

# OPTIMIZING DISTILLERY PROFITS BY IMPROVING YIELDS

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*Producing an enjoyable and high quality spirit is often the primary goal of a distillery. However, there are other factors that are important from a profitability standpoint. One of the most important being distillery yield. The simplest definition of yield is the amount of ethanol recovered per weight or volume of feedstock used. In grain-based spirits like bourbon, yield would be measured as proof gallons of ethanol produced per bushel of grain. In rum production, yield is measured as gallons of ethanol per ton of molasses or as a function of fermentable sugars. Often, distillery plant managers are expected to maintain a certain yield, which is a measure of success. The process of making a distilled spirit is complex and has many different components, from mechanical to microbiological and biochemical, all having a direct impact on yield. Here we examine the process of distilled spirits production and highlight areas that have the biggest impact on yield. We will also discuss how to identify yield issues and implement solutions for improvement. Our focus will be primarily on grain-based spirits like bourbon, but many of the same principles apply to other distilled spirits.*

## FEEDSTOCK CONCERNS

The feedstock is the material used in fermentation that supplies a source of fermentable sugars to the yeast for alcohol production. There are several important factors relative to the feedstock that are directly related to yield. For grain-based spirits, the most important considerations are starch and moisture content. Starch must first be broken down into fermentable sugar, so the amount of starch is directly related to how much ethanol you can produce. Moisture content is important for several reasons. If moisture is too high (for grain this equates to 17% or higher) this can cause issues with milling or can cause the grain to rot in storage. If you look at the price of a bushel of grain, you also don't want to pay for more moisture than you have to (water is normally cheaper than grain!).

Other grain-related problems that result in yield reduction

include foreign material like corn stover, dirt and rocks. Same as with moisture, if foreign material is excessive this translates to yield loss because it is not fermentable, yet included in the bushels that you paid for. Foreign material like rocks can damage milling equipment, which can add cost beyond lost ethanol yield. Fungal mycotoxins are another grain-associated problem that can lead to yield loss. Mycotoxins are metabolic byproducts that result from growth of certain contaminating fungi like *Aspergillus* and *Fusarium* species that produce aflatoxin and fumonisin, respectively. There are many other types of fungal mycotoxins and the yield loss results from toxic effects on the yeast during fermentation and manifests as stuck fermentations with leftover sugars. Mycotoxin production is favored by certain environmental conditions experienced during the growing season and harvest. Aflatoxins, for example, are produced when there are hot and dry conditions at harvest.

## COOK AND CONVERSION

Conversion of starch to fermentable sugars is very important to achieving a high ethanol yield. This starts with proper milling of the grains to produce the flour. If the grains are not ground sufficiently, the larger particle size can decrease exposure of the starch to the malt (or added) enzymes, which are responsible for breaking down the starch. Any starch that is not converted to fermentable sugars results in less potential ethanol, and a reduction in yield. Sieve analysis can be implemented to make sure you are getting a consistent particle size in the grinding process. It is also important to limit the amount of grain lost through dust or during transfer of the flour to the cooker. Bushels that never get to the fermentor make for a low yield!

Once a reasonable particle size has been achieved, the next step is enzymatic conversion of starch to fermentable sugars during the mashing process. This is dependent on enzymes present in the malt or addition of commercial enzymes if malted grains are not added. Enzymatic starch conversion hinges on several factors, the first being the amount of enzymes in the malt. This information is normally supplied with the COA accompanying the malt and is termed *enzyme activity*. Enzymes require several different conditions for optimum activity including temperature, pH, residence time in cook, and presence of certain co-factors (like calcium), among others. Insufficient cook temperature or residence time can lead to partial starch conversion and reduction in yield. If temperatures are too high (over boiling) this can lead to denaturing of the enzymes and loss of activity. Other factors like agitation are also important to make sure that the starch is getting good exposure

to the enzymes and that all of the milled grains are going into solution. Proper cooking will result in a sugar profile that has a high proportion of fermentable sugars like maltose and glucose, but also some larger dextrans that will continue to be digested during fermentation to release additional maltose and glucose. Table 1 line A shows a typical HPLC profile of a bourbon mash just after cook.

