

The Manual for the Home and Farm Production of Alcohol Fuel

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Chapter 1

AN OVERVIEW ALCOHOL FUEL

There is nothing new in the use of alcohol as a motor fuel. In 1872, when Nikolaus Otto invented the internal combustion engine, gasoline was not available. Ethyl alcohol at 180-190 proof was the specified fuel. The model "T" Ford was designed to run on the available crude gasolines, alcohol, or any combination of the two. Alcohols in general and ethanol, in particular, make excellent motor fuels. The reason alcohol fuel has not been fully exploited is that, up until now, gasoline has been cheap, available, and easy to produce. However, crude oil is getting scarce, and the historic price differential between alcohol and gasoline is getting narrower. Currently there is a big push to find and develop alternative sources of energy so that dwindling reserves of crude oil and other fossil fuels may be conserved. As Edward Teller, one of this country's leading physicists points out: "No single prescription exists for a solution to the energy problem. Energy conservation is not enough. Petroleum is not enough. Coal is not enough. Nuclear energy is not enough. Solar and geothermal energy are not enough. New ideas and developments will not be enough by themselves. Only the proper combination of all of these will suffice." Alcohol fuel can be an important part of the solution, but it is by no means a panacea. If all of the available agricultural surplus were converted to ethanol, alcohol would supply less than 5% of our motor fuel needs. Add the possibility of converting cellulose residues to ethanol and general biomass to methanol, and the most optimistic total falls short of 10% of our present needs! However, this is a very important 5 or 10% because it can be renewed each year, and each gallon of alcohol produced will save a gallon of oil.

USES OF ALCOHOL FUEL

One very important fact about alcohol fuel should be stressed. Alcohol is an excellent alternative motor fuel for gasoline engines. It is not a suitable alternative for home heating or for essentially stationary power requirements. The production of alcohol consumes energy. Exactly how much depends on the feedstock (raw material) and the efficiency of the distillation process. In a small operation, it would not be uncommon to expend 30-40,000 Btu per gallon of ethanol. It would be more sensible, in a home heating situation, to use whatever fuel you would use to run the still directly rather than using it to produce alcohol. The real advantage of alcohol is that it can be burned in the millions of existing vehicles with little or no modification. Alcohol fuel should only be considered for the jobs it can do best.

OTHER ALTERNATIVE FUELS

This book is about the small scale production of ethanol for use as a motor fuel. However, before becoming committed to ethanol, there are other alternatives that should be considered. The first that comes to mind is methanol, or "wood" alcohol. Like ethanol, methanol is a viable substitute for gasoline, and it can be produced from a wide variety of renewable biological resources. Methanol, however, is not as easy to produce on a small scale. The simplest and oldest method of producing methanol is by the destructive distillation (pyrolysis) of wood. The process is nothing more than heating the wood residues in a "dry" distillation apparatus and collecting the methanol at the other end. As such, the process requires relatively simple equipment and should be suitable for small scale production. The problem, then, is the fact that along with the methanol a considerable amount of impurities are produced that include acetone, acetic acid, and a number of other substances. These by-products are difficult and expensive to remove, and, if left in the methanol, they will quickly corrode an engine. Simply put, the small scale production of methanol by destructive distillation requires a large enough plant to justify the equipment and energy necessary to remove the impurities. If you happen to have a large source of suitable hardwood and are prepared to make the necessary capital investment, methanol production by this method might be considered. Other processes for producing methanol from renewable resources, such as hydrogen and carbon monoxide, or conversion of cellulose and biomass, also exist. Again, the problem is that these methods are only feasible on a very large scale. Methane gas has also been considered as a motor fuel. Methane is generated, for example, by the action of bacteria on manure. The problem here is that any methane production facility must be large enough to justify the equipment and energy required to compress the gas for storage. Also, methane has a very low heat value (energy content per unit of weight) and engine conversion is necessary. Methane is better suited to stationary power requirements

than for use as a motor fuel. Still, if you have a situation where a large amount of manure or other suitable biomass is available, methane generation should be considered. Natural gas, propane, and butane are also possible motor fuels. However, since all of them are basically petroleum related, they cannot be considered as renewable resources. Much research has been done to find better processes for separating water into hydrogen and oxygen in order to obtain the hydrogen for use as a fuel. To date no process has been developed that does not consume more energy than can be returned when the hydrogen is burned. Aside from alcohol and, perhaps, methane, there seems to be no other suitable alternative fuel that can be made from renewable resources and utilized in existing motor vehicles. Other means of powering vehicles, such as electricity, involve the development and production of completely new vehicles. What seems to be needed is a vehicle that can utilize a wide variety of fuels such as coal, wood, alcohol, gasoline, kerosene, corn cobs or whatever might be available--for instance, something similar, to the 1897 Stanley Steamer! But, in the meantime, ethanol is the best solution for a motor fuel from renewable resources that can be produced easily on a small scale.

Chapter 2

BASIC FUEL THEORY CHEMICAL COMPOSITION

Alcohol and gasoline, despite the fact that they are from different chemical classes, are remarkably similar. Gasoline is mostly a mixture of "hydrocarbons". Hydrocarbons are a group of chemical substances composed exclusively of carbon and hydrogen atoms. This is a very large chemical class containing many thousands of substances. Most of the fuels we use such as coal, gasoline, kerosene, fuel oil, butane, propane, etc. are chiefly hydrocarbons. Referring to Figure 2-1, the simplest member of this group is methane which consists of a single carbon atom and four hydrogen atoms. Next comes ethane with two carbons and six hydrogens. Propane has three carbons and butane has four. The substances just named are gases under ordinary conditions. As we add more carbons to the hydrocarbon molecule, the chemicals formed become liquids: pentane, hexane, heptane, octane and so on. As we continue with even more complex molecules, the substances get progressively oilier, waxier and finally solid.

CHEMICAL STRUCTURES

Alcohols can be thought of as hydrocarbons in which one of the hydrogen atoms has been replaced by a "hydroxyl group" which consists of a hydrogen atom bonded to an oxygen atom. Thus methane becomes the simplest alcohol, methanol. Ethane becomes

ethanol, propane becomes propanol and so on. Like hydrocarbons, there are many alcohols of ever increasing complexity.

COMBUSTION PROPERTIES

One of the most important properties of a fuel is the amount of energy obtained from it when it is burned. Referring to Figure 2-2, note that the hydrocarbon octane, which represents an "ideal" gasoline, contains no oxygen. In comparison, all of the alcohols contain an oxygen atom bonded to a hydrogen atom in the hydroxyl radical. When the alcohol is burned, the hydroxyl combines with a hydrogen atom to form a molecule of water. Thus, the oxygen contained in the alcohol contributes nothing to the fuel value

The relative atomic weights of the atoms involved are: hydrogen, 1 ; carbon, 12; and oxygen, 16. Since methyl alcohol has an atomic weight of 32, half the molecule cannot be "burned" and does not contribute any fuel value. As expected, methanol has less than half the heat value (expressed in Btu/lb) of gasoline. Ethanol, with 35% oxygen, is slightly better with 60% of the heat value of gasoline. If the heating value of methyl and ethyl alcohol were considered alone, they would appear to be poor choices as motor fuels. However, other redeeming qualities such as "latent heat of vaporization" and anti-knock values make alcohol fuels superior, in some ways, to gasoline. When a fuel is burned, a certain amount of air is required for complete combustion. When the quantity of air and the quantity of fuel are exactly balanced, the fuel air mixture is said to be "stoichiometrically" correct. Again referring to Figure 2-2, the stoichiometric ratio for gasoline is 15:1 or 15 pounds of air for each pound of gasoline. The figures for methyl and ethyl alcohol are 6.45:1 and 9:1 respectively. On a practical level, this means that to burn alcohol effectively, the fuel jets in the carburetor must be changed or adjusted to provide 2.3 pounds of methanol or 1.66 pounds of ethanol for each 15 pounds of air. Referring to the last entry in Figure 2-2, an interesting fact is that if we provide the correct stoichiometric mixture and then compare on the basis of the energy (in Btu's) contained in each cubic foot of the different fuel/air mixtures, the fuels are almost identical: gasoline 94.8 Btu per cubic foot; methanol 94.5 and ethanol 94.7! This means that gasoline and alcohol are about equal in what is called "volumetric efficiency" when burned in a correctly adjusted engine.

VOLATILITY

Another important quality in a motor fuel is "volatility", or the ability to be vaporized. As previously noted, methyl alcohol contains less than half the heat value of gasoline and ethyl alcohol contains only about

60%. The next higher alcohol, propyl alcohol with three carbon atoms, contains only 26.6% oxygen and thus about 74% of the heat value of gasoline. It is apparent that the more complex the alcohol, the closer its heat value comes to that of gasoline. Cetyl alcohol (Figure 2-1), for example, contains only about 6.6% oxygen and thus has about 90% of the heat value of gasoline. However, this alcohol is a solid wax! It can't be conveniently vaporized and mixed with air in an engine and so is useless as a motor fuel. Consequently, in considering alcohol fuels, a compromise must be made between heat value and volatility.

