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Matching Barley to Brewhouse Equipment

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Introduction

The majority of brewers utilise six roller mills, mash tuns and lauter tuns as processing equipment for malted barley in the brewhouse. This paper describes the operation and objectives of this equipment and discusses the brewer's raw material needs in order to optimise the process for cost efficiency and quality.

Milling

In practical terms, the milling operation is designed to reduce the malt to particle sizes suitable for rapid extraction and enzymic digestion, maximum extract yield and throughput. However, maximum extract yield is achieved with a fine grind while maximum throughput is achieved with a coarse grind, thus the brewer needs to find a balance.

The objectives of milling are to:

1. Split the husk longitudinally, exposing and separating the endosperm, without tearing the hulls

2. Crush the endosperm allowing complete wetting and therefore rapid extraction and enzymic digestion.

3. Minimise the quantity of fine flour produced.

Therefore the ideal grist for wort filtration in a lauter tun would contain:

1. No intact kernels

2. The majority of husks split end to end with no endosperm attached

3. The endosperm reduced to a uniform small particle size, called grits

4. A minimum of fine flour.

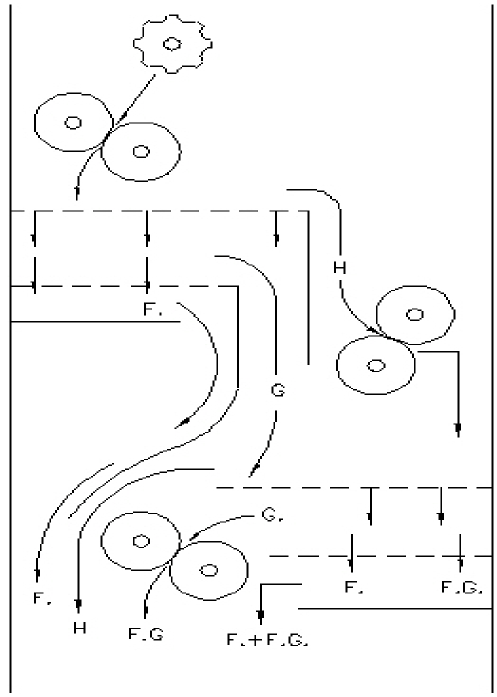

Figure 1. Six roll mill schematic F, flour; G, grits; H, husks; F.G, fine grits (Adapted from Briggs et al. 1981)

When used in combination with lauter tuns, the majority of brewers use six roller dry mills, as shown in Figure 1. A fluted feed roller aligns the grain so they are presented in a lengthwise manner to the first pair of reduction rollers. The grain is split longitudinally and kept reasonably intact. The mixture is then separated through vibrating screens, with fine flour falling through to the grist case and small grits being screened to the third pair of rollers. Hard endosperms are separated from the husk in the second pair of rollers, along with coarse grits. The mixture is again separated through vibrating screens, with flour and husks falling to the grist case and remaining grits being delivered to the third pair of rollers.

For good lauter tun performance Briggs et al suggest that the grist should contain 15% husks, 23% coarse grits, 30% fine grits and 32% flour, while Kunze suggests that the grist should consist of 18% husk, 8% coarse grits, 56% fine grits and 18% flour. In fact, the optimum grist size distribution is dependent on a brewery's specific requirements for extract yield and throughput, the modification of the malt and the loading on the lauter tun.

Mashing

The objective of mashing is to convert the malt into a fermentable extract suitable for yeast growth and beer production, in a controlled and predictable manner. The majority of Australian brewers use single temperature infusion mashing, where the grist is mixed with water at 65 - 70°C. At this temperature amylolytic conversion of starch to fermentable sugars and dextrins takes place as well as the enzymic and physical solubilisation of protein to give soluble polypeptides, peptides and assimilable amino acids. To control this complex range of biochemical reactions the brewer uses the simple control techniques of time, temperature and pH.

