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Making Ethanol for Fuel on the Farm

By Bob Ofoli and Bill Stout
Agricultural Engineering Department

INTRODUCTION AND OVERVIEW

Alcohol is an excellent fuel and will significantly reduce imported energy usage on the farm if petroleum or natural gas is not used to provide process energy.

The process of making alcohol from corn feedstock is shown in Fig. 1. First, the grain is ground, *mashed*[1] and cooked. *Enzymes* added during the mashing stage convert starch to sugar. The resulting broth is then fermented, using yeast. The process yields a beer (usually of 8 to 12% alcohol concentration, by volume) and carbon dioxide.

The beer is then distilled to 190 or 191 *proof* alcohol. A *dehydration* process will yield essentially 200 proof ethanol if *anhydrous alcohol* is required. The alcohol, at this or the previous stage, must be *denatured* by adding an appropriate chemical. Denaturing is not required for ethanol produced on the farm under an experimental permit if the fuel is used within farm boundaries.

Distillers grains, a major by-product of alcohol production can be extracted at three different points—just before fermentation if *saccharification* is complete, just before distillation, or after distillation (see Fig. 1). Alcohol losses will be no higher than 4.5% or 6.1%, respectively, if the by-product is removed before fermentation or before distillation, assuming that it is removed at no greater than 60% moisture content.

Where the by-product is withdrawn before distillation, the corn grind need only be fine enough to allow effective conversion of starches to sugars. However, when distillers grains are removed after distillation, the corn must be finely ground so the distillation column is not plugged.

The three major products—ethanol, distillers grains and carbon dioxide—are produced in nearly equal quantities.

Factors affecting alcohol yields most are grain mash preparation methods, how adequately pH and temperature are monitored and controlled during the process (see Fig. 2), and the time allowed for (and the efficiency and completeness of) saccharification.

Under optimum conditions, 1 lb of fermentable sugars will yield 0.51 lb of anhydrous (200 proof) alcohol. For example, a 56-lb bushel of shelled corn (65% starch) has up to 36.4 lb fermentable sugars and will yield up to 18.6 lb (2.81 gal) of 200 proof ethanol, on a theoretical basis.

SPECIFIC PROCESSES

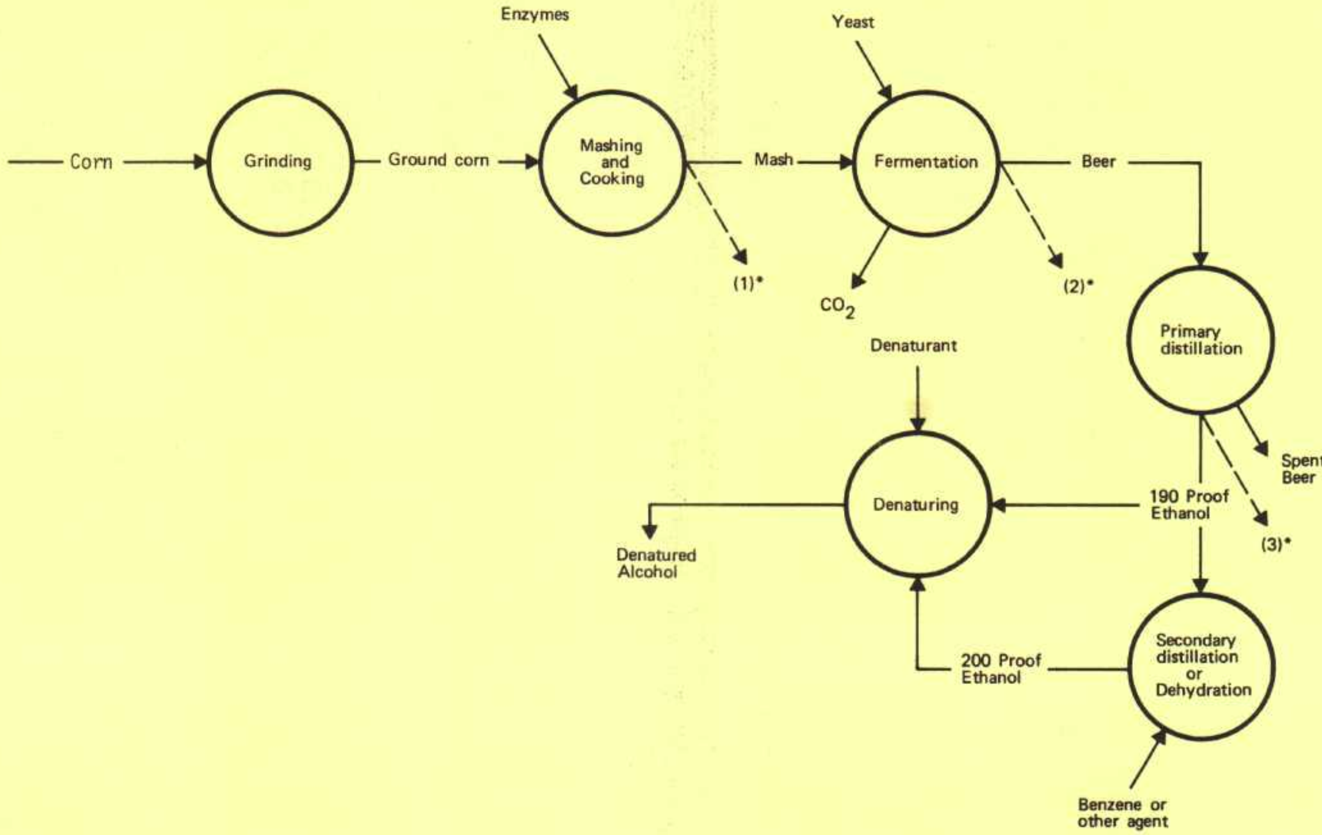
Grinding, Mashing, Cooking and Saccharification