Closely related to volatility is a quality called "latent heat of vaporization". When a liquid is at its boiling point, a certain amount of additional heat is needed to change the liquid to a gas. This additional heat is the latent heat of vaporization, expressed in Btu/lb in Figure 2-2. This effect is one of the principles behind refrigeration and the reason that water evaporating from your skin feels cool. Referring to Figure 2-2, gasoline has a latent heat of about 140 Btu/lb; methanol, 474 Btu/lb; and ethanol, 361 Btu/lb. In an engine, vaporization of the gasoline fuel/air mixture results in a temperature drop of about 40 degrees Fahrenheit. Under similar conditions, the temperature drop for ethyl alcohol will be more than twice that of gasoline, and for methanol the drop will be over three times as great. These temperature drops result in a considerably greater "mass density" of the fuel entering the engine for alcohol as compared to gasoline. The result is a greatly increased efficiency for alcohol fuels. To visualize why, remember that at a given pressure, the amount of space a gas occupies is directly proportional to the temperature. For example, if one pound of a gas fits into a certain container at a given pressure and the temperature is cut in half, the container will now hold two pounds of the gas at the same pressure. In an engine, a stoichiometric mixture of methanol and air would be over three times colder than the same gasoline/air mixture. This means that there is now over three times (by weight) as much methanol in the cylinder. Now, even though methanol has only half the heat value of gasoline, the net gain in "volumetric mass efficiency" is over three times. So, for example, if the gasoline/air mixture in a given engine cylinder produces 100 Btu on each stroke, the same engine would produce 150 Btu per stroke with methanol. This power gain due to increased volumetric mass efficiency is the primary reason for the popularity of methyl alcohol as a racing fuel. With ethanol the effect isn't quite as dramatic, but the greater heat value partially offsets the lower latent heat. Overall, this power increase with alcohol fuels considerably mitigates the liability of low heat value. However, the increased cooling due to latent heat sometimes creates a problem in an engine converted to run on alcohol. Once vaporized, a certain amount of heat is required to keep the fuel from condensing back to the liquid state before it reaches the cylinder. To accomplish this, an engine is designed to provide this heat to the intake manifold.

Alcohol, because of its greater latent heat, requires more heat than gasoline. This is one of the reasons that racing engines have short path manifolds and multiple carburetors. The shorter the distance the fuel must travel to the cylinder, the less chance of condensation and fuel distribution problems. On a practical level, most engines that have been converted to alcohol supply enough heat once they are warmed up. The main problem, as with high performance racing engines, is in starting a cold engine. This problem and the related fuel distribution problem will be discussed later in more detail.

OCTANE RATINGS

If a certain fuel is burned in an engine in which the compression ratio can be varied and this ratio is gradually increased, a point will be reached when the fuel will detonate prematurely. This is because as a gas is compressed, heat is generated. If the explosive fuel/air mixture in an engine cylinder is compressed enough, the resulting heat will cause it to detonate. Since gasoline engines are designed so that the mixture is detonated by the spark plug at the beginning of the downward movement of the piston following the compression stroke, preignition or "knock" occurring during the compression stroke is undesirable. Indeed, severe knock can quickly overstress and destroy an engine. Since greater compression ratios in an engine mean increased power per stroke and greater efficiency, the ability of a fuel to resist premature detonation is a desirable quality. The "octane" numbers assigned to fuels are based on the pure hydrocarbon, octane, which is considered to be 100. At the other end of the scale, n-heptane is considered to have an octane rating of zero. The octane number of an unknown fuel is based on the percentage volume of a mixture of octane and n-heptane that matches it in preignition characteristics. In practice, these tests are conducted in a special test engine with variable compression. As noted in Figure 2-2, alcohols have a relatively high anti-knock or octane rating. As noted in Figure 2-3, alcohols have the ability to raise considerably the octane ratings of gasolines with which they are mixed. The effect is greatest on the poorer grades of gasoline. A 25% blend of ethanol and 40 octane gasoline will have a net increase of almost 30 points! This increase is one of the major advantages of "gasohol". The ability to increase octane rating means that: (1) a lower (therefore cheaper) grade of gasoline can be used to obtain a fuel with a certain octane rating; and (2) the use of traditional pollution producing anti-knock additives such as tetraethyl lead can be eliminated. The addition of about 10-15% ethanol to unleaded gasoline raises the octane rating enough so that it can be burned in high compression engines that previously could not use unleaded fuel. This use of ethanol is not new, of course, because ethanol was the original gasoline additive for increasing the octane rating. The term "ethyl" used to describe a high-test gasoline comes from ethyl alcohol, not tetraethyl lead!

Figure 2-3: OCTANE INCREASE of ALCOHOL/GASOLINE BLENDS

WATER INJECTION

During World War II, the military made extensive use of water injection in high performance piston aircraft engines. Later, water injection was used by both civilian and military jet aircraft to provide extra thrust, principally on takeoff. Even today, water injection systems are available that can be installed in automobiles. The fact is that, within certain limits, these systems actually do increase power. Referring back to Figure 2-2, note that the latent heat of vaporization for gasoline is about 140 Btu/lb and for ethanol about 361 Btu/lb. Water has a latent heat of about 700 Btu/lb! Therefore, if a little water is injected into the carburetor in the form of an ultra-fine mist, the latent heat of the water will cool the charge and increase volumetric efficiency. In addition, when the charge is fired in the cylinder, the water will turn to high-pressure steam and provide additional power due to the pressure exerted by the steam. There are definite limits, however, to the amount of water that can be injected. Too much will cause excessive cooling and misfiring. The use of water injection with a gasoline fueled engine requires a separate metering and injection system because water and gasoline do not mix. Ethanol and water, however, do mix and the benefits of water injection can be had simply by adding the desired amount of water to the alcohol in the fuel tank.

EXHAUST COMPOSITION

In theory, a hydrocarbon fuel when burned should produce only water and carbon dioxide (CO₂) as exhaust gases. Carbon dioxide, of course, is completely non-poisonous being the gas we exhale when we breathe, the bubbles in carbonated beverages, and the gas plants turn back into oxygen during the photosynthesis cycle. However, such ideal combustion rarely occurs even in the most perfectly adjusted engine. What is actually produced is a large amount of poisonous carbon monoxide (CO) and other complex (and undesirable) emissions arising from impurities like sulfur and additives such as lead or phosphorus. Pure alcohol when burned under ideal conditions also produces, in theory, only carbon dioxide and water. Again, in practice, varying amounts of carbon monoxide are also produced. However, the amounts of carbon monoxide are usually much lower than with gasoline. In addition, alcohol fuel will contain no sulfur and no additives, and will not produce the related, undesirable combustion by-products. Pure alcohol fuels are extremely clean burning. Many studies have been made to determine whether alcohol/gasoline blends have any positive effect on emissions. In general, the data show that no great changes occur in blends of 20% or less. What happens is simply that in a 10% alcohol/gasoline blend, for example,

about 10% of the gasoline emissions are replaced with alcohol emissions. Since alcohol does burn considerably cleaner, the amount of emission improvement is proportional to the amount of alcohol in the blend. Pure alcohol, as an anti-pollution fuel, would easily meet and exceed all emission requirements without the need for exotic and costly exhaust plumbing and catalytic converters. With alcohol blends, the chief advantage would be in the use of ethanol to replace lead and other undesirable compounds used to raise the octane number.

ENGINE PERFORMANCE - STRAIGHT ALCOHOL

Having looked at a few of the basic factors which influence the performance of fuels in an engine, let us now examine some actual engine tests. Figure 2-4 is a plot of 198 proof (99%) ethyl alcohol as compared to gasoline. "Mean Effective Pressure" in the graph is a direct indication of the power produced. The increased mean effective pressure (M.E.P.) of alcohol at all mixture ratios is the most noticeable difference between the two fuels. This increase in M.E.P. is due mainly to the greater volumetric efficiency that results from the high latent heat of vaporization of ethanol and the resulting greater mass density of the fuel/air mixture.

Figure 2-4: ENGINE PERFORMANCE of ETHANOL vs GASOLINE

Note that the M.E.P. of ethanol increases with mixtures having up to 40% excess fuel, whereas for gasoline, the maximum pressure is reached at 20% excess fuel. It would seem that to achieve maximum power from an alcohol-burning engine there would be a temptation to burn very rich mixtures. Fuel economy aside, it should be noted that the rich mixtures necessary to obtain maximum M.E.P. are accompanied by incomplete burning of the fuel and the resultant lowering of overall thermal efficiency. The lean limits for alcohol and gasoline, therefore, are about the same, and both fuels develop maximum thermal efficiency at about 15% excess air. With mixtures leaner than 15% both fuels lose thermal efficiency. Figure 2-5: HORSEPOWER COMPARISON of ETHANOL vs GASOLINE Figure 2-5 compares engine horsepower and air/fuel ratios for ethanol and gasoline in a six cylinder engine. The fuels in this case were 190 proof (95%) ethanol and "regular" gasoline having a specific gravity of 0.745. In the tests, air was supplied to the intake manifold at a constant 100 degrees Fahrenheit, and the carburetor needle valve was adjusted to provide the desired fuel/air ratios. The 2/3 and 1/3 loads were established by adjusting the throttle to give the same manifold pressure for both fuels. The smaller air/fuel ratios for ethanol in comparison with gasoline are evident. In this test with the air supplied at the same temperature for both fuels, the correct fuel/air mixture should produce about 2% more power from gasoline than ethanol. However, alcohol, with its greater latent heat, requires more manifold heat to remain completely vaporized. In another test where this

additional heat was supplied, the correct alcohol/air mixture gave 8.6% more power with ethanol! Note also that the test depicted in Figure 2-5 was run with alcohol that contained 5% water. This benefit of water injection probably inflated the alcohol power results to a certain degree. However, the main point illustrated is that the two fuels are remarkably similar in performance in a correctly adjusted engine.