As the grist falls into the mashing vessel (mash tun) it is intimately mixed with water in a vessel, known as a Foremasher. This assures instantaneous and complete wetting of the grist and prevents starch from balling. The mash tun is a cylindrical dished bottom vessel with large slow rotating agitator. The mash must be treated gently as any shear during agitation or transfer will damage the husks, causing wort filtration difficulties. However a mash that is stirred too slowly can result in loss of extract and problems with heat transfer causing local hot spots.

Wort Recovery

Wort recovery or wort filtration is the process of separating the soluble material (wort) from the insoluble material (spent grain). The three objectives of wort recovery are:

1. To maximise extract yield.
2. To produce clear or non turbid quality wort.
3. To minimise wort filtration time, commonly called run off time.

Clear wort and maximum extract efficiency can be obtained by slow run offs however, considering that wort separation is often the rate determining process, this will be at the expense of brewhouse throughput. Therefore, as with milling, the brewer has to find a balance that will suit their specific requirements.

The most commonly used equipment for wort filtration is the lauter tun, Figure 2. The lauter tun is a cylindrical vessel of large diameter and comparatively shallow depth. Suspended approximately 10 cm from the true bottom is a false bottom of slotted stainless steel plates. These plates allow the wort to flow through, but retain the grain husks. Inside the lauter tun is a raking machine, this can be raised, lowered and rotated. Connected to the main shaft are radial arms that support the blades or rakes. While a brew is being run off the radial arms are rotated and the blades slice through and slightly lift the bed. This assists in preventing compaction, which can result in a slow or stalled run off and also provides access for the sparge water, thus increasing extract efficiency.

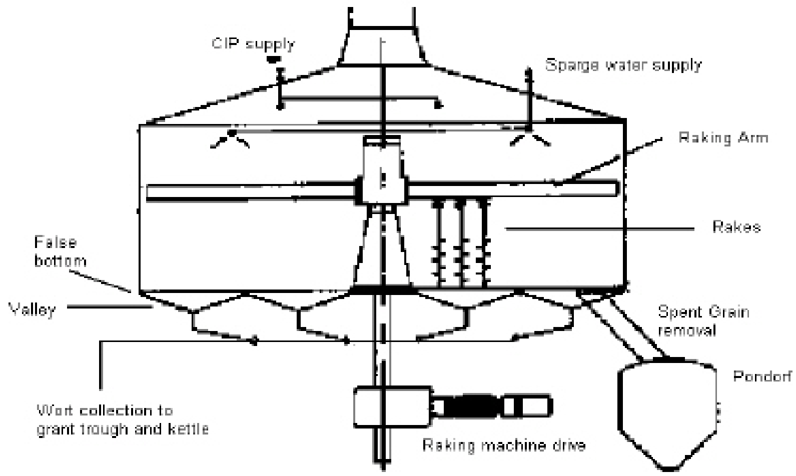

Figure 2. Lauter tun schematic

Malt requirements for milling, mashing and wort filtration

Essentially, malt provides all the ingredients necessary to make beer, including starch, nitrogen (foam proteins, amino acids, peptides), phosphates, silicates, polyphenols, vitamins (B1, B2, C, and E) and enzymes. However, the quality of the barley and how it is processed at both the maltings and in the brewhouse will have a significant impact on the quality and cost efficiency of the beer.

Impact of malt quality on beer quality

The reactions occurring during the mashing process determine the carbohydrate and protein profile of the wort and can be directly attributed to the malt.

The carbohydrate profile of the wort is adjusted by controlling the time and temperature of the malt in the mash tun. It can take three days before a change in the trend of the carbohydrate profile is known and then, if required, subsequent process adjustments can be made. This long feedback loop can possibly result in three days of beer production that is out of specification and therefore require blending.

