Relationship Between Physical Properties of Malt Measured Mechanically and by Machine Vision

Kshitiz K Krishna, Graduate student

Shahab Sokhansanj, Professor

Agricultural & Bioresource Engineering

University of Saskatchewan

S7N5A9

Introduction

When converting barley kernel to malt, the barley kernels are steeped in water to a moisture content of 0.79 d.b.(44 % w.b). The moistened kernel is germinated in humid chambers, followed by kilning (drying). The malting process causes extensive modification in the kernel, especially to its hygroscopic state and the development of natural enzymes. The kernel also undergoes an external change in size, shape, texture, and color during kilning. Barley malt is the only grain which is commercially dried for such a large moisture reduction of 0.79 d.b. to 0.02 d.b. Consequently, kilning is a highly energy-intensive process. Moreover the significant shrinkage in the malt bed occurs during drying. The use of engineered process controls for malt quality during kilning has not been researched adequately. Experienced maltsters control the process to achieve a desired quality.

The objective of this work was to characterise the physical properties of malt during kilning to better control the malting process. Samples of commercial green malt were dried in an air-oven according to a commercial kilning schedule. The volume and density at several levels of moisture content were measured by gas pycnometry. The microstructure of malt was observed under a scanning electron microscope. The interior pores and pitting on the starch granules of endosperm were observed on SEM. The changes in dimensional attributes of malt kernels during kilning were measured by a machine vision to correlate various physical attributes. A series of empirical equations were developed relating the density, volume and physical dimensions of the kernel to the moisture content.

This study was undertaken to investigate and quantify the changes in physical attributes of malt during kilning The samples of malt (green malt) before kilning were procured from a commercial production site. A commercial kilning regime was simulated in the laboratory, with the drying tests performed in an air convection oven. Three identical drying tests were performed to measure kernel volume and density.

The moisture content distribution of green malt kernel was examined. For malt ready to be **kilned** the moisture content of individual kernels ranged from 0.25 d.b. (20% w.b.) to 1.00 d.b. (50% w.b.), when the bulk moisture content was 0.79 d.b.(44% w.b.). With respect to dimensional attributes, the kernel perimeter correlated well with volumetric shrinkage during kilning. The density and bulk porosity showed a second order correlation with moisture content. In conclusion, monitoring the progress of the kilning operation could be greatly aided by the relationships between the visual (dimensional) features and/or the important attributes of malt.

Barley kernels were found to decrease in compactness **($P^2/4\pi A$)** as the moisture content increased. Malt kernel randomly changed the shape measured by machine vision and experienced volumetric shrinkage during moisture adjustments from 0.79 to completely dry stage. Machine vision extracted and analysed the two dimensional physical features. The change in perimeter **(P_c)** measured from machine vision showed correlation with volumetric shrinkage. The variation in volume measurements explained kernel shrinkage, and moisture behaviour of the malt kernel during drying. The kernel and bulk density variation correlated with the surface behaviour as well as interior structure and porosity of the malt kernel during drying. The trend in variation of kernel density, kernel volume and shape indicated major change in the range of 0.30 to 0.43 d.b.

The change in the physical structure of the endosperm was studied by observing the photographs taken by a scanning electron microscope. The interior pores in the endosperm was observed and the crystalline structure of starch in the protein matrix of malt kernel samples was witnessed at various stages of drying. The pitting on the starch granules showed the action of enzymes on the starch granules. The breakdown of the cell wall in endosperm was not complete. In the cured samples (completely dry sample of malt kernel), distortion of the starch granules was observed.

Objectives and experimental design

The experiments and measurements on laboratory-scale and then on commercial scale (on-line) were performed. The tests and measurements were performed on individual as well as bulk malt kernels undergoing drying in a commercial Flexi-kiln at Praire malt ltd. **. The** overall objective of this research is to analyse the physical properties during kilning:

1. Use machine vision to characterize physical attributes of malt and to identify and develop a shape/size factor as an index to represent malt at various stages of kilning
2. Use mechanical means to measure moisture content, mass, volume, density, and porosityof kernels and relate these measured attributes to the dimensional attributes of kernels during kilning.
3. Rank physical features according to their significant effect on the kilning operation and develop functional relations among these variables

Sample collection of malt from drying bed

The probe of length 7`and diameter 5" was used to collect the malt sample at various locations and depths in Flexi kiln. The probe had fifteen holes. The holes were 3.5" in length.