While grains should be ground well enough to enable proper cooking and saccharification, grinding is not crucial for efficient ethanol production.

Mashing the grains *solubilizes* the starchy material and prepares the starch content for conversion to sugar. Mashing is a *hydrolysis* reaction during which enzymes convert starch to sugar.

Cooking the grain helps burst the starch cells, making them more accessible to enzymes. It further prepares the grain for conversion to sugars by *gelatinizing* the starches. Cooking units need agitators

[1] Words in italic are defined in the Glossary.



*Distillers grains may be taken out at (1), (2), or (3).

Fig. 1. A flow diagram for Ethanol Production.

or stirrers because the mash should be stirred continuously during the cooking process to keep the solids in suspension.

Fig. 2 presents a mashing and cooking scheme. Ethanol can be made in many ways; Fig. 2 illustrates only one way to produce it. Enzymes used for this scheme were brandnames obtained from the Miles Laboratory in Elkhart,[2] Indiana, and are suited to operation at the temperatures shown in the figure.

Mashing is done by mixing ground corn with water, usually at a ratio of 20 gal of water to 1 bu of corn (assumed at 15% m.c.), to form a slurry. After this, saccharification begins. (Water temperature is not specified in Fig. 2 because it varies with locality, ranging from 45° F to 55° F.)

Saccharification is the process of converting starch (a *polysaccharide*) to simple sugars (*monosaccharides*) by enzymatic action. pH is an important factor in the process, as evident from Fig. 2. (Note: pH can be controlled by adding an acid to obtain lower pH numbers, or adding an alkaline to obtain higher pH numbers.) An alpha-*amylase*, such as Taka-Therm,[2] is added to the mash slurry to convert starch, amylose and amylopectin to soluble dextrins and small quantities of glucose and maltose (11). The slurry must be heated to 194° F and held at that temperature for 30 min.

The temperature of the mixture should then be raised to its boiling point—usually 212° F. (The boiling point will depend on the elevation of a given locality.) After the mixture has boiled for 10 min, the slurry must be cooled to 200° F. Then more alpha-amylase should be added and the mixture cooled (over 30 min) to 130° F.

At this point a gluco-amylase, such as Diazyme,[2] must be added to convert starch, amylose, amylopectin and soluble dextrins to glucose. The slurry temperature should be held at 130° F for 30 min, then cooled to 80°-90° F and yeast added for fermentation.[3] (Most farmers will find baker's yeast appropriate.)

[2] Use of trade names is for identification only, and does not imply endorsement, approval or criticisms of the products.

[3] Before yeast is added for fermentation, a starch test can be made to determine the completeness of starch conversion. A drop or two of iodine can be added to a small amount of the slurry. If the slurry changes color to purple, then it still contains starch. If there is no color change, then starch conversion is complete.

