break. Various stripping methods including tipping floors are used. Heat recovery and recycling has reduced energy needs.

The picture below shows a traditional kiln or ‘Oast House’ as they were known in England:

Current designs are now generally circular kilns offered with either rotating floors or fixed floors with rotating levellers. These designs are compatible with towers. The central column used for transfers. Two kilns interlinked gives advantage of continental system. Three kiln systems from Seager and Nordon offer further advantages on energy recovery and usage. Heating now almost always by indirect systems with heat recovery exchangers giving preheat from saturated exhaust.

The picture below shows a typical Single Deck Kiln:
**Kiln Heating**

There are various different heating systems that can be used:

1. **Direct heating**: The fuel type for this method is important and the formation of nitrosamine risk is higher (see later for a discussion). You may need to burn sulphur to remove the risk of nitrosamine formation.
2. **Indirect heating**: Good for reduced nitrosamine production but has inefficiencies. Normally uses steam.
There are energy saving options available, including:

- Glass tube heat exchangers
- Linked kilns
- Use return air

**Direct Heating**

Kilns were traditionally heated by direct means by wood, anthracite, peat, oil or gas flames. The water of combustion reduces the drying effect making it relatively inefficient. NOx (nitrous oxide gases) formed in the flames (especially Natural Gas) forms nitrosamines with certain proteins in the malt. Direct combustion is probably the cheapest in capital cost terms. There is a fire risk since cereal matter maybe in contact with flames. ‘LoNOx’ burners provide controlled combustion temperatures and reduced NOx formation. Fuels restricted to natural gas and low sulphur gas oil.

**Indirect Heating**

Indirect heating provides a physical barrier between flame and drying air. Heat can be transferred by pressurised water, thermal fluid or steam. Has the advantage of a remote heating plant. Specially designed heaters, e.g. Air Frohlich ‘Anox’ contains combustion in tubes with kilning air flowing over the tubes. The water of combustion does not affect the drying. No additional NOx is formed in kilning air. Conducive to high degree of heat recovery with flue gas cooled to <50°C and efficiencies >100% of Net Calorific Value.

This diagram shows a typical Indirect heating system:
The following diagrams show some examples of kilns with heat recovery systems:

*Kiln with Tipping Floor and Indirect Heating*

*Circular Kiln with Indirect Heating*
Circular Kiln with Indirect Heating and Heat Recovery

Air Flow in Kilning
Air flow control may be done by dampers which are inefficient or variable speed drives which are the method of choice. The air source may be fresh air – used during free drying, return air – used during forced drying and curing (as moisture content now very low). Air flow rates are higher before the break and slower after.

Nitrosamines

Are classified as being carcinogenic (cancer causing compounds) and may be reduced by:

- Using employing indirect fired kilns (heating of air via heat exchanger) which prevents airflow contamination with noxious gases
- Sulphuring the malt
- Using low NOx burners
- Avoiding building plant in areas with high air pollution

Nitrogen oxides are formed in flames due to temperature and concentrations. Collective term is NOx covering the 3 main oxides. Ambient air, especially urban environments has a high NOx level due to vehicles. Sulphur dioxide introduced during the pre-break phase will inhibit the nitroso reaction and may still be required to counter background levels. Conventional burners will give 10µg/kg, with sulphur, 2µg/kg, low NOx with sulphur, 1µg/kg. The accepted maximum is 2.5µg/kg.

Sulphuring can be achieved by burning elemental sulphur (1kg/tonne malt) or the addition of sulphur dioxide (6kg/t malt). This technique produces malt of lower colour and reduces the formation of nitrosamines from polluted noxious gases in direct fired kilns.