**Mother's Alcohol Fuel Seminar**
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# Mother Earth Alcohol Fuel

# Chapter 1

## Introduction to a Farmer's Fuel ... Alcohol

Our definition of alcohol fuel is a nearly 100 percent alcohol with a tad of water in it -- not a blend of alcohol with gasoline. So ... why an alcohol fuel? And why not a blend of gasoline and alcohol.?

There are several reasons why we chose an alcohol fuel. The first and probably most important one is that alcohol can be made by anyone, with a minimum of equipment. The knowledge necessary to make it can be obtained just by reading this book. As long as folks can grow certain plants, they can make alcohol fuel to run all or part of their power equipment. Dependence upon someone else to supply that fuel is no longer a problem or a threat. Second, alcohol is a good fuel, superior to gasoline in many ways: It can give extra power to certain engines, it is almost non-polluting compared to gasoline, it is safe and easy to handle. Third, the cost of conversion from gasoline to alcohol is inexpensive: For many engines it is merely an adjustment of the carburetor jets.

Why not a gasohol fuel? The problem is water. Water and alcohol are totally miscible liquids. That is, they mix in all proportions. Pure alcohol and gasoline are also miscible liquids. But water and gasoline are *not*. This means that an alcohol-and-gasoline blend must be almost free of water. To make a 200-proof alcohol on the farm would require expensive equipment and additional production expenditures. At this time, that added expense would price a fuel blend beyond reason. But alcohol of 167 proof (16.5% water) is as good a fuel as 200-proof (100%) alcohol and better than gasohol.

Really, it comes down to basic survival. Right now, the fuel shortage doesn't seem all that serious. It's something like having a leaking roof: When it isn't raining, the problem is not so bad ... but when it *is* raining? The bottom line to all this is that when the next fuel shortage comes -- and you can bet that one *will* -- the ones who have prepared best will survive with the least pain.

## Introductory Overview of the Alcohol Production Flow Chart

The process of making alcohol fuel is not complicated. However, certain steps in the production line must be adhered to or else efficiency falls off drastically. The Ethyl Alcohol Production Flow Chart shows one system that works when using dry starch, such as that found in grain crops.

The first step is to mill the grain. There is no one essential machine for doing this. However, the particles of the grain must be small enough so that all the starch granules can be gelatinized in the cooker. If particles are too large, the starch granules will be too deeply embedded in the matrix of the seed to be gelatinized and therefore will not be converted to sugar.

Cooking dry starch in a water slurry is one of the best methods of preparing the granule for hydrolysis of the starch chain. Although some starch granules -- such as those in potatoes -- need not be boiled, the starch granule in corn is too hard for mere soaking of the grain to produce a high percentage of conversion. The cooker should have an agitator built into it to keep the starch chain in suspension in the liquid at all times. This insures even cooking and also prevents hot spots (which can scorch the solids on the bottom in a direct heat cooker).

After the boil, hydrolysis (the breaking down of the starches to sugars) occurs. Hydrolysis can take place in the cooker, and that will probably be the best arrangement for a small distillery.

Cooling after the cook is part of the hydrolytic process, and if the cooker has steam coils, these can be used as cooling coils as well (the same as with a steam-jacketed cooker). Adding extra water is another method of cooling (as explained in the section on Basic Steps in the Production of Ethyl Alcohol). The mash should be agitated during the cooling phase as well as the heating phase of mashing.

Following hydrolysis comes fermentation. Because yeast cannot tolerate large amounts of iron, a separate tank should be provided for this phase: The fermenting vat needs to be made of wood, stainless steel, or a coated mild steel. In some large whiskey distilleries, the vat is open to the atmosphere; this does not present any contamination problems, because the big commercial firms distill immediately after fermentation and practice good sanitation. If the farm distillery is not as clean, however, then the tank should be covered. In case of a totally enclosed vat, the access hole should be only large enough to allow a person to enter, and it must be covered when not in use. An airlock on the tank is not necessary, but do not allow any contaminants, such as dust or insects, to enter.

Somewhere along the production flow -- if a batch still is being used -- a decision will have to be made as to the point at which the solids will be separated from the liquid. The solids are likely to settle to the bottom and scorch. Separation can take place after hydrolysis or after fermentation. The machinery for this process on a small scale is almost nonexistent. Rotary screens, perforated tubing with augurs, and wringing out in a gunnysack are some of the methods being used, but you will probably have to find your own solution. With a continuous-feed perforated-plate column still, however, there is no problem. Distill the solids with the liquid mash, and feed the spent grains with the liquid (see the section on Distiller's Feeds)

Immediately after fermentation, *distill*! Each hour after the mash is ready, other bacteria will be working their way into the potential alcohol fuel. Acetic acid will not work too well in a car, and that is what the alcohol turns into when the Acetobacter bacteria invades the ferment.

As to the type of still to use, the choice depends upon the needs of the producer (see the section on Still Designs to determine which type of still will meet your own requirements).

Once the alcohol fuel is made, it will have to be stored. Use the same precaution that is used for gasoline storage. Alcohol is hygroscopic (absorbs moisture), so keep the vents in the storage tank small.

## Flow Diagram for Ethyl Alcohol Production
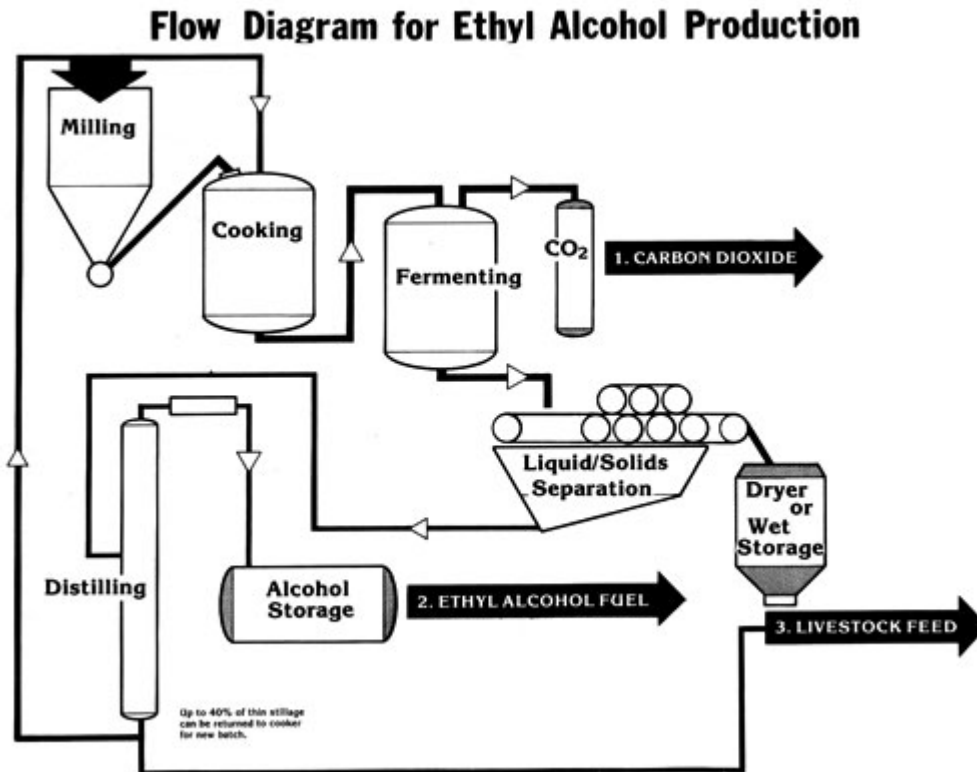


**PRODUCTS FROM ETHYL ALCOHOL FERMENTATION**

**1. C02**
One-half of the fermenting sugar is converted to carbon dioxide. It can be used for industrial application or in greenhouses for increasing plant growth.

**2. ALCOHOL**
The other half of the fermenting sugar is converted to ethyl alcohol. Since it contains all the fusel oil, esters, and aldehydes , it is not good for drinking, but a durn good fuel.

**3. DISTILLER'S GRAIN**
Nearly all the protein is left in the solids, so distiller's grain becomes a high-quality feed for livestock. Protein is 28-30% ; fiber is 12-13%; and moisture is 8-12%. Use it as a supplement to increase the protein in other feeds.

# A Short But Complex Story About Enzymes and Their Functions

Just how important is it for you to understand the technical side of alcohol fuel production?

After all, moonshiners -- for example -- have long made "white lightning" without knowing much about the inner workings of corn, sugar, and alcohol. On the other hand , the yield the oldtimers get from their raw materials is only a small fraction of the potential. So, if you're interested in getting the most from your time and effort, there's no substitute for knowing just what you're doing.

Ethyl alcohol -- the substance you're interested in making -- is an organic compound (C2H50H) which is also known as ethanol. Our alky closely resembles ethane (C2H6), one of the major by-products of gasoline refining. In fact, most of the commercially available ethanol in the U.S. is made from petroleum. However, sugar and starch crops are two other viable sources of alcohol.

The sugar extracted from cane or sweet sorghum can be directly fermented with little or no alteration, but the starches present in grains must be *converted* into sugars. Starch itself is nothing more than a long chain of individual glucose molecules, which must be broken apart or *hydrolyzed* with *enzymes*. However, the conversion process must be very carefully carried out, or your final alcohol yield will be seriously reduced.

The critters responsible for the transformation of starch to sugar and then sugar to alcohol are called enzymes, chemically known as protein biocatalysts. That hifalutin' word means that the enzymes are products of living cells, and that they encourage a chemical change without being consumed during the process. There are thousands of enzymes, and each one performs a specific task at an optimum temperature and acidity level (also known as pH). All enzyme names end in the suffix "ase", while the first portion of each of these terms describes the substance that enzyme specializes in converting. (For example, *cellul*ase converts *cellul*ose into sugar.)

All living cells produce enzymes, and grains are no exception. When a seed germinates, the enzymes are activated and begin the process of turning the stored food of the seed (starch) into a usable substance (sugar). Sprouted barley, for example, actually contains the right amount of enzymes to be used in an effective cooking process. Most grains, however, lack the proper amounts or kinds of enzymes to permit rapid, self-contained, complete conversion. Consequently, such grains need to have enzymes -- which are prepared from other sources -- added to the cooked meal during mashing.

It's important to understand that starch is actually a complex sugar. Each starch molecule is a long chain of up to a thousand glucose molecules bonded either in a straight line or branching like the leafless arms of a tree. Two enzymes are used to attack the "tree" at different points. Alpha enzyme attacks the branchpoints and reduces the tree into individual segments, while beta enzyme attacks the ends of each branch and nibbles off individual glucose molecules. In order to make all the starch available for enzyme activity, the carbohydrate granules must be held at a rapid rolling boil for 30 minutes. The heat causes the starch to expand and burst out of its cell wall, allowing our friends to get to work.

(Traditionally, barley malt has been used as an enzyme source, and also -- in the brewing industry -- as a flavoring agent. However, today's industrially prepared enzymes are more consistent and considerably less expensive.)

Mashing is basically a three-phase process which begins with the preboil. As the

temperature approaches 150 deg F, the available starch begins to gelatinize, whereupon it is attacked by the alpha enzyme -- or *alpha-amylase* -- and reduced to a simpler carbohydrate. (The enzyme also serves to keep the mash from becoming too thick.) Subsequently, the mash is brought to a vigorous boil and held there for 30 minutes, to release all the remaining starch into solution.

In the postboil stage alpha-amylase is reintroduced -- since the enzyme is destroyed at 200 deg F and above -- to hydrolyze any remaining starches into simpler sugars called *dextrins*. Once the mash has cooled to 90 deg F, yeast is added to the mixture, along with beta-amylase. The beta enzyme operates at the same temperature as the yeast and breaks down the dextrins to glucose for the yeast to consume.

During fermentation, the yeast produces its own internal enzymes. In fact, there are 11 separate internal stages that the yeast goes through while "brewing". Yeast is a *faculative* organism, which means that once it has begun to consume sugar, it has a choice between two processes: to reproduce or to digest. If oxygen is present, the yeast will merrily *bud* itself ... but if oxygen is in short supply, the fungi will produce waste in the form of carbon dioxide and -- you guessed it -- alcohol. Therefore, it's best to agitate the fermenting mash for about ten minutes to encourage reproduction, and then cover it up and let it stand

Remember, you're dealing with a fairly sensitive biological process. So, follow all directions, be sure all supplies are kept in cool, airtight containers, and keep equipment clean. The numerous undesirable, microscopic sweet-tooths that can find their way into your mash will give you something, but it won't smell too good, and you won't be able to put it in your gas tank.



THE CONVERSION OF STARCH TO SUGAR TO ALCOHOL
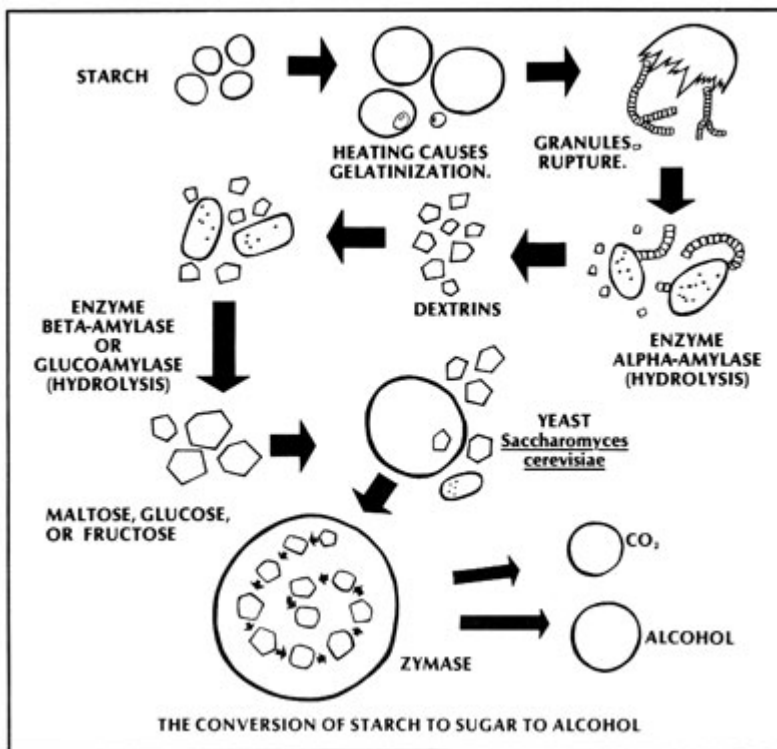
# Chapter 2

## Farm Crops for Alcohol Fuel

Agricultural products of many kinds can be made into alcohol. The choice is not merely a matter of which ones have the greatest yield, but also a question of economics. Since the cost of gasoline isn't yet as high as *world market price*, the choice of raw material for alcohol fuel must be determined on the basis of production cost, the selling price of the raw product, and the type of farm machinery the farmer has. Naturally, spoiled grains, vegetables, and fruits at a haul-away price would be best, but they are not always a dependable source of supply.

A farmer growing his own raw material would select his alcohol crop for the highest yield of starch or sugar. Right now, sugar beets seem an ideal product to turn into alcohol, as sugar beet prices are so low that many sugar refineries are closing their doors. And sugar beets give a high alcohol-per-acre yield. Corn is on the fence: At $2.50 a bushel, it would be a good deal for the farmer to turn his crop into alcohol and use the distiller's feeds for his own livestock ... but if the price climbs above $3.00 a bushel, then some figuring with a sharp pencil is in order. The price of gasoline is also a determining factor. As gas prices continue upward, the prospect of turning agricultural crops into fuel is the better deal, if crop prices remain depressed.

But using food crops for fuel is a short-term idea. As progress is made in understanding and using the enzymatic process, more waste material will be turned into alcohol fuel. Waste forest material, garbage, sewage, and crop residue can and will be converted to fermentable sugars. Marginal lands can grow special plants -- such as Jerusalem artichokes, kudzu, and others -- where regular food crops cannot produce a profit for the farmer.

Right now, production of enzymes for converting cellulose to sugars is only in the development stage, but it is expected that within a few years something will be available to small alcohol-fuel producers.

Until cellulose enzymes are cheaper, however, the farmer will have to decide pragmatically which crops to plant for his alcohol fuel.

## Raw Materials

Ethanol may be produced from a variety of farm crops and wastes. The suitability of each type of feedstock may be assessed in terms of its calculated yield of ethanol, its availability by season and region of the U.S., and its cost.

## TYPES OF FEEDSTOCK

Feedstock suitable for use in ethanol production via fermentation must contain sugars, starches, or cellulose that may readily be convertible to fermentable sugars. Feedstocks can be classified roughly into three groups: those containing predominantly sugars, starches, or cellulose, as shown below.

**Sugars**: sugar beets, sugar cane, sweet sorghum, ripe fruits

**Starches**: grains, potatoes, Jerusalem artichokes

**Cellulose**: stover, grasses, wood

The fermentation and distillation processes for two of the feedstock types, starch and sugar, are essentially identical. Their variations occur in storage requirements for the feedstock, the preparation of the fermentable sugar from the raw feedstock, and the" type of by-product produced.

The type of feedstock used has implications both for feedstock storage and in length of time during the year that an ethanol production plant could reasonably be expected to operate. Storage of any of the small grains would be the same whether they were to be used for feed or for alcohol production, i.e., moisture content, etc. would need to be controlled in order to prevent deterioration.

Sweet sorghum, sugar cane, and sugar beets have a short storage life in their harvest form.

Traditionally, the sugar industry has extended its processing season by extracting and storing the sugars in the form of molasses. The storage life of the feedstock is then considerably lengthened. Potatoes have approximately a six-month storage period prior to the start of any significant deterioration in their sugar/starch content.

Overripe or damaged fruits have an extremely short storage life and need to be processed quickly. However, alcohol production from these materials aids in alleviating their disposal problem.

## SUGAR CROPS

Preparation is basically a crushing and extraction of the sugars which the yeast can immediately use. But sugar crops must be dealt with fairly quickly before their high sugar and water content causes spoilage. Because of the danger of such spoilage, the storage of sugar crops is not practical.

**Sugar Cane**. At the present time only 4 states (Florida, Louisiana, Texas, and Hawaii) cultivate sugar cane, but there are hybrids (such as saccharum spontaneum) which can be

grown further north. High yields per acre of both sugar and crop residue are strong points of sugar cane production. The crop residue, called *bagasse*, is used in Brazil to provide heat for the distilleries.

**Sugar Beets**. Although sugar beets are grown in many areas of the U.S., they must be rotated with nonroot crops (1 beet crop per 4 year period is the general rule). While beet by-products cannot provide fuel for the distillery, the beet pulp and tops are excellent feed in wet or dry form. Or the tops may be left on the field for fertilizer and erosion control.

# More on Raw Materials

Excerpted directly from Fuel from Farms -- A Guide to Small-Scale Ethanol Production. United States Department of Energy, Washington, D.C. 20545. Any references to other parts of the text pertain to Fuel from Farms, not to this manual.

**OTHER SUGAR CROPS**

Interest in ethanol production from agricultural crops has prompted research on the development of sugar crops that have not been cultivated on a widespread commercial basis in this country. Three of the principal crops now under investigation are sweet sorghum, Jerusalem artichokes, and fodder beets.

**Sweet Sorghum**. Sweet sorghum is a name given to varieties of a species of sorghum: Sorghum bicolor. This crop has been cultivated on a small scale in the past for production of table syrup, but other varieties can be grown for production of sugar. The most common types of sorghum species are those used for production of grain.

There are two advantages of sweet sorghum over sugar cane: its great tolerance to a wide range of climatic and soil conditions, and its relatively high yield of ethanol per acre. In addition, the plant can be harvested in three ways: (1) the whole plant can be harvested and stored in its entirety; (2) it can be cut into short lengths (about 4 inches long) when juice extraction is carried out immediately; and (3) it can be harvested and chopped for ensilage. Since many varieties of sweet sorghum bear significant quantities of grain (milo), the harvesting procedure will have to take this fact into account.

The leaves and fibrous residue of sweet sorghum contain large quantities of protein, making the residue from the extraction of juice or from fermentation a valuable livestock feed. The fibrous residue can also be used as boiler feed

**Jerusalem Artichokes**. The Jerusalem artichoke has shown excellent potential as an alternative sugar crop. A member of the sunflower family, this crop is native to North America and well-adapted to northern climates [2]. Like the sugar beet, the Jerusalem artichoke produces sugar in the top growth and stores it in the roots and tuber. It can grow in a variety of soils, and it is not demanding of soil fertility. The Jerusalem artichoke is a perennial; small tubers left in the field will produce the next season's crop, so no plowing or seeding is necessary.

Although the Jerusalem artichoke traditionally has been grown for the tuber, an alternative to harvesting the tuber does exist. It has been noted that the majority of the sugar produced

in the leaves does not enter the tuber until the plant has nearly reached the end of its productive life [3]. Thus, it may be possible to harvest the Jerusalem artichoke when the sugar content in the stalk reaches a maximum, thereby avoiding harvesting the tuber. In this case, the harvesting equipment and procedures are essentially the same as for harvesting sweet sorghum or corn for ensilage.

**Fodder Beets**. Another promising sugar crop which presently is being developed in New Zealand is the fodder beet. The fodder beet is a high yielding forage crop obtained by crossing two other beet species, sugar beets and mangolds. It is similar in most agronomic respects to sugar beets. The attraction of this crop lies in its higher yield of fermentable sugars per acre relative to sugar beets and its comparatively high resistance to loss of fermentable sugars during storage [4]. Culture of fodder beets is also less demanding than sugar beets.

**Fruit Crops**. Fruit crops (e.g., grapes, apricots, peaches, and pears) are another type of feedstock in the sugar crop category. Typically, fruit crops such as grapes are used as the feedstock in wine production. These crops are not likely to be used as feedstocks for production of fuel-grade ethanol because of their high market value for direct human consumption. However, the coproducts of processing fruit crops are likely to be used as feedstocks because fermentation is an economical method for reducing the potential environmental impact of untreated wastes containing fermentable sugars.

## STARCH CROPS

In starch crops, most of the six-carbon sugar units are linked together in long, branched chains (called starch). Yeast cannot use these chains to produce ethanol. The starch chains must be broken down into individual six- carbon units or groups of two units. The starch conversion process, described in the previous chapter, is relatively simple because the bonds in the starch chain can be broken in an inexpensive manner by the use of heat and enzymes, or by a mild acid solution.

From the standpoint of ethanol production, the long, branched chain arrangement of six-carbon sugar units in starch crops has advantages and disadvantages. The principal disadvantage is the additional equipment, labor, and energy costs associated with breaking down the chain so that the individual sugar units can be used by the yeast. However, this cost is not very large in relation to all of the other costs involved in ethanol production. The principal advantage in starch crops is the relative ease with which these crops can be stored, with minimal loss of the fermentable portion. Ease of storage is related to the fact that a conversion step is needed prior to fermentation: many microorganisms, including yeast, can utilize individual or small groups of sugar units, but not long chains. Some microorganisms present in the environment produce the enzymes needed to break up the chains, but unless certain conditions (such as moisture, temperature, and pH) are just right, the rate of conversion is very slow. When crops and other feeds are dried to about 12% moisture -- the percentage at which most microorganisms cannot survive -- the deterioration of starch and other valuable components (for example, protein and fats) is minimal. There are basically two subcategories of starch crops: grains (e.g., corn, sorghum, wheat, and barley) and tubers (e.g., potatoes and sweet potatoes). The production of beverage-grade ethanol from both types of starch crops is a well established practice.

Much of the current agronomic research on optimizing the production of ethanol and livestock feed from agricultural crops is focused on unconventional sugar crops such as sweet sorghum. However, opportunities also exist for selecting new varieties of grains and tubers that produce more ethanol per acre. For example, when selecting a wheat variety, protein content is usually emphasized. However, for ethanol production, high starch content is desired. It is well known that wheat varieties with lower protein content and higher starch content usually produce more grain per acre and, consequently, produce more ethanol per acre.

## CROP RESIDUE

The "backbone" of sugar and starch crops -- the stalks and leaves -- is composed mainly of cellulose. The individual six-carbon sugar units in cellulose are linked together in extremely long chains by a stronger chemical bond than exists in starch. As with starch, cellulose must be broken down into sugar units before it can be used by yeast to make ethanol. However, the breaking of the cellulose bonds is much more complex and costly than the breaking of the starch bonds. Breaking the cellulose into individual sugar units is complicated by the presence of lignin, a complex compound surrounding cellulose, which is even more resistant than cellulose to enzymatic or acidic pretreatment. Because of the high cost of converting liquefied cellulose into fermentable sugars, agricultural residues (as well as other crops having a high percentage of cellulose) are not yet a practical feedstock source for small ethanol plants. Current research may result in feasible cellulosic conversion processes in the future.

## FORAGE CROPS

Forage crops (e.g., forage sorghum, Sudan grass) hold promise for ethanol production because, in their early stage of growth, there is very little lignin and the conversion of the cellulose to sugars is more efficient. In addition, the proportion of carbohydrates in the form of cellulose is less than in the mature plant. Since forage crops achieve maximum growth in a relatively short period, they can be harvested as many as four times in one growing season [5]. For this reason, forage crops cut as green chop may have the highest yield of dry material of any storage crop. In addition to cellulose, forage crops contain significant quantities of starch and fermentable sugars which can also be converted to ethanol. The residues from fermentation containing nonfermentable sugars, protein, and other components may be used for livestock feed.

The principal characteristics of the feedstock types considered in this section are summarized in Table IV-1.

## COPRODUCT YIELDS

### Ethanol

The yield of ethanol from agricultural crops can be estimated if the amount of fermentable components -- sugar, starch, and cellulose -- is known prior to fermentation. If the yield is predicted based on percentages at the time of harvest, then the loss of fermentable solids during storage must be taken into account. This factor can be significant in the case of sugar crops, as discussed earlier.

The potential yield of ethanol is roughly one-half pound of ethanol for each pound of sugar. However, not all of the carbohydrate is made available to the yeasts as fermentable sugars, nor do the yeasts convert all of the fermentable sugars to ethanol. Thus, for estimating purposes, the yield of ethanol is roughly one gallon for each 15 pounds of sugar or starch in the crop at the time the material is actually fermented. Because of the many variables in the conversion of liquefied cellulose to fermentable sugar, it is difficult to estimate active ethanol yields from cellulose.

**Carbon Dioxide**

The fermentation of six-carbon sugars by yeast results in the formation of carbon dioxide as well as ethanol. For every pound of ethanol produced, 0.957 pound of carbon dioxide is formed; stated another way, for every 1 gallon of ethanol produced, 6.33 pounds of carbon dioxide are formed. This ratio is fixed; it is derived from the chemical equation:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + heat$$

(glucose)        (ethanol)     (carbon dioxide)

**Other Coproducts**

The conversion and fermentation of agricultural crops yield products in addition to ethanol and carbon dioxide. For example, even if pure glucose is fermented, some yeast will be grown, and they would represent a coproduct. These coproducts have considerable economic value, but, since they are excellent cultures for microbial contaminants, they may represent a pollutant if dumped onto the land. Therefore, it becomes doubly important that these coproducts be put to good use.