ENGINE PERFORMANCE - ALCOHOL BLENDS

Although alcohol blends can be made from both ethanol and methanol, the primary interest seems to be in the direction of ethanol. Methanol and gasoline have a limited miscibility (mixability) while ethanol and gasoline can be mixed in all proportions. Economic reasons also dictate the interest in ethanol since it is more readily made from renewable resources. In addition, ethanol is a slightly superior motor fuel alternative under most conditions. Economics aside, a major advantage of blends is that up to a certain concentration (somewhere between 10 and 20%) they can be used with absolutely no modification of the engine. Many studies on how the various blends affect engine performance are contradictory. The recent "Two Million Mile" test in Nebraska, claims slightly higher fuel economy. Other tests claim a slight decrease. Some tests claim slightly better emissions, others claim no significant change. In relation to power output, the tests are equally ambiguous. However, when all the data is sifted, the overall conclusion is that in the areas of fuel economy, emissions, and performance there just isn't any real difference. Figure 2-3, as discussed under Octane Ratings, illustrates another major advantage of alcohol blends, namely the ability of alcohol to raise the anti-knock quality of the gasoline with which it is mixed. This means, of course, that lower, cheaper grades of gasoline can be used to obtain a fuel with the desired octane rating, and the use of pollution producing additives can be eliminated. This is a significant advantage from the economic standpoint because the manufacture of high-octane blending stocks is expensive. Also, as previously mentioned, it is possible to raise the octane rating of unleaded gasoline so that it can be used in engines that previously required high-test leaded gasoline. Alcohol blends do have one relatively minor drawback. The presence of even small amounts of water in the blend will cause a portion of the alcohol and gasoline to separate. At room temperature, less than 1% water can do the damage. As the temperature is lowered, amounts as small as 0.01% can cause separation. However, various substances such as benzene (benzol), acetone, and butyl alcohol can be added to the blend to increase water tolerance. Closed fuel systems, now in use, prevent moisture from forming inside the gas tank. Oil companies, given the proper incentive, could dry out their storage facilities and pipelines. Also, extensive use of alcohol blends over the past 50 years is ample evidence that the problem can be solved.

Chapter 3

UTILIZATION OF ALCOHOL FUELS

METHODS OF UTILIZATION

Alcohol fuels may be utilized in three basic ways: as a blend with gasoline; as a straight, unblended fuel; or as an alcohol/water mixture in an injection system. Each method has certain advantages and disadvantages.

ALCOHOL BLENDS

Alcohol blends have the advantage that up to a 10, 20 or even 25% concentration of alcohol may be used without modification to the engine. The actual concentration that may be used varies with each engine type, but generally a four-cylinder engine will tolerate a stronger blend than a six or eight. Small single-cylinder engines, such as lawn mowers, can often be run on pure alcohol by merely adjusting the mixture control screw. Even with larger engines, slight modification such as adjusting the carburetor and, perhaps, advancing the timing a little may allow the use of blends in the 25-40% range. If you are producing your own blend, you have the advantage of being able to use the cheapest gasoline available and ending up with a good, high octane fuel. The disadvantage is that the alcohol you use must be perfectly dry. As will be discussed in the section on distillation, the highest concentration of alcohol that can be achieved by ordinary methods is 190 proof or 95%. In order to blend the alcohol with gasoline, the remaining 5% water must be removed. Several methods of removing this residual water will be discussed in Chapter 12, and one of them may be practical for you. However, drying the alcohol does require a separate manufacturing step and the expenditure of additional energy.

PURE ALCOHOL

The advantages of burning relatively pure 80-95% alcohol are several. First of all, because the drying step is unnecessary, you should be able to produce the fuel for less than the cost of gasoline. Secondly, there will be little, if any performance penalty, and by leaving 5-15% or more water in the alcohol you also gain the benefits of water injection. The only disadvantage is the trouble and expense of modifying your engine(s) to burn alcohol and the lack of dual-fuel capability. The principal engine modification is the enlargement of the carburetor jet(s). If you are a reasonably competent mechanic, you should be able to do the job in a couple of hours at a very small cost. In addition to the carburetor jets, there is also the problem of cold starting. As

mentioned earlier, alcohol has a higher latent heat of vaporization than gasoline and requires more manifold heat to keep the mixture in the vapor state. With most engines there will be no problem that can't be solved by installing a higher temperature thermostat since the engine runs fine as soon as it is warmed up. However, the engine will be difficult to start, especially in cold weather. The easiest solution to this problem is simply to start the engine on gasoline and, after it has warmed up, switch to alcohol. To accomplish this, merely install a small gasoline tank located, perhaps, under the hood and a selector valve mounted in some convenient location near the driver. It is my experience that it is also desirable to replace the automatic choke with a manual control. Also, switching back to gasoline prior to shutting down the engine will aid in restarting. A more complex solution to this problem would be to install a priming pump and manifold heater glow plugs similar to those found on diesel engines. Other alternatives are to preheat the fuel or squirt an easily volatilized liquid such as pentane into the carburetor. The addition of about 8% pentane directly to the alcohol in the fuel tank will also solve starting problems in below zero weather. Another problem, also related to latent heat, is that of fuel distribution. Larger engines are more likely to encounter this problem than small ones. What happens is that there is insufficient heat to keep the fuel vaporized and some of it liquefies before it reaches the outer cylinders. This causes misfires and general poor performance. Simple solutions include insulating the intake manifold or installing a higher temperature thermostat. Heating the fuel before it enters the carburetor also helps, as does heating the intake air. The ultimate solution is, usually, to install multiple carburetors and a short-path manifold. However, you are likely to encounter this problem only in engines that are, by some design fault, prone to the same poor fuel distribution with gasoline. It must be stressed that, although most engines are easily converted to alcohol, each engine is different. Some people have been able to successfully run Volkswagens and Hondas on alcohol merely by adjusting the jets and playing with the timing a little. Others, especially those with older, ultra-high performance V-8 engines, have had to resort to more extensive modifications.

Alcohol engine modification is a relatively "rediscovered" field. To the best of my knowledge, there is no comprehensive information on the modification of specific modern engines, and there are no manufacturers making conversion kits. (nb. This was written in 1978)

With all the interest in alcohol fuels, however, this should change in the near future. At present, though, it seems that modifications must be made on an individual basis. For those with special engines, there is good news and bad. Turbocharged engines present no special conversion problems once the jets, etc. have been enlarged. Alcohol and turbochargers then work very well together. Fuel injected engines are another matter. To convert them can be a simple adjustment of

the metering pump, or it can be virtually impossible. Very little data seems to be available in this area. **DIESEL ENGINES** Contrary to the opinion of most "experts", diesel engines can be run on pure alcohol. The main problem is in the lubrication of the injectors. This is solved by the addition of 5-20% vegetable oil (or other suitable lubricant) to the alcohol. It is also possible to make a diesel "gasohol" with up to 80% alcohol. Since alcohol and oil will not mix when water is present, both the alcohol and the oil must be anhydrous. Different engines may also require adjustment of the metering pump for optimum performance. Diesel engines, especially turbocharged diesels, may also be run with an alcohol/water injection system as described later.

ENGINE MODIFICATION

The following are some specific guidelines to assist in the modification of a carburetor. Remember that there are many different types and makes of carburetors, and that a certain amount of experimentation will be necessary. First, of course, you will have to remove the carburetor from the engine, clean it, and disassemble it to a point where you can remove metering jet(s). This will involve removing the air horn from the float valve and disconnecting any linkage. Next you must locate the main jet (or jets on a multi-throat model). Most carburetors have removable jets. They are almost always brass and are threaded into place. With the jet removed, the next step is to measure its diameter. This is best done with a micrometer. You will want to enlarge the area of the jet about 27% for ethanol and 40% for methanol. Suppose, for example, your jet is 0.054" in diameter. The formula for the area of a circle is 3.14 (pi) times the square of the radius. The radius is half the diameter, so we multiply $0.027 \times 0.027 \times 3.14$ to get an area of 0.002289 square inches. Multiply this times 1.27 (for a 27% enlargement) and we get 0.00291 square inches. Working the formula in reverse we get a diameter of 0.06087 inches. This is close to a #53 drill which is slightly too small. Since it is easier to enlarge a hole than to make one smaller, a wise choice for the first trial in this instance would be a #53 drill. Carefully drill out the jet, reassemble the carburetor, and reinstall it on the vehicle. The vehicle should then be run on alcohol as a test. Start the engine and slowly enrich the mixture (using the idle screw adjustment) until the engine starts to stall. Then adjust the idle until the roughness evens out. Take the vehicle for a short test drive, and then pull the spark plugs. If the tips are white, the mixture is too lean, and the main jet will have to be further enlarged. If they are wet, the mixture is too rich, and you have made the jets too large. In addition, if the mixture is too lean, the engine will backfire and miss. It will also burn the valves if left in this condition. On the other hand, if the hole is too large, the mixture will be too rich and you will waste fuel. It may be necessary to make several trials before the perfect jet size is found for your particular engine. In addition to the main jet, some carburetors will also require a slight enlargement of the idle circuit jet. This is accomplished in the

same manner as above except that a smaller percentage of enlargement will usually suffice. Note that this modification isn't always necessary.

Often merely backing out the idle adjustment screw will be enough. If the engine still doesn't run properly, there are several other things you can try such as advancing the timing a little, disconnecting the vacuum advance line, and closing the spark plug gaps a little. If you want to go the whole route, you can increase the engine's compression by milling the head and installing high compression pistons because the alcohol's high anti-knock qualities will allow compression ratios to 10:1.