The goal of brewhouse is to produce wort that is "right first time", this will result in beer that doesn't require blending. To achieve this goal the brewer needs consistent diastatic power in the malt or a very good indicator that could be used to predict the required stand time. Since neither is available the brewer must continually adjust stand times or temperatures to meet the carbohydrate profile target for his beer.

Australian brewers add sugar adjuncts directly to the kettle and therefore do not require high levels of diastase to convert starch adjuncts. In fact, high levels of diastase convert starch too quickly and controlling the process becomes difficult if not impossible. Ideally, the malt would contain a level of diastase that resulted in a stand time of thirty minutes. This allows enough time for amylolytic conversion of the starch to maximise extract yield, shorter times can result in low extract yields, while longer stand times can result in damage to the husks due to shear and subsequent problems with wort filtration.

The protein profile of the wort determines the foam quality and to some extent the shelf life of the final beer it also has to be suitable for yeast growth. While there have been reports on some specific proteins that affect foam quality (Evans et al., 2000) and beer stability, such as protein Z4, LTP1 and hordein derived polypeptides respectively, these are not routinely analysed, so the brewer relies on a soluble and total nitrogen specification that will provide enough protein for foam quality and yeast nutrition, while not adversely affecting beer stability.

Impact of malt quality on cost efficiency

Obviously, the available hot water extract of the malt has the greatest impact on cost. As mentioned previously cost efficient beer production requires a balance between extract yield and throughput. When using dry mills, which have a tendency to damage the grain, in combination with lauter tuns, which need the husk to be intact, consistency of grain size (grain plumpness) has a large impact on extract yield and throughput. During the milling process variable grain size can result in the following:

1. Small grains may not be effectively crushed. Wetting of large grain particles or grain with the husk still intact is slow, and often incomplete. Therefore the access of enzymes to starch is restricted. This leads to lower extract yield and higher extract cost.

2. Large grains tend to be crushed too severely. This causes the grain to shatter resulting in too much fine flour and shredded or torn husks. Fine flour can ball in the mash leaving unconverted starch, which can cause irreversible carbohydrate hazes in the beer. Fine flour also blocks the lauter tun resulting in slow run offs and further problems during diatomaceous earth filtration. Torn husks are not effective in forming a filtration bed for wort separation and so also result in slower run offs. Inefficient filtration will also result in "dirty" wort, with an increase in polyphenols, which contribute to a harsh palate in the beer and increase the potential of the beer to form polyphenol - protein hazes.

For grain size which follows a normal distribution, a greater standard deviation will result in a greater proportion of grain either being to small or too large, with the resulting problems mentioned above. For example, normal distributions with standard deviations of 1 and 1.5 will result in 5% and 19.4% of grain falling outside 1.96

standard deviations from the mean respectively, Figure 3. Screening alleviates problems with small grain however, it does not provide a solution for malt batches with a large grain size distribution.