**TABLE IV-1. SUMMARY OF FEEDSTOCK CHARACTERISTICS**

| Type of Feedstock | Processing Needed Prior to Fermentation | Principal Advantage(s) | Principal Disadvantage(s) |
|---|---|---|---|
| Sugar Crops (e.g., sugar beets, sweet sorghum, sugarcane, fodder beet, Jerusalem artichoke) | Milling to extract sugar. | 1. Preparation is minimal.<br>2. High yields of ethanol per acre.<br>3. Crop coproducts have value as fuel, livestock feed, or soil amendment. | 1. Storage may result in loss of sugar.<br>2. Cultivation practices are not wide-spread, especially with "nonconventional" crops. |
| Starch Crops:<br>Grains (e.g., corn, wheat, sorghum, barley)<br><br>Tubers (e.g., potatoes, sweet potatoes) | Milling, liquefaction, and saccharification. | 1. Storage techniques are well developed.<br>2. Cultivation practices are widespread with grains.<br>3. Livestock coproduct is relatively high in protein. | 1. Preparation involves additional equipment, labor, and energy costs.<br>2. DDG from aflatoxin-contaminated grain is not suitable as animal feed. |
| Cellulosic:<br>Crop Residues (e.g., corn stover, wheat straw)<br><br>Forages (e.g., alfalfa, Sudan grass, forage sorghum | Milling and hydrolysis of the linkages. | 1. Use involves no integration with the livestock feed market.<br>2. Availability is widespread. | 1. No commercially cost-effective process exists for hydrolysis of the linkages. |

Sugar crops, after the sugar has been extracted, yield plant residues which consist mostly of cellulose, unextracted sugar, and protein. Some of this material can be used as livestock feed, although the quantity and quality will vary widely with the particular crop. If the crop is of low feeding value, it may be used as fuel for the ethanol plant. This is commonplace when sugar cane is the feedstock.

Sweet sorghum may yield significant quantities of grain (milo), and the plant residue is suitable for silage, which is comparable to corn or sorghum silage except that it has a lower energy value for feeding. Sugar beet pulp from the production of sugar has always been used for livestock feed, as have the tops. Jerusalem artichokes, grown in the Soviet Union on a very large scale, are ensiled and fed to cattle, so the plant residue in this case would be suitable for silage. All of these residues can supply significant amounts of protein and roughage to ruminants.

It is evident that all silage production has the potential for the production of significant quantities of ethanol without affecting the present uses or agricultural markets. By planting silage crops of high sugar content and extracting a part of the sugar for the production of ethanol, the ensiled residue satisfies the existing demand for silage.

Starch feedstock consists mostly of grains and, to a smaller extent, root crops such as potatoes (white or sweet). The production of nonfermentable material in these root crops is much less than in grains, and the use of the residue is similar.

In the case of grains, it is commonplace to cook, ferment, and distill a mash containing the whole grain. The nonfermentable portion then appears in the stillage (the liquid drawn off the bottom of the beer column after stripping off the ethanol). About three-quarters of the nonfermentable material is in suspension in the form of solids ranging from very coarse to very fine texture, and the remainder is in solution in the water. The suspended material may be separated from the liquid and dried. The coarser solids, in this case, are distillers' light grains. The soluble portion may be concentrated to a syrup with from 25% to 45% solids, called distillers' solubles. When dried together with the coarser material, the product is called distillers' dark grains. These nonfermentable solids derived from grain are valuable as high-protein supplements for ruminants in particular. However, if very large quantities of grain are fermented, the great quantity supplied may exceed the demand and lower the prices. Fortunately, the potential demand exceeds the present usage as a protein supplement, since feeding experience has shown that these coproducts can substitute for a significant part of the grain. When the liquid stillage is fed either as it comes from the still or somewhat concentrated, it is especially valuable, since it permits the substitution of straw for a significant proportion of the hay (e.g., alfalfa) normally fed to ruminants.

The nonfermentable portion of the grain can also be used as human food. In the wet milling industry, the grain components are normally separated and the oil is extracted. The starch may be processed for a number of uses, or it may be used as feedstock for ethanol production. The gluten (the principal portion of the protein in the grain) may be separated and processed for sale as, for example, vital gluten (from wheat) or corn gluten. As another option, the solids may be sent through the fermenters and the beer still to appear as distillers' grains.

Grain processing as practiced in large plants is not feasible for small plants. However, a simple form of processing to produce human food may be feasible. Wheat can be simply processed to separate the starch from the combined germ, gluten, and fiber. They form a cohesive, doughy mass which has long been used as a base for meat-analogs. This material can also be incorporated into bread dough to enhance its nutritional value by increasing the protein, fiber, and vitamin (germ) content.

Work at the University of Wisconsin has resulted in the development of a simple, practical processing machine that extracts about 60% of the protein from forage crops in the form of a leaf juice [6]. The protein in the juice can be separated in a dry form to be used as a very high quality human food. The fibrous residue is then in good condition to be hydrolyzed to fermentable sugars. Most of the plant sugars are in the leaf juice and, after separation of the protein, are ready for fermentation. Forage crops have the potential for producing large amounts of ethanol per acre together with large amounts of human-food-grade protein. The protein production potential is conservatively 1,000 pounds per acre, equivalent to 140 bushels per acre of 12%-protein wheat [7].

Representative feedstock composition and coproduct yields are given below. Appendix D provides additional information in the table comparing raw materials for ethanol production. As discussed earlier, these data cannot be applied to specific analyses without giving consideration to the variable nature of the composition of the feedstock and the yield per acre of the crop.

Representative yields of some major domestic feedstocks:
Crop -- Ethanol Yield
Cereal grains -- 2.5 gal/bu
Potatoes -- 1.4 gal/cwt
Sugar beets -- 20 gal/ton

## AGRONOMIC CONSIDERATIONS

A simple comparison of potential ethanol yield per acre of various crops will not rank the crops in terms of economic value for production of ethanol. The crops vary considerably in their demands on the soil, demands for water, need for fertilization, susceptibility to disease or insect damage, etc. These factors critically influence the economics of producing a crop. Fortunately, forage crops which have the potential for producing large amounts of ethanol per acre have specific agronomic advantages relative to some of the principal grain crops (e.g., corn).

The nonfruiting crops, including forage crops, some varieties of high-sugar sorghum, and Jerusalem artichokes, are less susceptible to catastrophic loss (e.g., due to hail, frost, insects, disease, etc.), and, in fact, are less likely to suffer significant loss of production due to adverse circumstances of any sort than are fruiting crops such as grains. Furthermore, forage crops and Jerusalem artichokes are less demanding in their culture than almost any grain. Their cost of culture is usually lower than for grains on the same farm, and they have great potential for planting on marginal land.

## FEEDSTOCK CONSIDERATIONS

It is apparent from the foregoing discussion that the selection of feedstocks for ethanol production will vary from region to region, and even from farm to farm. The results of development work now being carried out will influence choices but, most significantly, the additional choices open to farmers resulting from the opportunity to produce feedstocks for ethanol production from a large variety of crops will alter the patterns of farming. It is not possible to predict what new patterns will evolve. However, it is clear that there will be benefits from the creation of choices in the form of new markets for existing crops and alternative crops for existing markets.

In the near future, ethanol is likely to be produced primarily from grain. However, the development of processes for the effective use of other crops should yield results in the near term which could bring about a rapid increase in the use of nongrain feedstocks.

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## COMPARISON OF PROCESS FACTORS OF OTHER FEEDSTOCKS TO CORN

| | Storage Length of Time | Feedstock Preparation | Sugar Extraction | Cooking Hydrolysis | Fermentation | Distillation | Dehydration | By-product Processing |
|---|---|---|---|---|---|---|---|---|
| Corn | Grain bins 12 months | Grind | None | Heat and hydrolyze | With solids | 2 columns | Benzene extraction | DDGS or wet stillage |
| Wheat | Grain bins 12 months | Grind | None | Heat and hydrolyze | Same | Same | Same | DDGS or wet stillage |
| Milo/sorghum | Grain bins 12 months | Grind | None | Heat and hydrolyze | Same | Same | Same | DDGS or wet stillage |
| Sweet sorghum | Piles 3 months | Crush in roller mill | Separate sugar and fiber | None | Liquid only | Larger size | Liquid only | Low value fiber |
| Sugar cane | Piles 3 months | Crush in roller mill | Separate sugar and fiber | None | Liquid only | Larger size | Liquid only | Low value fiber |
| Sugar beets | Piles 4 months | Slice | Extensive extraction | None | Liquid only | Larger size | Liquid only | Beet pulp dry or wet |
| Potatoes | Controlled atmosphere 12 months | Grind | None | Heat and hydrolyze | Same | Somewhat larger size | Same | Potato pulp dry or wet |
| Starch | Bins 12 months | None | None | Heat and hydrolyze | Same | Same | Same | Yeast only |
| Molasses | Tanks 12 months | None | None | None | Same | Same | Same | Yeast only |

# Feedstock Handling and Storage

Excerpted directly from Fuel from Farms -- A Guide to Small-Scale Ethanol Production. United States Department of Energy, Washington, D.C. 20545. Any references to other parts of the text pertain to Fuel from Farms, not to this manual.

**Grain**. A small plant should be able to use cereal grains. Since grains are commonly stored on farms in large quantity, and since grain-growing farms have the basic equipment for moving the grain out of storage, handling should not be excessively time-consuming. The increasing popularity of storing grain at high moisture content provides advantages since harvesting can be done earlier and grain drying can be avoided. When stored as whole grain, the handling requirements are identical to those of dry grain. If the grain is ground and stored in a bunker, the handling involves additional labor since it must be removed from the bunker and loaded into a grainery from which it can be fed by an auger into the cooker. This operation probably could be performed once each week, so the grains need not be ground daily as with whole grain.

**Roots and tubers**. Potatoes, sugar beets, fodder beets, and Jerusalem artichokes are generally stored whole in cool, dry locations to inhibit spontaneous fermentation by the bacteria present. The juice from the last three can be extracted but it can only be stored for long periods of time at very high sugar concentrations. This requires expensive evaporation equipment and large storage tanks.

Belt conveyors will suffice for handling these root crops and tubers. Cleaning equipment should be provided to prevent dirt and rocks from building up in the fermentation plant.

**Sugar Crops**. Stalks from sugar cane, sweet sorghum, and Jerusalem artichokes cannot be stored for long periods of time at high moisture content. Drying generally causes some loss of sugar. Field drying has not been successful in warm climates for sugarcane and sweet sorghum. Work is being conducted in field drying for sweet sorghum in cooler climates; results are encouraging though no conclusions can be drawn yet.

Canes or stalks are generally baled and the cut ends and cuts from leaf stripping are seared to prevent loss of juice.

A large volume of material is required to produce a relatively small amount of sugar, thus a large amount of storage space is necessary. Handling is accomplished with loaders or bale movers.

# Chapter 3

## Basic Steps in the Production of Ethyl Alcohol

THE usual sources of raw material for alcohol production from starch are cereal grains such as corn, wheat, rye, barley, milo (sorghum grains), rice, etc. Other types of starch are available from potatoes of all kinds, Jerusalem artichokes, and other high-starch vegetables. Starch conversion is the standard method of production and the one we will discuss here.

It is possible, however, to make alcohol from sugar-producing plants (saccharine material) such as sugar beets, sugarcane, fruits, and others. These substances need no milling (as do grains), but they do require some kind of grinding or squeezing process. Rapid, efficient fermentation of these sugars has not been as well explored as the process using starch.

A third source of fermentables is cellulose, as found in wood and waste sulphite liquor. This more complex process requires the use of acids to reduce the material to wood sugars. Consequently, most do-it-yourselfers should stick to either starch or sugar.

**MILLING**

All grains must be ground before mashing to expose the starch granules and help them remain in suspension in a water solution. The grain should be ground into a meal -- *not a flour!* -- that will pass a 20-mesh screen. On a hammermill, however, a 3/16" screen will suffice.

Potatoes and similar high-moisture starch crops should be sliced or finely chopped. Since potato starch granules are large and easily ruptured, it isn't necessary to maintain the hard rapid boil which is required of the tougher, dryer "flinty" starches found in grains.

**CONVERSION WITH MOTHER'S ENZYMES**

For small batches (5 bushels or less), fill the cooker with water (30 gallons per bushel), and add the meal slowly, to prevent lumps from forming. (When, cooking with steam, or at higher temperatures, it is possible to save energy by using less water at the beginning. But for the "small batcher" with an ordinary cooking apparatus, the most complete conversion is obtained by using the full amount of water right from the start to encourage a rapid rolling boil.)

Next, add 3 measuring spoons -- as provided -- per bushel of MOTHER's Alcohol Fuel Mash Cooking Enzyme (mixed in water) to the mixture and raise the temperature of the mash to 170 deg F (77 deg C), the optimum working environment for the enzyme. Hold the solution at that temperature for 15 minutes while agitating it vigorously.

At this point all the starch available at 170 deg F has been converted to dextrins, so it's time to raise the temperature of the mash to the boiling point. The concoction should be liquid enough to roll at its own rate -- if not, add 2 to 3 gallons of water. Hold the boil for 30 minutes to complete the liquefaction stage. All the starches are now in solution.

Now reduce the temperature to 170 deg F, using the cooling coil, and add 3 more measuring spoons per bushel of MOTHER's Cooking Enzyme (mixed in water). After 30 minutes of agitation at this temperature, all the previously released starches will have been reduced to dextrins, thereby completing primary conversion.

During secondary conversion the dextrins are further reduced to simple sugars (maltose and glucose) by the beta, or -- to be more exact -- glucoamylase enzymes. Because MOTHER's Alcohol Fuel Fermentation Powder contains both the enzymes *and* the yeast necessary to carry out secondary conversion and proper fermentation simultaneously, you can add 6 measuring spoons per bushel of the fermentation powder (mixed in water) as soon as you've brought the temperature down to 85 deg F (29 deg C) using the cooling coils.

## CONVERSION WITH BARLEY MALT

Instead of using commercial enzymes, it is possible to affect conversion by employing barley malt -- at the ratio of 15% by weight, or 7 pounds per bushel -- in both the pre- and post-boil. However, such a technique requires a more acidic medium (about pH 4-5) and lower temperatures -- about 145 deg F (63 deg C) is optimum -- than MOTHER's powders. Though the weights and temperatures differ, the same sequence is followed as discussed in "Conversion With MOTHER's Enzymes".

(One way to speed up the cooking process is with steam, which -- at 350 deg F, 177 deg C -- reduces the cooking time to one minute. Another commercial approach is to use extruders: machines much like meat grinders that compress, grind, and convert the grain in a one-step process.)

## FERMENTATION

If you use barley malt for the conversion process -- or if you are following some alternative recipe that does not employ MOTHER's Fermentation Powder -- you will need to add your own yeast.

Mix up two ounces of distiller's or baker's yeast in a quart or two of the liquid mash, and add the concoction to the wort. Vigorous agitation will oxygenate the mixture and encourage a rapid initial growth of the yeast culture.

Yeast plants can propagate in a solution with or without air, so agitate only enough to saturate the wort with air and then let it stand still. If the mash is continually agitated, the yeast will reproduce faster and make less waste: carbon dioxide and alcohol. But if the solution becomes anaerobic (without air) the yeast slows down reproduction and makes *more* alcohol and carbon dioxide.

Yeast also produces enzymes of its own to convert complex sugars. Since sugar conversion and alcohol conversion can take place simultaneously, the amylase enzymes and the yeast

work in cooperation to convert the dextrins to glucose and fructose and then to alcohol and C02.

Fermentation is a chemical process and produces heat. In concentrated or particularly large mashes, the temperature can actually rise to levels dangerous to yeast. Since the ideal temperature for yeast is around 85 deg F, it's best to maintain that temperature by either utilizing cooling coils or keeping the water-to-grain ratio at about 40 gallons per bushel.

Conversion of sugars to alcohol and C02 will be completed in three to five days, depending on the temperature of the mixture and the type of yeast used. You can tell when the mash is done by watching the "cap" of solids on top of the solution. During fermentation, the rising C02 keeps the solids in constant motion, but when the bubbling stops, the solids fall to the bottom. At this time, you're ready to separate the solids from the liquids and begin distillation.

**KEEP IT CLEAN!**

Remember, sanitation is extremely important! There are many kinds of invading bacteria, including strains which can withstand boiling temperatures. So, observe the same standards that any restaurant or kitchen follows. And keep the fermenting vat well covered: a fly in the ointment will turn your mash into something that it's best to keep upwind of.

# More On Conversion and Fermentation

Acid hydrolysis of starch is accomplished by directly contacting starch with dilute acid to break the polymer bonds. This process hydrolyzes the starch very rapidly at cooking temperatures and reduces the time needed for cooking. Since the resulting pH is lower than desired for fermentation, it may be increased after fermentation is complete by neutralizing some of the acid with either powdered limestone or ammonium hydroxide. It also may be desirable to add a small amount of glucoamylase enzyme after pH correction in order to convert the remaining dextrins.

**High-temperature versus low-temperature cooking.** Grain must be cooked to rupture the starch granules and to make the starch accessible to the hydrolysis agent. Cooking time and temperature are related in an inverse ratio: high temperatures shorten cooking time. Industry practice is to heat the meal-water mixture by injecting steam directly rather than by heat transfer through the wall of the vessel. The latter procedure runs the risk of causing the meal to stick to the wall; the subsequent scorching or burning would necessitate a shutdown to clean the surface.

High-temperature cooking implies a high-pressure boiler. Because regulations may require an operator in constant attendance for a high-pressure boiler operation, the actual production gain attributable to the high temperature must be weighed against the cost of the operator. If there are other supporting rationale for having the operator, the entire cost does not have to be offset by the production gain.

**Continuous versus batch processes.** Cooking can be accomplished with continuous or batch processes. Batch cooking can be done in the fermenter itself or in a separate vessel.

When cooking is done in the fermenter, less pumping is needed and the fermenter is automatically sterilized before fermenting each batch. There is one less vessel, but the fermenters are slightly larger than those used when cooking is done in a separate vessel. It is necessary to have cooling coils and an agitator in each fermenter.

If cooking is done in a separate vessel, there are advantages to selecting a continuous cooker. The continuous cooker is smaller than the fermenter, and continuous cooking and hydrolysis lend themselves very well to automatic, unattended operation. Energy consumption is less because it is easier to use counterflow heat exchangers to heat the water for mixing the meal while cooling the cooked meal. The load on the boiler with a continuous cooker is constant. Constant boiler load can be achieved with a batch cooker by having a separate vessel for preheating the water, but this increases the cost when using enzymes.

Continuous cooking offers a high-speed, high-yield choice that does not require constant attention. Cooking at atmospheric pressure with a temperature a little over 200 deg F (93 deg C) yields a good conversion ratio of starch to sugar, and no high-pressure piping or pumps are required.

**Separation versus nonseparation of nonfermentable solids.** The hydrolyzed mash contains solids and dissolved proteins as well as sugar. There are some advantages to separating the solids before fermenting the mash, and such a step is necessary for continuous fermentation.

Batch fermentation requires separation of the solids if the yeast is to be recycled. If the solids are separated at this point, the beer column will require cleaning much less frequently, thus increasing the feasibility of a packed beer column rather than plates. The sugars that cling to the solids are removed with the solids. If not recovered, the sugar contained on the solids would represent a loss of 20%o of the ethanol. Washing the solids with the mash water is a way of recovering most of the sugar.

**FERMENTATION**

**Continuous fermentation.** The advantage of continuous fermentation of clarified beer is the ability to use high concentrations of yeast (this is possible because the yeast does not leave the fermenter). The high concentration of yeast results in rapid fermentation and, correspondingly, a smaller fermenter can be used. However, infection with undesired micro-organisms can be troublesome because large volumes of mash can be ruined before the problem becomes apparent.

**Batch fermentation.** Fermentation time periods similar to those possible with continuous processes can be attained by using high concentrations of yeast in batch fermentation. The high yeast concentrations are economically feasible when the yeast is recycled. Batch fermentations of unclarified mash are routinely accomplished in less than 30 hours. High conversion efficiency is attained as sugar is converted to 10%-alcohol beer without yeast recycle. Further reductions in fermentation require very large quantities of yeast. The increases attained in ethanol production must be weighed against the additional costs of the equipment and time to culture large yeast populations for inoculation.

**Specifications of the fermentation tank.** The configuration of the fermentation tank has very little influence on system performance. In general, the proportions of the tank should not be extreme. Commonly, tanks are upright cylinders with the height somewhat greater than the diameter. The bottom may be flat (but sloped for drainage) or conical. The construction materials may be carbon steel (commonplace), stainless steel, copper, wood, fiberglass, reinforced plastic, or concrete coated on the inside with sprayed-on vinyl. Usually, the tanks are covered to permit collection of the $CO_2$ evolved during fermentation so that the ethanol which evaporates with it can be recovered.

Many potential feedstocks are characterized by relatively large amounts of fibrous material. Fermentation of sugar-rich material such as sugar beets, sweet sorghum, Jerusalem artichokes, and sugarcane as chips is not a demonstrated technology and it has many inherent problems. Typically, the weight of the nonfermentable solids is equal to or somewhat greater than the weight of fermentable material. This is in contrast to grain mashes which contain roughly twice as much fermentable material as nonfermentable material in the mash. The volume occupied by the nonfermentable solids reduces the effective capacity of the fermenter. This means that larger fermenters must be constructed to equal the production rates from grain fermenters. Furthermore, the high volume of nonfermentable material limits sugar concentrations and, hence, the beer produced is generally lower in concentration (6% versus 10%) than that obtained from grain mashes. This fact increases the energy spent in distillation.

Since the nonfermentable solid chips are of larger size, it is unlikely that the beer containing the solids could be run through the beer column. It may be necessary to separate the solids from the beer after fermentation because of the potential for plugging the still. The separation can be easily accomplished, but a significant proportion of the ethanol (about 20%) would be carried away by the dewatering solids.
If recovery is attempted by "washing out," the ethanol will be much more dilute than the beer. Since much less water is added to these feedstocks than to grain (the feedstock contains large amounts of water), only part of the dilute ethanol solution from the washing out can be recycled through the fermenter. The rest would be mixed with the beer, reducing the concentration of ethanol in the beer which, in turn, increases the energy required for distillation.

Another approach is to evaporate the ethanol from the residue. By indirectly heating the residue, the resulting ethanol-water vapor mixture can be introduced into the beer column at the appropriate point. This results in a slight increase in energy consumption for distillation.

The fermenter for high-bulk feedstocks differs somewhat from that used for mash. The large volume of insoluble residue increases the demands on the removal pump and pipe plugging is more probable. Agitators must be sized to be self-cleaning and must prevent massive settling. High-speed and high-power agitators must be used to accomplish this.

The equipment for separating the fibrous residue from the beer when fermenting sugar crops could be used also to clarify the grain mash prior to fermentation. This would make possible yeast recycling in batch fermentation of grain.

**Temperature control.** Since there is some heat generated during fermentation, care must be taken to ensure that the temperature does not rise too high and kill the yeast. In

fermenters the size of those for on-farm plants, the heat loss through the metal fermenter walls is sufficient to keep the temperature from rising too high when the outside air is cooler than the fermenter. Active cooling must be provided during the periods when the temperature differential cannot remove the heat that is generated. The maximum heat generation and heat loss must be estimated for the particular fermenter to assure that water cooling provisions are adequate.

**Figure 1.** Fermentation Vat Cooling Coil
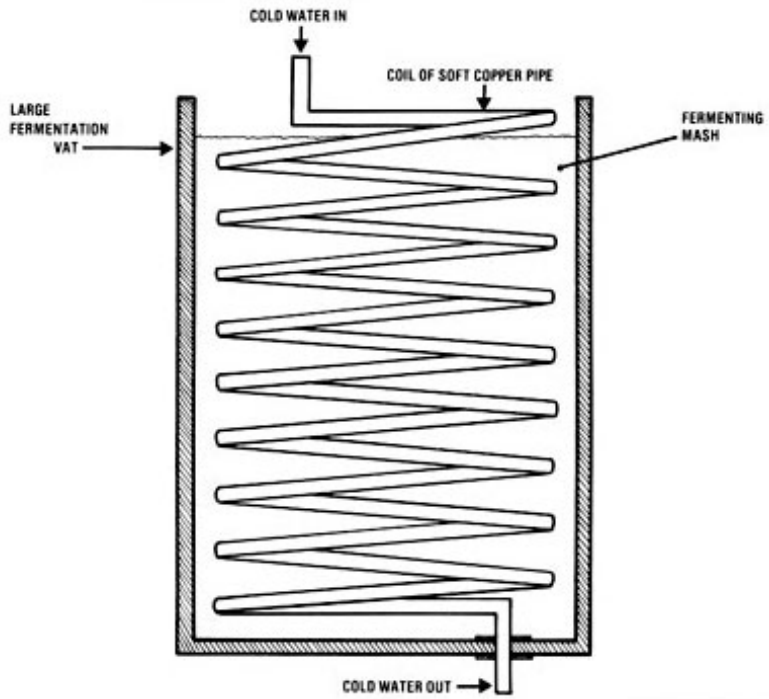


# Fermentation Addendum

The optimum fermentation conditions are a temperature of 86 deg F (30 deg C) and a pH of 4 to 5. When the grains are left in the sweet wort or when backset is utilized, a buffering capacity is added that assists in maintaining the required pH (acidity). The expected alcohol yield from a 15-25% solution of fermentable sugars is 6.75 to 11.25% by weight.

The time required to complete the fermentation is dependent upon the strain of yeast used. A variety of yeasts were tested for molasses fermentation in order to find a yeast strain that is highly efficient under variable conditions. (A group of 12 so tested is listed in the table below.) The ATCC 4132 produced 93 to 95% of the theoretical yield of alcohol from molasses without molasses pretreatment. The remainder of the yeasts were less efficient in alcohol production with the 48-hour fermentation efficiency ranging down to 35% (Heinz, September 11, 1979).

**Yeast Strains and Their Relative Fermentation Efficiency**

| Yeast Strain | 48-hr. Fermentation Efficiency (%) | Ethanol per Ton of Molasses (gallons) |
|---|---|---|
| ATCC 4132 | 93 | 73 |
| CBS 1237 | 90 | 70 |
| Y 7494 | 86 | 67 |
| UCD 505 | 83 | 65 |
| UCD 595 | 81 | 63 |
| ATCC 26603 | 81 | 63 |
| DADY | 77 | 60 |
| BAKER | 77 | 60 |
| ATCC 26602 | 62 | 48 |
| NCYC 90 | 57 | 44 |
| Y 2034 | 55 | 43 |
| CBS 1235 | 35 | 27 |

## Source of yeast:

ATCC -- American Type Culture Collection
CBS -- Centraalbureau voor Schimmelcultures, The Netherlands
Y -- Northern Region Research Center, USA
UCD -- University of California, Davis
DADY -- Universal Foods Corporation
BAKER -- Local procurement
NCYC -- National Collection of Yeast Culture, Brewing Research
Foundation, England.

Source: Heinz, Don J., Technology of Ethanol Production, Experiment Station, Hawaiian Sugar Planters' Association, Media Briefing on Energy, September 11, 1979.

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For small-scale production, the most readily available yeast is active dry yeast especially designed for distillers' use in grain mash fermentation. This product has been found to work well for beet, cane, and citrus molasses fermentation. The yeast is designed to produce uniform, rapid fermentation and maximum alcohol yields under a wide range of temperatures and pH. The time required for fermentation will vary with the temperature, although most estimates are for 48 to 72 hours.