Figure 1 shows the plan view of Flexi Kiln. Flexi is divided in many compartments of about 200' x 25' as shown in Figure. The height of the bin is 6' approximately. The average depth of green malt. bed is 4'. Flexi kiln operates on 8 fans. These fans work as supply, exhaust and for re-circulation of air according to the temperature regime of the drying cycle. Samples were taken from various location and at different depth of the kiln ##4. The locations of sample collection is shown in Figure as cross. Samples were collected almost every hour or an hour and half so that the samples presented all states of temperature regime in kilning.

Measurement of malt grain temperature was measured right after collection of the sample (immediately after probing from the bed). The measurement was performed by thermocouple attached to digital display. Samples were stored in a cooler approximately at 4 °C immediately after the temperature was measured. The analysis of results is under process. Some of the conclusions and findings until now are mentioned in following section.

Conclusions

1. The moisture content change versus drying time was studied by following the commercial drying regime. The moisture content of the green malt kernel was distributed in the range of 0.25 to 1 .OO d.b. The moisture distribution in green malt seems to cause variable shrinkage (random change in shape and size) in the malt kernels during drying.

2. The dimensional attributes of malt kernels were measured by machine vision at various moisture contents during drying. The distribution of length of green malt kernels approximated on two-dimensional shape was right hand skewed with an average of 12.1 mm (n=120 kernels). The majority of the kernels with an average moisture content of 0.79 d.b. have the length variation from **10.6** to **13.9 mm.** However, some of the kernels chosen arbitrarily at later stages of drying experiments were found to be more than 13.9 mm. The large variation in the length was attributed to non-uniform growth in the rootlets.

3. Pitting on the starch granules showed the action of enzymes during kilning The SEM also indicates the presence of cell-walls in the malt kernel, suggesting that cell-walls were not completely broken during malting. SEM photographs show evidence of interior pores in the malt kernels.

4. The kernel and bulk density increased with a decrease in the moisture content in the initial stage of drying. The density peaked in the range of 0.41 d.b. to 0.49 d.b. The density decreased as the moisture decreases further from 0.41 d-b. to completely dry stage during drying. The kernel and bulk densities of malt could be accurately represented by second or third-order polynomial equations.

5. Shape factors such as compactness, roughness, geometrical index were determined. Geometrical index which is a combination of projected area, breadth, length and thickness of a kernel, showed a general decrease in malt kernel with decrease in moisture content.