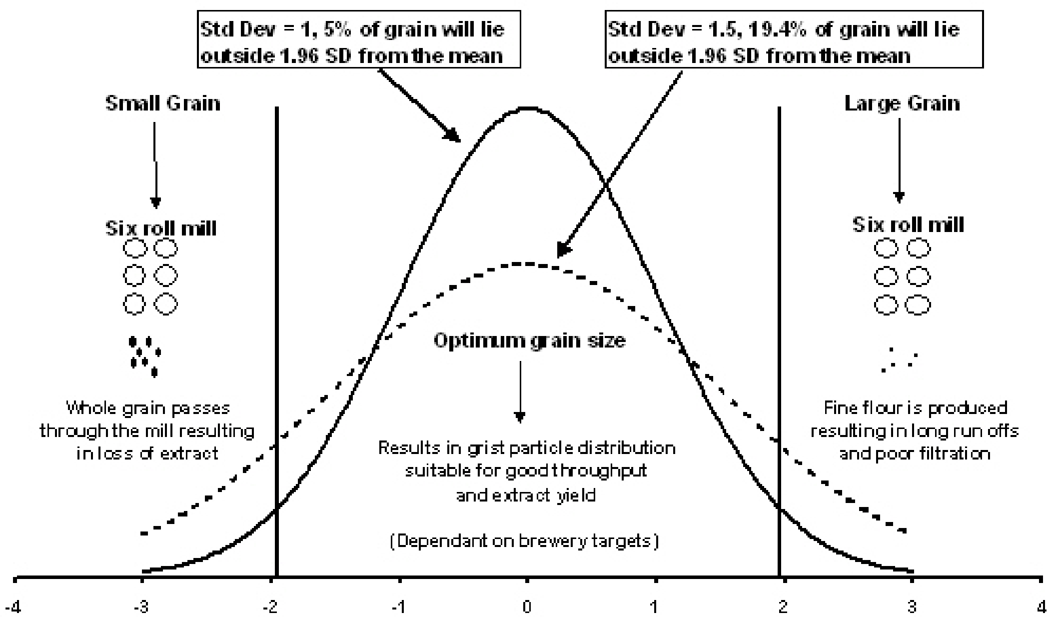

Figure 3. Schematic of the effect of variable grain size on mill performance.

The moisture content, husk adherence, husk thickness and friability of the malt will also have an impact on how the grain performs in the mill and subsequently in the lauter tun. The brewer prefers not to pay for water, however if the grain is too dry it will have a much greater propensity to shatter. If a grain has poor husk adherence, harvesting, storage and handling, malting and milling may also be affected. There are also issues with the potential of dust to cause explosions.

Apart from the physical characteristics of the malt, mentioned above, the biochemical attributes of the malt also can have an impact on cost. High concentrations of beta glucans, particularly those with high molecular weight, can impede:

- wort filtration, resulting in long turn around times
- diatomaceous earth filtration, resulting in short filter runs and therefore greater DE usage
- micro filtration, resulting in short filter runs with the need for more regenerations, thus increased use of cleaning chemicals and reduced filter life.

Considering Australian brewers mash in at 65-70°C the natural beta glucanases and proteases, which are heat labile, will be inactivated and have little effect. Therefore, it is imperative that the malt is well modified. Exogenous heat stable enzymes can be added to the mash, but at a cost.

Hazes that result from protein / polyphenol complexes have been well documented (Siebert 1999). Polyphenols originate from malt and hops, however the levels in the malt are not specified or routinely measured. It has been reported that grain with a thick husk contains more polyphenol. Never the less, to ensure good shelf life, the use of expensive treatments, such as polyvinylpolypyrrolidone (PVPP) may be required. Proteins are equally important in the formation of haze. High protein malts contain relatively more hordein protein and it is the fragments derived from hordein proteins that have been reported to be "haze active". So, while the brewer specifies an upper protein limit, to ensure good final product stability, haze active proteins may still require treatment with silica gel. Higher protein malts require larger doses of silica gel. High protein barleys also consist of more small starch granules relative to large starch granules. Examination of spent grain, reveals that unconverted starch is mainly small starch granules, which unlike large starch granules are not fully gelatinised during mashing. Therefore high protein barleys may result in lower extract yield. Small starch granules have also been implicated in haze and particle formation in the final beer.

Conclusion

In this paper the operation and the objective of six roller mills, mash tuns and lauter tuns has been described. To optimise cost efficiency the brewer needs to find a balance between extract yield and throughput. Hot water extract has the largest impact on cost however, consistency of grain size, beta glucan, polyphenol and haze active protein levels will also affect the cost of production. In order to optimise the process for quality the brewer needs malt where the starch conversion is easily and consistently controllable, a nitrogen profile that provides enough nutrition for yeast growth, fermentation, and foam quality while not adversely impacting on product stability. Currently these needs are met with broad parameters such as diastatic power and total and soluble nitrogen. More research leading to a greater fundamental understanding of the biochemistry of malting and brewing is needed to define the raw material needs more closely.

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