Yields of alcohol may be reduced if there is any contamination of the sweet wort. Contamination with undesirable micro-organisms will decrease the yield of alcohol as these will compete with the yeast for the sugar. Prior to the addition of the yeast, contamination from external sources or from the equipment itself may occur readily in the cooling of the sugar mixture.

At this point in the process, the sugar solution is a suitable medium for growing a variety of microbes that may be pathogenic or produce toxic substances (Crombie, 1979). Microbes may be introduced with the raw materials initially, via the addition of cooling water, or from the air; thus, provision needs to be made for high-quality water, and the design must incorporate some protection from possible contamination from the air.

Fortunately the contamination problem is mitigated by the fact that yeast populations grow quite rapidly, and overwhelm many of the potentially competing organisms. In addition, the initial inoculation introduces a large yeast population that allows the yeast a head start. Provided care is exercised and, thus, unwanted microbial action does not occur, decreases in the yield of ethanol resulting from competing reactions can be held to a minimum.

Undesirable microbial reactions occurring in the fermentation step may produce unwanted substances in the stillage, but since these cannot be predicted in advance and would be batch-specific, they would need to be handled on an individual batch basis.

The solution to the contamination problem involves the design of the production facility and the training of the process operator. The plant must be designed in such a fashion that sanitation is readily accomplished and contamination of the sweet wort may be avoided when reasonable care is exercised. Once the operating procedures for a plant are established, these problems should be minimal.

All equipment currently being marketed utilizes a batch fermentation process; however, continuous fermentation units have been used in some industrial applications. A continuous fermentation process allows the use of smaller fermenters and supplementary equipment; it has been of interest for many years.

Continuous fermentation methods have been used successfully on waste sulfite liquor in Europe. Since sulfite liquors are sterile and even antiseptic, continuous fermentation is possible and desirable.

With fermentable substances such as molasses, however, any contamination is cumulative and soon spreads throughout the system to reduce yields. The contamination can be controlled to some extent using penicillin or other antibiotics, but their use to control organisms competing for sugars and decreasing alcohol yields creates another problem: the use of by-product feed. The antibiotic content of feeds for livestock is carefully controlled by the Food and Drug Administration. FDA requires tests to show that antibiotics and their degradation products in the resulting by-product feeds are below the maximum allowable levels. Most of these antibiotics are destroyed in the drying process. One commercial ethanol producer looked at and experimented with a continuous process, but finally gave up because of the contamination problems involved.

However, continuous fermentation could conceivably work well if the fermentable solution could be sterilized. But with grains or cellulose feedstocks, the grain particles and fiber present in the sweet wort make such sterilization extremely difficult.

Although continuous fermentation offers a more rapid method of producing ethanol with smaller tanks, etc., problems remain to be worked out before the system is feasible for the small-scale operator using grains as a feedstock. Work is underway at the present time to develop continuous automated equipment for small-scale ethanol production.

If wheat is used as the feedstock, special provisions must be made for the additional foaming that occurs during fermentation because of the presence of the gluten protein. Three possibilities exist to handle this problem: increasing the capacity of the equipment over that for the same quantities of corn; using a defoaming agent; or removing the gluten

protein prior to the fermentation process.

Since the fermentation process produces heat and the optimum fermentation temperature is about 90 deg F (32 deg C), cooling is necessary in order for the yeast to survive and work efficiently. The formation of ethanol is accompanied by approximately 287 kilocalories per kilogram of ethanol produced: 517 BTU per pound or 3,418 BTU per gallon (Alfa-Laval, undated). If insufficient cooling is provided, the fermentation times are increased. Where no provision is made for removal of the heat of fermentation, heat losses may occur in both of these ways: [1] from the evolution of carbon dioxide, and [2] from convection and radiation from the walls and other surfaces of the fermenter vessel. Heat removal in the off-gas is relatively small, even though the gas is saturated with water vapor and its attendant evaporative cooling effect. If heat evolution is too great to be dissipated by radiation, the increasing temperature of the contents results in a decreased yeast activity and a greater heat release.

# Alcohol Yield

**Table 1. Average yield of 99.5 percent alcohol per ton\*\***

| Material | Gallons | Material | Gallons |
|---|---|---|---|
| Wheat (all varieties) | 85.0 | Yams | 27.3 |
| Corn | 84.0 | Potatoes | 22.9 |
| Buckwheat | 83.4 | Sugar beets | 22.1 |
| Raisins | 81.4 | Figs, fresh | 21.0 |
| Grain sorghum | 79.5 | Jerusalem artichokes | 20.0 |
| Rice, rough | 79.5 | Pineapples | 15.6 |
| Barley | 79.2 | Sugarcane | 15.2 |
| Dates, dry | 79.0 | Grapes (all varieties) | 15.1 |
| Rye | 78.8 | Apples | 14.4 |
| Prunes, dry | 72.0 | Apricots | 13.6 |
| Molasses, blackstrap | 70.4 | Pears | 11.5 |
| Sorghum cane | 70.4 | Peaches | 11.5 |
| Oats | 63.6 | Plums (nonprunes) | 10.9 |
| Figs, dry | 59.0 | Carrots | 9.8 |
| Sweet potatoes | 34.2 | | |

**Table 2. Average yield of 99.5 percent alcohol per acre ‍**

| Material | Gallons | Material | Gallons |
|---|---|---|---|
| Jerusalem artichokes**** | 1200.0 | Grapes (all varieties) | 90.4 |
| Sugarcane | | Peaches | 84.0 |
| (Hawaii, 18 to 22 months) | 889.0 | Barley*** | 83.0 |
| Sugar cane (Louisiana)*** | 555.0 | Prunes, dry | 82.8 |
| Sorghum cane*** | 500.0 | Wheat (all varieties)*** | 79.0 |
| Sugar beet*** | 412.0 | Pineapples | 78.0 |
| Potatoes*** | 299.0 | Oats*** | 57.0 |
| Corn*** | 214.0 | Rye*** | 54.0 |
| Sweet potatoes*** | 190.0 | Pears | 49.3 |
| Rice, rough*** | 175.0 | Molasses, blackstrap | 45.0 |
| Apples | 140.0 | Apricots | 41.0 |
| Dates, dry | 126.0 | Buckwheat | 34.2 |
| Grain sorghum*** | 125.0 | Figs, fresh | 31.5 |
| Carrots | 121.0 | Figs, dry | 29.5 |
| Raisins | 101.7 | Plums (nonprunes) | 21.8 |
| Yams | 94.0 | | |

* Probable yield from a short ton of the raw material, calculated from the average fermentable content.
** Jacobs, P. B., and H. P. Newton, U. S. Dept. Agr, Misc. Pub. 327, December, 1938.
*** USDA, Ag. Stat., 1978.
**** Estimate for three harvests of heads per year.

# Chapter 4

## Control of Infection by Planned Sanitation in the Production of Fuel or Gasohol Alcohol

Since the primary purpose of mashing, fermentation, and distilling is to produce the maximum amount of ethanol from a given mass of starch, whether from corn or other cereal grain, potatoes, sugar, molasses, whey, or cellulose products, it follows that growth of organisms other than distiller's yeast must be controlled. Otherwise, sugar and alcohol are lost to bacteria, which do not produce alcohol, and wild yeast which produces it less efficiently or produces acids.

**TYPES OF INFECTION**

Unwanted organisms such as the Acetobacter, which produces vinegar, and the Lactobacillus family, which produces lactic acid, are in the air and in the materials and equipment used to produce ethanol. They will always be with us and must be controlled in order to get maximum alcohol yields from our equipment and materials.

Infinitely small quantities of these organisms -- if present -- can reduce yield in the following ways:

[1] Acetic acid bacteria convert alcohol to acetic acid, thus reducing the alcohol yield. Exclusion of air from the fermenting or fermented mash reduces this hazard.

[2] Lactic acid bacteria take away the sugar from the yeast before and during fermentation.

Effect of infection on yield:
Infection Level (Bacteria per ml.) -- Loss in Yield (Percentage)
0-1 million -- up to 1%
I- 10 million -- 1-3%
10-100 million -- 3-5%
over 100 million -- over 5%

**LOSS IN YIELD**

A loss of 5%, which is quite probable under conditions favorable to bacteria growth, of course means a loss of alcohol of 5 gallons/day on a 100 gallon/day operation and 50 gallons/day on a 1,000 gallon/day operation. At a cost of $1.50/gallon in a 300 day/year operation, this amounts to around $22,000/year for the larger operation or about $2,200/year for the smaller operation.

**WHERE INFECTION OCCURS**

It is very difficult for infectious organisms to gain a foothold and multiply on smooth, clean surfaces. They are harbored on surfaces covered to any extent with deposits of starchy, sugary, protein-rich, or mineral-rich materials. They occur in places that are hard to clean, such as porous surfaces, cracks, sharp angles, corners, gaskets, valves, pressure gauges, in-place thermometers, and pump packing. Deposits in these areas protect the organisms in them from heat and sterilizing solutions.

Prior to boiling mash, assuming the time from commencement of mashing to boiling is not long, these bacteria are not dangerous. Storing the mash for any length of time without heating to temperatures over 180 deg F, will allow the infectious organisms to take over and use up some of the potential yield-producing materials. Distressed, damp, long standing raw materials are probably loaded with bacteria (just as water can be if it is not fresh or is from an impure or untreated source). Backset, the hot liquid separated from the spent mash at the end of distillation, which can be reused as a hot mashing-in liquid, can also harbor organisms if the temperature before use has been allowed to drop. It is necessary, therefore, to heat to boiling as soon after mashing-in as possible.

The greatest infection danger occurs at temperatures below 180 deg F before the addition of yeast at commencement of fermentation.

Therefore, the faster the cooling down is completed, the less danger of infection there is. Cooling down by standing overnight can be *dangerously* infectious. You will get alcohol, but the yield will almost certainly be adversely affected.

**CARE AND CONTROL 0F YEAST**

Once you have reached the correct temperature for fermentation to begin, normally between 85-90 deg F, the yeast should *immediately* be put in, or "pitched", as it is referred to in the trade, before any deleterious microorganisms can take over. Yeast should be slurried beforehand in clean, tepid water (100-110 deg F), *not hot*, to give it a start. If a good vigorous uncontaminated yeast is used, it will commence to "bud" or grow after a period of several hours and will greatly reduce or eliminate any danger from infectious organisms by "smothering" or outgrowing them. In this respect, it is sometimes of benefit to increase the pitching rate in order to increase the "smothering" effect. The number of yeast cells used for pitching should be about 5-10 million cells per ml. (20 drops) or 2-4 lbs. dried active distiller's yeast per 1,000 gallons of mash. The use of yeast food in a bubbling system will also help.

Depending on the starting temperature, there will be a 6-12 hour lag, after which the fermentation will start in earnest. Depending on the original percent of solids in the brew, the yeast will multiply from 5 to 20 times before the end of fermentation.

In the yeast family, Saccharomyces cerevisiae, there are many variants. For example, members of the same family, baker's and brewer's yeast, do not produce alcohol as efficiently as distiller's yeast, which produces the most alcohol in the shortest time and therefore should be used in the production of ethanol.

With good microbiological control, it may be economically worthwhile to maintain an expanded yeast culture supply in a large operation. Expanded means grown from one or

several cultures of yeast cells to a sufficient amount to start a batch. In the event of contamination (defined as more than 1,000 to 2,000 bacteria per 1,000,000 yeast cells) a yeast crop can be cleansed by two methods:

[1] **Acid Wash** -- Recommended for slightly infected yeast, or routine use. To a slurry (0.2% dry yeast basis) of the yeast, add enough tartaric, phosphoric, or sulfuric acid to bring the pH down to 2.2 and let stand for at least 2 hours.

[2] **Acid-Oxidizing Wash** -- Recommended for highly contaminated yeast, where discarding is not practical. To the yeast slurry add 0.75% by weight of ammonium or sodium persulfate. Acidify to pH 2.2 and hold for 2 hours, no more, as a longer time may weaken or deactivate the yeast ... or acidify to pH2.8 and hold for 12-24 hours.

**YEAST WASHING**

**Acid-oxidizing wash** (for infected yeast)

[1] To a slurry of the yeast solution add 0.75% by weight of ammonium or sodium persulfate.

[2] Add sufficient tartaric, phosphoric, or sulfuric acid to bring the pH down to 2.2 and let stand for 2 hours, no more, then pitch.

or [3] After adding the ammonium or sodium persulfate, add sufficient of any of the above acids to bring the pH down to 2.8 and let stand for 12-24 hours before pitching.

The effect is to disable the bacteria without affecting the yeast so that, at the start of fermentation, the yeast can take over before the bacteria have a chance to multiply. If, despite washing, attenuation (and so the efficiency of conversion of sugar to alcohol) is not satisfactory, the original yeast characteristics may have been affected ... and therefore, a fresh supply of yeast is recommended.

For the smaller distiller, a supply of fresh viable dried active distiller's yeast is mandatory. Dried active distiller's yeast will maintain 90-95 % of its activity for up to 6 months if held at 35-55 deg F but can lose 30% of its activity if held at 70 deg F for 4 months, which points out the need for holding at low temperatures and not holding yeast for more than a few months before use.

Pressed yeast, even if refrigerated, should be used in a matter of days as the presence of water causes yeast to lose its activity.

To keep the yeast operating at full potential, the following conditions should be observed:

[1] Keep the fermenting mash below 100 deg F as temperatures over this may weaken the yeast.

[2] Avoid concentrations of iron, copper, and other heavy metals. Iron should not be in too high a concentration in either the water or the raw materials, so iron and steel surfaces should be coated. A small amount of copper is good for the yeast but in large amounts it has

a poisonous effect. Aluminum is without effect ... however, effective cleaning solutions may seriously erode this metal.

[3] Normally, alcohol percentages over 11-12% by volume have an adverse effect on yeast growth but by use of variants of the present strains, now being developed, it should be possible to ferment at higher alcohol levels.

[4] Normally, there is enough protein (amino acids) for yeast growth ... but sluggish, poor yielding fermentations will sometimes require additions of inorganic or organic nitrogen, such as ammonium salts, urea, or amino acids.

[5] Too low pH's from acids and other end products of bacterial growth may not only use up some of the starches and sugars, but may adversely affect the yeast's attenuative powers.

[6] It should be kept in mind that distiller's yeast ferments best at pH's between 4. 0 and 5.0, so the faster the start, the sooner the pH becomes optimum. Also, with lowering of pH, growth of bacteria is discouraged.

**CONTROL OF MICROORGANISMS**

These are best controlled by ensuring that all surfaces, especially those directly in the preparation and fermentation areas, are kept clean and maintained in a sanitary condition. This is made easier by proper design of equipment.

All surfaces should be smooth. This is possible with polished stainless steel, glass-lined or plastic-coated iron, and copper, with the tanks preferably in one piece. Copper must be kept shiny with use of acids (not caustic solutions) to minimize copper pickup. Wood fermenters have been used but are subject to leaking between staves and must be coated with pitch, or bacteria will nest on and below the surface. Use of pitch does not allow use of hot sanitizing solutions.
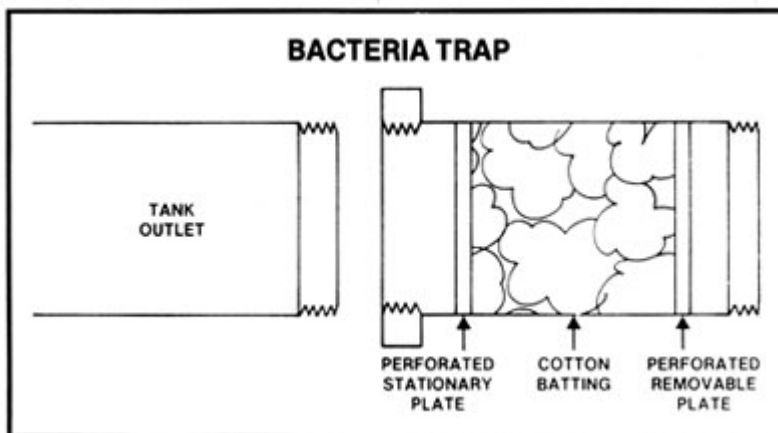


During active fermentation there is always a slight pressure on a closed fermenting vessel which does not allow microorganisms in the air to enter, but *before* and *after* active fermentation there may be air pressure fluctuations in and out of a closed tank. It may then be preferable to trap these organisms in an easily sterilized and connected trap. This bacteria trap contains cotton batting which is easily replaceable and can be sterilized before

each use by placing in an oven for 1/2 hour at 250 deg F. In some geographical locations, contaminants in the air may be massive. In any case, open fermenters could be covered by sterile sheets to prevent microorganisms from falling into the fermenting mash.

As little equipment as possible should be inside all vessels, especially in cooling down and/or in the fermentation area. Here jacketed cooling is preferred but where this is not economically feasible, as few cooling coils as possible should be installed, preferably single large coils which lend themselves to easier cleaning than many small coils. Coils should also be spaced to facilitate cleaning.

**CLEANING**

In all operations, any solids adhering to the inner surfaces of all vessels must be removed between batches or at routine intervals in continuous operations, not only to facilitate heat transfer, but to remove potential pockets of infection. In small operations, the cookers and fermenters may be pressure hosed down after use, then filled with hot (over 180deg F) water or preferably hot 2-3% caustic soda solution, left draining overnight, and again pressure rinsed down before use. The caustic soda solution may be pumped out to a holding vessel, made up to strength, and heated and re-used several times before discarding ... that is when it contains a discernibly large amount of solids. This simple system may be used for open cookers and fermenters. Hot caustic soda solutions should contain surfactants (wetting agents) to improve penetration and should be circulated for 1/2 to 1 hour.

The above system may be used for small and large operations but by far the most efficient method to maintain effective sanitation is use of cleaning-in-place or C.I.P. systems used with closed equipment.



**STORAGE & FERMENTING TANK CLEANING SYSTEM**
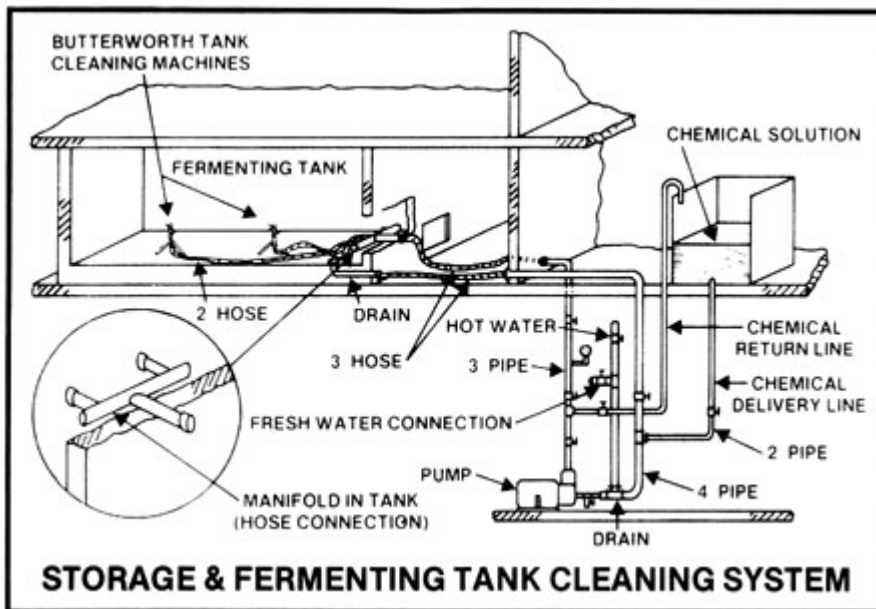
A simple C.I.P. system consists of a caustic solution tank and connections to and from the tank. Pre-rinsing and flushing out after cleaning can be done from a hose connection to the water supply. Sanitation of equipment between batches with chlorine or iodine solutions may be done from a smaller tank. Connections to and from tanks are made with a flexible

hose. With the tank outlet higher than the solution tank, only one pump is needed: the pump used for transferring the mash. It must always be kept in mind that when a heated tank is cooled down, a more than sufficient supply of displacement air must be available so that collapsing of a tank, because of the vacuum formed, cannot occur.

A more sophisticated C.I.P. system is composed of a cleaning water tank, a caustic solution tank with heating device, a sanitizing solution tank, and permanent connections. Two pumps are used, one to supply the cleaning jets and the other for return from the cooker or fermenter. Automated cleaning controls may also be incorporated.

Many such rotary cleaning jets are available on the market. One such cleaning jet is fed with pressures from 50 to 160 lbs. per square inch from the cleaning system tanks, and it very effectively and quickly removes accumulated material from all surfaces by its pattern of impingement on the sides of vessels and on the internal equipment in the fermenter or vessel. Such cleaning jets are normally permanently attached to the ceiling of a tank.

A single portable cleaning-in-place device, incorporating a jet which is introduced through a bottom or top manhole with a plastic dummy door, may also be used to clean one or more tanks in succession. When pumping hot caustic solutions, care must be taken to avoid splashing and all conveying lines and equipment must be maintained in leakproof condition. It is recommended that operators wear face shields and plastic or rubber gloves.

**FOAMING**

When excessive foaming occurs in fermenters, this foam may enter the blowoff or $CO_2$ collection lines. In the course of time, the liquid in the lines will become infected and drip back into the fermenting mash, resulting in a partly or greatly infected mash and lowered yield. This can be eliminated by adding an antifoam solution to the mash at the start of fermentation. Addition of an antifoam results in:

[1] Reduced foam head and clean $CO_2$ blowoff lines.

[2] A smaller yeast ring above the mash at the end of fermentation brought about by the reduced foam head and, therefore, easier cleaning.

[3] The possibility of increasing the fermenting mash volume and still containing it in the fermenter.

The recommended rate of use of an antifoam is 25 parts per million or 1/4 lb. per 1,000 gallons of mash.

**BASIC C.I.P SYSTEM**
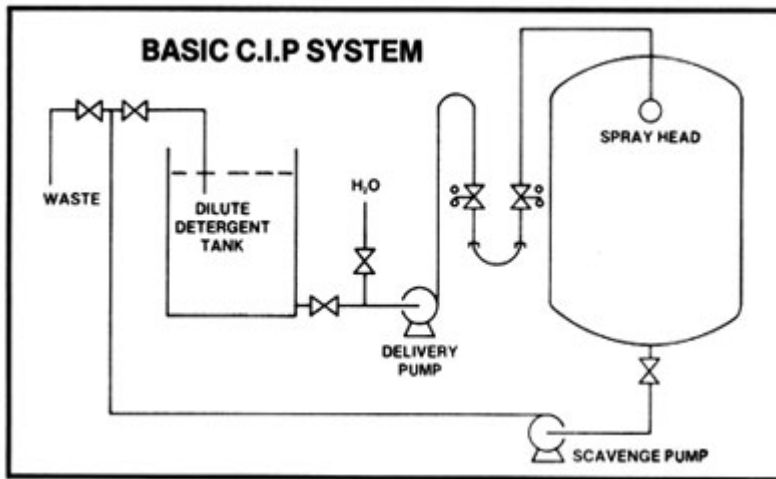
## START OF DISTILLATION

When the reading on your saccharometer has not changed for 6-12 hours, distillation should commence. Otherwise acetic acid may start to convert the alcohol to vinegar. If a layer of carbon dioxide is maintained above the surface of the fermented mash, however, acetic acid bacterial action will not occur or will be minimal.

## SANITIZERS

The following chart indicates the rates of use, etc., and the advantages and disadvantages of the various sanitizers normally used:

**Characteristics of Sanitizers**

**Active Chlorine**

**Recommended Applications and Suggested Concentrations**
Rate: 200 ppm*
1. C.I.P. cleaning
2. Porous surface
3. Stainless steel equipment
4. Water treatment (20 ppm*)

**Advantages**
1. Good germicidal efficiency
2. Nontoxic in recommended dilution
3. Fast
4. Non-film-forming
5. Ease of measurement
6. Ease of use
7. Low cost

**Disadvantages**
1. Toxic at shelf strength

2. Low shelf life
3. Stability in use varies with temperature
4. Poor penetration
5. Highly affected by organic matter
6. Affected by low pH

## Iodophor

**Recommended Applications and Suggested Concentrations**
Rate: 25 ppm*
1. Aluminum equipment
2. C.I.P. cleaning
3. Hand dip, production
4. Hard water
5. High-iron water
6. Stainless steel equipment

**Advantages**
1. Fast
2. Good penetration
3. No or slight formation of film
4. Ease of measurement
5. Ease of use
6. No effect to skin
7. Noncorrosive to stainless steel
8. Moderate cost

**Disadvantages**
1. Germicidal efficiency with vegetative cells only
2. Toxicity in recommended dilution depends on wetting agent
3. Toxic at shelf strength
4. Shelf life varies with temperature
5. Moderately affected by organic matter
6. Affected by high pH

## Quat

**Recommended Applications and Suggested Concentrations**
Rate 200 ppm*
1. Bacteriostatic film
2. Presence of organic matter
3. Porous surface

**Advantages**
1. Excellent shelf life
2. Excellent stability in use
3. Fast
4. Excellent penetration
5. Low effect by organic matter

6. No corrosiveness
7. Moderate cost

**Disadvantages**
1. Selective germicidal efficiency
2. Moderately toxic in recommended dilution ... depends on wetting agent
3. Toxic at shelf strength
4. Forms film
5. Affected by other water constituents
6. Produces high foam

**Acid Sanitizer (Anionic)**

**Recommended Applications and Suggested Concentrations**
Rate: 130 ppm*
1. C.I.P. cleaning
2. Prevention of film formation
3. Hard water
4. Stainless steel equipment

**Advantages**
1. Good germicidal efficiency
2. Excellent shelf life
3. Excellent stability in use
4. Fast
5. Good penetration
6. Non -film -forming
7. Low effect by organic matter
8. Ease of measurement
9. No affect on skin
10. Moderate cost

**Disadvantages**
1. Toxicity in recommended dilution depends on wetting agent
2. Toxic at shelf strength
3. Affected by high pH
4. Produces high foam
5. Corrosive to mild steel

* Parts Per Million (ppm)
1 lb. in 1 million lbs. = 0.01 lb. (0.15 oz.) in 1,000 gallons water (8,300 lbs.). Percentage of active material in a compound must, however, be taken into consideration. Example: If a chlorine compound contains only 30% active chlorine, amount to be used would be per 1,000 gallons water to get a 200 ppm solution: 0.15 oz. X no. of ppm needed (say 200) X 100% -- 30% = 100 oz. or 6 lbs. 4 oz. of the chlorine compound

# Chapter 5

## MOTHER's Mash Recipes for Alcohol Production

Romantic notions of the mountain moonshiner stoking up his still deep in the woods soon fade away when one seriously attempts to produce his or her own "liquid sunshine". For example, though distillation is the fun part of the process, preparing the mash, fermenting it, and using the by-products are the real work -- as well as the keys to running an efficient operation. MOTHER's staffers have been hard at it for the last year -- mixing and mashing -- and we've put together a series of formulas to help take the mystery and confusion out of ethanol fuel production.