Finally, if you have an engine where it is impossible to modify the carburetor, for one reason or another, (an excess of emission "plumbing", for example) you can usually replace your carburetor with an earlier model. Usually, the older the carburetor, the easier it is to convert. Also, it is possible to purchase adjustable jets for many carburetors, or your carburetor may already have such jets. Adjustable jets make it easier to change from alcohol to gasoline and vice versa should the need arise.

ALCOHOL INJECTION

Alcohol injection is a third alternative for the utilization of alcohol fuel. It is similar to water injection except that alcohol or an alcohol water mixture is injected into the engine. Since the water/alcohol injection mixture ratio can be as low as 50/50%, first run product from a simple still can be used. This is a considerable saving because most of the energy used in alcohol production is expended in the distillation stage to obtain 95% alcohol. Another advantage is that engines with an injection system still retain complete dual fuel capability. Finally, alcohol injection can be used with fuel-injected, turbocharged, and even diesel engines.

BASIC INJECTION SYSTEM

The alcohol/water mixture is contained in a separate tank and is fed, under a couple pounds pressure, to a misting nozzle located at the throat of the carburetor. The mixture is metered into the carburetor airstream where it mixes with the air and is taken into the engine. There are many ways of metering the alcohol/water mixture. For example, it can be done by mechanically linking a metering valve to the throttle. Other methods include using combinations of vacuum and/or manifold pressure. Whatever system is used, the metering system should work in parallel with the throttle. That is, the flow of alcohol/water mixture should increase as the load increases. Figure 3-2 diagrams a similar system for turbocharged engines. This is an extremely simple system. The alcohol/water tank is pressurized by bleed air from the compressor on the turbocharger. The mixture is

metered into the turbocharger airstream by an orifice.

The size of the orifice is determined by individual engine requirement. The metering system operates with the turbocharger. As the boost increases, more pressure is supplied to the tank and, thus, more mixture to the engine. On a diesel tractor rated at 125 horsepower and consuming 8-1/2 gallons of fuel per hour, the injection system produced the same power with only six gallons of diesel fuel and two gallons of a 50% alcohol/water mixture. This is an overall saving of 6% in fuel consumption and a saving of almost 30% in diesel fuel. Other benefits include trouble-free, automatic operation, increase in available power, lowering of engine operating temperatures, and prolonged engine life.[]

Chapter 4

ETHANOL PRODUCTION - GENERAL DISCUSSION / RAW MATERIALS

Ethyl alcohol may be made by the fermentation process from three basic types of raw materials, called "feedstock". The three basic types of feedstock are:

(1) **SACCHARINE** (sugar containing) materials in which the carbohydrate (the actual substance from which the alcohol is made) is present in the form of simple, directly fermentable six and twelve carbon sugar molecules such as glucose, fructose, and maltose. Such materials include sugar cane, sugar beets, fruit (fresh or dried), citrus molasses, cane sorghum, whey and skim milk.

(2) **STARCHY MATERIALS** that contain more complex carbohydrates such as starch and inulin that can be broken down into the simpler six and twelve carbon sugars by hydrolysis with acid or by the action of enzymes in a process called malting. Such materials include corn, grain sorghum, barley, wheat, potatoes, sweet potatoes, jerusalem artichokes, cacti, manioc, arrowroot, and so on.

(3) **CELLULOSE MATERIALS** such as wood, wood waste, paper, straw, corn stalks, corn cobs, cotton, etc., which contain material that can be hydrolyzed with acid, enzymes or otherwise converted into fermentable sugars called glucose.

MANUFACTURING STEPS

Certain materials require less processing than others. Generally, small scale production is easiest (and most economical in terms of labor and energy consumption) from the saccharine materials. However, starchy materials usually produce the most alcohol on a weight/weight basis,

and cellulose materials are the cheapest. Manufacturing alcohol from saccharine feedstocks generally requires:

(1) extraction or crushing to make the sugars available to the yeast enzymes during fermentation:

(2) dilution, which is only required with certain materials;

(3) fermentation; and

(4) distillation.

Starchy materials require the steps of:

(1) milling to free the starchy material from, for example, grain kernels;

(2) dilution;

(3) cooking to dissolve and "gelatinize" the starch; and

(4) conversion of the starch to fermentable sugars by malting, enzymes, or acid hydrolysis in addition to the steps of fermentation and distillation. Cellulose materials are similar to starchy materials in that they must be converted prior to fermentation.

PROCESS DESIGN

There are a great many variables in the manufacture of ethanol. Even materials from the same basic group can require radically different processing. The following chapters cover the individual manufacturing steps for processing each of the three main groups of feedstock. In addition, Chapter 10 contains "recipes" and individual processing requirements for specific materials from each of the three groups. The reader is urged to study all of the information presented before attempting to choose a specific process for a material.

Chapter 5

PROCESSING STEPS COMMON TO ALL MATERIALS

DILUTION

Dilution is simply the addition of water to adjust the amount of sugar in the mash or (ultimately) the amount of alcohol in the beer. It is necessary because the yeast, used later in the fermentation process, can be killed by too great a concentration of alcohol. Also, during the mashing and conversion of starchy material, dilution is necessary to make the mash easier to stir and handle. The object of dilution is to

end up with a beer as close to (but, not more than) 10% alcohol when fermentation is complete. The optimum dilution, then, is a compromise between the highest alcohol concentration and the point where the particular yeast strain being used will be killed. Optimum dilution requirements for each material are listed in Chapter 10. A rule of thumb for an unknown material, though, is that the final alcohol concentration will be about half the sugar content prior to fermentation. To determine the amount of fermentable sugar in a mash, it is best to have the material tested by a laboratory. If this is not possible, the sugar content can be estimated with a hydrometer. The use of hydrometers and tables for converting specific gravity readings to approximate sugar content are covered later in this chapter. It should be noted that any solution being tested with a hydrometer must be filtered to remove any undissolved solids. Otherwise the readings will be inaccurate. Sugar content of a solution can also be determined with the use of an optical instrument called a sugar refractometer. These devices, however, cost several hundred dollars. Since the use of a hydrometer to measure sugar content of a mash is, at best, an approximation, the amount of dilution can be "fine tuned" by measuring the alcohol content of the beer after fermentation. A hydrometer is used for this measurement also, but the readings are much more accurate. Naturally, if the alcohol content of the beer is less than the toleration level of the yeast you are using, the mash is overdiluted.

pH CONTROL

The pH is a measure of the acidity or alkalinity of an aqueous solution expressed on a scale of 1-14. Neutral is pH 7, pH 1-7 is acid, and pH 7-14 is alkaline. The pH is most conveniently measured with test papers that change color according to the pH of the solution being tested. These papers are available from swimming pool supply houses, garden shops, and laboratory supply companies. Control of pH during the mashing and fermentation process is important for two reasons: The growth of harmful bacteria is retarded by acid solutions, and yeast will grow only in an (slightly) acid solution. Most grain mashes have a naturally acid pH of between 5.4 and 5.6 after malting or conversion has been accomplished. Other materials, notably saccharine substances like molasses and fruit pressings, have a naturally alkaline pH and must be acidified prior to fermentation. The principal bacterial contaminants in a distillery are those that form lactic acid. Although the production of fuel alcohol is not concerned with the taste of the product, any lactic acid formed subtracts from the yield of alcohol. The production of lactic acid and other contaminants should therefore be avoided as much as possible. The development of these micro-organisms is severely repressed at pH values under 5.0. Above 5.0 their growth is rapid. The optimum pH range then is 4.8 to 5.0. Anything below about 4.1 to 4.4 is detrimental to other (desirable) processes taking place during the mashing and fermentation.

Consequently, the pH should be checked during the cooking and conversion. If it is much above 5.0, it should be reduced by the addition of acid. The acid most commonly used is sulfuric, although any mineral acid is perfectly suitable. Hydrochloric (muriatic) acid, for example, is available from swimming pool suppliers. The acid should be added cautiously, the mash stirred, and the pH checked, because it is very important not to add too much. If you happen to add a little too much, the pH can be raised with sodium hydroxide (caustic soda) solution or with ordinary lime. But after a certain point, this is useless and the mash must be scrapped. While adjustment during mashing is desirable, the proper pH during fermentation is absolutely essential. As soon as the pH in fermentation falls below about 4.11 the fermentation stops. If this occurs prior to complete conversion of the sugars, the yield will be low. On the other hand, yeast needs a slightly acid environment in order to grow. Consequently, the pH should be kept between 4.8 and 5.0 for optimum results. There are two ways of adjusting pH. The first, as discussed, is the addition of acid. The second, and probably the best, is the addition of the naturally acid residues left from a previous distillation. These residues are called "stillage", and adding them to the mash is called "backslopping". Backslopping is discussed in more detail in the next section.

It should be stressed that the pH should be checked periodically during the fermentation as well as before. Certain fermentations will produce substances that alter the pH during the fermentation. Once the pH goes beyond the optimum range, attempts to salvage the process by adding acid or caustic soda do more harm than good. So keep a close watch and adjust before the pH goes out of range.

BACKSLOPPING

Backslopping, or the addition of still residues from the previous batch, has several advantages. First (as discussed in the previous section) is the adjustment of the pH to control bacteria growth. Second, the stillage provides nutrients that are needed by the yeast for rapid growth. The third reason is that the stillage provides a "buffering" action. Grain mashes and starchy material generally provide enough nutrients for the growth of the yeast. Other materials, notably molasses and other saccharine materials, often do not. The addition of stillage can provide these nutrients where they are needed. The buffer capacity of the mash is important. When an acid and a base are mixed together, they react violently to produce a salt. Buffering can be thought of as a barrier between the acid and the base that allows only limited contact and thus moderates the reaction.