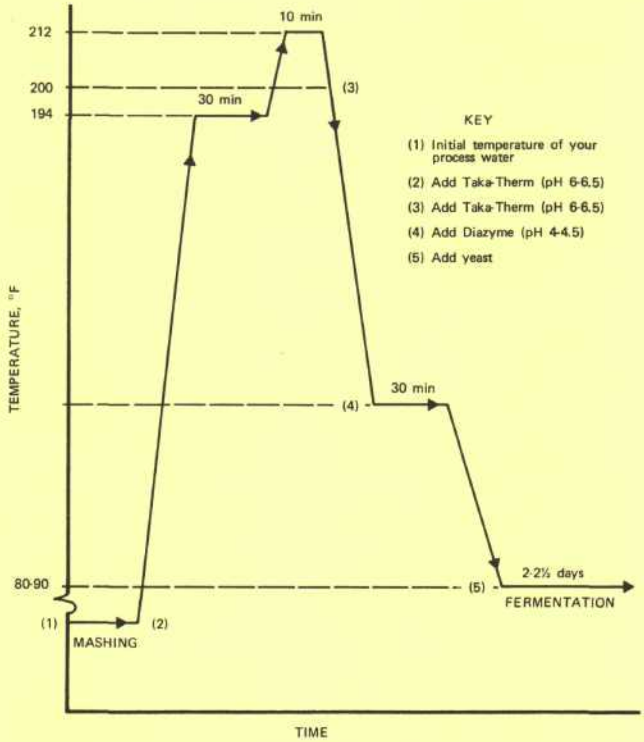


Fig. 2. A scheme for cooking corn for ethanol production (horizontal axis not to scale).

Fermentation

Fermentation is the conversion of sugar to alcohol and carbon dioxide through yeast activity. The process must be monitored and adjusted for pH (4.0-4.5), nutrient availability to yeasts, and temperature. Although it is an anaerobic process, small amounts of oxygen promote yeast cell growth (6).

For best results, maintain the temperature between 80° F and 90° F. The higher end of this range reduces fermentor residence time for the mash, but if temperatures exceed 90° F, the yeast cells will die. The low end will assure yeast survival but prolong fermentor residence time. Complete fermentation takes about 2 to 2½ days.

The beer produced after fermentation is usually 8 to 12% alcohol. Most baker's yeasts currently used in fuel alcohol production will not survive in an alcohol concentration of more than 12%. Therefore, if the sugar content of the mash is such that fermentation will yield a beer of more than 12% alcohol, the mash must be diluted with an adequate amount of water before adding yeast for fermentation. Some wine yeasts will tolerate concentrations up to 17%.

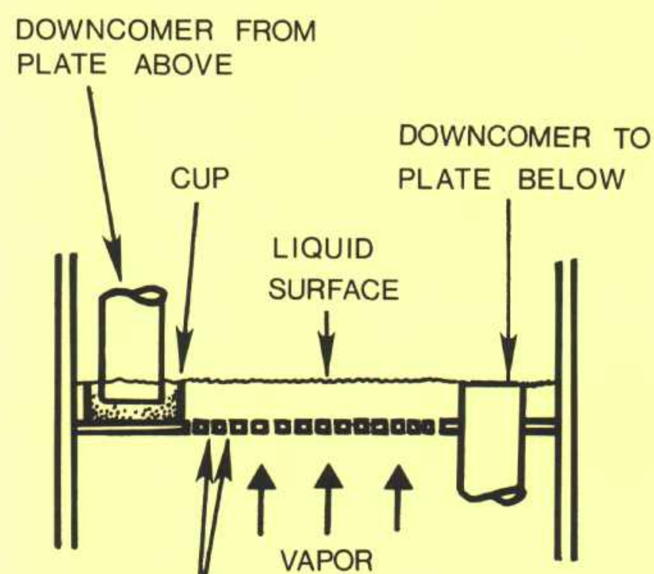
Fermentation efficiency depends on the process duration, pH, temperature, the completeness of the prior hydrolysis phase and the level of yeast activity.

Distillation

Distillation is the separation of a liquid mixture of two or more substances into individual or groups of components (1,9). Separation is achieved through repeated vaporization and condensation of the liquid mixture until the desired concentration or composition is attained.

Distillation is possible in a packed column or a plate column. Currently, the plate column is more commonly used for distilling alcohol. The arrangement of plates in a column is shown in Fig. 3. Beer or aqueous alcohol flows down the column through a downcomer, accumulates on the plate and in the cup, and overflows down the next downcomer to the plate below. Vapor, on the other hand, flows up the column through the perforations in the plate and strips the liquid of alcohol. This method forces intimate contact between vapor and liquid until equilibrium is established.