The list of raw materials that can be used to make alcohol grows each day. Newcomers -- such as mangel-wurzels (or fodder beets), Jerusalem artichokes, manioc, poplar trees, cellulose waste, and even cattails -- have been added to the list of traditionals, which includes corn, sugar cane, potatoes, rice, and barley. (There are also peculiar -- but potentially fruitful -- food industry byproducts such as waste pastry and stale tortilla chips.)

Despite the variety, every alcohol-producing raw material belongs to one of three groups: starches, sugars, or cellulose. And though the materials in each category are treated differently, the end product is always the same: glucose (or simple sugar), which yeast can easily convert to alcohol. The chart accompanying this section covers most of the major raw materials and how they are prepared.

### STARCHES

All starches are *converted* to sugar with the help of *enzymes*, which are used during the cooking process. These biochemical activators function only at the correct temperature and can be destroyed by boiling. (Enzymes are available from a variety of sources, including THE MOTHER EARTH NEWS, or you can produce your own at home by sprouting barley.) You'll also need to agitate the mash thoroughly and later in the process you'll need to maintain a full rolling boil to bring about complete conversion. (However, if you use a high-speed mixer or pump to create the violent agitation, the boll can be eliminated by holding the mash at 180 deg F for 45 minutes while mixing the brew continuously.)

### SUGARS

Sugar crops -- such as sugar beets, sugar cane, and molasses -- give a greater yield per acre than starch crops as a rule, because the material doesn't require conversion. Unfortunately, sugars don't store well. Processing includes squeezing the juice out of the stalks of plants or leaching it from their tubers. Whichever way you extract the sugar, be sure to sterilize the syrup to discourage contamination. Then, before you add the yeast, the sugar concentration should be adjusted to 18% (using a saccharometer). In addition, yeast food should be

introduced along with the yeast to increase alcohol production.

Cheese whey also contains sugar (in the form of lactose) but is treated somewhat differently from the other sugars, although the end result is still good old ethanol.

**CELLULOSE**

America "produces" 500 million tons of cellulose waste (such as wood chips and paper-processing by-products) a year. This waste, if properly handled, could yield almost 40 billion gallons of ethanol annually. However, cellulose is a hard nut to crack ... in fact, it's made virtually indestructible by a binding agent called lignin. Only in the last few years have researchers begun to develop economical methods for converting cellulose. There are successful approaches based on both enzymatic and acidic conversion. Cellulase (the enzyme that converts cellulose to glucose) was isolated by the U.S. Army in 1945. Since then, that enzyme has been improved, and though it is now fairly expensive, it will be available at reduced prices as demand increases.

Another method of converting tough cellulosic fiber involves forcing cellulose pulp (under high temperature and pressure) into a short -- but intense -- acid bath. The acid immediately converts the cellulose to glucose, but must be removed quickly to avoid further processing and the *destruction* of the glucose. Researchers at New York University and the University of Pennsylvania have developed still other methods -- very effective extrusion systems -- but they're well beyond the pocketbook of the small-time operator.

The following chart is meant to serve as a rough guideline to mashing. Once you start your own operation, you'll probably discover shortcuts that will allow you to use less heat and/or enzyme powder than the chart indicates. In addition, you'll need to look into proper mash testing and fermentation procedures, as well as the best ways to handle and sell your by-products.

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**STARCHES**

### Wheat, Corn, Rye, Barley, Milo, Rice, Cattails

**Preparation**: Grind to a fine meal using a 3/16" screen on a hammermill; add 30 gal. water per bushel.

**Additives (Enzymes)**: Add 3 spoons mash cooking powder* per bushel.

**Preboil**: Raise temp. to 170 deg F for 15 min.; agitate vigorously.

**Cook**: Hold at rapid rolling boil for 30 min.

**Cool Down**: Cool with coil to 170 deg F; add 3 spoons mash cooking powder*; agitate for 30-60 min.

**Culture**: Reduce temp. to 90 deg F; add 6 spoons mash fermenting powder*; agitate for 10 min.; cover.

**Comments**: Results: 9% alcohol. Wheat, rye, and barley may cause foaming: Use Low-FoaM** or mix with cornmeal.

## Pastry Waste

**Preparation**: Break apart, do not grind; add 30 gal. water per 55 lb.

**Additives (Enzymes)**: Add 3 spoons mash cooking powder* per bushel.

**Preboil**: Raise temp. to 170 deg F for 15 min.; agitate vigorously.

**Cook**: Hold at rapid rolling boil for 30 min.

**Cool Down**: Cool with coil to 170 deg F; add 3 spoons mash cooking powder*; agitate for 30-60 min.

**Culture**: Reduce temp. to 90 deg F; add 6 spoons mash fermenting powder*; agitate for 10 min.; cover.

**Comments**: Results: 9% alcohol. Remove oil (if content is high) before fermentation.

## Potatoes, Cassava (Manioc), Taro

**Preparation**: Slice, crush, or break apart; add 10 gal. water per 100 lb., or as little water as possible.

**Additives (Enzymes)**: Add 5 spoons mash cooking powder* per 100 lb.

**Preboil**: None.

**Cook**: Raise temp. to 180 deg F for 30 min., agitate vigorously.

**Cool Down**: None.

**Culture**: Reduce temp. to 90 deg F; add 10 spoons mash fermenting powder*; agitate 10 min.; cover.

**Comments**: Results: 9% alcohol.

**SUGARS**

## Sugar Beets, Mangel-wurzels (Fodder Beets), Artichoke Tubers

**Preparation**: Slice or crush; add 10 gal. water per 100 lb., or as little as possible.

**Additives (Enzymes)**: Acid may be added to beets to reach pH 5.0.

**Preboil**: None

**Cook**: Raise temp. to 190 deg F for 20 min.; agitate.

**Cool Down**: None

**Culture**: Reduce temp. to 90 deg F; add yeast; agitate 10 min.; cover.

**Comments**: Results: 7% alcohol. Beets may require some molasses yeast food**.

## Sweet Sorghum, Cane, Artichoke Stalks

**Preparation**: Squeeze out juice.

**Additives (Enzymes)**: None.

**Preboil**: Raise temp to 180 deg F for 10 min. to sterilize.

**Cook**: None.

**Cool Down**: None.

**Culture**: Reduce temp. to 90 deg F; add water to make 18% sugar; add yeast; agitate 10 min.; cover.

**Comments**: Results: 9% alcohol. Molasses yeast food** may be added to increase yield.

## Molasses, Sugar Products

**Preparation**: None.

**Additives (Enzymes)**: Molasses from beets may need neutralization with acid.

**Preboil**: If necessary, raise temp to 180 deg F for 10 min. to sterilize.

**Cook**: None.

**Cool Down**: None.

**Culture**: Reduce temp. to 90 deg F; add water to make 18% sugar; add yeast; agitate 10 min.; cover.

**Comments**: Results: 9% alcohol. Use molasses yeast food** to insure proper yield. High NaCl content may interfere with fermentation.

## Cheese Whey

**Preparation**: None.

**Additives (Enzymes)**: None.

**Preboil**: None.

**Cook**: Raise temp. to 210 deg F for 10 min. to sterilize.

**Cool Down**: Separate protein with NH40H; adjust pH to 5.0.

**Culture**: Reduce temp. to 90 deg F; Add Kluyveromyces fragilis or Torula cremoris yeast. Fermentation takes only 12 hrs.

**Comments**: Results: 3% alcohol. Aeration may increase yield. Whey may be used as liquid with corn, but lactase must be added for conversion.

**CELLULOSE**

**Preparation**: Chop straw or soft material. Wood must be fine sawdust or treated with 400 deg F steam for 2 hrs.

**Additives (Enzymes)**: Add a 1% caustic solution; hold at 140 deg F for 3 hrs. to separate lignin.

**Preboil**: Draw off lignin, neutralize.

**Cook**: Cook at 140 deg F for 4 hrs. in 1% solution of Biocellulase**.

**Cool Down**: Remove sugar liquid.

**Culture**: Reduce temp. to 90 deg F; add brewer's yeast; agitate for 10 min.; cover.

**Comments**: Results: 2.5% alcohol. Acid hydrolysis is an alternative but expensive method.

\* Available from THE MOTHER EARTH NEWS, P.O. Box 70, Hendersonville, N.C. 28791.
\*\* Available from Biocon, Inc., Dept, TMEN, 261 Midland Ave., Lexington, Ky. 40507.

# Important! Read Before Making Mash

**MOTHER's New, Improved Three-step Mashing Recipe**

**MILLING**

Shell, clean, and grind a bushel of corn (56 pounds) into a fine meal of about the size needed for livestock feed. Use a 3/16" screen on a hammermill (or a similar grinder) to eliminate any large starch grains. However, *do not* grind the corn into a flour. If the grains are too small, it'll be very difficult to separate the solids from the mash, with a resulting loss of feed grain *and* a miserable mess inside your still.

**STEP ONE: COOKING**

Start with 30 gallons of water in your cooker, and then add the cornmeal slowly, to prevent lumping. Once the meal is stirred in, stir in 3 level measuring spoons of MOTHER's Alcohol Fuel Mash Cooking Enzyme (mixed in water) and bring the mixture up to 170 deg F (77 deg C). Hold the mash at this temperature for 15 minutes, stirring vigorously throughout the process. Then bring the liquid to a rapid rolling boil and hold it there for 30 minutes more. Be particularly careful that the mash doesn't stick to the bottom of the cooker. (For batches larger than a bushel, we recommend using an automatic agitator, which should spin at 30 to 45 RPM.)

**STEP TWO: CONVERTING**

Using the cooling coil, bring the temperature of the mash down to 170 deg F (77 deg C), and add 3 more measuring spoons of MOTHER's Cooking Enzyme (mixed in water). Keep the mixture at this temperature for 30 minutes, while you agitate it constantly.

**STEP THREE: FERMENTATION**

Start cold water flowing through the cooling coil again, to reduce the temperature to 90 deg F (32 deg C) as rapidly as possible. Once the mash has cooled, add 6 measuring spoons of MOTHER's Alcohol Fuel Fermentation Powder (a complex glucoamylase, yeast, *and* denaturant combination), stir the mash for 10 minutes, and then cover the tank.

While it's fermenting, the mash must be kept between 85 and 90 deg F (29-32 deg C). Consequently, you may need to cover the tank with wet burlap in hot weather, or insulate it during colder months. At this temperature, the mash will reach maturity in 2-1/2 to 3 days.

**TESTING PROCEDURES**

**Using a saccharometer**: At the beginning of fermentation, the specific gravity of the mash should be about 1.080 (8 to 12% alcohol potential), while by the end of the process it will have dropped to 1.007 or less (0 to 1% alcohol potential). Once the specific gravity has remained constant for 6 hours, you can be sure that the mash is ready for distillation. But to double check that complete conversion has been attained, both a standard starch test (using iodine) and a glucose test (using glucose test strips available at drug stores) must read negative.

**YOU MUST HAVE A COOLING COIL**

To make a cooling coil, just wind a 30-foot length of soft copper tubing around a large pipe (6 inches, or more, in diameter), and add garden hose adapters at each end. Attach the hoses to the tube, and drop the assembly into your cooking vat.
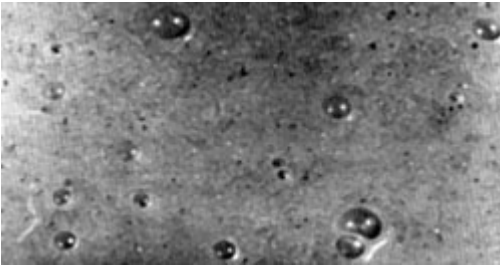
Properly fermenting mash.



Saccharometer floating in fermenting mash.

# Preparing a Mash From Saccharide-rich Materials

Alcohol can easily be produced from sugar-bearing crops instead of the standard complex carbohydrates such as corn or grain. For example, sugar cane, sugar beets, or fruit can be processed -- by crushing the raw material to extract the juices -- to form a perfectly acceptable mash. Furthermore, the more refined examples of sacchariferous compounds -- such as raw sugar or molasses -- can also easily be turned into a high-yield fermentation material.

**SUGAR CONCENTRATION**

Once the sugar juices have been extracted -- in a cider press, for example -- the sugar concentration in a potential mash must be adjusted to suit the growth of yeast: between 14 and 18%. Such a concentration should be measured with a Balling hydrometer -- sometimes called a saccharometer -- at 60 deg F. Excessively high sugar concentrations (which inhibit yeast growth by promoting more rapid alcohol fermentation) should be diluted with water, whereas liquids with low readings (which are wasteful of fermenting space *and* the energy used in distillation) should be augmented with a concentrated sugar.

(EXAMPLE: Molasses which contains 60% sugar by weight should be diluted with three parts water to form a 15% solution.)

**pH ADJUSTMENT**

The pH should be maintained between 4.0 and 4.5 to give the yeast a healthy environment for growth, while retarding bacterial formation. Sulfuric acid is the most common and least expensive substance available for lowering pH, though lactic acid does the same job, while restricting the growth of butyric acid bacteria. It's also possible to inoculate the mash with lactic acid bacteria before fermentation to provide a substitute for the acid itself.
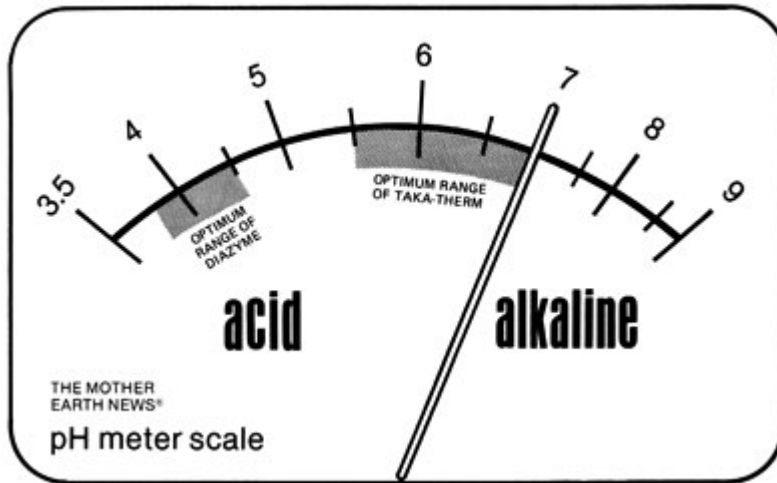


**ADDITION OF NUTRIENTS**

Some of the more sophisticated distillers actually go so far as to augment their sugar-heavy mashes with nitrogen and phosphorus, two nutrients which sugars tend to be deficient in. A variety of ammonium salts -- such as ammonium sulfate or phosphate -- can be added to encourage a healthy yeast culture. Such a procedure is usually more complicated than the backyard alcohol producer should consider, but -- in the event of yeast growth problems --

some cautious experimentation might be in order.

**MIXING A YEAST STARTER**

For every 100 gallons of mash remove 1 quart of solution and add 2 ounces of dry activated yeast to it. Then allow the inoculated wort -- as it is called in brewing technology -- to incubate for 60 to 90 minutes while holding the temperature between 77 and 95 deg F. This technique promotes the rapid growth of yeast and speeds the entire fermentation process.

**PITCHING THE WORT**

Combining of the yeast-inoculated mixture with the main mash is called "pitching". There are several ways in which the yeast starter can be added to the fermentation tank, but the most important aspect of the process is keeping the mash well aerated. One technique consists of using baffles which the mash flows over as it enters the tank. The splashing introduces air to the wort, which encourages a thriving yeast population. Another approach is to place a compressed air line -- with a bacterial filter -- in the bottom of the tank. However, for the small producer a human-powered stirrer (a canoe paddle, for example) will be satisfactory. (Of course, once the yeast population is thoroughly established, aeration must be halted to allow the microbes to adapt to the anaerobic conditions which result in maximum production of alcohol.)
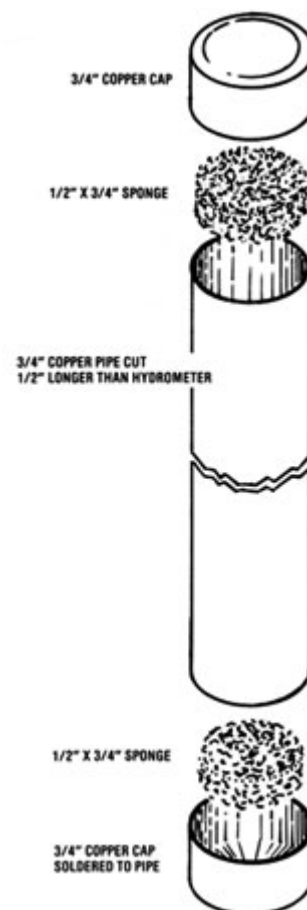
**TEMPERATURE CONTROL**

Since the temperature of the fermenting mash should -- ideally -- be around 85 deg F, the pitching temperature will be determined by the ambient air temperature. For example, if the outside mercury is quite high, the initial temperature of the mash should be in the low seventie, and it may be necessary to cool the wort as the yeast begins to produce warmth of its own. On the other hand, low air temperature dictates an introductory level of 85 to 90 deg F. (Note: Any temperature over 90 deg F will both evaporate alcohol and encourage bacterial growth.)

**COMPLETION OF FERMENTATION**

Assuming that you have properly controlled the sugar concentration, the pH, the yeast nutrition, and the temperature, fermentation should be completed in about 50 hours. Activity will lessen in the mash, and the cap on top of the mixture will break apart and sink once the yeast has done its job.

# A Handy Hydrometer Jacket

A hydrometer is actually quite a delicate instrument, and will easily break if handled roughly. By making one of these protective jackets, you'll not only guarantee that your hydrometer will be in one piece when you're ready to use it, but also reap a second



3/4" COPPER CAP

1/2" X 3/4" SPONGE

3/4" COPPER PIPE CUT
1/2" LONGER THAN HYDROMETER

1/2" X 3/4" SPONGE

3/4" COPPER CAP
SOLDERED TO PIPE

benefit: The sturdy cylinder will serve as a vessel to "float" your proof-measuring tool in while you take alcohol strength readings.

To make the protective device, merely cut a length of 3/4" rigid copper pipe about 1/2" longer than the hydrometer itself, then locate two 3/4" copper pipe end caps. Solder one of the caps to one end of the tube, then cut a small piece of sponge, inner tube, or neoprene stopper to fit snugly into the bottom of this permanently plugged end (shove the "shock absorber" into the cylinder with a long pencil or a dowel). Now just drop your instrument into the tube, and cap the open end. If you wish, you can also glue a piece of padding inside the removable tip. This will just about guarantee that no matter how roughly you handle the copper jacket, its delicate cargo will remain unscathed. To use the cylinder as a vessel, just uncap it, fill it nearly to the brim with your alcohol product, and "float" the hydrometer in the liquid. The proof strength will be indicated on the scale stamped on the side of the



Boiling Point Diagram for Ethanol/Water at 1 atm.
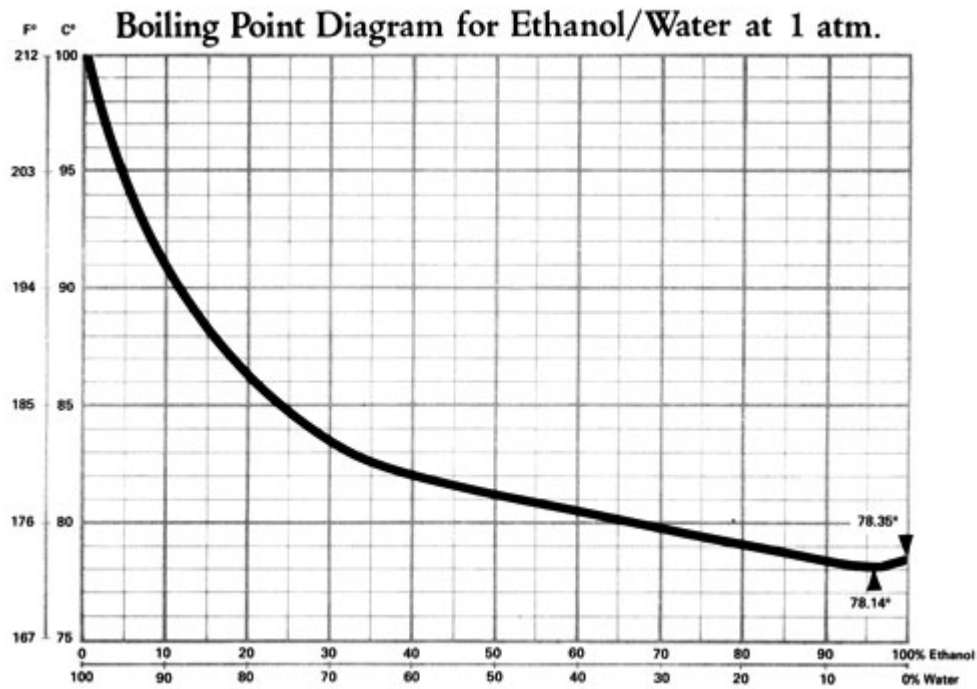
instrument.

# Chapter 6

## Distiller's Feeds

The nutrients in the mash residue (after fermentation) are concentrated threefold. (This can be determined by weight ratio.) Yeast cells and metabolites formed during the fermentation also add to the highly nutritious and palatable feed ingredients. The product is called distiller's feeds, a mixture which is high in protein and rich in water-soluble vitamins and minerals. Because the fermentation process removes only starch, all the remaining digestible nutrients are left in the distiller's grain. In addition, some unidentified nutrients called GFF (grain fermentation factors) help to stimulate growth and rumen function in cattle.

There are four types of distiller's feeds produced in the industry. They are:

--- Distiller's Dried Grains with Solubles
--- Distiller's Dried Grains
--- Distiller's Dried Solubles
--- Condensed Distiller's Solubles.

(The blank space ahead of each feed would be filled in with the name of the predominant grain from which each is derived, eg, Wheat Distiller's Dried Grains.)

Distiller's grains are the solids that are separated from the spent stillage (removed prior to -- or right after -- fermentation). The solubles are the water-soluble nutrients and the fine solid particles that have escaped separation.

### PROXIMATE TOTAL DIGESTIVE NUTRIENTS OF DISTILLER'S FEEDS

| | CORN | | | MILO |
|---|---|---|---|---|
| | Dist. Dried Grains | Dist. Dried Solubles | Dist. Dried Grains With Solubles | Dist. Dried Grains |
| Moisture % | 7.5 | 4.5 | 9.0 | 10.0 |
| Protein % | 27.0 | 28.5 | 27.0 | 34.0 |
| Fat % | 7.6 | 9.0 | 8.0 | 8.0 |
| Fiber % | 12.8 | 4.0 | 8.5 | 13.0 |
| Ash % | 2.0 | 7.0 | 4.5 | 4.0 |

Source: Distiller's Feed Research Council, Cincinnati, Ohio.
NOTE: The remaining percentages are composed of bulk (cellulose and other nitrogen-free extracts).

Distiller's feeds should not be fed as a whole or complete ration. They should constitute no more than 30% (wet or dry) of the total when mixed with other feeds. Since each farmer has his own particular feed stocks, he should consult with the county livestock agent in his

area to determine the best formulation for his particular livestock needs.

# By-product Utilization

The by-product, stillage, from ethanol production is a thin slurry containing about 10% solids. Most distilleries dry this product and market it as distiller's dried grains with solubles (DDGS). The dried product is a well-known feed ingredient generally used by feed manufacturers.

There are disadvantages to the use of stillage:

- The weight of material which is transported consists mostly of water.
- Animals are limited in their ability to consume water.
- The wet product deteriorates rapidly and should be fed within one to two days to avoid large nutrient losses.

The major advantage of using stillage is the elimination of the costs for the equipment and energy used to process DDGS.

Dried grains can be transported economically over larger distances and are much simpler for feed manufacturers and farmers to handle.

The price of distiller's dried grains with solubles will be less than the price of soybean meal because of its lower 27% protein content compared to 44 % for soybean meal. The price of DDGS will be determined by the prices of protein feeds such as soybean meal and energy feeds such as corn. The figure on the following page shows the relationship between the prices of DDGS, corn, and soybean meal at Chicago during the past 10 years. These price relationships would indicate relative prices if DDGS were sold as a feed ingredient on the wholesale feed ingredient market. The January 1979 Chicago price of DDGS was about $145 per ton.

For use on farms, stillage would compete with other protein sources which the farmer might use. Few farmers can purchase and use bulk carloads of soybean meal or other protein ingredients. Farmers who purchase protein supplements from feed manufacturers pay about 50% above bulk wholesale soybean meal prices for the soybean meal component. For formulated rations, the wholesale price of soybean meal was increased by 50% above the Kansas City price to compare the value of stillage at the farm level.

Stillage would probably be limited to use in beef, dairy, and swine rations. Two major assumptions were made in formulating appropriate rations:

- Liquid in the ration should not exceed four times the weight of the solids content.
- Feeds were formulated to use stillage as a protein source rather than a source of energy except for the heavier steer finishing ration where supplemental protein is ordinarily supplied by urea.

The value of stillage for various rations was:

Calves, 550 lb. - $.066-$.083/gallon
Steers, 770 lb. - $.04/gallon
Dairy Cows - $.079/gallon
Swine - $.06/gallon
With normal feeding practice the amount of stillage which could be consumed by one animal would be:

Calves, 550 lb. - 6.3 gallons/day
Steers, 770 lb. - 9.2 gallons/day
Dairy Cows - 7.2 gallons/day
Pigs, 60 lb. - 1.2 gallons/day

When stillage is used in the rations of high production animals it must be available every day. The texture and taste of stillage rations is very distinct and animals would reduce their consumption with frequent formula changes. Small farm stills which produce stillage intermittently would have to restrict its use to low production animals, e.g., dry cows, or provide refrigeration or other means of preservation.

Transportation costs will be high for stillage compared to other feeds because about 90% of a load is water.

Transportation costs for feed delivery trucks are now about $1.00 per mile or $2.00 per mile on a round trip basis. A five-ton load of stillage would have a value of $84 when priced at $.07 per gallon. On this basis, if a truck delivered the stillage a distance of 42 miles, the transport costs would be equal to the value of the stillage. Similarly, a 20-ton load would have a maximum delivery distance of 168 miles, i.e. at a distance of 168 miles the value of the stillage would be zero.

The two primary by-products obtained during the production of ethanol by fermentation of agricultural products are the residue, commonly utilized as an animal feed, and carbon dioxide.