Grain mashes are generally well buffered between pH 5.0 to 6.0, poorly buffered between 4.4 and 5.07 and well buffered between 3.5 and 4.4. The addition of stillage aids in buffering the mash between 4.4 and 5.0. This provides stability and generally higher yields than

mashes without stillage. Different materials can tolerate differing amounts of backslopping. It is possible to have too much of a good thing, and too much backslopping can be detrimental. The limits for various materials are discussed in Chapter 10.

CLEANLINESS

The cleaning of fermenting tubs, pipes, and the like is extremely important. If mash and fermentation residues are allowed to accumulate, bacterial contamination will be rampant and will greatly reduce alcohol yield. Cleaning of the mashing and fermentation apparatus is usually done with steam in commercial operations. However, in a small plant, a thorough washing with disinfectant is usually adequate. Any disinfecting cleaner can be used, but, in the interest of economy, it is best to buy formaldehyde solution from a chemical supply house. For use it should be diluted 20:1 or more. Be advised that formaldehyde is a horribly foul smelling chemical that is intensely irritating to the skin, nose and eyes. The fumes also should not be inhaled. An alternate to formaldehyde is ammonia (ammonium hydroxide) solution, but the same cautions apply. After disinfecting with formaldehyde or ammonia, the apparatus should be thoroughly washed out with clear water. It is best to clean equipment after every batch, but in some climates and at certain times of the year when the bacteria count is low, cleaning every second or third time might be all right. In any event, at the first sign of problems, a thorough cleaning is absolutely necessary.

HYDROMETERS

Hydrometer

Hydrometers are little floats with calibrated stems used to measure the specific gravity of a liquid. The most familiar example is the device used to check battery charge or anti-freeze protection.

Sugar Content vs Specific Gravity

Hydrometers can be calibrated in a number of different scales, depending on their purpose. The most common calibration is for specific gravity. Water has a specific gravity of 1.000. Liquids lighter than water have specific gravities less than 1.000, and those heavier, greater than 1.000. The hydrometer can be used to measure the approximate dissolved solids in a mash or the concentration of alcohol before or after distillation. For measuring the solids dissolved in a mash the hydrometer is calibrated in degrees "Balling". One degree on this scale is equal to about 1% dissolved solids. Other hydrometers can be purchased to show alcohol content in proof or

percent. To obtain accurate measurements, a set of hydrometers, each covering a small range, is better than one hydrometer covering a large range. Hydrometers can be purchased from any laboratory supply house. So that you do not have to purchase several sets, Figures 5-2 and 3 convert sugar and alcohol content to specific gravity.

Because liquids change density with changes in temperature, corrections must be made for readings taken at temperatures other than that for which the hydrometer is calibrated. More often than not, the temperature of the solution you are testing will not be the same as the hydrometer calibration. Figure 5-4 is a correction table for non-standard temperatures. Note that this table is very accurate for determining the correction for aqueous ethanol solutions and less accurate for sugar or dissolved solids concentration. An alternate method of determining sugar content is the use of a sugar refractometer. These instruments are available from laboratory supply houses, but are expensive. However, the readings are very accurate.

Specific gravity can also be determined by weighing exactly one liter of the liquid at the proper temperature. The weight in grams, divided by 1000 will be the specific gravity. Due to the difficulty of measuring exactly one liter of the solution being tested, the weighing method is usually not as accurate as the method using a hydrometer.

Chapter 6

PROCESSING STEPS SPECIFIC TO SACCHARINE MATERIALS

GENERAL DESCRIPTION

As stated earlier, saccharine materials require the least processing of any of the ethanol feedstocks. Referring to Figure 4-1, it can be seen that molasses and other sugar-containing syrups need only to be diluted and pH adjusted prior to fermentation. Other materials, such as grapes and other fruits, need to be either crushed or extracted to make the sugar readily accessible to the yeast enzymes.

In addition to extraction, the requirements of pH control, dilution, backslopping, and cleanliness as discussed in Chapter 5 also apply.

Recipes for specific materials are contained in Chapter 10.

EXTRACTION

Prior to fermentation, saccharine materials, such as fruits, beets, etc., are usually put through an extraction process. This means that the sugar-containing juice is separated from the rest of the material. This

is usually done in a press like those used for crushing grapes or making cider. Extraction, per se, is not absolutely necessary. The materials can also be simply crushed to expose the juices for the fermentation process. However, with most distillation equipment, the solids will have to be removed prior to going into the still. There are certain problems and considerations associated with either extraction or crushing. Extraction in a press, at best, leaves an appreciable amount of fermentable material behind.

Typically, only 75% of the sugars can be extracted from apples and about 80% from grapes. One technique that can be used with press extraction to increase the yield is to take the residue from the first pressing, soak it in a minimum amount of water to dissolve more of the sugar, and then press it again. However, this method creates additional dilution which lowers the alcohol content of the fermented mash (called "beer") requiring more energy and time in the distillation process.

If a fruit juice contains, for example, 10% sugar, the final alcohol concentration going to the still will be about 5%. Any water used to wash additional sugar from the residue will further dilute this final concentration. The lower the alcohol concentration, the more water must be removed from the alcohol during distillation. However, in many instances, the greater total amount of alcohol gained justifies the additional dilution. Crushing the material instead of extracting it in a press leaves all the sugar available for fermentation, although the material usually must be strained prior to distillation. Again, some of the valuable liquid will be retained in the residue and the only solution is to wash it with a little water. If you are using a simple pot still, such as described in this book, filtering the residue isn't absolutely necessary as long as the still pot is cleaned out after each run. In this case, the crushing method is superior. Certain materials such as sweet corn stalks, sugar cane, and the like, require heavy hydraulic presses to effectively extract the juice. The alternate process here is to shred the material and then heat it with as little water as possible to dissolve out the sugar. Note that to obtain complete recovery of the sugar, the process described must be repeated several times. Again, a point is reached where dilution offsets the amount of sugar released and some compromise must be made. Note also that two extractions of one gallon each will dissolve more sugar than a single two gallon extraction.

Chapter 7

PROCESSING STEPS SPECIFIC TO STARCHY MATERIALS

PREPARATION OF STARCHY MATERIALS

Starchy materials fall into two main categories:

(1) materials, such as grains, in which the starch is encased or protected by grain hulls; and

(2) those materials, such as potatoes, where the starch is more readily available. Milling or grinding the material to expose the starch is necessary for the former group, but not the latter. Otherwise, all starchy materials require a certain amount of cooking and conversion of the starch to sugar prior to fermentation. There are two basic methods of conversion. The first uses malt or an extract of the enzymes contained in malt and the second uses dilute acid in a process called "acid hydrolysis".

MILLING

Grains and similar starchy materials must be milled to expose the starches to the cooking, conversion and fermentation processes. The ideal is to grind the material as fine as possible without producing an excessive amount of flour. This is because fine (flour) particles are difficult to remove if the material must be filtered prior to distillation. Again, if you are using a simple pot still, the material need not be filtered and the presence of fine flour particles is not objectionable. Large amounts of flour can also make the mash too viscous (thick) and hard to handle. This is only objectionable if it must be pumped from container to container or otherwise handled. If you are doing everything in the same pot, the viscousness can often be tolerated. Otherwise, premalting, as discussed later, will solve the problem. Almost any kind of grain-milling equipment can be used, or the grain can be milled by your local feed plant. Unfortunately, there is no alternate process, and if you are going to use grain as your feedstock, it will have to be milled.

COOKING

Cooking is necessary for all starchy materials. The object is first to dissolve all the water soluble starches and then, as much as possible, gelatinize them. In commercial operations, cooking is almost always done with steam, under pressure, and usually in a continuous process. Water boils at 212 deg Fahrenheit at sea level and at a lower temperature as altitude increases. By using pressure cooking equipment, higher temperatures and shorter cooking times can be obtained. At 150 pounds pressure, for example, grain starches can be cooked in six minutes or less. Large scale pressure cooking equipment is expensive and, in this manual, the cooking times for various materials will be given for the "atmospheric" process where temperatures are in the 208-212 deg range. Cooking times for different materials are listed under the individual feedstocks in Chapter 10.

Because a lot of energy is needed to boil the water used in the cooking process, it is best to cook with as little water as possible. Then, after cooking, additional water may be added to dilute the mash to optimum concentration for fermentation. If the additional water is added at a time when it is desirable to cool the mash, for example after cooking and prior to conversion, cooling time is saved. Most grains can be cooked with as little as 15-20 gallons of water per bushel. Note that when cooking with minimum water, special attention must be given to stirring the mash. Otherwise lumping and burning may occur. New methods of cooking are being developed that help to conserve energy. The most interesting is a method that combines milling and cooking into one operation without the use of water. The process uses heat generated by friction in the milling process to simultaneously cook the grain. It is all done in a specially designed grain mill.

CONVERSION

Conversion is the process of converting starch to fermentable sugars. It can be accomplished either by the use of malt, extracts of the enzymes contained in malt, or by the treatment of the starch (or cellulose) with acid in a process called "acid hydrolysis". Each method is discussed separately.