Each plate constitutes a stage. Once equilibrium is reached after each stage, the vapor becomes richer in alcohol and the liquid becomes richer in water. At the top of the still, the vapors are collected and condensed to a liquid which may be any composition of ethanol up to 191 proof.



Sieve Plate

Fig. 3. Arrangement of plate, downcomer and cup in a distillation column. Source: (10).

Major parts of a distillation column are shown in Fig. 4. The stripping and absorption sections can be separate columns, or combined (as shown). The stripping section rids the incoming beer of alcohol, while the absorption section extracts water from the vapor and sends the water down the column. The absorption section is also called the rectifier.

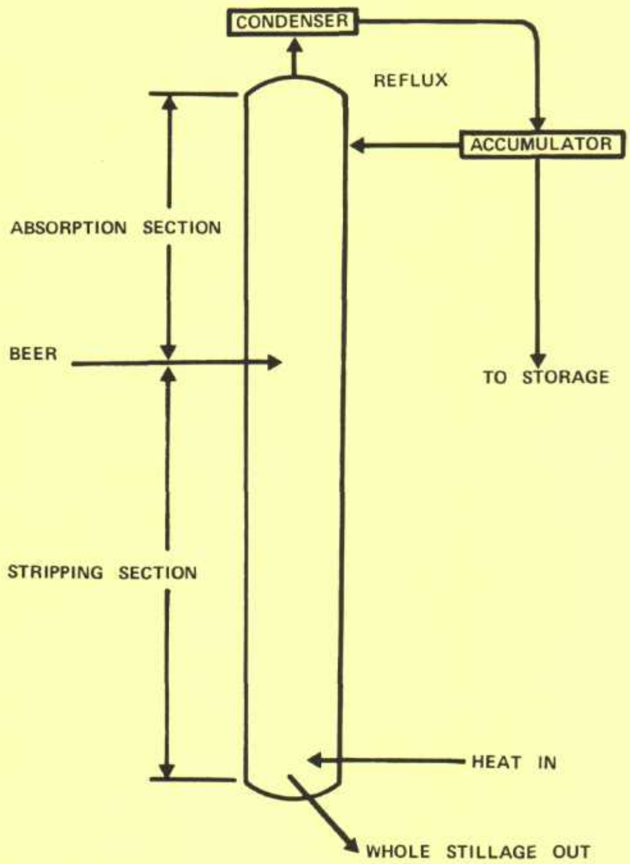


Fig. 4. A distillation column with combined stripping and absorption sections.

Vapors cool to liquid form in the condenser. Condensed alcohol is stored in the accumulator and can be withdrawn and returned to the top of the tower as a *reflux*. The reflux helps to maintain a given temperature at the top of the tower. For example, at atmospheric pressure and sea level, the temperature at the top of the tower should be 172.7° F for 190 proof alcohol to be withdrawn from the column.

Under atmospheric pressure and at sea level, the highest proof of ethanol obtained by ordinary distillation is 190-191. At this concentration, alcohol and water form a constant boiling mixture and can no longer be separated. Further separation, for example to anhydrous alcohol, can be done by *azeotropic distillation*, where benzene or another agent is added to the mixture of alcohol and water to change its composition. The new compound can then be separated under atmospheric pressure. Azeotropic distillation is complex and not recommended for farm level operations.

Raw Materials

Ethyl alcohol can be produced from a wide range of raw materials:

a) sacchariferous materials or raw materials that contain sugar naturally, e.g. sugarcane, sugar beet or apples.

b) amylaceous or starchy materials, including cereal grains, sweet potatoes, potatoes and Jerusalem artichokes; and

c) cellulosic materials.

Sugars can be directly fermented to alcohol, but starches, hemicelluloses and cellulose must first undergo saccharification. Starches can be saccharified using enzymes, but celluloses and hemicelluloses usually require one form or another of acid hydrolysis (see Fig. 5). Table 1 lists selected materials and their theoretical alcohol yields. Practical yields will be lower and will depend on such factors as the efficiencies of hydrolysis, fermentation and distillation.

Table 1. Theoretical yields of selected raw materials (with stated conditions)

	Yield (at 200 proof)	
Material	Gal/ton	Gal/unit
Corn (65% starch)	100	2.81/bu
Grain sorghum (60% starch)	90	2.53/bu
Mandioc (cassava)—(60% starch)	93	—
Molasses, beet (45% sugar)	70	0.44/gal
Molasses, cane (50% sugar)	77	—
Potatoes (17% starch)	27	1.4/cwt
Potatoes, dried (54% starch)	84	—
Rice (55% starch)	85	1.9/bu
Sugar beet (15% sugar)	23	—
Sugarcane (10% sugar)	15	—
Wheat (55% starch)	85	2.56/bu

The choice of raw material to use should be based on (15):

a) yield of alcohol per ton or bushel of material (use consistent units when comparing two materials);

b) percent of fermentable sugars obtainable and the alcohol yield per acre of crop; and

c) cost of the feedstock.