Price relationships of DDGS, and stillage, to corn and soybean meal based upon Chicago historical prices
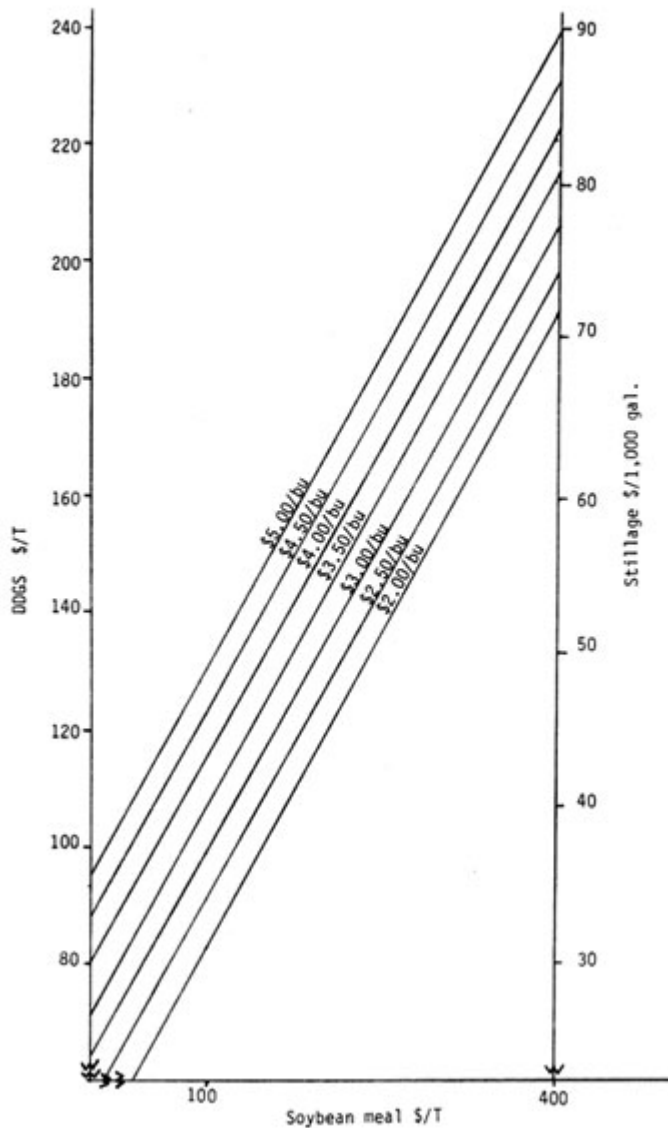
# Animal Feed By-product

Reprinted from Small Scale Alcohol Production, The United States Department of Agriculture, Washington, D.C. 20250.

**FORMS OF GRAIN BY-PRODUCTS**

Distillery by-products from grain are a high quality ingredient for animal feed. Four products are commercially available and have been defined by the American Feed Control Officials.

**Distiller's Dried Solubles** is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing the thin stillage fraction

and drying it by methods employed in the grain distilling industry. The predominating grain must be declared as the first word in the name (Proposed 1963, Adopted 1964).

**Distiller's Dried Grains** is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by separating the resultant coarse grain fraction of the whole stillage and, drying it by methods employed in the grain distilling industry. The predominating grain shall be declared as the first word in the name (Proposed 1963, Adopted 1964).

**Distiller's Dried Grains with Solubles** is the product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing and drying at least 3/4 of the solids of the resultant whole stillage by methods employed in the grain distilling industry. The predominating grain shall be declared as the first word in the name (Proposed 1963, Adopted 1964).

**Condensed Distiller's Solubles** is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing the thin stillage fraction to a semi-solid. The predominating grain must be declared as the first word in the name (Proposed 1969, Adopted 1970).

Because of the high energy requirements for drying products such as distiller's and brewer's by-products there have been continuing efforts to utilize undried products. Various brewers have marketed wet grains within reasonable distances of the brewery, primarily for feeding ruminants. The untreated distiller's by-product (stillage) has presented greater difficulties because of its higher liquid content; distiller's stillage is approximately 90% water compared to 70% water in brewer's wet grains. The reason for this difference is that brewers remove as much of the liquid as possible from the solid feedstock after enzyme treatment and this liquid (wort) is then fermented. Distillers simply distill the alcohol out of the fermented solid-liquid mixture.

Distillers could remove the solids fraction from the stillage and sell a wet grain product, but a problem of disposing of the liquid would remain. Too, a significant loss of nutrients (particularly soluble protein) in the liquid fraction would occur.

The equipment and operating costs for drying stillage is high, but for large distillers the advantages of marketing a dry product (or condensed solubles) are enough to overcome the high production costs. The major advantages of dry products include the following:

- Microbial decomposition is prevented in dry products. Wet products decompose rapidly and must be fed within one to two days in warm weather. Some preservatives might be used to increase the allowable storage life, but insufficient research has been done to determine the types of preservatives and their overall economics. Refrigeration could be used to extend storage time, but operating costs would be high; however, refrigeration costs would be lower than drying costs.
- The transportation costs for marketing dry products are reduced by eliminating the transport cost for water.
- Feed manufacturers are usually better equipped to handle dry ingredients.
- Farmers are usually equipped to feed dry feeds rather than slurries.

## QUANTITY OF ANIMAL FEED BY-PRODUCT

About 16 pounds of by-product (dry weight) are produced from each bushel of corn. About 6 pounds are realized per gallon of 200-proof alcohol.

If the by-product is not dried but utilized as stillage, then the same equivalent solid materials will be produced. The concentration of solids in the stillage will depend upon the operation of the cooking and fermenting process. In normal operations, about 30 gallons of mash will be used per bushel of grain. After removal of the alcohol, there will be about 27 gallons (224 lb.) of stillage containing about 16 pounds of solids. The quantity will be reduced slightly if some of the liquid from the stillage is set back for use in a succeeding batch. The amount of liquid which may be set back has not been accurately determined but may be as much as 50% of the liquid. A stillage can probably be produced which will be more concentrated than the normal stillage. With maximum (50%) setback there would be 14 gallons (116 lb.) of stillage with 12% solids per bushel of corn.

A large increase in fuel alcohol production would lead to a change in the supply of vegetable protein supplement available for animal feeds. A major increase in alcohol production, say to the point of utilizing one billion bushels of corn per year, would increase the DDGS supply from the present 450,000 tons per year to 8,000,000 tons per year. Obviously this would have a significant effect on the supply and price of vegetable protein supplements. However, this diversion of corn would be equivalent to about 10,000,000 acres of corn production at about average yields. Such a diversion of corn supplies could change the relative corn-soybean acreages to reduce soybean supplies, and overall protein supplies might not be affected greatly. An additional 8,000,000 tons of DDGS would represent a very significant increase in that supply but a much smaller percentage of increase in the overall supply.

## STILLAGE AS A FEED INGREDIENT

In spite of the advantages of dry products, stillage is probably the preferred form of disposing of by-products from small stills. The quantity of stillage should be small enough to allow it to be fed within a reasonable distance from the point of production.

Since stillage feeding has not been widely practiced, there is limited research or documented use-data on which to base recommendations for feeding from either nutritional, animal performance, or technical (handling) standpoints.

The Kentucky Agricultural Experiment Station (Wilford, 1944 and Garrigus, 1948) reported some research on stillage feeding during the 1940s. This research was directed toward maximum utilization of stillage rather than a most efficient use of its nutrient elements.

In general, the Kentucky recommendations were that adult beef animals should be limited to 40 gallons of stillage per day and swine to 4 gallons per day. Beyond these limits, urinary and other animal problems arose. When stillage is fed at these levels, animals are being forced to consume water at an above normal level and protein, particularly, is supplied in excessive amounts.

## ANIMAL CONSUMPTION OF DISTILLER'S BY-PRODUCTS

| Feed | Production rate | Feed kg./day | Feed lb./day | DDGS lb./day | Stillage, gal./day 10% solids | 20% solids |
|---|---|---|---|---|---|---|
| **Type of animal** | | | | | | |
| 550 lb. calf (hay ration) | 2 lb./day gain | 6.2 | 13.7 | 5.8 | 6.3 | 3.1 |
| 770 lb. steer | 2.8 lb./day gain | 8.8 | 19.4 | 8.5 | 9.2 | 4.6 |
| 1,300 lb. cow | 50 lb./day (3.5% milk) | 16.8 | 37.0 | 6.6 | 7.2 | 3.6 |
| 60 lb. pig | 1.3 lb./day gain | 1.5 | 3.3 | 1.1 | 1.2 | .6 |
| Pullet, age 3.7 weeks | | .057 | .13 | .13 | NA | NA |
| Pullet, age 7.5 weeks | | .1 | .22 | .22 | NA | NA |

NA = not applicable

# More Information On By-product Utilization

Reprinted from Small-Scale Fuel Alcohol Production. The United States Department of Agriculture, Washington, D. C. 20250.

Stillage and wet grains must be used in a relatively short time to avoid excessive microbial decomposition. Little research has been reported, but a recent publication by Stechley, et al. (1979) reports on the effect of storage on brewer's yeast slurry. Slurry was stored at 4 deg, 21 deg, and 30 deg C for 35 days. Storage at 4 deg C showed small changes in chemical composition during the 5-week period. Storage at 21 deg C (70 deg F) showed significant changes in the first seven days; 15% of the dry matter was lost, and true protein dropped from about 30% to 20% (a 30% loss) on a dry matter basis. At 30 deg C the dry matter loss was about 16% and protein dropped from about 30 to 13%. Total crude protein increased slightly as dry matter decomposed, but the true protein was converted to ammoniacal form. The protein conversion would have little effect on ruminants, but it would be undesirable for monogastrics.

Miller (1969) evaluated the losses when distiller,'s wet grains were ensiled. Dry matter losses ranged from 11 to 21%, but the loss of soluble carbohydrates was high in relation to other lower value fractions such as fiber. Removal of spoiled material which should not be fed was difficult.

The conclusion to be reached is that stillage and/or wet grains must be fed within one or two days to avoid significant nutrient loss or be given special treatment, probably refrigeration. Although this problem is not insurmountable, it will be a significant problem, particularly for the smaller farm-size still which may not distill a batch every day.

Stillage or wet grains have a distinct odor and cannot be added to or removed from rations randomly without an adverse effect on feed consumption and animal performance. This will be a very important factor with dairy cattle. Also, with dairy cattle, the material may affect milk flavor; hence, it is probably best to feed just after, rather than shortly before, milking.

Possible physical forms of by-products which appear practical for small plants include:

- stillage which is probably the only practical form for disposing of by-products from

farm stills.
- wet grains from medium-sized operations.
- condensed solubles from medium-sized or large operations.
- distiller's dried grains or distiller's dried grains with solubles from medium-sized or large operations.

## SOME UNIQUE PROBLEMS OF STILLAGE UTILIZATION

Stillage will produce rations of unique physical form, odor, and palatability. High production animals must be kept constantly on such rations to maintain the feed consumption levels required. Frequent interruption of supply would drastically reduce the value of the stillage; consequently, if frequent interruptions occur, perhaps due to shutdown for maintenance, then it might be necessary to maintain refrigerated supplies for emergency use.

Rapid loss of nutrients due to microbial action will require that stillage holding time be limited; it should be fed within 24 hours during summer months.

Handling and feeding stillage during very cold weather will present some new and unique problems because of freezing. It will be necessary to feed twice a day under many conditions where feed bunks are located outside in Northern regions.

Feed bunks will have to be capable of holding feeds containing large amounts of liquid. Concrete bunks would probably be adequate with some sealing at joints. The dry feed could be placed in the trough and then the stillage placed on top. It may be possible to mix roughage and stillage in the normal mixer-feeder wagons.

Slurry feeding equipment has been developed for swine feeding in Europe and should be available with little modification.

Stillage and wet distiller's grains have not been defined by the American Feed Control Officials. This will be necessary before they can be widely marketed.

One potential use of condensed solubles was considered but not investigated. Liquid feed supplements for beef are becoming increasingly popular. Usually they are molasses-urea mixtures, but some natural protein would be preferred by many nutritionists. Some feed manufacturers are using large quantities of condensed solubles in their liquid feed formulations.

## OTHER BY-PRODUCTS

The foregoing discussion focused on grain distiller's by-products. Although certain characteristics of the by-products produced from other feedstock differ, the analysis of their utilization would be analogous. Distinct properties of potato and sugar crop by-products are delineated below.

## POTATO DRY BY-PRODUCT

The by-product of potatoes should contain a higher ash content by a factor of at least 5

compared to that of corn distiller's grains. The protein content should be slightly less and the fiber content about equal to those for corn distiller's grains. Amino acid data are not readily available. B-vitamin composition should be about the same since this originates from the yeast. Because of the lower protein, the material would have a lower value than DDGS.

## SUGAR BEET BY-PRODUCT

Sugar beet pulp is a well-defined commercial feed ingredient which is presently priced in Chicago at $130 per ton compared to $145 per ton for distiller's dried grains. If the solubles were condensed, the price should be about the same as for brewer's dried yeast which is now priced at about $400 per ton in Chicago; hence, the overall value of these by-products should be greater than that for grain by-products.

## SUGAR CANE BY-PRODUCTS

The plant residue from sugar manufacture (bagasse) is of relatively low value; some is used for the manufacture of building board but most is used for boiler fuel. Its yeast residue could be recovered and should have the same value as other dried yeast.

## SORGHUM BY-PRODUCTS

The plant residue may have a slightly higher feeding value than sugar cane but no nutritional data have been found. The yeast by-product would be valuable.

## CARBON DIOXIDE

### Quantity and quality

Carbon dioxide is produced in about equal weights with alcohol during the fermentation process. One pound of carbon dioxide has a volume of 8.1 cubic feet. A million-gallon-per-year still would -- therefore -- produce approximately 21,000 pounds of carbon dioxide per day, having a volume of 170,000 cubic feet.

The gas from the fermenters would be relatively pure carbon dioxide (and water vapor) if the fermenters were relatively tight and would be suitable for many uses. Keeping a slight positive pressure inside the fermenter would exclude air.

# Chapter 7

# Still Designs

## How the Distillation Process Works

Though there are many different designs used for alcohol-producing stills, every installation operates on the same set of principles. These general theories of distillation are impressively complicated, but -- fortunately -- once you understand a few of the basics, you should know enough to design and build your own ethanol plant.

Distillation is the separation of a liquid from other liquids or solids. Because each substance has a fixed rate of vaporization (which varies with heat) -- determined by the pressure the vapors develop in a closed container to achieve equilibrium with the fluid -- one liquid can be separated from other matter by carefully controlling the heat applied to the mixture. Alcohol's vapor pressure happens to be higher than water's, so ethanol's vapor pressure reaches an equilibrium with atmospheric pressure (the point at which a liquid boils) before water's vapor pressure does.

But when water and alcohol are mixed, the boiling point of the combination falls between the boiling points of the separate constituents (water will boil at 100 deg C; alcohol boils at 78.3 deg C). It is the ratio of the water to alcohol which determines the actual temperature of boiling for the mixture. More alcohol lowers the boiling point and less raises it -- so you can see that the temperature of the mash will rise throughout the distillation run as the alcohol is drawn off.

Because alcohol has a higher vapor pressure than water, the vapors given off by boiling a combination of the two will have a disproportionately large share of alcohol. For example, in a mash that has 10% alcohol and 90% water, the vapors released will be about 80% alcohol. To increase that percentage (and raise the proof), the vapors must be condensed and revaporized. Each redistillation raises the proof of the batch further until the liquid reaches an azeotropic condition at 95.57%. The process of enrichment (or rectification) is halted by the balance (azeotropy) of alcohol and water in the vapors.

During simple pot distillation, the proof of the product at the beginning of the run is high ... but as the proof of the mash drops, the proof of the distillate also declines. In fact, the depletion in proof strength is geometric.

Moonshiners can manage to increase proof strength by adding "thumper kegs" or doublers to their stills. This involves running a line from the pot down into a secondary barrel before it continues to the condenser. Vapors from the pot condense in the doubler and raise the heat of low-proof distillate in the bottom of the tank to the boiling point. High-proof alcohol vapors are then released. Several doublers can be added in series to boost alcohol content.

Though "thumper kegs" are sound in principle and do raise proof, they are very energy-inefficient. Still designers discovered that the enrichment process could be more effectively accomplished by stacking one still atop another. This technique is called the pipe column.

The first column still was a form of what is called "batch run bubble cap plate" design. The pipe column was divided into sections by plates, each of which had a hole in the middle with a short section of pipe (known as a riser) extending upward into the column directly over the hole. An inverted cup or cap was placed above the riser so that it didn't block the pipe's opening. Then another pipe (called a downcomer) was added, extending from a half-inch above one plate, through the next plate up, and ending one inch above that plate. Eight or more of these plates were used in a still.

Before operation, the column was filled with beer so that each plate was covered to the top of the downcomer. When heated, the vapors would rise from the bottom plate and be forced into the liquid above the next plate by the caps. The heat transferred to the liquid by condensation raised the temperature of that level's fluid to boiling, so that a higher-grade vapor was emitted. By the time the vapors reached the top of an eight-or-more-tiered column, the proof was very high. While the vapors rose, the distilled water descended through the downcomers. Hence the name "countercurrent stream" was developed. The countercurrent method was basically just a more efficient simple pot with doubler design -- which still suffered from rapidly declining proof toward the end of the run.

The next design innovation was the development of a continuous-run still, which could take off a steady proof product throughout the run. Early designs had the mash introduced after being preheated to near saturation point midway in the column. At the bottom of the column a reboiler was used to add pressure and heat to the system. These two sources of heat served to equalize the distillation conditions throughout the column. Each plate had the right amount of heat for the percentage of water and alcohol present.

As beer was added to the column, the alcohol vaporized (along with a little water) and rose to the next plate. At this point the water (with a little alcohol) was stripped off and descended to the lower plate. By the time the water fell all the way to the bottom plate, any alcohol that could be released by distilling was on its way to the top of the pipe. With this method, distillation could be maintained indefinitely by adding additional feed at the entry in mid-column.

Today this system has been developed into three basic designs of equilibrium stills: the packed column, the perforated plate, and the bubble cap plate. All three work by the pre-established principles of enrichment and countercurrent flow.

# Packed Column

The easiest equilibrium still to design and build is the packed column. Its components are a firebox, a "pot" (which is a tank of some sort), a pipe packed with a material which will leave 60-90% air space, and a condenser.

Here's an example of how such a still might be constructed: Find a 100-gallon tank and build a firebox under it. On top of the pot, make a port -- to allow access for cleaning and loading -- and then weld on a two-foot length of 5" pipe. Atop this tubing, add a reducer and three feet of 2" pipe. Pack this section with a material such as brass, copper, or stainless steel wool. Then reduce the column to 3/4" for the condenser. A still of this design provides 180-proof alcohol for about two-thirds of the run, and then proof dwindles. (MOTHER's packed 6" column still provides an additional example.)

There are a number of advantages to the packed column design. Improvements can yield proof of about 190, and the still can be run either continuously or on a batch basis. On a small scale, packed columns are inexpensive to build and quite easy to operate. However, on a large scale the design presents problems. In order to run continuously, the mash would have to be free of solids to avoid accumulations in the pot. But batch running would be very fuel-inefficient in a large-scale packed column still.
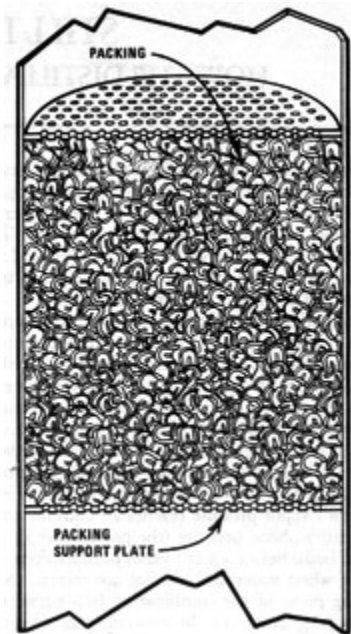


Packed column

# Perforated Plate

For continuous-run applications, it's hard to beat a perforated plate column. Because the construction is simpler than a bubble cap plate and involves only drilling or punching holes in the plates, it tends to be less expensive than the other plate design. Vapors flow through holes in the plates and are cooled by liquid flowing across the plates. Alcohol stays vaporous and rises, while the water sinks through downcomers.

There is one significant disadvantage to perforated plate stills, though. A minimum pressure must be maintained in the still or the liquid on the plate will "dump". Dumping occurs when the pressure holding the liquid on the plate drops far enough to allow the liquid to fall through the holes and down to the next lower plate. This stops distillation, and allows undistilled mash to escape through the spent mash drain. Thus, the perforated plate design presents certain problems for wood or biomass fuel systems where heating tends to vary.
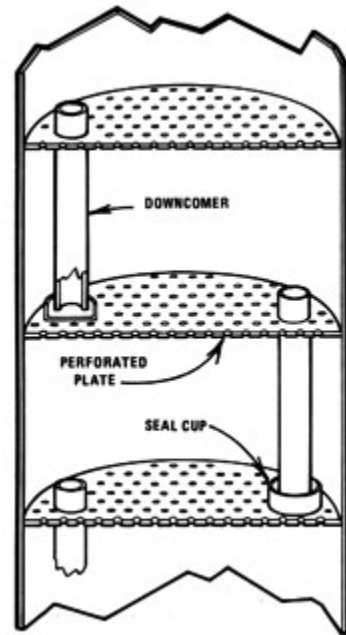

Perforated plate column

A typical -- and quite good -- perforated plate design was developed by Dr. Paul Middaugh, of the University of South Dakota. Start with two 16' pieces of 12" thin-wall tubing and make 18 plates (from 1/8" metal) the same diameter as the inside of this pipe. Drill 1/2" holes in each plate to occupy about 8-10% of the surface area -- roughly 50-57 holes. Place these plates about 10-1/2 inches apart in one tube to form the stripper column. Then take 24 more plates and drill 490-520 holes (5/32" in diameter) in each one. These plates are spaced 7-1/2 inches apart in their 16' tube to form the rectification column. Each plate also has a 1-1/8"-diameter downcomer with a seal cup on the bottom. Each downcomer extends 1-1/8 inches above its plate.

A 4' thin-wall tube leads from the top of the stripper to the bottom of the rectification chamber. (It takes additional pressure to make the vapor flow downward, so ideally the stripper and rectification columns would be combined in one length. However, this makes the still impractically tall.) Another 4" pipe leads from the top of the rectification chamber to the condenser.

Mash is pumped through the condenser for preheating, and is dropped into the top of the stripper column. The spent mash and solids are pumped out the bottom. Alcohol -- at about 100 proof -- leaves the top of the stripper column and enters the bottom of the rectification tower. Alcohol leaves the top at about 190 proof, and water (with about 0.05% alcohol) drains from the bottom.

Heat is provided by a steam generator or boiler and is introduced live or through coils at the bottom of the stripper column in the section called the "reboiler".
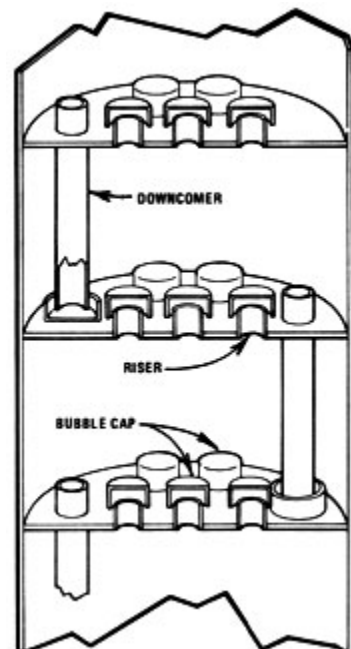

Bubble cap plate column

# Bubble Cap Plate

The bubble cap plate distillation column is the oldest design still in use -- it is a derivation of the principle described at the beginning of this section. There are some obvious limitations for do-it-yourselfers in this system. Mash would have to be very free of solids to avoid clogging downcomers and caps, the risers, and the plates themselves. Such a still would probably require the construction of ports for cleaning between the stages of the column.

# Solar Stills

In certain areas of the country, solar energy is a viable source of heat for distillation. In other areas it may not be worth the time to even think about it. The advantages seem obvious: solar energy is free, unending, and nonpolluting. However, the disadvantages seem to outweigh the advantages unless one is in an area where the sun can be counted on to shine. For example, the mash has to be run when it has finished the fermentation process, or it will turn to acetic acid within a few days. There are certain chemicals that can be added to the mash to hold it for a while, but doing so only adds to the cost of fuel production.



MOTHER's solar furnace

To make a large amount of alcohol fuel, it would take a considerable number of collectors to make it worthwhile. Also, solar panels seem to be very slow in production and low in product proof.
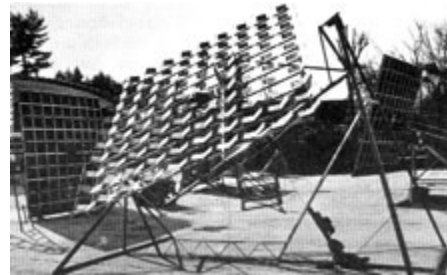
The research staff of THE MOTHER EARTH NEWS built a collector (see Issue No. 56, page 114), according to Lance Crombie's specifications. The results were very discouraging: we never could get more than 20-proof alcohol. However, for those who wish to pursue the quest, here are a few guidelines that the staff discovered which will make the solar still function better.

A solar still works best if the mash is preheated first. A serpentine pattern copper pipe solar panel to preheat the mash before it reaches the still can raise the mash temperature to anywhere from 120 to 180 deg F (48.8-82.2 deg C), depending on the square footage of the panel. Then, as the hot mash enters the still, it will easily flash to a vapor. Remember that water is taken with the alcohol, so this is not more than about 90- to 100-proof vapor. Also, considerable alcohol is left in the discharge, and that will have to be recirculated to remove all the alcohol from the mash. The second running will have an even lower proof.

Alcohol vapors rise, so -- to prevent adding more water to the distillate -- it's best to provide a means of removing the alcohol at the top of the still, not the bottom. If the condensed alcohol vapors are allowed to run down the glass, they will gather the water droplets that have condensed on the
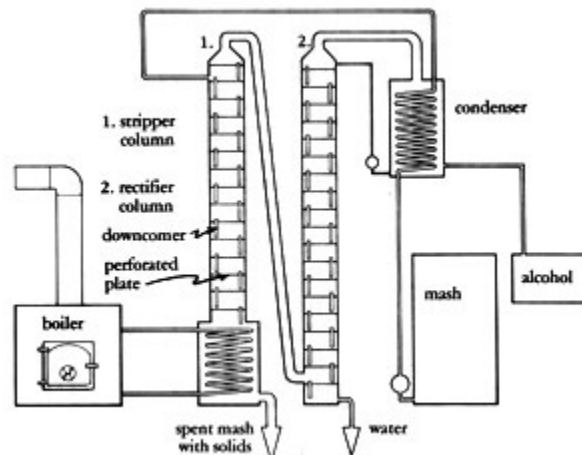


Diagram of 2-Column/Continuous Feed Still

lower portion of the glass and thus reduce the proof.

Perhaps one of the better methods of using solar energy is as a heat source in conjunction with a regular still ... to preheat the mash (as described above) and thus reduce the amount of fuel required to bring it to a boil. Also, a large mirrored solar furnace (see THE MOTHER EARTH NEWS No. 55, page 93, No. 56, page 142, and No. 57, page 66) could make enough steam to operate a small distillery.

Much research will have to be done to make a solar still produce large enough quantities of alcohol fuel to warrant the cost of equipment. People with small fuel requirements may find it an acceptable method of production, but they might still wish to have a backup system just in case "ol' Sol" isn't allowed to shine just when the mash is ripe .

# The Reasoning Behind MOTHER's Still Design

The correct designation for MOTHER's column design is *differential* column. A differential column is one that is packed with some sort of material that provides surface for vapor contact between the phases of fractionating. Three different types of packed columns are used in today's industry:

1. Those that use a conventional packing -- such as ring packings, saddle packings, and other types of designs -- which is dumped or random-packed into the column.

2. Those that use a systematic and geometrical packing, with the packing units placed by hand in particular reference to each other.