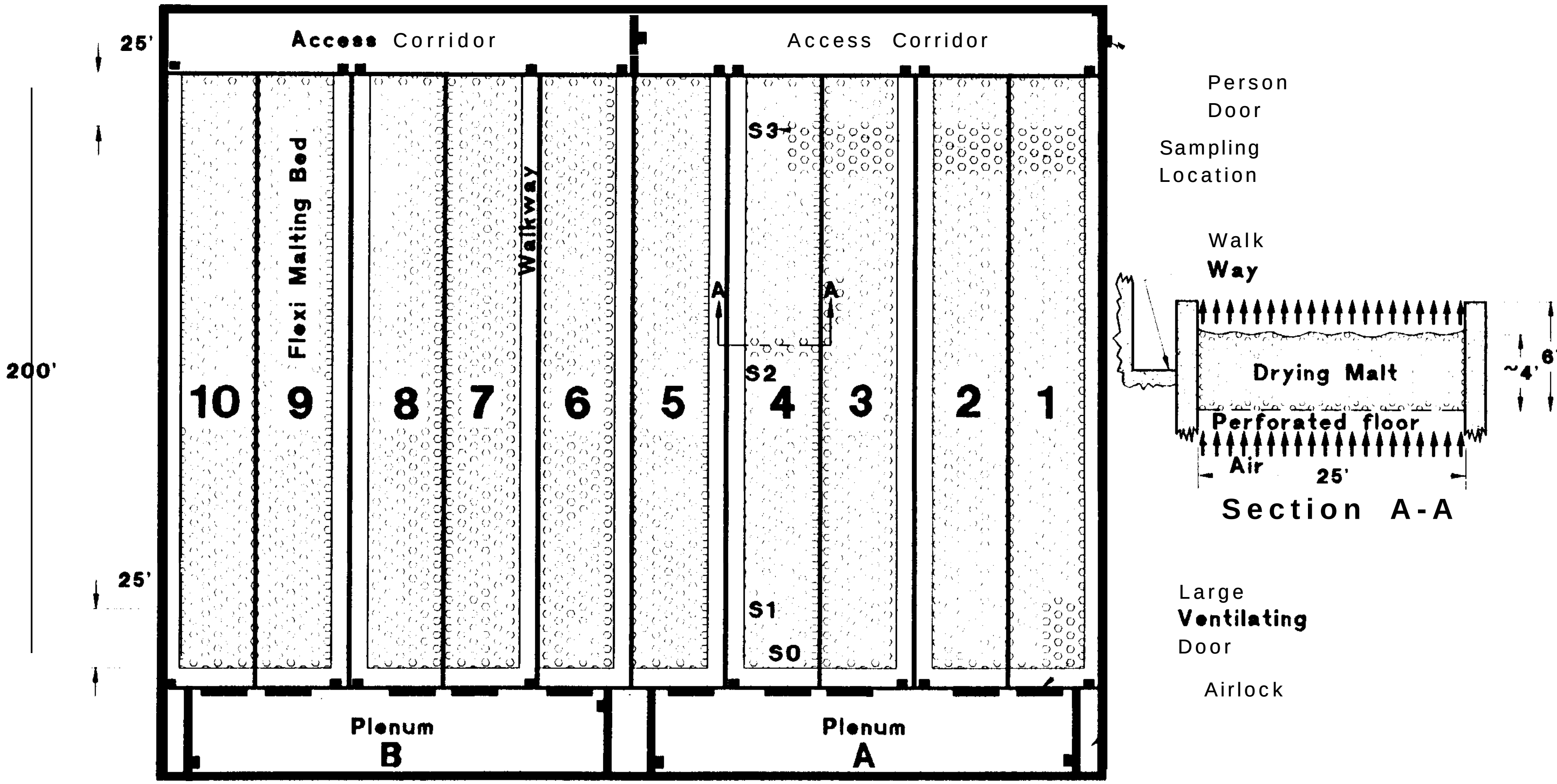

Figure 1: Layout of Commercial Malt kilning (Flexi) Facility

The geometrical index could be used to estimate the kernel moisture content during drying if the proper information about the change in thickness of kernel is provided.

6. The ranking of the physical attributes of malt during kilning based on the measurements performed using machine vision, pycnometer, air- convection oven, 0.5 L container. and scale were as follows: kernel volume (V_k), perimeter (P_c), breadth (B_r), bulk density (ρ_b), length (L_m), perimeter (P), kernel density (ρ_k), compactness, roughness, elongation, and projected area (A_m). This ranking showed the usefulness of physical attributes which can be measured and predicted to follow the decreasing trend with moisture content during kilning

7. Table 7.1 lists the coefficients of a second order polynomial equation fitted to predict the attributes based on the measured physical features. Moisture content, kernel volume kernel density, perimeter (P_c) and geometrical index were used as important variables. The measured one could be used as indicator of the value of the others.

Table 7.1: Regression coefficients of quadratic equations ($y = a + bx + cx^2$) developed to predict various physical attributes during drying of malt. Physical attribute could be a function of given variables. Y is dependant variable and x is independent variable.

Y	x	a	b	c	r^2	S.E.	F-stat
Kernel density (ρ_k, g/cc)	M	1.14	1.04	-1.20	0.92	0.022	162.69
Kernel volume (V_k, mm^3)	M	36.36	17.25	9.32	0.98	1.011	277.53
Bulk density (ρ_b, kg/m^3)	M	522.67	271.42	-252.08	0.93	6.875	106.19
Geometrical index (G)	M	0.633	-0.002	0.016	0.60	0.002	5.99
Perimeter (P_c, mm)	M	21.39	-0.76	6.84	0.95	0.27	190.79
Kernel volume (V_k, mm^3)	PC	-1429.16	122.21	-2.50	0.99	0.535	735.5
Bulk density (ρ_b, kg/m^3)	ρ_k	-2200	4.13	-0.002	0.76	13.24	22.13
Moisture content (d.b.)	G	-2894	9020	-7027	0.60	0.172	6.09
Bulk density (ρ_b, kg/m^3)	V_k	-694.55	53.61	-0.55	0.93	8.57	54.00

$G = \frac{1}{4} + \frac{3}{8A^2} + \frac{3}{8B^2}$ where: $A = \frac{a}{L}$; a is defined as half length of the kernel, and, L is thickness of the kernel. $B = \frac{b}{L}$; b is defined as half breadth of the kernel.