Generally, the feedstock material does not affect the quality or fuel value of the ethanol produced.

Sacchariferous Materials

These materials are directly fermentable to ethanol and, therefore, do not require enzymes. They usually have high yields per unit of land area (12).

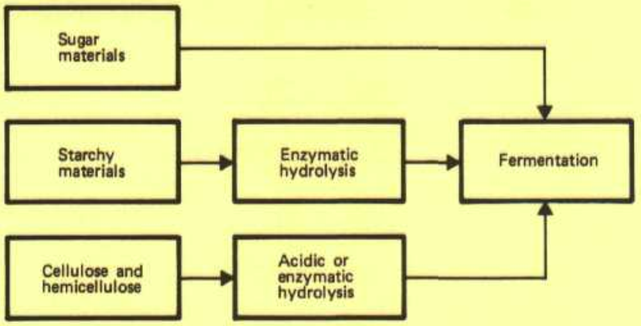


Fig. 5. Routes to fermentation.

Molasses is about 50% sugar and, generally, no pretreatment is needed before fermentation.

Sugar cane—a perennial grown in Florida, Texas, Louisiana, Hawaii and Puerto Rico—has high biomass yields.

Sweet sorghum has the potential of giving sugar crops a three-*quad* energy potential (7). Without it, contributions from sugar crops will be small. It is resistant to most diseases and insects, needs little fertilizer and water, and can be harvested with conventional farm machinery (15).

In the U.S., sugar beets and sweet sorghum have a wider geographical range than sugarcane.

Amylaceous Raw Materials

Starches must be broken down into simple sugars, e.g. glucose, before fermentation.

Yield of alcohol from grains depends on the starch content of the grain. The theoretical yield is 0.568 lb alcohol per pound of starch. Actually, the yield is about 90% of the theoretical value, or 0.51 lb per pound of starch.

Sprout-damaged grain can be used for alcohol production if the grain does not lose too much starch from weathering or germination. But, losses may be as high as 30 to 40% of the starch content (8).

Wheat's high gluten content causes excessive foaming during fermentation (2). Special processing equipment and techniques are needed to handle it.

Cellulosic Raw Materials

These are the cheapest feedstocks. However, the conversion technology is more complex than the other two, and is not commercially available currently.

Principal sources of biomass residues are agricultural crop refuse, logging residues and collectable manure waste (6). However, sewage, urban wastes, and paper contain up to 0.8 ton of fermentable sugars.

Many species of timber can be used for alcohol production. The eucalyptus tree, with its low water requirement and high energy conversion rate is a good energy source (15). In addition to live timber, wood wastes from milling and the pulp and paper industries provide a raw material for alcohol production.

By-products

Apart from carbon dioxide and distillers grains, fusel oil forms from 0.1 to 0.7% of the crude distilled spirit and is a mixture of amyl and isoamyl alcohols (14). It can be separated, and in beverage manufacture, usually is. Corn oil, another possible by-product, can be separated by wet-milling. Corn gluten, corn germ and fodder yeast can also be separated as by-products, but for many small operations, this is not done. For farm-size operations, carbon dioxide recovery for commercial use is generally not feasible.

Distillers feeds: These result from the fermentation residue. The reduced bulk resulting from starch removal (corn is about two-thirds starch) causes a three-fold increase in nutrient concentration.

The Distillers Feed Research Council (DFRC) describes four feeds available for dairy supplement formulation. These result from the whole stillage—the bottom product of the distillation process (see Fig. 4). Whole stillage contains 6% solids on the average.

1) Distillers dried grains with solubles (DDGS): This fermentation residue results from processing and drying whole *dealcoholized* stillage.

2) Distillers dried grains (DDG): These are coarse fibrous materials which are dried after being separated from the stillage with a screen or centrifuge.

3) Condensed distillers solubles (CDS): This is the liquid residue from screens or centrifuge condensed to 25 to 40% solid content. The liquid residue contains finely suspended material and water-soluble nutrients.

4) Distillers dried solubles (DDS): This is obtained by drying condensed distillers solubles on drum driers.