3. A "pseudoplate" column where plates of various design without downcomers are used. The Zelthamer plate column (see MOTHER NO. 59, page 80) is an example of such a design.

MOTHER's six-inch column is of the conventional random-packed type. The column is filled with 5/8-inch Pall rings. They provide approximately 131 square feet of surface per cubic foot and at the same time allow about 90% free gas space.



**Illustration No. 1**

The packing and a packed column are nothing new as far as still designs go. The difference is at the point of introducing the vapors into the column and the method of removing the heat from the column. The usual manner is to mount the column on the batch pot and feed the vapor into the column at the very bottom. Since the column must maintain temperature equilibrium (that is, a decreasing temperature rate in the column, starting with the boiling temperature of the mash at the bottom and ending with approximately 175 deg F (79.4 deg C) at the top), this method controls that equilibrium by the amount of heat in the vapor as it is introduced into the column.

MOTHER's still increases the quantity of distillate produced per hour by forcing more alcohol vapor into the column than it can typically handle. That sounds like a paradox, because if too much vapor is
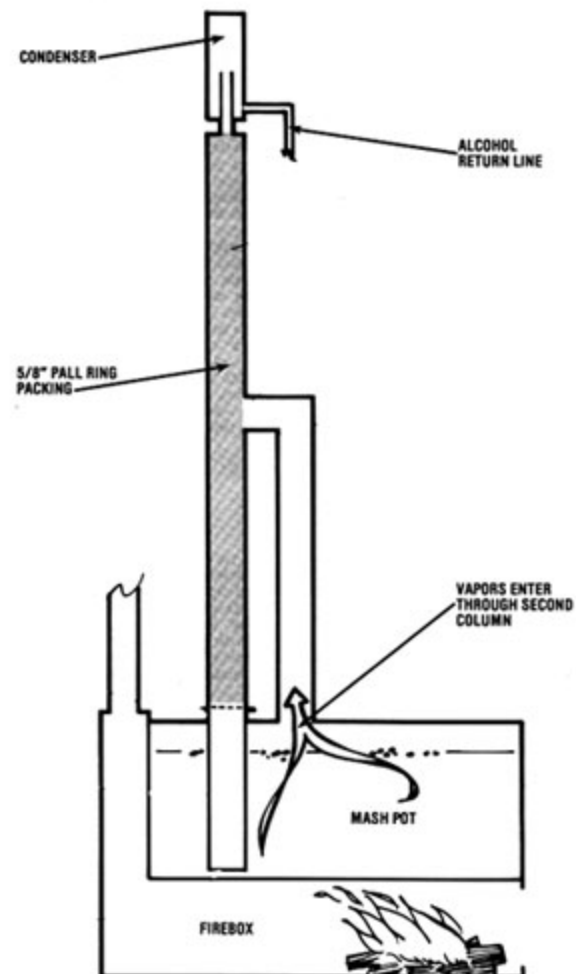
introduced into the column, the heat in the column becomes too high and therefore reduces the column to a simple distillation process. But to overcome this problem, two heat exchangers are built in, which remove the heat and at the same time leave the alcohol. These heat exchangers bring the column into equilibrium and increase the output of distillate from six gallons per hour to eight gallons per hour. Of course, nothing is free in the energy business, and the price that has to be paid is the use of extra amounts of cooling water.
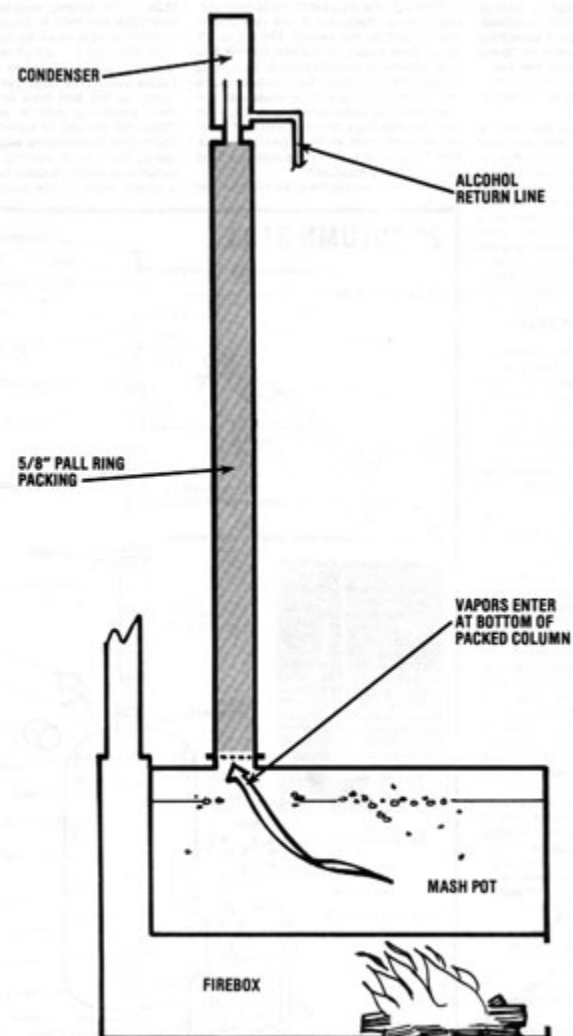
There are two ways of building this type of still. In **Illustration No. 1**, the vapor is channeled up a separate column and introduced at the midpoint of the packed column. Immediately, the vapor hits the cooling coil (heat exchanger) and its temperature is reduced to 185 deg F (85 deg C). The vapors are condensed to a liquid, and the heat rising from the reboiler revaporizes it. Because of the partial vapor pressure phenomenon, more alcohol is revaporized than water, so alcohol ascends in the column and the water descends in like manner. This vapor/liquid transfer reoccurs time and again throughout the entire length of the column (if the equilibrium is maintained). If any alcohol enters the reboiler, it will "reboil" back up into the column.

The second method (**Illustration No. 2**) is to do away with the reboiler and the second column and introduce the vapor into the column at its bottom. No testing has been done yet to show definitive advantages or disadvantages of either design. However, one feature of the reboiler design is that the water stripped from the alcohol is pure and clean. This water is hot and can be used for cooking the next batch of mash. However, if you do not expect to be running a continuous operation, the bottom introduction design is probably the best method of building this still, since manufacturing costs are lower.

Both methods use the two heat exchangers in the column. Also, reliable thermometers must be placed within inches of the top side of the heat exchangers. Depending upon the sophistication desired, this column can be controlled manually or with instrumentation.

The size of the still can be scaled up or down: the principle works, no matter what the size. A larger tank for the batch pot can be used, and the column can be increased to eight or ten inches (you can use a ratio of about 24:1, height to diameter)



**Illustration No. 2**

CONDENSER

ALCOHOL RETURN LINE

5/8" PALL RING PACKING

VAPORS ENTER AT BOTTOM OF PACKED COLUMN

MASH POT

FIREBOX

The firebox need not be all metal like MOTHER's (it was made this way to make the still movable), but can be made of stone and brick.

In all, this is a very flexible still, capable of many modifications. You can even obtain as high as 190-proof alcohol by returning some of the distillate from the top condenser for reflux.

However, for an alcohol fuel, all that is needed is 170 to 175 proof -- and this still will give you this moderate proof at a high gallons-per-hour delivery.

# Still Operation

When you set up your still, the unit should be leveled and placed upon nonflammable material. If you plan to locate and operate your still indoors, take the necessary precautions in routing the stovepipe outdoors or through an available chimney. Remember also to keep your stovepipe at least 18 inches from walls or other potentially flammable materials, and to make sure the exhaust gases are always traveling upward on their way out the stack.

Even if you operate your still out-of-doors, similar safety rules apply. Clear the area of any leaves or dry grass, and be sure to install at least a five-foot section of stovepipe to the firebox exhaust flue -- this will help to create a draw, and the fire will naturally burn better.

# Making Your First 'Run'

- Fill the boiler tank with your mash solution and clamp the access hole lid on tightly.
- Start a blaze in the firebox and keep it burning constantly to assure a steady "steam" flow within the still. Remember that it will take several hours to bring 250 gallons of mash up to temperature.
- Begin running water slowly through all three cooling coils as vapor temperatures within the tank approach 170-175 deg F (76.6-79.4 deg C). (This is the temperature of the vapors above the liquid, not the temperature of the liquid itself.)
- Observe the lower cooling coil temperature -- as it approaches 176 deg F (80 deg C), the alcohol/water "steam" is ready to move up the column. Don't let the temperature. get above 185 deg F (85 deg C), but it's all right to let it stabilize at that point.
- The upper cooling coil should be maintained at 175 deg F (79.4 deg C). Since alcohol vaporizes at 173.8 deg F (78.7 deg C), and water boils at 212 deg F (100 deg C), only the alcohol vapors will pass into the condensation chamber at the very top of the column. The partially vaporized water will fall back into your reboiler to be redistilled.
- At this point, the alcohol will condense (turn from vapor to liquid) in the condensation chamber and drain into your storage container.
- Take periodic proof readings from this point on. (Remember to cool your ethanol product to about 60 deg F (15.5 deg C) -- by soaking your alcohol-filled vessel in cold water -- for the most accurate reading.) If the proof strength starts to weaken, recalibrate your upper and lower cooling coil controls to the optimum temperatures for distillation. Chances are that your thermometers are not totally accurate, so it may take a few "runs" to get the feel of your new still. Also, as the boiler

temperature rises (which it tends to do as more alcohol is driven off), so does the column temperature, so to maintain a high proof, more cooling must take place, especially at the upper coil. Let the lower coil temperature rise to 194-200 deg F (90-93.3 deg C) toward the end of your run (after about four hours), and then -- when you can't maintain a good flow rate -- allow the upper cooling coil temperature to rise and switch over to a low-proof storage tank.

## 'Economizing' Your Alcohol Production

A 250-gallon container of mash takes about four hours to come to a boil, and about four more hours to complete the distillation process -- which will yield 20 or more gallons of 180- to 190-proof alcohol, and another couple of gallons of lower-proof distillate. It is possible to make your entire run straight through and get 180-proof ethanol, but it would take a long time and would waste energy. Instead, take your final gallon off quickly at a lower proof and add it to your next run, thus saving yourself several hours and a pile of firewood.

Also, you can drain your "spent" mash from the still and pour it directly into your mash-cooking vat. If the liquid is still hot, you might want to start a new batch of mash -- but even if it has cooled down, you can still take advantage of the "fortified" water. By the same token, don't waste the heated return water from the condenser coils. It's about 160 deg F (71 deg C), and can be put to use in heating your next batch of mash or even in supplementing your domestic hot water system.

# MOTHER's Still Plans

## Six-Inch Column Still Plans

COOKING VAT

DRILL A 7/8" HOLE

2" X 3" DIAMETER
TANK DRAIN

1/2" X 10" REBOILER
DRAINPIPE

REBOILER TUBE

1/2" 90° ELBOW

DRILL A 7/8" HOLE

MASH VAT

FIREBOX

1/2" X 27" SCHEDULE 40 PIPE

REBOILER DRAINPIPE

1/2" X 12" SCHEDULE 40 PIPE
REBOILER OVERFLOW
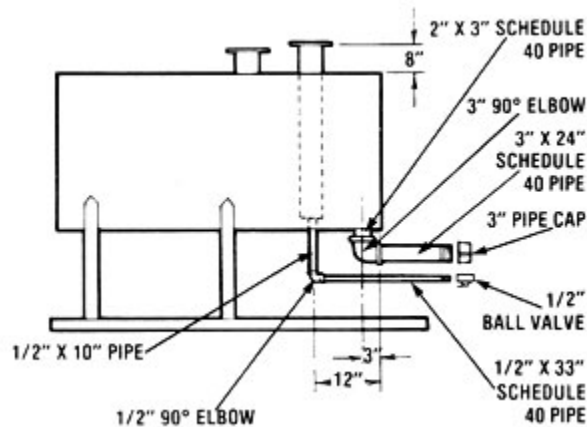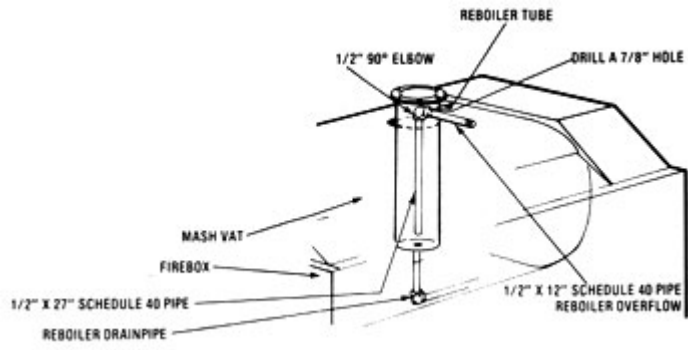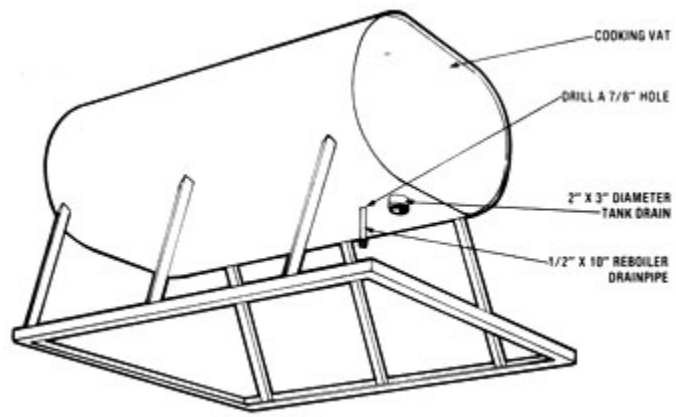
PLACE TOP THERMOMETER WITHIN
A COUPLE OF INCHES OF THE TOP

PLACE LOWER THERMOMETER
DIRECTLY OVER COIL

USE PVC OR CPVC PIPE
TO REDUCE COST

ALCOHOL TO STORAGE TANK

HOT WATER DRAIN

ATTACH GARDEN HOSE OR
PERMANENT CONNECTOR TO
COLD WATER LINE

CONDENSER

REFLUX COLUMN

STRIPPING COLUMN

MASH TANK

REBOILER

FIREBOX

**Three-Inch Column Still Plans**
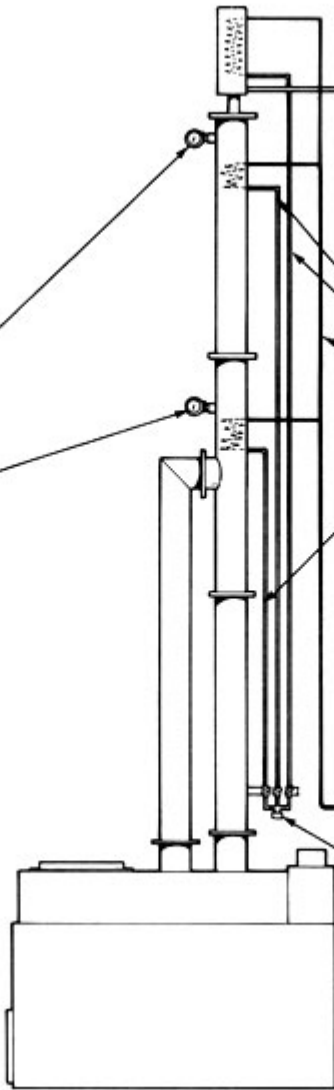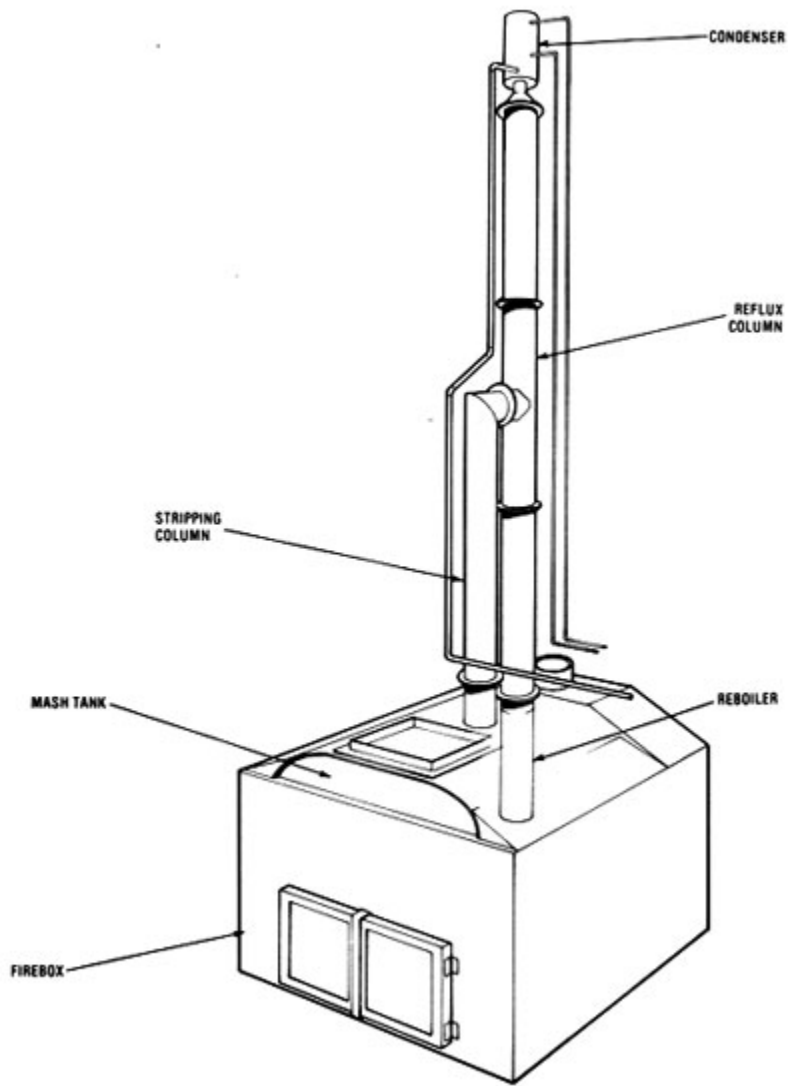
# 3" COLUMN STILL



3/8" X 5" COPPER PIPE (SOLDERED HALFWAY INTO COLUMN)

3/8" PIPE CAP

DRILL 3/8" HOLE

1/8" COPPER TUBING COILED TO 1-1/2" X 5"

3/32" X 3" COPPER CAP

1/8" COPPER TUBING COILED TO 1-1/2" X 10"

ALL CONDENSERS: 1/8" TUBING AND FITTINGS, FEED AND RETURN

3/32" X 3" X 12" COPPER CONDUIT

1/16" X 3/4" X 3" COPPER PIPE

1/16" X 3/4" X 2" X 3" COPPER CONE

1-1/2" X 3" X 3" 45° "Y"

1-1/4" TO 1-1/2" REDUCER

1/2" TO 1-1/4" 90° REDUCER ELBOW

1/2" 90° ELBOW

1/2" X 1" COUPLER

1/2" 45° ELBOW

1/16" X 1" X 1-1/4" COPPER PIPE

1/2" X 6" COPPER PIPE

1/2" COPPER PIPE (CUT TO NECESSARY LENGTH)

1/2" PIPE TO ALCOHOL STORAGE TANK (CUT TO NECESSARY LENGTH)

1/2" 90° ELBOW

1/2" COPPER PIPE (CUT TO NECESSARY LENGTH)

1/2" PIPE TO 1/2" SWEAT FITTING

1/2" TO 3/4" BUSHING

3/4" X 2" NIPPLE

3/4" GATE VALVE

DRILL 1/4" HOLES

MARBLES

3" COUPLER

1/16" X 1-1/2" X 2" COPPER PIPE

1/2" 90° ELBOWS

1/2" TO 1-1/2" REDUCER

EXISTING 3/4" FITTINGS

CUT 3" HOLES

CUT 6" HOLE

3/8" NUTS (TACK IN PLACE)

1/4" NUTS (TACK IN PLACE)

3/32" X 3" COPPER CAP

30-50 GALLON NONGALVANIZED ELECTRIC WATER HEATER TANK

3/32" X 3" X 10" COPPER CONDUIT

3" COUPLER

1/8" COPPER TUBING COILED TO 1-1/2" X 5"

3/32" X 3" X 42" COPPER CONDUIT

3/32" X 3" X 7" COPPER CONDUIT

3/8" X 5" COPPER PIPE (SOLDERED HALFWAY INTO COLUMN)

DRILL 3/8" HOLE

3/8" PIPE CAP

1/8" X 3" PERFORATED PLATES

3/32" X 3" COPPER CONDUIT (CUT TO NECESSARY LENGTH)

3" 90° ELBOW

3" X 3" X 3" TEE

3/32" X 3" X 18" COPPER CONDUIT

3/32" X 3" COPPER CONDUIT (CUT TO NECESSARY LENGTH)

0°-250°F THERMOMETER

1/2" X 3" THERMOMETER WELL

3" COUPLER

1/2" TO 3/4" BUSHING

1-1/2" X 3" X 3" TEE

1/2" COPPER PIPE (CUT TO NECESSARY LENGTH)

1/4" WING NUTS

3/8" X 2" COMPRESSION SPRINGS

1/4" FLAT WASHERS

1/4" X 4" EYEBOLTS

1/4" X 1-1/2" MACHINE BOLTS

1/8" X 1/2" X1" X 1/2" X 9-1/2" CHANNEL IRON W/1/4" X 2" SLOTTED ENDS

1/8" X 7" STEEL PLATE

1/8" X 3/4" X 7" DIAMETER FLAT STEEL

1/8" X 1" X 6" PIPE SECTION

3/32" X 3" COPPER CONDUIT (CUT TO NECESSARY LENGTH)

SOLDER 3/8" DRAIN COCK

DRILL 3/8" HOLE

CONDENSER WATER RETURN LINES
1/4" BRASS TEE
WIRE SERVES AS CLAMP
CONDENSER WATER FEED LINES
1/4" NEEDLE VALVES
3/16" X 1" X 5-1/2" STEEL BAR
1/4" PIPE TO 1/4" HOSE BARBS
3/16" X 3" FLAT STEEL (CUT TO LENGTH)
3/8" REBAR (CUT TO FIT)

1/8" SWEAT TO 1/4" PIPE FITTINGS
1/4" TO 1/2" BUSHINGS
1/2" BRASS TEE
1/4" CLOSE NIPPLE
1/2" SWEAT TO 1/2" PIPE FITTING
4" HOSE CLAMPS
1/2" COPPER PIPE TO DRAIN (CUT TO NECESSARY LENGTH)
3" HALF-SECTION CUT FROM 3" PIPE
1/8" X 1/2" X 1" X 1/2" X 3" CHANNEL IRON
GARDEN HOSE TO 1/2" PIPE ADAPTERS
GARDEN HOSE "Y" ADAPTER

1/4" BRASS TEE

3/16" X 1" X 3" FLAT STEEL

CUT 4" HOLE
3/8" X 1" MACHINE BOLTS
CUT 13-1/2" X 13-1/2" OPENING
EXISTING HEATING ELEMENT HOLE

4" X 6" SCHEDULE 40 PIPE (MUST ACCEPT 4" STOVEPIPE)
30-50 GALLON NONGALVANIZED ELECTRIC WATER HEATER TANK
3/8" X 2" MACHINE BOLT
1/8" X 3" X 5" FLAT PLATE CUT TO SIZE
1/2" X 2" COMPRESSION SPRING
1/8" X 1" X 1-1/2" X 1-1/2" ANGLE IRON

3/16" X 1" X 2" FLAT STEEL
3/16" X 1" X 3" FLAT STEEL

1/4" TO 1/2" BUSHINGS
1/4" CLOSE NIPPLE
1/4" MALE TO FEMALE BRASS ELBOWS
1/4" AIR HOSE (CUT TO NECESSARY LENGTH)
3/16" X 1" X 2" FLAT STEEL W/3/16" X 1/2" NOTCH
3/8" X 1" MACHINE BOLT
3/16" X 13-1/2" X 13-1/2" STEEL PLATE
3/16" X 1" X 1" FLAT STEEL
3/16" X 1" X 5" FLAT STEEL
3/16" X 1" X 11" FLAT STEEL
1/8" X 1/2" X 1" X 1/2" X 13-1/2" CHANNEL IRON
1/8" X 2" x2" X 15" ANGLE IRON
1/8" X 2" X 2" X 11" ANGLE IRON

# Bill of Materials

| | | Prices US dollars (1980) |
|---|---|---|
| (2) | 30-50 gallon nongalvanized electric water heater tanks | $ 4.00 |
| 14' | 3/32" x 3" copper conduit | 82.00 |
| 5' | 1/8" x 2" x 2" angle iron | 2.00 |
| 7' | 1/8" x 1/2 " x 1 " x 1/2" channel iron | 3.00 |
| (1) | 3/16" x 13-1/2" x 13-1/2" steel plate | 1.00 |
| 4' | 3/16" x 1 " flat steel | 1.00 |
| 10' | 3/16" x 3" flat steel | 3.50 |
| 40' | 3/8" concrete reinforcing bar (rebar) | 4.40 |
| (1) | 1/8" x 8" x 22" flat plate | 2.00 |
| (1) | 3" x 3" Schedule 40 pipe | .35 |
| (1) | 4" x 6" Schedule 40 pipe | .75 |

| | | |
|---|---|---|
| 2" | 1/8" x 1-1/2" x 1-1/2" angle iron | - - |
| (2) | 4" hose clamps | .95 |
| (2,500) | glass marbles | 17.34 |
| 100' | 1/8" copper tubing (1/4" O.D.) | 43.29 |
| 10" | 3/8" (O.D.) copper pipe | .25 |
| (2) | 3/8" copper pipe caps | .20 |
| (3) | 3" couplers | 10.86 |
| (1) | 1-1/2" x 3" x 3" tee | 3.98 |
| (1) | 3" x 3" x 3" tee | 4.18 |
| (1) | 1-1/2" x 3" x 3" 45-deg "Y" | 4.09 |
| (1) | 3" 90-deg elbow | 3.23 |
| 10' | 1/2 " rigid copper pipe | 4.56 |
| (4) | 1/2" copper 90-deg elbows | 1.48 |
| (1) | 1/2" copper 45-deg elbow | .35 |
| (1) | 1/16" x 1-1/2" x 4" copper pipe | .70 |
| (1) | 1-1/4" to 1-1/2" reducer | .75 |
| (1) | 1/2" to 1-1/2" reducer | .80 |
| (1) | 1/16" x 1" x 1-1/4" copper pipe | .30 |
| (1) | 1/2" x 1" coupler | .45 |
| (1) | 1/2" to 1-1/4" reducer elbow | .45 |
| (1) | 1/2" sweat to 1/2" pipe fitting | .30 |
| (2) | 1/2" to 3/4" bushing | .35 |
| (1) | 1/2" x 3" thermometer well | 1.05 |
| (2) | 0-212 deg F straight thermometers | 8.25 |
| (1) | 0-250 deg F threaded thermometer | 6.48 |
| (1) | 3/4" x 2" nipple | .55 |
| (1) | 3/4" gate shutoff valve | 3.10 |
| (1) | 3/8" drain cock | .95 |
| (1) | 1/16" x 3/4" x 3" copper pipe | .50 |
| (1) | 1/16" x 6" x 10" copper plate | 1.65 |
| (2) | 1/4" x 4" eyebolts | .60 |
| (4) | 1/4" flat washers | .10 |
| (2) | 3/8" x 2" compression springs | .60 |
| (2) | 1/4" wing nuts | .10 |
| (6) | 3/8" hex nuts | .12 |
| (3) | 3/8" x 1" machine bolts | .15 |
| (1) | 3/8" x 2" machine bolt | 05 |
| (2) | 1/4" x 1-1/2" machine bolts wi nuts | .15 |
| (1) | 1/2" x 1" compression spring | .20 |
| (1) | 3/8" flat washer | .02 |
| (1) | 1/8" x 1" x 6" pipe section | .25 |
| (2) | 1/8" tubing threaded unions (if desired) | .30 |
| (6) | 1/8" sweat to 1/4" pipe fittings | .90 |
| (6) | 1/4" pipe to 1/4" hose barbs | 1.05 |
| (2) | 1/4" brass tees | .65 |

| | | |
|---|---|---|
| (2) | 1/4" male to female brass elbows | .70 |
| (3) | 1/4" needle valves | 6.42 |
| (1) | 1/2" brass tee | .45 |
| (4) | 1/4" to 1/2" bushings | 1.00 |
| (2) | 1/4" close nipples | .30 |
| (1) | 1/2" sweat to 1/2" pipe fitting | .24 |
| (2) | garden hose to 1/2" pipe adapters | .85 |
| (1) | garden hose "Y" adapter | .98 |
| 12" | baling wire | - - |
| 3' | 1/4" air hose (cut to necessary length) | 1.48 |
| (1) | 4" stovepipe 90-deg elbow | 2.09 |
| (1) | length 4" stovepipe (as needed) | - - |
| 1 | piece fiberglass insulation batting (if desired) | - - |
| **Total Cost** | | **$244.42** |

Note: The figures above represent new material prices. By scrounging and buying from salvage or scrap dealers (especially with regard to the copper items), the total cash outlay for your wood-burning still project can easily be halved.