MALTING

Starch can be converted to fermentable sugars by the action of enzymes in malt. When the seeds of any cereal grain are moistened and allowed to sprout, certain enzymes (amylases) are produced which have the ability to convert starch to a form of fermentable sugar called maltose. All cereal grains produce these enzymes to a greater or lesser degree. However, barley produces by far the most and is usually the most economical to use. You can either purchase dried, ground barley malt, or you can produce your own from the grain. However, undried or "green" malt, such as that you might produce yourself, will not keep unless dried. On a small scale, it is often better to use the commercial product. In converting starch to sugar, malt enzymes exert two forms of chemical activity: liquefaction and saccharification. The intensities of these two activities depend on the temperature of the mash. The liquefying power is greatest at about 158 deg Fahrenheit. It begins to weaken at 175 and ceases at about 200. The saccharifying (sugar making) power is strongest between 120-130 deg F. and is destroyed completely at 175 deg. Both of these actions are desirable. Therefore a compromise must be made. The conversion process is therefore usually begun after the cooked mash is allowed to cool to about 150 deg F. The material is held at this temperature for a certain length of time (depending on the material) and then allowed to cool to the optimum fermenting temperature. The average malting recipe calls for the use of between half to 1 pound of

dried malt for each 10 pounds of grain. Again, specific recipes are covered later. The dried malt is usually mixed with warm water at a ratio of about 2.5 pounds per gallon to form a slurry. This slurry should be mixed about an hour ahead of time and added to the mash when it cools to the proper temperature. Because barley malt is expensive, usually more expensive than the material it is used to convert, it is best to use as little as possible. The minimum amount can be determined after several trial conversions. To do this, make a trial malting using the amounts listed in Chapter 10. Then take a little of the converted mash and filter it through a cheesecloth or some similar material. Place a little of the filtered liquid in a white dish and add several drops of a solution composed of 5 grams potassium iodide and 5 grams of iodine crystals in one quart of (distilled) water. Any blue color produced indicates the presence of unconverted starch. Naturally, if the test indicates no blue color, the next trial should be run with less malt and vice-versa. The test solution can be compounded by your local druggist or the chemicals can be purchased from any laboratory supply house.

PREMALTING:

During the cooking process, the starch in the grain is gelatinized. When the mash is cooled, it may become too thick to be stirred and handled effectively during the malting operation. The technique of premalting cures this problem by taking advantage of the liquefying properties of malt prior to the conversion. To premalt, simply add about 10% of the total malt weight to the mash prior to cooking. This causes sufficient liquefaction to facilitate handling the mash during subsequent operations. It also helps to prevent thermal destruction of the malt enzymes later on and so reduces the production of undesirable by-products. After cooking, the remaining 90% of the malt slurry is added, and the conversion is continued as usual.

PREPARATION OF MALT

The following is a basic process for making malt, for those who prefer to prepare their own. Any grain can be used to make malt, but as stated before, barley is by far the best. However, if you are working with corn, for example, you can simply set aside about 20% of the grain, prepare a malt as described below, and use it in the same way you would use barley malt. The same is true of similar materials. Malt is simply sprouted grain. The basic requirements for sprouting are moisture, warmth, and darkness. Grain can be sprouted in anything from a five-gallon plastic pail to a 55-gallon drum. The container should either have small holes poked in the bottom or, with larger containers, a valve protected by a screen or mesh that will allow water to drain but retain the material being sprouted. Begin by soaking the grain until the kernels can be crushed between the fingers and the inside is soft. This takes about 8-12 hours for barley and considerably longer for corn.

Then drain the water. Thereafter, sprinkle the grain several times a day with warm water. The object is to keep the grain moist but not wet. If too wet, the grain will rot. After a watering, the water will work its way down through the grain and out the holes (or valve) in the container. The sprouting will generate some heat. The optimum temperature for sprouting is about 80 deg F. but the most enzymes seem to be produced at about 60 deg F. When sprouting in large containers, be careful that the grain doesn't get too warm. If it does, it can be spread out on a concrete floor in a dark place and the sprouting continued. Small containers will not have the problem of too much heat. Sprouting will take about 4 days. The malt is ready when the sprout is about a half inch long.

Prior to use, the malt will have to be crushed. This can be done in a mill or, on a small scale, a heavy duty garbage disposal can be adapted. It is also possible to use an ordinary blender or food processor. Fresh, undried malt is called "green" malt. It must be used immediately or dried because it will rot if stored wet. It should be used in the same manner as dried malt, and it is not usually necessary to adjust the recipe to allow for the green malt's moisture content because the green malt is slightly more potent.

ENZYME CONVERSION

The enzymes contained in malt are available commercially from several manufacturers. The procedures for using them are very similar to malt conversion. In addition, the use of enzyme extracts is usually superior to malt. First of all, the enzyme extracts are usually cheaper. They are also specifically designed for the job at hand, and they generally produce more predictable results and higher yields. The three basic types of commercially available enzymes are alpha, beta, and gluco amylases. Alpha amylases randomly split the starch molecules to produce a type of sugar called dextrose. Beta amylases act similarly to produce maltose. Together, these two enzymes can convert about 85% of the starch to fermentable sugar. Gluco amylases can reduce the remaining starches, and the use of all three can achieve almost total conversion of the starch. The two principal manufacturers of enzymes suitable for starch conversion are Miles Laboratories and Nova Laboratories, as listed in the appendix. Enzymes are used in much the same manner as malt. However, because different enzymes require slightly different pH, times, and temperatures, it is best to follow the recommendations of the manufacturer. A typical recipe for the use of Miles Laboratories "Taka-Therm" and "Diazyme L-100" for the conversion of corn is included in Chapter 10.

ACID HYDROLYSIS

Starch (and cellulose) may also be converted to fermentable sugars by the action of acid. This process is relatively simple, but it requires

acid proof equipment, high temperatures, and the handling of acid. For these reasons, it is not really recommended for small scale production. Basically, dilute mineral acid (usually sulfuric) is added to the grain slurry prior to cooking at a concentration of 1-4% as calculated on a weight/weight basis. The mash is then cooked at a temperature of about 350 deg F.

Cooking and conversion of the starch take place simultaneously. The mash is then immediately neutralized with calcium hydroxide (lime), or some other base, and fermented in the usual manner. The high temperatures essential in this process are obtained by the use of pressure cooking. The steam pressure required is about 150 pounds per square inch. This, together with the necessity for acid proof equipment, make this process unsuitable for small scale use. However, it is an excellent process for large operations because cooking and fermentation times are short and the method is readily adaptable to continuous operation.

MASH COOLING

Malting is conducted at a temperature of about 145-150 deg F. As is discussed later, fermentation is commenced at an optimum temperature of 70-80 deg Fahrenheit. Between the two steps the mash must be cooled. One of the biggest problems affecting alcohol yield is bacterial contamination of the mash either before or during fermentation. The chief protection against this is the pH or acidity control of the mashing and fermentation operations. However, even with perfect pH control bacterial infections can set in. This happens mostly during the cooling stage between mashing and fermentation. If bacterial contamination becomes a problem, the only solution (other than the obvious need for cleanliness) is to shorten the cooling time as much as possible. The less time at the temperatures conducive to bacteria growth the better. Therefore, it might become necessary to make a cooling coil as illustrated in Chapter 13. The cooling coil is the best long term solution, but if the problem only occurs occasionally, as during the summer months, a plastic bag full of ice and suspended in the mash might do the trick. Just be sure the plastic bag doesn't leak and dilute your mash!

Chapter 8

PROCESSING STEPS SPECIFIC TO CELLULOSE MATERIALS

CELLULOSE CONVERSION

Cellulose feedstocks, which include a wide variety of material from corn stalks, wood, straw, and cotton, to old newspapers (paper) and trash, are potentially good sources of alcohol. If fully converted, for

example, a ton of old newspapers would yield up to 70 gallons of alcohol. Cellulose materials are also extremely cheap and, often, free. Cellulose is converted by either enzymes or acid hydrolysis. Nova Laboratories produces special enzymes called "Cellulast" and "Cellobiase 250L" for conversion of cellulose to fermentable glucose. Other manufacturers make similar products. The acid process involves either strong acid and relatively low temperatures, or weak acid and high temperatures. The strong acid process has the problem that the glucose is destroyed almost as fast as it is formed unless the contact time with the acid is very brief. The weak process requires acid proof pressure cooking equipment as described earlier. Again, for the obvious reasons, these methods are not recommended on a small scale. The main problem with cellulose as an ethanol feedstock is getting at the cellulose itself. In a plant, cellulose is encased in a substance called "lignin" in much the same way that a steel reinforcing rod is encased in concrete. Lignin is the substance that gives wood its strength. To get at the cellulose, the lignin must be dissolved away. The paper industry uses substances like sulfur dioxide, calcium bisulfite, sodium sulfate, sodium sulfide, and sodium hydroxide (lye) to dissolve lignin. Concentrated mineral acid, mentioned earlier, also dissolves lignin. Unfortunately, as it is dissolving the lignin, the strong acid also converts and then destroys the glucose. Commercial processes are being developed to process cellulose into alcohol with the use of strong acid without destroying the cellulose. However, the process is complicated and economically feasible only on a very large scale.

The only alternative to dissolving the lignin is to reduce the cellulose material to as fine a state as possible so that at least some of the cellulose may be recovered. This is done by powdering, grinding or pressing. The yield of cellulose is directly proportional to how finely the starting material is reduced. Other cellulose materials are somewhat easier to process than those with high lignin content. Some forms of paper, like newspaper, are almost pure cellulose and are easily converted by either the enzyme or acid process. Also, in order for a plant to produce cellulose, it must first produce glucose, which is the sugar we are trying to obtain. Therefore, plants that are processed while they are still wet and green have the advantage of having fermentable sugar already available. These materials can be simply fermented without conversion and considered as low-yield saccharine feedstocks.