## YEAST AND FERMENTATION

The yeast is the workhorse of fermentation and is what consumes the fermentable sugars to produce ethanol, so it is easy to see how this part of the process directly relates to the yield. There are several different yeast strains available for distilled spirits production and they can be added to fermentation in a variety of ways. On a basic level you want to have a strain capable of completely fermenting the sugars in the mash, which normally requires a certain population per volume. 100 to 300 million yeast cells per ml of mash is a good inoculum level that should result in excellent production and yield. Whether the yeast is added in active dried or liquid form straight to the fermentor or is first propagated separately can influence kinetics of fermentation. For example, if the yeast is propagated prior to addition to the fermentor it is important that the cells are actively growing and in the exponential phase of growth. Successful propagation requires a specific amount of time and involves other factors like aeration, dilution of the mash and management of sugars. If using an active dried or liquid formulation, the yeast must have an acceptable level of viability. Fermentation will not proceed normally if the yeast

**TABLE 1:** High Performance Liquid Chromatography results from cooked mash and various fermentations at drop (end of fermentation). Notice the major symptoms of each problem compared to the normal fermentation sample. For example, high temperatures result in leftover sugars and less ethanol, whereas bacterial contamination had elevated lactic and acetic acids in addition to leftover sugar and less ethanol.

LINE		DP4+	DP3	MALTOSE	GLUCOSE	LACTIC ACID	GLYCEROL	ACETIC ACID	ETHANOL
A	Cook	4.347	1.815	9.503	2.174	0.025	0.018	0.011	0.034
B	Normal	0.464	0.111	0.245	0.012	0.110	0.699	0.013	8.598
C	High Temp (>105°F)	0.678	0.245	2.345	0.876	0.117	0.626	0.023	5.432
D	Bacteria	0.564	0.113	1.230	0.926	0.876	0.678	0.12	6.234

DP4+= glucose polymers 4 glucoses or larger. DP3= maltotriose (polymer with 3 glucose subunits).

population is not viable and yield losses can result.

There are a variety of other issues that can affect fermentation and result in yield losses. For any given grain mash, there is a minimum time it will take for the yeast to consume the sugars. Thus, the time allotted for fermentation is important. Temperature control is another important variable and should be controlled throughout fermentation. If temperatures are too low, this can result in slow fermentation such that the yeast don't finish all the fermentable sugars in the allotted time. Likewise, if the fermentation gets too hot (>95F), there can be similar issues. Keep in mind that even if you start at the appropriate temperature (80-90F works well), the yeast give off heat during fermentation that can quickly increase the temperature. Thus, it is best to incorporate some kind of temperature control, such as cooling coils, jacketed fermentation tanks or other type of heat exchange. Table 1, Line B shows a fermentation profile from a successful batch. Table 1, Line C, shows what you might expect if there are temperature issues.

Depending on the feedstock there may be a requirement for additional nitrogen or nutrients. Molasses often requires nitrogen depending on the sugar levels. Likewise, high gravity grain-based fermentations may also require nitrogen to finish all the sugars in fermentation.

## CONTAMINATING BACTERIA AND WILD YEAST

Microbial contamination is a vast topic worthy of its own series of articles, and is a major source of distillery yield loss. Wild yeast (yeast other than the one that was intentionally put into fermentation) compete with the "normal" yeast for sugars and nutrients and often produce off-flavored by-products. Wild yeast will often have a different cell morphology than the primary

yeast, which is one way to differentiate. Non-Saccharomyces cerevisiae yeast, like certain *Pichia* strains may form a pellicle (white biofilm) on top of the fermentation mash (or test tube), which is another way to differentiate from the primary yeast. Although wild yeast are definitely an issue worthy of mention on the topic of microbial contamination of distilleries, the real culprits are bacteria.