**For would-be homestead distillers...**

# Two Low-cost Backyard Stills

(This article was originally published in the July/August 1980 issue of THE MOTHER EARTH NEWS)

Now that the "grassroots" homemade alcohol fuel movement is rapidly gaining momentum, it's no wonder that farmsteaders and town dwellers alike are searching for simple, cost-effective ways to "brew up their own". And, of course, the major start-up expense -- especially for a smallscale operation -- is the cost of the equipment itself.
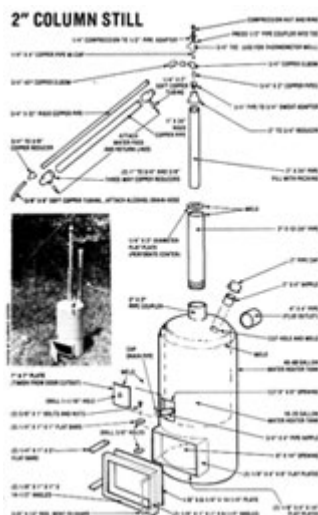
With this concern in mind, MOTHER is glad to provide her readers with a couple of backyard still designs from alcohol researcher/self-publisher Clarence Goosen, which have not only proven themselves effective, but which anyone with welding skills can construct inexpensively in a matter of hours.



Click here for larger image

The first distillery -- simply a tank within a tank -- makes a great "test bed" for various column designs and mash recipes. By scrounging parts, anyone should be able to construct the mini-still for about $25, and the tiny "percolator" can turn out almost 1/2 gallon of 180-proof fuel per hour.

The major components of Clarence's baby distillery are two discarded water heater tanks (formerly electrically fired models are easier to work with, and nongalvanized units don't give off noxious fumes during the cutting and welding process as do their "coated" cousins), some pipe for the column, filler, and drain, copper conduit for the condenser assembly, and a few assorted fittings and pieces of steel stock.

When choosing the tanks you'll use, make sure your "vat-to-be" is leak-free, and about 4" smaller in diameter (and 12" to 16" shorter in height) than is the "firebox" container. Before you cut the top off the larger tank and weld the small cauldron to it, mark the spot where the drain pipe will protrude through the firebox wall, and cut a 6" x 6" opening in the larger container's jacket at that point.

Follow our exploded drawing to assemble the remainder of your "budget" still. The two-inch column can be filled with rolled-up nylon window screening, or -- if you weld a perforated plate at the bottom of the tube -- it can be packed with short sections of 1/2" copper conduit, loosely woven rustproof metal scrubbing pads, or commercial packing (if you're willing to pay the additional cost of the manufactured material).

The condenser is nothing more than a conduit set within a larger tube that serves as a water jacket. (If you want to keep track of column temperature for testing purposes, replace the outlet elbow for the vapors with a tee fitting, which can then be adapted to serve as a thermometer well.)

# A Slightly Larger Unit, Too

The second design -- a four-inch column model -- is capable of producing about two gallons per hour of 90% pure ethanol fuel. Naturally, because this model is larger and somewhat more sophisticated than the two-inch column still, its cost is greater, but the entire assembly can probably be built for under $200 in about 30 hours of spare time tinkering in your shop.
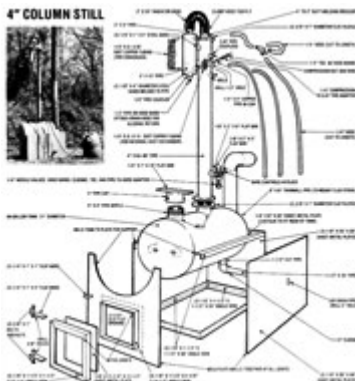


Click here for larger image

Although the illustration is largely self-explanatory, there are a few fine points that should be mentioned. The 40- to 80-gallon tank should, of course, be leak-free and preferably nongalvanized, and all its unused fittings must be plugged. Since the column will have to be filled with pall rings (or some other loose material), it will also be necessary to insert a drilled packing support plate in the pipe -- at its bottom flange -- to prevent the packing from falling into the mash vat.

Both the internal heat exchanger and the condenser are

simply lengths of 1/4" O.D. copper tubing, wound into 2"-diameter coils and held in place -- within their respective columns -- by compression-to-pipe adapters, which are themselves fastened to pipe couplers welded to the tube's walls. (The coils can be formed by wrapping the soft tube around a 1-1/2" thick section of pipe or wooden dowel.) Since the amount of water flow controls the critical temperature within the packed tower, the rush of cooling liquid -- to the column, at least -- should be regulated by a needle valve on the supply side, although separate controls and lines to the heat exchanger and condenser (using a tee and a single water-return hose) may be more practical. Remember, too, that you may want to install a thermometer well at the top of the column, in order to keep vapor temperatures within the desirable 175-180 deg F (79.4-82.2 deg C) range.

Though neither of these two stills will -- by itself -- be capable of producing all the fuel an average American family consumes, either one certainly would be able to supply a motorcycle, home-generating unit, garden tractor, or any of countless other normally gasoline-powered pieces of equipment that are in use on homesteads and in communities across the country today ... and that's certainly nothing to sneeze at, especially when there may eventually be no gasoline available in this nation for long periods of time!

# Alcohol as an Engine Fuel

Before you begin to convert your automobile or truck engine to use alcohol, it's important that you understand the properties of - and the differences between - the two fuels.

Gasoline is a complex mixture of hydrocarbons ... substances comprising just hydrogen and carbon atoms. These hydrocarbons can appear in all forms (as a gas, liquid, or solid), but for our purposes, we're concerned with the fuel in its liquid state.

To derive various hydrocarbon fuels, the industry merely refines crude oil (made many millions of years ago as a result of geological and biological cycles) and draws off the desired product at a certain temperature and pressure. Hence there are the lighter, gaseous fuels such as butane, propane, and ethane ... the liquids like octane, pentane, and hexane ... the heavier, oily liquids such as kerosene and fuel oil ... and so on all the way down through waxes and finally solids.

Gasoline as we know it is a combination of octane, benzene, toluene, various other aromatics, tetraethyl lead, detergents ... and compounds of sulfur, phosphorus, and boron. Because of this complex mixture of ingredients - and because the refineries vary the blend to suit climate, seasonal changes, and altitude - it's difficult to choose a "representative" sample of gasoline for comparison purposes. Nonetheless, the figures that are given in the "Properties of Gasoline, Ethanol, and Methanol" chart which follows are fairly typical of average high-test automotive gasoline. [Chart not included.]

Alcohol, on the other hand, has to be manufactured ... in our case through fermentation and distillation processes. Because of the steps involved in its manufacture, alcohol has always been more expensive than gasoline to produce. But now, with dwindling crude oil supplies, the price of gasoline is skyrocketing ... and soon gasoline itself will probably have to be synthetically manufactured, at a cost far greater - since the production process is much more complicated than that of alcohol.

Alcohol compounds are also hydrocarbons ... but in alcohol, one of the hydrogen atoms has been supplanted by a hydroxyl radical (hence the OH symbol), which is an oxygen atom bonded to a hydrogen atom. Alcohols, too, take many forms and have various levels of complexity, but we're concerned mainly with ethanol (grain-derived alcohol) and - just in passing - methanol (wood- or cellulose-derived alcohol).

These two alcohols are the only practical alcohol fuels ... and of the two, ethanol is more economically feasible on a small scale. (The raw material used to make methanol - wood chips, garbage, or cellulose matter - is relatively inexpensive, but the manufacturing process necessary to produce methyl alcohol is economical only on an industrial level.)

On the surface, the difference between alcohol and gasoline might appear relatively minor: Alcohol contains oxygen, while gasoline doesn't. In reality, however, the dissimilarities are far more complex than that. Additionally, under compression - as is the case in an engine's combustion chamber - things get even more complicated ... but we'll get more into detail on these points later.

Regardless of the inherent differences between gasoline and alcohol, though, the fact is that alcohols make ideal motor fuels. The first practical internal combustion engine - patented by Nikolaus Otto in 1877 - ran on alcohol (gasoline had not been "discovered" yet), and the Model A Ford, produced from 1928 to 1931, was designed to burn a variety of fuels ... alcohol being one of them. In addition, Studebaker trucks built for export in the 1930's (and various domestic tractors sold both in the U.S. and

abroad) were offered with either gasoline or alcohol fuel systems. (Indeed, at the start of the "motorized era", alcohol was just as common as - if not more so than - fossil fuels. But as time went on, the petroleum industry - which was organized and thus more powerful than the independent, often farm-based alcohol producers - lobbied successfully for the wholesale use of "superior" gasoline fuels. Strangely enough, in areas where petroleum had to be exclusively imported, or during time of war when gasoline supplies were rationed, alcohol suddenly became an excellent motor fuel again ... and was touted as such by the petroleum distributors who were selling it!)

Be that as it may, alcohol has characteristics that make it a natural engine fuel: [1] It has a high "octane" rating, which prevents engine detonation (knock) under load, [2] it burns clean ... so clean, in fact, that not only are noxious emissions drastically reduced, but the internal parts of the engine are purged of carbon and gum deposits ... which, of course, do not build up as long as alcohol is used as fuel, [3] an alcohol burning engine tends to run cooler than its gasoline-powered counterpart, thus extending engine life and reducing the chance of overheating.

At this point, we can detail exactly how these and other characteristics of alcohol affect engine performance.

## "OCTANE" RATING

Actually, when referring to alcohol fuels, the word "octane" does not apply, since octane (in its pure form) is merely the hydrocarbon in gasoline which is assigned the numerical value of 100 for fuel-rating purposes. The octane number given automotive fuels is really an indication of the ability of the fuel to resist premature detonation within the combustion chamber. (Premature detonation, or engine knock, comes about when the fuel/air mixture ignites spontaneously toward the end of the compression stroke because of intense heat and pressure within the combustion chamber. Since the spark plug is supposed to ignite the mixture at a slightly later point in the engine cycle, pre-ignition is undesirable, and can actually damage or even ruin an engine.)

Because a high compression ratio in an engine results in more power per stroke, greater efficiency, and better economy, it's easy to see why a fuel that resists pre-ignition even under high compression conditions is especially desirable ... and alcohol is, on the average, about 16 points higher on the research octane scale than premium gasoline.

## HEAT VALUE

The heating value of a fuel is a measure of how much energy we can get from it on a per-unit basis, be it pounds or gallons. When comparing alcohol to gasoline using this "measuring stick", it's obvious that ethanol contains only about 63% of the energy that gasoline does ... mainly because of the presence of oxygen in the alcohol's structure. But since alcohol undergoes different changes as it's vaporized and compressed in an engine, the outright heating value of the ethanol isn't as important when it's used as a motor fuel.

The fact that there's oxygen in the alcohol's structure also means that this fuel will naturally be "leaner" in comparison to gasoline fuel without making any changes to the jets in the carburetor. This is one reason why we must enrich the air/fuel mixture (add more fuel) when burning alcohol by increasing the size of the jets, which we'll discuss further in another section.

## VOLATILITY

The volatility of a fuel refers to its ability to be vaporized. This is an important factor, because if vaporization doesn't occur readily, the fuel can't be evenly mixed with air and is of little value in an engine. Some substances that are highly volatile can't easily be used as a motor fuel ... and others, which have excellent heating value, aren't volatile enough to be used in an engine (such as tars and waxes).

Another point to keep in mind is that a very volatile fuel is potentially dangerous, because of the chance of explosion from heat or sparks. This is one reason why alcohol, with a higher flash point than gasoline, is a much safer automotive fuel ... especially considering that the average car's storage tank is really quite vulnerable.

## LATENT HEAT OF VAPORIZATION

Latent heat of vaporization is the phenomenon that results in an alcohol-powered engine's running cooler than its gasoline-fueled counterpart. When a substance is about to undergo a change in form (from a liquid to a vapor, in this case), it must absorb a certain amount of additional heat from its surroundings in order for the change to take place. Since alcohol must absorb roughly 2-1/2 times the amount of heat that gasoline does, and the heat naturally is taken from the engine block, the engine should operate at a much lower temperature ... in theory, that is.

What happens in reality is that the alcohol/air mixture doesn't have time to absorb all the heat it could during its short trip through the engine manifold. So instead of running 2-1/2 times cooler on alcohol than it does on gasoline (which, by the way, would not be desirable ... since an engine must retain a certain amount of heat to run efficiently), the engine operates at temperatures only slightly cooler - about 20-40 deg F lower, depending on the specific engine when using alcohol fuel.

## EXHAUST EMISSIONS

When gasoline is burned in an engine, it produces carbon monoxide and other poisonous fumes ... mostly because of the fact that the fuel never combusts completely, and also because it's subjected to extreme temperatures and pressures. In addition, as we mentioned before, gasoline is a complex mixture of many substances ... and some of those substances are lead, sulfur, and other noxious materials. These, too, add to the contaminative effects of the engine's exhaust fumes.

Alcohol, on the other hand, burns much cleaner. Even though it, too, never combusts completely, the volume of noxious fumes is drastically reduced in an alcohol-burning engine ... because alcohol contains oxygen in its structure (which means more thorough combustion) but doesn't contain all the other pollutants necessary as additives in gasoline.

For comparison purposes, MOTHER's researchers ran tests on a 1978 Chevrolet taxicab ... which, operating in New York City, was subject to some of the most stringent pollution controls in the nation. (In order for cabs to be licensed, they must undergo - and pass - four scheduled EPA tests a year for carbon monoxide and hydrocarbons emissions.) Naturally, the taxi that MOTHER's crew tested was a lot less polluting than the average American automobile, but even in perfect tune it just "squeaked by" the tests using gasoline ... registering nearly a 1-1/2% CO and a 200 parts per million HC exhaust content (both just under the legal limit).

With alcohol fuel, however, the test results improved enormously. Even with all pollution controls

removed from the engine (except for the PCV valve), the cab registered a mere 0.08% CO and only 25 PPM of HC ... the equivalent of 95% less CO and 87.5% less HC, or a total of about 92% cleaner!

## ALCOHOL/WATER MIX

As we all know (some of us from experience), water and gasoline don't mix. The gasoline tends to float to the top of the mixture, leaving the water to settle below it. In a car's fuel tank, this can be disastrous, particularly during the winter season.

Alcohol, however, mixes quite well with water: The water particles distribute evenly within the mixture. As a result, not only is the winter freezing problem solved, but pure alcohol is not necessary for fuel purposes. This is very important to the small-scale alcohol fuel producer, since nonindustrial stills are generally not capable of producing more than 192-proof (96% pure) alcohol.

As far as its use in an engine is concerned, MOTHER's researchers have had excellent results with various strengths of alcohol, from 160 proof to anhydrous (200 proof). Additional water added beyond the 20% limit causes the engine to hesitate and idle roughly ... hence that practice is not recommended. As an extra benefit, the water in the fuel helps cleanse and "lubricate" the internal parts of the engine, including the valve seats, piston head surfaces, and combustion chamber.

## ENGINE ECONOMY

The fuel economy of an engine is directly proportional to how rich the air/fuel mixture is ... and that, of course, is dependent upon how large the main jet in the carburetor is. Alcohol requires a richer air/fuel mix than does gasoline (9-to-1 as opposed to 15-to-1), but that difference is not reflected proportionately with respect to economy ... partially due to the fact that alcohol has a higher "octane" rating and can be utilized more efficiently.

By experimenting with orifice sizes (diameters) of the carburetor's main jet, it is possible to reach a happy medium between power and economy in a standard auto engine using alcohol. Referring to the "Economy" chart that follows, you'll see that a 40% increase in diameter over the standard jet size in MOTHER's truck resulted in a loss of only 12% of the total fuel economy ... as compared to burning gasoline and using the standard jet (the truck was fully loaded in both cases).

ENGINE ECONOMY WITH
ETHANOL USING VARIOUS MAIN JET SIZES
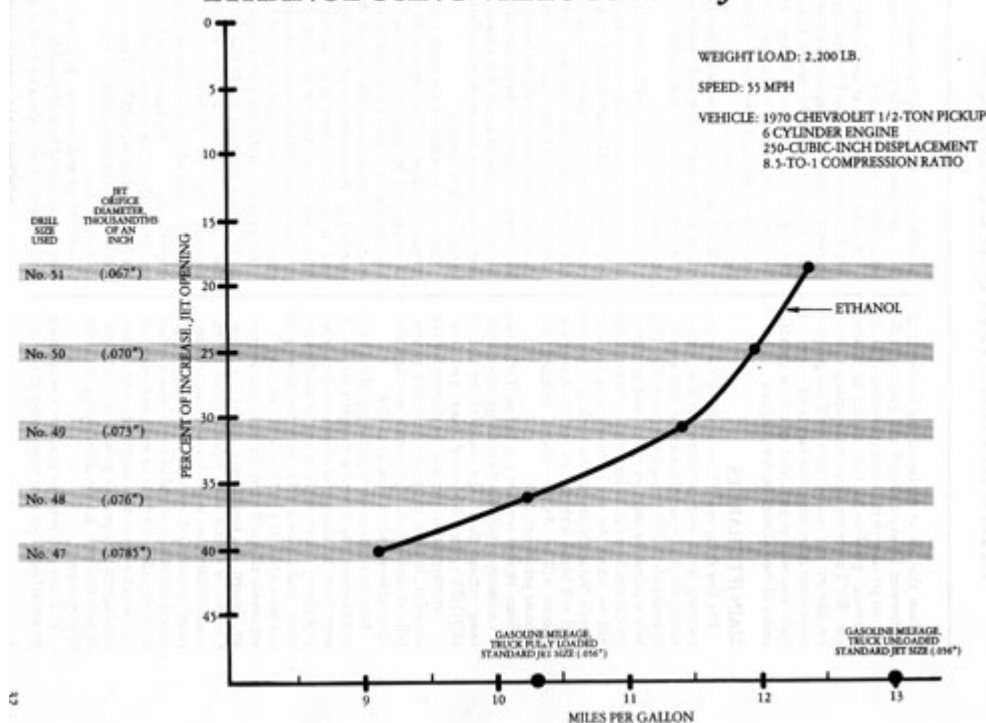
With a step-by-step decrease in jet size - down to 19% larger than the original - only about 5% was lost when compared with the unloaded truck using gasoline and its normal jetting. When that test was made comparing both fuels in the fully loaded vehicle, the alcohol-powered version actually showed an increase in mileage ... by a whopping 16%. This is because an alcohol-powered vehicle - partly as a result of the fuel's high "octane" rating - will maintain its economy even under extreme loads, unlike most gasoline-powered cars. The figures given above were recorded when MOTHER's 1/2-ton pickup was pulling over 2,200 pounds ... and only improved slightly when the load was removed. In comparison, when the weight was removed from the truck in its gasoline mode, mileage improved substantially ... as indicated in the chart.

It should also be noted that an increase in engine compression ratio will improve alcohol mileage considerably ... to the point where loaded or unloaded, any vehicle should equal or better its gasoline fuel mileage.

## ENGINE PERFORMANCE

An engine powered by alcohol - if converted correctly - will have performance equivalent to, if not greater than, the same powerplant burning gasoline. This is because of the fact that alcohol has a higher "octane" rating (hence the timing can be advanced slightly), and it can stand much greater compression ratios.

Even without changing the compression ratio, an alcohol-powered engine with fairly low compression (MOTHER's pickup has a ratio of 8.5-to-1) still holds its own against its gasoline-burning counterpart. And, if the timing is advanced safely short of the "knock" limit, the torque range is broadened considerably, allowing the vehicle to pull under load exceptionally well ... in fact, it does much better under such conditions than the gasoline version does!

# ENGINE PERFORMANCE: ETHANOL VS. GASOLINE
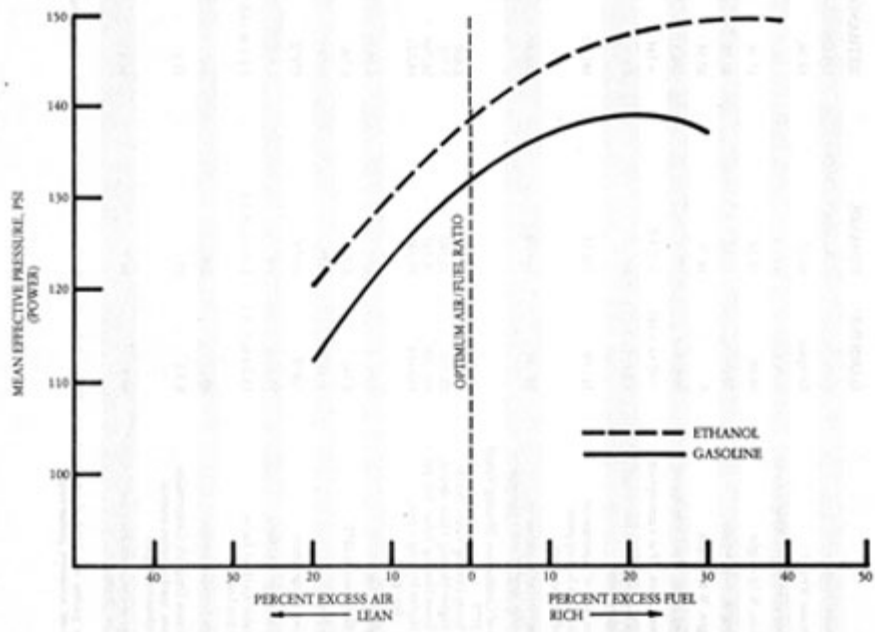
# How To Adapt Your Automobile Engine For Ethyl Alcohol Use

Now that we've explained the fundamental differences between alcohol and gasoline fuels, we can get on with the actual conversion of a conventional gasoline-burning engine to alcohol use. We'll cover the three major changes (main jet, idle jet, and timing), and we'll also go on to cover some other areas that may be of interest to those who want to go further to increase the efficiency of their alcohol-burning engines.

## MAINJET CHANGES

The first thing you'll have to alter is the main metering jet in your carburetor. In most carburetors, this is a threaded brass plug with a specific-sized hole drilled through the center of it. This hole is called the main jet orifice, and its diameter dictates how rich or lean the air/fuel mixture will be when the car is traveling at cruising speeds. Naturally, the smaller the hole is, the less fuel will blend with the air and the leaner the mixture will be. As the orifice is enlarged, the mixture gets richer.

Since alcohol requires a richer air/fuel ratio, it's necessary to bore out the main jet orifice when using ethanol fuel. The standard jet size in MOTHER's alcohol-powered truck was .056" ... in other words, this was the diameter of the jet orifice. In order to operate the engine successfully on alcohol fuel, it's necessary to enlarge this opening by anywhere from 20 to 40%.

Start your conversion by gathering all the tools and hardware you'll need to complete the job. A screwdriver, an assortment of end wrenches, visegrip pliers, a putty knife, a pair of needle-nose pliers, and a power drill - with bits ranging in size from a No. 51 (.067") to a No. 46 (.081") are usually all you'll need. To make your job easier, though, you might want to refer to a Motor, Chilton, or Glenn auto repair manual for exploded illustrations to guide you through the necessary carburetor disassembly and reassembly. (A second alternative would be to purchase a carburetor rebuilding kit for your make and model car ... which will not only supply you with a working diagram, but provide gaskets, seals, and other parts that may get damaged during the stripdown process.)

You may also need to purchase several main jet assemblies from your auto dealer (if the carburetor you're converting has a removable main jet), since you'll probably want to experiment with different air/fuel ratios.

In order to take the carburetor apart, you'll first have to remove its air filter housing and all its hoses, tubes, and paraphernalia from the engine. Then disconnect the throttle linkage from the engine and any choke linkage rods that aren't self-contained on the carburetor body. (If you've got a manual choke, remove its cable and tie it out of the way.)

You'll also have to unscrew the fuel line from the carburetor inlet fitting and remove any other hoses that fasten to the unit, including vacuum and other air control lines.

When the carburetor is free from all external attachments, remove it from the manifold by loosening the hold-down bolts at its base, and turn the unit upside down to drain out any gasoline that may be in the float bowl. Remove the carb's air horn (you may have to unfasten the choke stepdown linkage rod) and locate the main jet. (Some carburetors have the jet installed in a main well support, while others mount the brass fixture right in the float bowl body.)

Once you've removed the main jet, you can prepare to enlarge it. First measure the diameter of its opening by slipping a drill bit of known size into the hole (this bit should fit snugly, of course). In some cases, the size of the jet is stamped in thousandths of an inch right on its face, so you don't have to go to this trouble. When you know what the standard jet size is, you can calculate the additional enlargement necessary to operate the engine on alcohol.

For example, MOTHER's truck originally had a .056" main metering jet. In order to increase that opening's diameter by 40%, we first had to multiply .056" by .40 (which yielded .022"), then we had to add that additional .022" to the original .056" ... this figured out to a total diameter of .078". The nearest size drill bit to this is a No. 47, which is .0785" in diameter ... this was the bit necessary to bring the jet to 40% over its original size.

Hold the jet with your vise-grips and carefully bore out its central hole (if possible, use the jetholding body of the carburetor itself as a mount while you drill). Be sure to do your drilling as nearly straight as possible, and clean any brass residue out of the carburetor and its components after the operation is over.

There are some carburetors that do not use fixed-size jets alone, but also utilize what is known as a "metering rod". This is usually a thin tapered or stepped brass rod that's suspended within a brass jet orifice, which may or may not be removable. The fuel is, in this case, drawn through the space between the rod and its brass "housing". Depending on how far the throttle is opened, the metering rod is lifted out of the hole ... and - since the rod is thick at its "base" (near the top), and progressively thinner at its tip (toward the bottom) - the farther it's drawn out of the hole, the more fuel is allowed to flow between the central rod and the opening.