Chapter 9

YEAST AND FERMENTATION

Yeast is an organism belonging to the vegetable family. The yeast itself does not take a direct part in the fermentation process, but it

secretes a complex of enzymes that act upon the sugar and convert it to alcohol and carbon dioxide gas. The yeast used in alcoholic fermentation is a special strain bred to be tolerant to variations in pH and resistant to alcohol. In the past, distilleries bred and propagated their own yeast strains. The yeast was kept alive in cultures and grown in batches of ever-increasing size to be used in the fermenters. Keeping yeast alive and growing cultures is a tricky business that requires precise control of temperature, nutrients, and the like. However, a simplified method is described later. Fortunately, special active dry yeast is available. To use it, you merely add warm water to reactivate it and then add it to the mash in the fermenter. Two pounds is sufficient for 1000 gallons of mash. It is available from Universal Foods Corporation as listed in the appendix. This yeast should be rehydrated for 15 minutes prior to use at a temperature of 100-105 deg Fahrenheit, or it can be added dry to the fermentation tank prior to filling. In a pinch, it is possible to use ordinary baker's yeast from your grocer's shelf. However, this yeast is not bred for alcohol tolerance, and you will probably not get the yields associated with the distiller's yeast.

YEAST PROPAGATION

It is possible to grow and propagate your own yeast cultures if you observe certain precautions. Above all, the conditions must be absolutely sterile. Ordinary boiling water does not kill all of the bacteria present. It is necessary to use a pressure cooker. Make a solution of (proportionately) one cup sugar, one cup flour and two quarts water. Place the solution in a pressure cooker and boil at elevated pressure for at least 45 minutes. Without opening the pressure cooker, cool the solution to about room temperature. Then open the container and add a cake of baker's or distiller's yeast. Close the container and keep it in the refrigerator. The yeast will slowly grow. Some carbon dioxide will be given off, so be sure to leave the vent open. If desired, the yeast slurry can be transferred to jars. Just be sure they are sterile and remember to poke a small hole in the lid to let the carbon dioxide escape. To use the yeast culture, merely remove a teaspoon or so, place it in another (sterile) container, feed it some sugar and warm it to room temperature. When it becomes active, it is ready for the fermenter. If at any time your refrigerated culture goes bad (due to bacterial contamination) it must be thrown out and the procedure started again. Also, yeast cultures should not be frozen.

FERMENTATION

All that is necessary to begin fermentation is to mix the activated yeast and the cooled, pH-adjusted mash in the fermentation tank. Aside from the considerations of pH as discussed earlier, the most important thing during the fermentation is temperature control. When

the fermentation begins, carbon dioxide gas will be given off. At the height of fermentation, the mash will literally "boil" from the carbon dioxide produced. The reaction also produces some heat. The optimum temperature for the fermentation process is between 70-85 deg F., and it is desirable not to let the temperature go much above 90-95 deg F. Cooling is readily done with the use of ice bags, as discussed earlier, or by the use of a cooling coil. A less desirable method of controlling temperature is to dilute the mash. The actual time required to ferment a mash varies with the material being fermented, the pH, temperature, and several other factors. It can take from one to four days. You will know that the fermentation is complete when the mash ceases bubbling and the yeast cake, which forms on top, sinks to the bottom. At this point, the fermented liquor is known as "beer" and it is ready to be distilled. It is advantageous to distill the beer as soon as possible. Occasionally, if it is allowed to sit, it will turn to vinegar. Vinegar is alcohol that has been oxidized to acetic acid. Certain enzymes present after fermentation act as catalysts and allow any air present in the mash solution to react with the alcohol to form acetic acid. In fact, if you want to produce vinegar, all you have to do to start the reaction is to bubble air through the fermented mash. Once the vinegar reaction has set in, the mash is lost. There is no cure. The only prevention is to separate the beer from the mash sediment and distill it as soon after fermentation is complete as possible.

It is also advantageous to use a fermentation lock as described in Chapter 13, to prevent alcohol vapors from escaping the fermenter. Otherwise, the CO₂ gas can carry with it a considerable amount of alcohol. Note that the small, glass fermentation locks available from wine-making supply houses are suitable, at most) for a 5-gallon container. Larger containers must have proportionately larger fermentation locks or a dangerous amount of pressure will build and the vessel could explode. It is permissible to open the fermenter to check progress and take samples for pH analysis, etc. as long as care is taken not to introduce bacteria that could contaminate the mash.

FERMENTATION BY-PRODUCTS

The principle products of fermentation are alcohol, carbon dioxide, and fermentation residue. The alcohol is distilled from the beer and used as fuel. The carbon dioxide gas in large distilleries is usually compressed or made into dry ice. Another use for the gas would be to pipe it into a greenhouse. The plants will then use it in the photosynthesis cycle, removing the carbon and giving off oxygen. Lacking a use for the carbon dioxide, it can be simply vented into the air as it is totally non-polluting and non-toxic. What will be left is a lot of water and solids. A portion of the water can be used for backslopping. The remaining solids contain proteins, vitamins, minerals, fats, and yeast cells. All of the nutrition value of the original

feedstock, except the starch or sugar that has been turned into alcohol, survives intact. It may be fed to cattle, or if suitably processed it can be used for human consumption. However, in the wet state, it will keep for a maximum of 3-5 days depending on conditions. After this it will begin to rot. Therefore, for long term storage these residues (stillage) must be dried. This can be done by straining out the solids and spreading them in a thin layer to dry in the sun, by use of rotary grain dryers, or similar equipment.

NOTE OF CAUTION

Alcohol produced for human consumption is made under special conditions and purified to a high degree. Ethanol that is produced according to the procedures in this book will contain fusel oils (high boiling alcohols), aldehydes, and ketones. None of these chemicals affect fuel performance but, if ingested, could cause fatal poisoning at worst or a horrible hangover at best. In addition, if the distillation equipment used later on is not tinned copper or stainless steel, many toxic metal oxides can be introduced to the alcohol. Solder, for example, contains a lot of lead and can react to form poisonous lead oxides. So besides being illegal, drinking your fuel could be hazardous to your health!

Chapter 10

INDIVIDUAL RAW MATERIALS

This chapter contains specific processing information and recipes for individual raw materials. If a material you are interested in using is not listed, you can usually approximate an appropriate process by using the information about a similar material. Note that feedstock materials are not consistent in the amount of fermentable materials, moisture content, and many other factors. The figures given here are averages. More specific information about particular materials can be obtained from your state agricultural service, or the material in question can be tested by an agricultural laboratory for a modest fee. Remember, then, the following information is intended only as a guide.

SUGAR/STARCH CONTENT vs ALCOHOL

On the average, the amount of alcohol that can be produced from a given feedstock will be about half (on a weight/weight basis) of the convertible starch or sugar content. Ethanol weighs about 6.6 pounds per gallon. A ton of grapes, for example, with a 15% sugar content is capable (assuming 100% extraction) of producing about 150 pounds or 22.7 gallons of alcohol. Corn, with 66% convertible starch should produce 660 pounds or 100 gallons. Remember, this is only an approximation and actual yield depends on many interrelated factors.

SACCHARINE MATERIALS

The process of fermenting saccharine materials is relatively simple and straightforward. The steps involved are usually:

- (1) extracting or crushing,**
- (2) pH adjustment through acid or backslopping, and**
- (3) fermentation.**

Dilution is usually not necessary because the extracted juices often contain less than the 20% maximum of fermentable material. Exceptions to the above are the various types of molasses that do not require extraction, but usually require dilution.

FRUITS

The following are some fruits and their average sugar content: grapes, 15.0%;

bananas, 13.8%;

apples, 12.2%;

pineapples, 11.7%;

pears, 10.0%;

peaches, 7.6%;

oranges, 5.4%;

prickly pear, 4.2%;

watermelon, 2.5%; and

tomatoes, 2.0%.

Allowing 75% extraction with apples, for example, the total fermentable material would be about 9% of the original weight. On this basis, a ton of apples would yield about 13 gallons of alcohol. Assuming an 80% extraction with grapes, a ton should yield about 17 gallons.

With watermelons and a 90% extraction, a ton would yield only about 3 or 3-1/2 gallons. Clearly, some materials are better than others.

In all the above cases, the percentage of fermentable material in the

extracted juice is low enough so that dilution is unnecessary and undesirable. To ferment these materials, the juice need only be adjusted to the proper pH (between 4.8-5.0) and the yeast added at the usual rate of 2 pounds per 1000 gallons of mash. To provide proper nutrients to the yeast, backslopping of about 20-25% by volume is desirable. Also, all of the above materials may be simply crushed or pulped instead of extracted in a press. This way the total sugar content is available for fermentation. If you are using simple batch distillation equipment that does not require the beer to be strained, this method is recommended.

MOLASSES

Beet or cane molasses is the residue from the manufacture of sugar. These materials, if available, are excellent sources of alcohol. They contain 50-55% fermentable sugar, and a ton should yield between 70-80 gallons of alcohol.

Molasses with a sugar content above 15-20% will need to be diluted. Since most molasses is low in the nutrients necessary for proper yeast growth, backslopping is of particular advantage. Up to 50% stillage (by volume) may be used. Also, most molasses is naturally alkaline, and acid will be needed in addition to the stillage to obtain the proper pH value.

CANE SORGHUM

Cane sorghum is a good alcohol source because it is easily grown and averages about 14% fermentable sugar content. The main drawback to using this material is that the extraction requires heavy-duty shredding and pressing equipment. An alternate process is to shred the stalks as much as possible and dissolve the sugar by heating (not quite to a boil) with a minimum amount of water. The process must be repeated several times to retrieve most of the sugar. Note that in this type of process, two extractions of one gallon each are better than one extraction of two gallons. A conservative 65% extraction should yield about 13-14 gallons of alcohol per ton. Acidification to proper pH is necessary and backslopping to about 25% can be tolerated.