The types of bacteria that affect fermentation the most include lactic acid bacteria (LAB). This broad group of bacteria includes species of gram positive *Lactobacillus*, *Pediococcus*, and *Weissella*, to name a few. These bacteria are ubiquitous in nature and get into the process through common ingredients like grain and water. While LAB are considered typical bacterial contaminants, there are also atypical bacteria such as those belonging to the Family Enterobacteriaceae (think *E.coli* and related microbes, which stain gram negative). Bacteria that contaminate distilleries typically can live and grow both in aerobic or anaerobic conditions and are thus referred to as *facultative anaerobes*. Thus, when culturing for contaminating bacteria there may be requirements for regulating or eliminating oxygen. Like wild yeast, the bacteria compete with the yeast for sugar and nutrients and also produce metabolic byproducts such as lactic and acetic acid. There is much debate over whether these organic acids actually improve the flavor of the finished spirit and is the foundation for why many distillers use backset (sour mash process) or other methods to incorporate bacterial byproducts into the fermentation. While the flavor argument rages on, there is little debate about whether bacterial contamination affects yield. Table 1, Line D shows what a final fermentation reading might look like when bacteria are problematic. Due to the acids produced by actively growing bacteria, serious contamination events are often marked by lower than average pH in addition to higher residual sugars and

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lower ethanol.

The best strategy for limiting the growth of yeast and bacterial contaminants is maintaining a high level of cleaning and sanitation. For example, fermentation tanks should be cleaned intensively between batches and any piping or transfer hoses should be well rinsed or steamed after each use. The high heat and 1-2 hour residence time of the mashing/cook process greatly reduces any contamination present on the grain, water, backset and other ingredients. Therefore, when resolving bacterial issues, your investigation should start from where the mash was cooled to temperatures that support yeast and bacteria growth (<100F). Some common areas for bacteria to build includes heat exchangers, on cooling coils inside of fermentors, agitation devices, and piping- all areas with a lot of surface area and in some cases hidden or hard-to-reach surfaces making them hard to clean properly.

## DISTILLATION AND BEYOND

Now that we have gone through the process, including fermentation, with great success we should get a great yield, right? Not just yet. Even though we made the ethanol, we still have to *recover* it through distillation before we can start calculating our yield. This involves a few different factors. Starting with the beer in the fermentor you should consider any losses through material staying behind in the tank or piping or any spillage. Once in the still (column or pot), recovery of ethanol is largely a matter of temperature control and watching proof throughout distillation. Any ethanol lost when making heads and tails cuts lowers the yield. The same is true for any ethanol left behind in the stillage. Both scenarios involve ethanol that was made that was not recovered as part of the final distillate. To increase ethanol recovery and improve yield, heads and tails are often

recycled by adding to beer from a later batch.

Once you have recovered the ethanol after distillation (measured as proof gallons) you can compare that number to the amount of grain used to make the beer to get the yield. For example, if you are making bourbon and you used 20 bushels to make a batch and you recovered 100 proof gallons of ethanol, your yield would be 5 proof gallons per bushel, which is reasonable for a craft distilling operation. More highly automated industrial distilleries (including fuel ethanol plants) can achieve yields upwards of 5.5 to 5.6 proof gallons per bushel when using commercial enzymes and single grains, most often 100% corn. You can further calculate yield as distillate recovered after barrel aging, a process where additional loss is common through evaporation.

## CLOSING REMARKS

Here, we have touched on some of the major factors that affect ethanol yield in a distillery, also considered the critical control points for running an optimized process. While some areas require a higher level of understanding like enzyme activity, starch conversion and yeast metabolism, there are other areas of equal importance like cleaning and sanitation that involve common sense. When optimizing a plant one must look at each section of the process and think about what is happening on the microbiological and biochemical levels. By understanding the process, one can fine tune each step to obtain a highly enjoyable distilled spirit as well as maintaining excellent yields for maximized profitability. 🍷

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