The conversion on this type of metering system is basically the same as the fixed-jet conversion. To enlarge this orifice, you can either remove the metering rod and very carefully drill out the brass jet (take it out of the carburetor if it's removable), or take the tapered brass rod to a machine shop and have it turned down slightly (the same effect can be accomplished less accurately by sanding the rod down with emery cloth). If you choose to drill the jet to a larger dimension, the diameter should be increased anywhere from 10 to 32%.

With the fixed-jet type of carburetor, the diameter of the jet orifice can vary from about 20% over standard to 40% larger - or even more - depending on the engine's size, its compression ratio, and the vehicle's weight. Probably the best way to determine what is right for your needs is to experiment, since many instruments used to measure the proper air/fuel ratio don't register correctly when the engine is burning alcohol.

By planning on a diameter enlargement of anywhere from 35 to 40% at first, you'll be perfectly safe, since the engine will tolerate this size easily. If you go too much larger than this, you'll probably just be wasting fuel. On the other hand, by going too small, you may find that you'll lose power ... or even worse, that you may burn valves because of an overly lean mixture.

On the other hand, it is true that a lean mixture - to a point - will result in improved economy with hardly a noticeable loss in performance. With MOTHER's vehicle, the absolute limit was a 19% enlargement in jet size ... although the truck does run slightly better with a 25% larger-than-standard main jet. You may find, as we did, that your vehicle performs well with a smaller jet opening than the suggested 35-40% increase but to be on the safe side, periodically check your spark plugs, especially after an extended drive. If they are white in color, or otherwise appear to be subject to excessive heat

(look for hairline cracks on the center electrode's insulative jacket), this is an indication that your engine is burning too lean ... and the jet must be enlarged.

## IDLE ORIFICE CHANGES

Most carburetors will require additional idle circuit enlargement in order for the engine to run at slowest, or idle, speeds. This is because the circuit that's fed by the main jet operates fully only when the throttle plate within the throat of the carburetor is opened past the idle position. When the plate is in the idle position, the air/fuel mixture is allowed to enter the manifold only through the idle orifice itself ... which, if it isn't large enough, will not provide the needed amount of air/fuel blend to keep the engine running.

On some engines, it may only be necessary to loosen the idle mixture screw at the base of the carburetor in order to provide the correct amount of fuel, since this threaded shaft has a tapered tip which allows more mixture to pass as the tip is backed off. On other engines, it's possible that the seat itself, into which the tapered screw extends, must be enlarged in order to accomplish the same thing.

In most cases, if the seat has to be bored out, it can be enlarged by 50%, using the same method of measurement as was detailed in the main jet section. This will allow a full range of adjustment with the idle mixture screw, even if you should want to go back to gasoline fuel. (When drilling, be careful not to damage the threads in the carburetor body.)

As a precaution against the idle screw's vibrating loose from its threaded opening, you can shim the idle mixture screw spring with a couple of small lock washers ... this will prevent the screw from turning even if it's drawn out farther from the seat than it normally would be.

## POWER VALVE CHANGES

Most modern auto carburetors have what is known as a power valve that allows extra fuel to blend with the air/fuel mixture when the accelerator is depressed, in order to enrich the mixture under load conditions. This vacuum-controlled valve is spring loaded, and shuts off when it isn't needed in order to conserve fuel.

The power valve used in the carburetor illustrated is somewhat difficult to alter and, besides, is sufficient for alcohol use in its normal configuration if it's working properly. However, there are other carburetors - specifically the Holley and Ford (Autolite or Motorcraft) brands - that have easily replaceable power valves which are available from auto parts stores in various sizes. If you use a power valve with a 25% or so greater flow capacity than the one that originally came with the carburetor, your air/alcohol mixture will be sufficiently enriched when your engine needs more power.

## ACCELERATOR PUMP CHANGES

In addition to a power valve, almost all automotive carburetors utilize an accelerator pump. This is a mechanically activated plunger or diaphragm that injects a stream of raw fuel directly down the throat of the carburetor when the accelerator is suddenly depressed. The fuel is injected through a small orifice located in the throat wall at some point above the carburetor venturi (the point at which the throat narrows).

The reason the accelerator pump is incorporated into modern carburetors is that as the accelerator is

pressed and more air/fuel mixture is drawn into the cylinders, some of the liquid particles in the blend tend to stick to the walls of the intake manifold, effectively leaning out the mixture by the time it reaches the combustion chambers. The extra squirt of fuel that's added by the accelerator pump makes up for this initial lean condition.

In order to adapt your accelerator pump to use alcohol effectively, you'll probably have to enlarge the size of the injection orifice slightly (anywhere from 10 to 25% is fine ... if you go larger than that, you'll risk the possibility of altering the pump pressure enough either to turn the fuel stream into a dribble or to empty the pump reservoir before the pump has made a full stroke).

As an alternative to enlarging the hole, you may be able to simply adjust the stroke length of the pump arm in order to feed more fuel. Most carburetors installed on Ford products already have a provision for seasonal adjustment, so it's just a matter of putting the pump on its richest setting. Other carburetors, too, have threaded rods that can be adjusted to accomplish the same thing.

## CHOKE ALTERATION

Although it's not absolutely necessary to adapt your car's choke system to burn alcohol fuel, it has been our experience that a manually operated choke is more desirable on an alcohol-powered car. If your vehicle's engine is already so equipped, fine. If not, you can purchase - for about $7.00 from any auto parts store - a manual choke conversion kit that will allow virtually any automatic choke to be adapted for manual control.

## IGNITION TIMING

In order to take advantage of the great antiknock qualities that alcohol fuel provides, you'll have to advance the engine's ignition timing by turning the distributor housing opposite to the direction in which the rotor spins (the housing is held in place by a bolted clamp).

Normally, an engine using gasoline has its timing set so the spark occurs at anywhere from 8 deg BTDC (Before Top Dead Center) to TDC (Top Dead Center). Since alcohol has a higher "octane" rating, you can advance the timing considerably more than this. (In the case of MOTHER's truck, we adjusted it to operate at approximately 22 deg BTDC without any sign of pre-ignition, even under load.) Of course, care should be taken when you adjust the timing on your vehicle, since a 22 deg advance might be excessive for your car. Remember, it's not safe to be just short of detonation, since inaudible knocking can also damage the engine ... the best procedure is to set the distributor timing at least two degrees retarded from the point of detonation.

## COMPRESSION RATIO CHANGES

Increasing the compression ratio of the engine will be impractical for most people, because of the expense and work involved ... however, this modification will do a great deal to improve engine performance and economy. Just like a timing advance, a compression ratio hike will take advantage of the potential that alcohol has to offer as a fuel. Optimally, the ratio can be increased to 14- or 15-to-1 ... but even a nominal increase - to perhaps 12-to-1, a figure that some manufacturers have already offered in the past for premium gasoline use - will result in a vast improvement over the standard 8- or 8.5-to-1 that most manufacturers incorporate into their engines today.

If you intend to convert an automobile that already has a compression ratio of 10-to-1 or better, it

probably won't pay to make any internal changes. However, if the engine you're considering needs an overhaul, it would be wise to modify it regardless of its compression ratio.

The most inexpensive way to increase your compression ratio is to install a set of high compression pistons. The forged units are designed to pack the air/fuel charge tightly into the combustion chamber for increased power, and have special relief notches built into their heads for valve clearance. Be cautioned, however, that some engines may not tolerate a 15-to-1 compression ratio with standard connecting rods and bearings ... these components, too, may have to be replaced with high-strength competition grade parts.

Another way of increasing compression ratio slightly is by "milling" (planing) the surfaces of the cylinder head and/or block. With some engines, this may result in only a 1/2-point ratio increase ... with others, slightly more. It would be best to check with your local engine rebuilder or automotive machine shop to determine exactly what you'll gain with your particular model engine before you go to the trouble of dismantling it.

A third - and perhaps the most versatile - way of effectively increasing the compression ratio is by installing a supercharger or turbocharger. These units, although ranging in price from $800 to over $1,200, provide a pressure boost in the combustion chamber proportional to the engine's RPM. Hence, compression would not be excessive during engine start-up as it would be with the other methods.

You should encounter no problem with a severe compression ratio increase, unless you decide to switch back to gasoline fuel ... and in this case, you could install a water injection system that would allow you to operate the car even on regular fuel without fear of detonation.

## FUEL PREHEATING

In extremely cold climates, it may be necessary to preheat your alcohol fuel before it enters the carburetor float bowl. This can be accomplished easily by splicing into the fuel feed line - near the point where it passes the upper radiator hose - and installing a fuel heater at this location.

You can fabricate a fuel heater in a matter of minutes by first locating a 5" section of copper or other metal pipe with an outside diameter equal to that of the inner diameter of your upper radiator hose. Then find several feet of soft copper tubing that will slip snugly inside your fuel feed line. (If your fuel line is steel, you'll have to cut it and splice in two short sections of the appropriately sized neoprene hose.) Wrap the soft tubing several times around the middle of the large pipe section (the number of coils depends on how warm you want the fuel to become, but anything from three to eight wraps will suffice), and solder it in position if possible.

To install the unit, just clamp it in place between the existing radiator hose and another short section of hose connected to the radiator neck, and attach the fuel line to the inlet and outlet of the copper coil. As the engine reaches operating temperature, the hot water flowing through the engine's cooling system will heat the coils and the fuel passing through them.

## AIR PREHEATING

Most trucks and autos have air filter housings which are designed to allow heated air from around the exhaust manifold to channel through a duct and enter the carburetor when the engine first starts from a cold state. As the engine warms up, a flap within the air cleaner "snorkel" shuts off this supply of warm

air and allows ambient air from the engine compartment to enter in its stead.

This flap is usually either thermostatically or vacuum controlled ... but either way, you may find it helpful during the winter months to leave this valve closed to the cold outside air. This can be done either by disconnecting the bimetallic thermostat spring that controls the flap and installing a small spring of your own that will hold the valve in the required position, or - if the flap is vacuum activated - by connecting an existing permanent vacuum line to its control fitting. (You can, of course, remove the control line entirely, plug it up, and hold the flap closed with a spring if you wish.)

## THERMOSTAT CHANGE

In order to get maximum efficiency from your engine, you may need to change the thermostat within the engine block. Thermostats are available in various heat ranges from 140 to 200 deg F, and these temperatures indicate how hot the engine coolant will be allowed to get before the thermostat opens to initiate the cooling process. (A thermostat is designed to hold the coolant within the cylinder head till it achieves the desired temperature ... at which point the heated liquid is allowed to escape into the radiator to be cooled, and is replaced by a fresh supply of cool fluid. Depending on the engine's operating conditions, the thermostat may cycle open and shut regularly over the span of a few minutes.) If the water in your vehicle isn't getting warm enough to provide hot air through the heating system, you should replace the thermostat with a higher-rated unit. By the same token, the intake manifold of your engine should be warm to the touch when burning alcohol. If it's cold - or iced over - the alcohol most likely isn't being given a chance to vaporize sufficiently, and therefore is not being used efficiently. By using a hotter thermostat, you'll be able to warm up the entire engine, including the intake manifold.

## COLD WEATHER STARTING

Since alcohol doesn't vaporize as easily as does gasoline, cold weather starting can be a problem ... especially if the engine itself is cold. To alleviate this undesirable situation, MOTHER's research staff has designed a combination coldstart/dual-fuel system that'll work with any car.

All it requires is a five-gallon fuel storage tank with a fuel filler neck brazed into its top (we used an old propane bottle), an auxiliary electric fuel pump, some steel brake or fuel line, neoprene hose, an elbow, a length of copper pipe, a small metering jet, and several needle valves, tees, and hose barbs. (Details and illustrations of the installation are shown in the article reprints from MOTHER NOS. 59 and 60, which are included in this workbook.)

The five-gallon tank is mounted in some safe place on the truck or automobile and used to store gasoline. This cache of petroleum fuel serves a dual role: When it's needed for cold starting purposes, the electric pump is activated momentarily from inside the car and a fine stream of gasoline is injected down the throat of the carburetor. And, in the event that your alcohol supply is unexpectedly depleted on the highway, the gasoline stored in the small tank can be routed into the carburetor normally for emergency use.

## INITIAL USE OF ALCOHOL FUEL

An engine altered as outlined in this chapter will run well on alcohol. Nonetheless, there are certain things to be aware of as you begin to make use of the new fuel. First, remember that the alcohol will act as a cleansing agent ... and - as such - will not only clean out your tank, fuel lines, and filters, but will

also purge your engine's internal parts of built-up carbon, gum, and varnish deposits.

In effect, what this means is that suddenly a lot of filth will be floating around in your fuel ... and it may be enough to clog your fuel filter to the point of not allowing any fuel to pass. By the same token, loosened internal engine deposits can foul the spark plugs badly ... so if your vehicle begins to function poorly soon after your conversion, check these two areas first.

In addition to the fact that alcohol is a cleaning agent, it is also a solvent ... and this means that certain types of plastics used in the fuel system of your vehicle may be attacked by it. Actually, most of the plastics deterioration problems associated with ethanol fuel are caused by the substances used to denature it - such as acetone or methyl ethyl ketone - rather than the alcohol itself. If you manufacture your own alcohol and denature it with gasoline, as federal regulations now permit, deterioration problems will be reduced to a minimum.

Most vehicles manufactured prior to 1970 used stainless steel or brass components in their fuel systems ... hence there is little chance of parts failure. In cars that use plastic components, however, there are several areas of potential deterioration: [1] Within the fuel tank, both the float and the strainer on the fuel intake tube may be plastic ... replace them if necessary. [2] The fuel lines themselves - if they are the clear, flexible type - may also soften ... you can install neoprene hose in their place. [3] The fuel pump diaphragm may also be subject to failure ... either replace it with a piece of spring steel, or replace the entire pump with an electric gear-type model available from your auto parts store. (Jaguars and Alfa-Romeos also use all-metallic pumps if you're willing to pay the price.) [4] Plastic in-line fuel filters should be replaced with metal ones. [5] Many modern carburetors use plastic float needles, seals, and floats ... you can usually purchase the equivalent carburetors - but ten years older - from an auto wrecking yard for about $5.00. These should contain metal components, and can be salvaged for parts.

Of course, not all plastics are subject to corrosion, and neither are all types of rubber. Generally, butyl rubber (like the type used in inner tubes) should be avoided. Neoprene, however, holds up well even at higher temperatures, and might only present a problem (because of swelling) if it's used as a tip on carburetor float needles. Automotive plastics vary greatly in their composition ... the table below indicates the performance of various types of plastic substances.

One final thing to be aware of when burning alcohol in your vehicle is that the new fuel does not contain the additives which the engine has become used to over the years ... specifically the leads which help to lubricate the valve seats. Of course, any car built in 1975 or later is already equipped with hardened valves and seats, so there should be no problem with them ... but even vehicles of other years (with the possible exception of large-block 1972-1974 Ford products) can tolerate alcohol fuel safely.

One reason for this is that water in the alcohol acts as a "cushion" and lubricant for the valves ... but if you are still wary of using alcohol fuel in its pure form, you can add up to 1% kerosene or diesel fuel to your alcohol supply. This will provide the lubrication of petroleum fuels with a minimum of pollution.

**FUEL INJECTION SYSTEMS**

Since some vehicles are equipped with fuel injection rather than carburetors, we will briefly touch on the use of alcohol with that system. There are two important factors in a fuel injection setup: injection timing and control jet diameter. Fortunately - since many systems now use an electronically controlled timing sequence - injection timing is not critical in a fuel injected engine. Neither performance nor

economy improve substantially by either advancing or retarding the injection timing process.

Control jet diameter, on the other hand, is an important factor. If you increase the size of the control jets (which are the equivalent of the metering jets in a carburetor), the engine will operate well on alcohol fuel. An increase of 15-20% is all that's necessary to accomplish the conversion. (Ignition timing should, of course, be advanced as explained previously.)

An interesting feature of the fuel injection system is that it doesn't require any gasoline during the cold weather starting process to fire the engine up. Since the fuel is injected at a pressure of about 250 PSI, the alcohol fuel is sufficiently vaporized to ignite easily within the combustion chamber.

## DIESEL ENGINES

Because of the fact that diesel engines do not use conventional spark ignition systems, it's difficult for pure alcohol to ignite within the combustion chamber. This, coupled with the fact that diesel injector pumps won't tolerate water, could be a problem ... especially if the alcohol used was not nearly pure.

Fortunately, there are several other ways to utilize homemade ethanol in a diesel engine by introducing vaporized alcohol to the engine along with diesel fuel. Probably the simplest way is to mount an automobile carburetor right on the diesel's air intake manifold and supplement the diesel fuel with alcohol metered through that piece of equipment. Of course - just as in a conventional gasoline engine - as incoming air rushes down the air inlet tube, it will pick up alcohol vapor metered through the carburetor ... which should have a controllable throttle to match tractor load.

Another way to use ethanol in a diesel engine is to install fuel injectors into the intake manifold to accomplish the same result. This system would require a separate pump that would have to be timed in order to inject alcohol at the proper moment.

A vaporizer - like those found on propane fuel systems - can also be used to add alcohol to the diesel fuel system. This, again, provides the diesel intake manifold with ethanol vapors that help combustion.

Since a diesel engine has closer tolerances and is more costly to repair than a conventional gasoline engine, you should take extreme care when altering and running diesel equipment on other than pure diesel fuel. If you don't consider yourself competent to work on diesels, find someone who is ... since the diesel fuel injector pump must be adjusted to provide less flow when alcohol fuel is used, plus the fact that a lean mixture condition - and even increased horsepower outputs - can damage a diesel engine in short order.

Turbocharged diesels can be equipped with what is known as an "aquahol" injection system, to be marketed by the M & W Gear Company of Gibson City, Illinois early in 1980. This setup injects a fine mist of alcohol and water in a 50/50 ratio directly into the engine's air intake, which results in a lowering of fuel consumption and a tolerable increase in horsepower.

DURABILITY OF VARIOUS PLASTICS: ALCOHOLS VS. GASOLINE

|  | Ethanol | Methanol | Gasoline |
|---|---|---|---|
| Conventional Polyethylene | good | excellent | poor |
| High-density Polyethylene | excellent | excellent | good |
| Teflon | excellent | excellent | excellent |

| | | | |
|---|---|---|---|
| Tefzel | excellent | excellent | excellent |
| Polypropylene | good | excellent | fair |
| Polymethylpentene | good | excellent | fair |
| Polycarbonate | good | fair | fair |
| Polyvinyl Chloride | good | fair | poor |

Excellent: Will tolerate years of exposure.

Fair: Some signs of deterioration after one week of exposure.

Good: No damage after 30 days of exposure, should tolerate several years of exposure.

Poor: Deteriorates readily.

NOTE: All tests were made with liquids at 122 deg F.

# Ron Novak's Do-It-Yourself Water Injection System

**One of MOTHER's seminar students gave a few lessons of his own!**

You can improve your car engine's starting ability, pickup, and fuel economy by constructing a homemade water injection system -- for a total cost of under five dollars! And you'll spend that small amount of money (heck, it takes more cash than that to buy one tank of gas nowadays!) entirely on parts -- because all the information you'll need to "inject" your own auto is right here in this article!
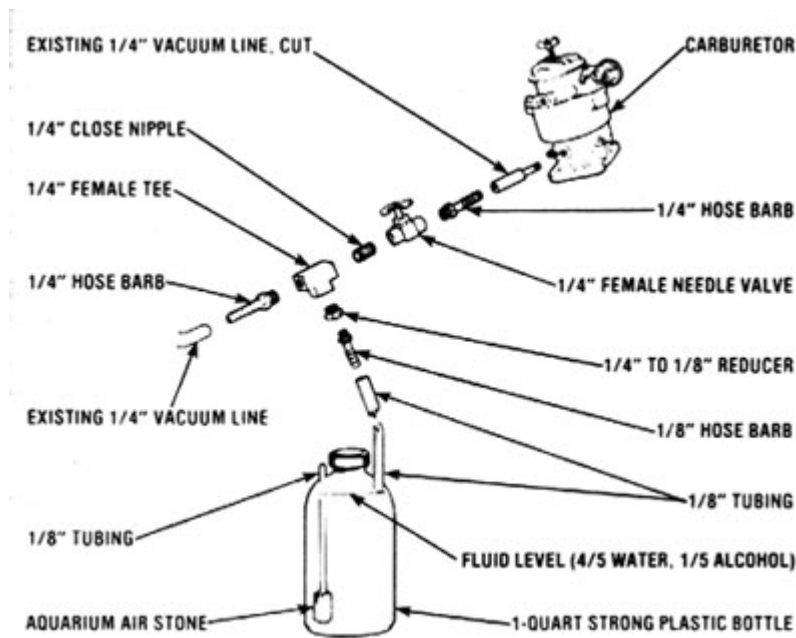


MOTHER's staffers have installed and tested one of the "engine aids" (and, by jeepers, the thing works!), but we can't take the credit for inventing the build-it-yourself device. Nope, all the know-how for this half-hour (or less) shop project comes from a very generous -- and clever -- visitor to this magazine's seminars ... Mr. Ron Novak.

Ron openly shared his under-the-hood "secret" during the July Mother Earth Week with everyone who was interested. (And once the word of his brainstorm got out, the inventive fellow spent as much of his visit teaching as he did studying!)

Actually, Mr. Novak made two improvements to his 1978 Honda CVCC station wagon before he started the long trek from his upstate New York home to MOM's western North Carolina land. The traveling seminarian's major modification was to install a homemade water injection system that feeds a 4:1 $H_2O$/alcohol mist into his vehicle's carburetor ... but he also added a drag-reducing "air dam", under the Honda's front bumper, to further improve his car's gas mileage. [EDITORS NOTE: MOTHER's ever-busy researchers are hoping to report -- in an upcoming issue -- on this second (the "fender extender") idea.]

Ron got the notion for his water injector from some automotive magazine advertisements that offered a $50 fuel-saving device. The canny Nor'-easterner carefully read the literature about the expensive accessory and realized that the mileage-extender consisted of little more than a bottle (partly filled with some "miracle" solution) that was rigged with [1] an underwater air intake line that bubbled air through

the liquid and [2] a mist-grabbing outflow tube to feed the "foamed-up" vapor directly into the engine's carburetor. The wet air was reputed to help produce more efficient fuel-burning (by "atomizing" the gasoline droplets and lowering the fuel's temperature) and to improve the power plant's overall performance and life span (by cleaning out the engine's carbon buildup).

Novak figured that he could make a similar fuel-saver himself ... if he could solve one problem: What "gadget" could he put on his underwater air tube to produce those myriad tiny air bubbles? Well, the tinkerer tried just about every device he could think of (including the pinched end of a cigarette holder), but - in spite of his efforts - the bubbler had him stumped. For lack of one simple piece, Ron couldn't get the whole dang system to work!

Then one day, while the New Yorker was running an errand in a pet shop, he noticed a small aquarium "air stone" that was (what else?) busily breaking an incoming oxygen supply into tiny little bubbles ... to mix air into the fish tank's water. Ron bought one of the low-cost objects, attached it to his homemade injector's underwater tubing, and - eureka! - he was in business!

The entire installation procedure was easy, inexpensive, and legal (Ron didn't fiddle with his car's EPA emissions devices). And Novak's "new" water-injected Honda ran better -- and further on one tank of gas -- than it ever had in its life!

Since that first attempt, Ron has installed his "bubbling bottles" on all sorts of vehicles ... from a BMW R60/2 motorcycle ... to a 1973 Opel GT ... to a 1968 Cadillac. In each case, gas mileage improved dramatically! So, folks, there "ain't no reason" why you can't get better performance and gas mileage by building your own water injector ... no matter what form of gasoline-engined transportation you're driving! All you have to do is read this article's sidebar, head off to the nearest pet store for your "auto parts", and then get to work!

EDITOR'S NOTE: People who read about Pat Goodman's water injection system (see "Water Injection Wizardry" in MOTHER NO. 59, page 46) may wonder about the differences between Ron's homemade "carburetor squirter" and Pat's more sophisticated - and, of course, more expensive - device.

The most important functional distinction between the two is that Novak's injector "bubbles " most rapidly when the car is idling and least intensely when the vehicle's under full throttle. Goodman's smog pump-controlled instrument, on the other hand, increases its vaporizing activity with higher engine output. Pat's "mistifier" will therefore produce a much greater overall boost in gas mileage than the do-it-yourself device does ... but can only be added to a car that already has a smog pump. Ron's homemade system can be installed on just about any vehicle on the road today.

## Water Injection: 6% Gas Savings and More Power - For As Little As $3.72

Installing a hydro-atomization system on your car -- a modification which adds damp air to the engine's intake mixture and produces a variety of benefits -- involves little more than the purchase of a three-inlet valve (such as a fish tank's air regulator), an aquarium air stone, five feet of 1/8" clear tubing, and a strong plastic bottle ... plus about 15 minutes of under-the-hood tinkering.

When MOTHER's mechanics tackled the job, they were able to pick up all of the necessary pieces -- with the exception of the $1.98 brass valve -- at a local pet shop for only $1.74. The boys then simply drove around the corner and recycled a photochemical bottle from a trash bin behind a photo shop, stopped by a nearby plumbing supply store to pick up the three-way valve, and returned to the research

center to actually install the parts, which took just a shade over ten minutes.

You can begin your installation by splicing the valve into one of the vacuum lines which comes from the base of the carburetor. (In many cars the distributor advance hose would be the best choice for valve-insertion. However, the Honda Civic CVCC that MOTHER operated on has a very convenient 1/4" vacuum line running to a fresh air valve, so MOTHER's crew tapped into that hose with their makeshift control.)

Next, securely suspend the liquid-containing bottle in the engine compartment. (In this case our research team fabricated a holder from an old coat hanger and bolted the assembly to an existing fastener on the left wheel well of the Honda.) Once your tank is in position, drill two 1/8" holes in the top of the container, one on each side of the cap. Then run a suitable length of the 1/8" hose from the remaining outlet on the three-way valve to one of the 1/8" openings, and allow 1/2 " of the tubing to enter the reservoir.

Now take the rest of your 1/8" hose, insert it through the unoccupied 1/8" hole, attach the air stone to the inside end of this line, and slide the aerator and tube into the bottle until it just touches bottom. The leftover 1/8" line -- which protrudes from the container -- should be snipped off to about three inches in length.

Finally, fill the reservoir -- to about an inch from the top -- with a solution of four parts water to one part alcohol (the latter keeps the water from freezing in winter), start your motor, let it warm up, and then adjust the valve until a gentle bubbling comes from the air stone. Once that's done, it's time for a test drive!

MOTHER's researchers noted an immediate improvement in low-RPM power which helped the Honda to accelerate up hills that had previously required a downshift -- and a significant reduction in vibration. Better yet -- after we ran three tanks of gas (and a quart of fluid) through the engine -- the Civic's gas mileage jumped from 32 to 34 MPG. Plus, much to the auto owner's surprise, water injection cured a longstanding cold weather starting problem. In fact, the driver claims that the modification "paid for itself" with that starting improvement alone ... and that, in his opinion, the power gain and gas savings are icing on the cake!