SUGAR BEETS

Sugar beets are an excellent material for ethanol production. They contain about 15% sugar, 82% water, and the rest in various solids. The juice can be extracted in a press, or the beets can be crushed and fermented as described in the section on fruits. Because the beets contain a certain amount of starch, the addition of small quantities of malt (1-2% by weight) or enzyme will greatly improve the alcohol yield.

Adjustment of pH is, of course, necessary, and backslopping in the 20-25% range is desirable. A ton of beets should produce 20-25 gallons or more of alcohol.

SUGAR CORN WASTES

Stalks from sugar corn contain 7-15% sugar and should be considered as an alcohol source if they are available. The stalks need to be shredded and extracted in a manner similar to sugar cane or sorghum stalks. A relatively efficient operation should yield 8-18 gallons of alcohol per ton of material. Again, backslopping to 20-25% and acidification are necessary.

STARCHY MATERIALS

Starchy materials generally require milling, cooking, and conversion prior to fermentation. Exceptions are materials, such as potatoes and sweet potatoes, that do not require milling, and materials, such as artichokes, that do not require conversion. Relatively high alcohol yields often offset the necessary additional manufacturing steps, and most starchy materials are good alcohol sources.

GRAINS

Grains must be milled, diluted, cooked, and converted prior to fermentation. However, they contain large amounts of potentially fermentable material. The average content of convertible starch and sugar in some typical grains are: barley, 50%; maize (indian corn), 66%; oats, 50%; rye, 59%; sorghum seed, 67%; and wheat, 65%. Alcohol yield per ton is dependent on how completely the starches are converted to fermentable sugar, but should be between 70-100 gallons. After milling, the grain must be diluted prior to cooking and fermentation. The average dilution is between 56-64 gallons per 100 pounds of grain, depending on moisture and starch content. The method of cooking with minimal water and adding the balance prior to conversion, as described previously, has the dual advantage of reducing the energy needed for cooking and shortening the cooling time. Premalting with malt or enzymes is generally desirable. Cooking is accomplished by heating the diluted and premalted mash to a slow boil and holding at this temperature for 30-60 minutes. Generally, the mash is sufficiently cooked when it is soft and mushy. The mash is then cooled to 145-150 deg F and the malt slurry is added. The malt slurry consists of about 2-1/2 pounds of dried or green malt per gallon of water as described in the section on malting.

On a weight/weight basis, corn or wheat will require about 8-10 pounds of malt per 100 pounds of grain. Rye will require about 10-12 pounds of malt for the same 100 pounds of grain. Other grains will fall somewhere in between. The malt slurry is stirred constantly during conversion. For

wheat, the conversion will be complete in 5-15 minutes. Corn will require about 30 minutes, and rye between 30-60 minutes. The actual time, as well as the minimum amount of malt necessary, can be determined through trial mashes and the starch test as described in the section on malting. When the conversion is complete, the mash is cooled to 70-75 deg F. and yeast slurry is added. Note that most grain mashes have an acceptably low pH and often do not need much adjustment. Backslopping should be limited to 20-25%. The following is the general procedure for converting corn with Miles Laboratories enzymes. The procedure for other materials and other enzymes will differ slightly, and the manufacturer's recommendation should be followed. After milling, the grain is partially diluted (slurried) at a ratio of 35 gallons of water per 100 pounds of grain. The pH is adjusted above 5.5 with an optimum range of 6.0 to 6.5.

"Premalting" or liquefaction, is accomplished by the addition of 0.3 ounces of Taka-Therm enzyme. The mash is then slowly heated. Gelatinization will begin at about 150 deg F. and the mash will rapidly thicken. Constant stirring is necessary at this point. At about 160 deg the liquefying action of the enzyme will begin. Heating may be more rapid after the liquefying action of the enzyme begins to take effect. After the mash reaches 200-212 deg an additional 1.3 ounces of Taka-Therm enzyme is added. After the mash has been held at a slow boil for 20-30 minutes, an additional 33 gallons of water is added to complete dilution and cool the mash.

When the mash has cooled to 135-140 deg the pH is adjusted to 4.2 with acid and Diazyme L-100 enzyme is added at a ratio of 4 ounces per 100 pounds of grain. This enzyme completes the conversion in about 30 minutes and, after cooling to 70-80 deg, the mash is fermented in the usual manner.

JERUSALEM ARTICHOKEs

Jerusalem artichokes deserve special mention as a source of alcohol because they contain between 16-18% fermentable material. In addition, the starches present can be converted without the use of malt or enzymes if cooked for a sufficient length of time. A ton should yield about 25 gallons of alcohol. To prepare artichokes for fermentation, they should be crushed to a pulp and cooked for 2-3 hours. If the starch test (described in Chapter 7) indicates that some unconverted starch is still present, conversion with small amounts of either malt or enzyme might be needed. Shorter cooking times are possible if a greater amount of malt or enzyme is used.

For example, a 30 minute cooking time should be sufficient with a conversion using 3-6% malt or the equivalent amount of enzyme. Dilution is not necessary because the root usually contains 79-80% water. After cooking, the pH is adjusted and fermentation commenced

in the usual manner.

POTATOES

Potatoes contain between 15-18% fermentable material and are a traditional source of alcohol. On the average, a ton of potatoes will yield about 22-25 gallons of alcohol. Damaged or sprouted potatoes are not objectionable, and the use of sprouted potatoes will reduce the amount of malt or enzyme required for conversion. Commercially, potatoes are usually cooked with steam, under pressure. An acceptable alternate method is as follows: The potatoes should be shredded or cut up and placed in the cooker with as little water as possible; cover the cooker and steam until the potatoes are reduced to a soft mass. Premalting to reduce viscousness is a definite advantage. After cooking, the mash is cooled to the conversion temperature. Usually only 3-4 pounds of malt per 100 pounds of potatoes are all that is required. The mash must be constantly stirred during conversion, which will take about 15-20 minutes.

Because cooking and conversion times will vary, depending on starch content and the like, test mashings and the use of the starch test is recommended. Once converted, the pH should be checked and the mash fermented in the usual manner. For specific procedures for the use of enzymes to convert potatoes, consult the manufacturer. Otherwise, about half the amounts listed in the corn recipe should be sufficient.

SWEET POTATOES

Sweet potatoes average about 22% starch and 5-6% sugar for a total of 27-28% fermentable material. A ton should yield up to 40 gallons of alcohol. Sweet potatoes are cooked and converted in a manner similar to potatoes with the exception that they contain only about 66% water and some dilution is necessary.

CELLULOSE MATERIALS

The following "recipe" for the conversion of cellulose is based on the use of two enzymes available from Novo Laboratories. "Celluclast" enzyme is produced from a variety of the *Trichoderma viride* fungus and is active in breaking cellulose into cellobiose and glucose. The former is not a fermentable sugar, therefore, a second enzyme, "Cellobiase" is used in conjunction with Celluclast to convert the cellobiose. Together the two enzymes have the ability to convert cellulose to sugar with near 100% efficiency.

However, in order for the enzymes to work, the cellulose must be accessible. Any cellulose material should be shredded, ground, or otherwise reduced to as fine a state as possible. After shredding, or

whatever, the material is mixed with as little water as possible to make a thick, soupy mass. The pH is adjusted to between 4.5-6.0, and the enzymes are added. It will be impossible to determine the exact amount of "accessible" cellulose, and the amount of enzyme needed must be estimated. Generally, dry cellulose materials such as wood, straw, corn cobs, etc. will have the lowest yields. This is because the cellulose is encased in lignin, and the amount that is ultimately accessible to the enzymes is proportional to how finely the material is divided. Materials such as grass clippings and all moist, green cellulose containing materials will have the next highest yields. This is partly because the lignin content is lower and partly because some fermentable glucose is already present. The highest yields will come from materials such as paper and cotton that are almost pure cellulose.

A trial amount of enzyme for all of the above materials would be about 2% Celluclast and 0.2% Cellobiase on a weight/weight ratio to available cellulose. Thus, if wood chips were estimated to have 5% by weight available cellulose, about 0.1% of the first enzyme is needed and 0.01% of the second. This would work out to 32 ounces of Celluclast and 3.2 ounces of Cellobiase per ton of wood. Newspapers, on the other hand might have 50-80% available cellulose and the amount of enzyme needed would be greater. Optimum temperature for the enzyme reaction is 140 deg F. The mash should be held at this temperature for about 16 hours. The temperature should then be reduced to 80-90 deg and fermentation commenced in the usual manner. Prior to adding the yeast, the pH should be checked and adjusted to the optimal range for the yeast strain. It is suggested that trial conversions and fermentations be made to determine the minimum amount of enzyme needed to produce maximum yield. A simplified "recipe" for green cellulose material of almost any kind is shredding followed by fermentation. As noted earlier, plants first produce glucose (a fermentable sugar) and then convert the glucose to cellulose. Yields will be based entirely on the amount of glucose present as cellulose is not converted by this method.

MULTIPLE ENZYME TREATMENT

All materials used in the production of ethanol will contain some cellulose. Therefore, it might be worthwhile to experiment with small amounts of cellulose enzymes in conjunction with the other processes. Saccharine materials might benefit from a separate cellulose conversion step. Starchy materials could have the cellulose enzymes added during conversion in addition to the starch enzymes. Depending on the amount of available cellulose, this procedure could dramatically increase yields.

Here is a link to buy Turbo-yeast, enzymes, and other distillation related products. <http://www.distillery-yeast.com/>