If there are livestock on or near the farm where the alcohol fuel is produced, much energy (and money) can be saved by feeding the distillers grains wet.

Denaturing

Denaturing is the process of making alcohol unfit to drink. The Bureau of Alcohol, Tobacco and Firearms (BATF) has a number for formulas that can be used to denature ethanol. These are provided on request.

Michigan residents can obtain formulas and permit applications from the Department of Treasury, BATF, 6519 Federal Office Building, 550 Main Street, Cincinnati, Ohio 45202 (1-800-543-1932).

REFERENCES

1. Badger, W. L., W. L. McCabe (1936). *Elements of Chemical Engineering*, McGraw-Hill, N.Y.
2. David, M. L. *et al.* (1978). Gasohol, economic feasibility study. Prepared for the Energy Research and Dev. Center, Lincoln, Nebraska, by the Dev. Planning and Res. Associates, Inc., Manhattan, Kansas.
3. Distillers Feed Research Council (DFRC). (undated). Distillers feeds, DFRC, Cincinnati, Ohio.
4. Distillers Feed Research Council. (undated). Feed formulation, DFRC, Cincinnati, Ohio.
5. Distillers Feed Research Council. (undated). Make more milk with distillers feeds, DFRC, Cincinnati, Ohio.
6. Energy Research and Dev. Administration (1977). *Fuels from Biomass*, ERDA Solar Program Assessment: Environmental factors, March, 1977.
7. Jones, J. L. *et al.* (1978). Mission analysis for the federal fuels from biomass program, vol. 5. Final report on the biochemical conversion of biomass to fuels and chemicals. Prepared by SRI International, Menlo Park, CA, for the U.S. Dept. of Energy, December, 1978.
8. Klosterman, H. J. *et al.* (1977). Production and use of grain alcohol as a motor fuel—an evaluation. North Dakota Farm Research 35(2), pp. 3-9, Nov.-Dec., 1977.
9. Larian, M. G. (1958). *Fundamentals of Chemical Engineering Operations*, Prentice Hall, Englewood Cliffs, N.J.
10. McCabe, W. L., J. C. Smith (1976). *Unit Operations of Chemical Engineering*, McGraw-Hill, N.Y.
11. Miles Laboratory, Elkhart, Indiana. (undated). Company literature.
12. Nathan, R. A., editor (1978). *Fuels from Sugar Crops*, Technical Information Center, U.S. Dept. of Energy, TID-22781.
13. Prescott, S. C., C. G. Dunn (1949). *Industrial Microbiology*, McGraw-Hill, N.Y.
14. Sklar, S. (1979). Alcohol fuels: the most often asked questions—a political and technical overview of the "American Alcohol Issue." National Center for Appropriate Technology, Washington, D.C. Paper presented at the Alcohol Fuels Technology 3rd International Symposium, Asilomar, CA, May 28-31, 1979.
15. Willkie, H. F., P. J. Kolachov (1942). *Food for Thought*, Indiana Farm Bureau, Inc., Indianapolis, Indiana.

Glossary

Amylase	any of several enzymes that accelerate conversion of starch to sugar
Anhydrous alcohol	water-free alcohol, essentially 200 proof
Azeotrope	a constant boiling mixture whose vapor has the same composition as the liquid from which it came
Azeotropic distillation	separation of the components of an azeotrope after another component has been added to change the characteristic of the azeotrope
Dealcoholize	remove alcohol from
Dehydration	the removal of water from 190 or other proof alcohol to obtain 200 proof alcohol
Denature	make alcohol unfit to drink as a beverage
Enzyme	a complex substance that speeds up a reaction, usually in a given temperature range
Gelatinize	to convert into a jelly
Hydrolysis	a decomposition process that involves splitting a chemical bond and adding elements of hydrogen and oxygen from water
Mash	put the raw material in a form that enables conversion of starches to sugars by enzymes
M.C.	moisture content
Monosaccharide	a sugar that cannot be decomposed to simpler sugars through hydrolysis
Polysaccharide	a carbohydrate that can be decomposed by hydrolysis to monosaccharides
Proof	twice the percentage (by volume) of alcohol concentration, e.g. 70% ethanol is 140 proof
Reflux	a liquid stream with a high alcohol concentration returned to the top of the distillation column
Quad	one quadrillion Btu (1×10^{15} Btu)
Saccharification	the conversion of starches to sugars
Solubilize	to make a substance soluble or dissolvable

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