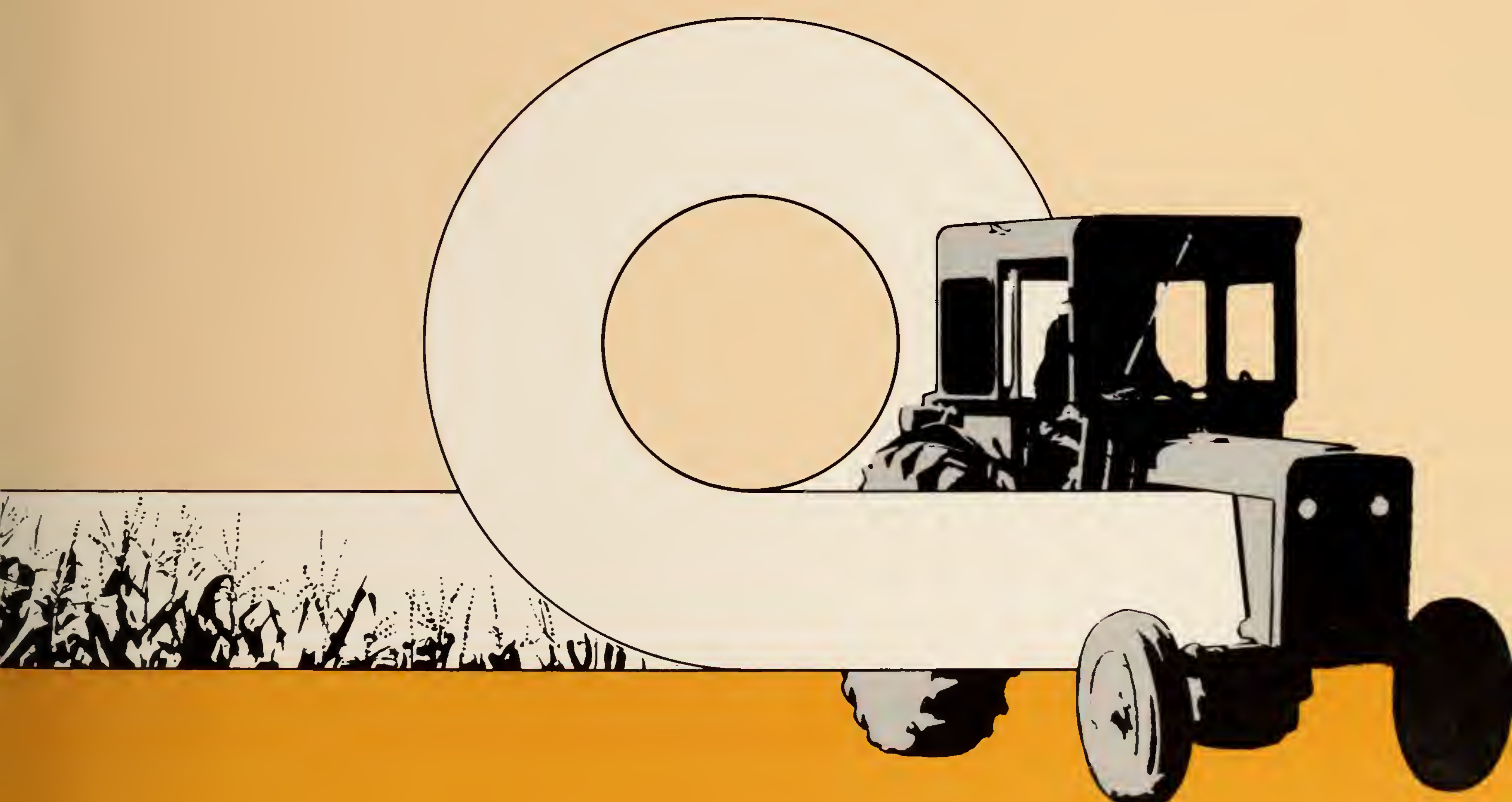
FARM-SCALE PRODUCTION AND USE OF FUEL ALCOHOL

opportunities and problems



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INTRODUCTION

Recent publicity of "gasohol" and "on-farm production of alcohol fuels" programs in the United States has many Canadian farmers considering the possibility of alcohol (ethanol) production. Can this be profitable and provide a measure of energy self-sufficiency on the farm? This is one of the many questions you must ask before deciding to produce and use alcohol fuel.

There are both potential opportunities and possible problems. Not all opportunities will apply to you, nor will you find all problems insurmountable. You have to carefully weigh all considerations before making a decision. The process is not beyond the scope of a farm, but you must understand it if you are to make it work.

Remember, hazards are involved in both alcohol production and storage, and this publication discusses some of the recommended safety precautions. Most farmers are already familiar with such hazards, as they routinely handle other dangerous chemicals and fuels.

GENERAL OUTLINE OF THE PROCESS

There is *no single recipe or recommended process* for alcohol production. The choice must be tailored to the resources (feedstock and energy), capital investment, byproduct use, and alcohol use of each individual producer. In general, the following steps are required:

1. Prepare feedstock by crushing or milling (cereal grains, corn, etc.), chopping (potato, Jerusalem artichoke) or squeezing to extract sugar juices (sugar beet, sweet sorghum, fruits).
2. Convert starch to sugar (in all but sugar crops). This is accomplished by adding water, enzyme (barley malt or commercial enzymes), adjusting the pH (acidity) by adding acid or alkali, and cooking for a specified time. The exact procedure is provided by the company supplying the enzyme.
3. Add water so that the final concentration of sugar in the "mash" is about 20-22%. Although cooking kills many of the microorganisms that can lower alcohol yield, it may be desirable to sterilize the mash.
4. To ensure maximum rate of ethanol production, adjust the acidity to pH 4-5, and hold the temperature at 27-32°C. Small amounts of nutrients such as urea or ammonium salts may have to be added.
5. Add yeast to the mash in a closed tank (fermenter) and allow it to ferment for 2 to 3 days (it can take up to 6 days or longer if there are problems with the yeast, pH, temperature or nutrient composition). Make provision for carbon dioxide to escape while preventing air from entering. (About 1 m^3 of CO_2 is produced for every 2 L of alcohol).
6. When fermentation is complete, the fermenter will contain a mixture of 10-12% alcohol and water ("beer") plus a residue ("spent mash"). You can separate the beer from the solids at

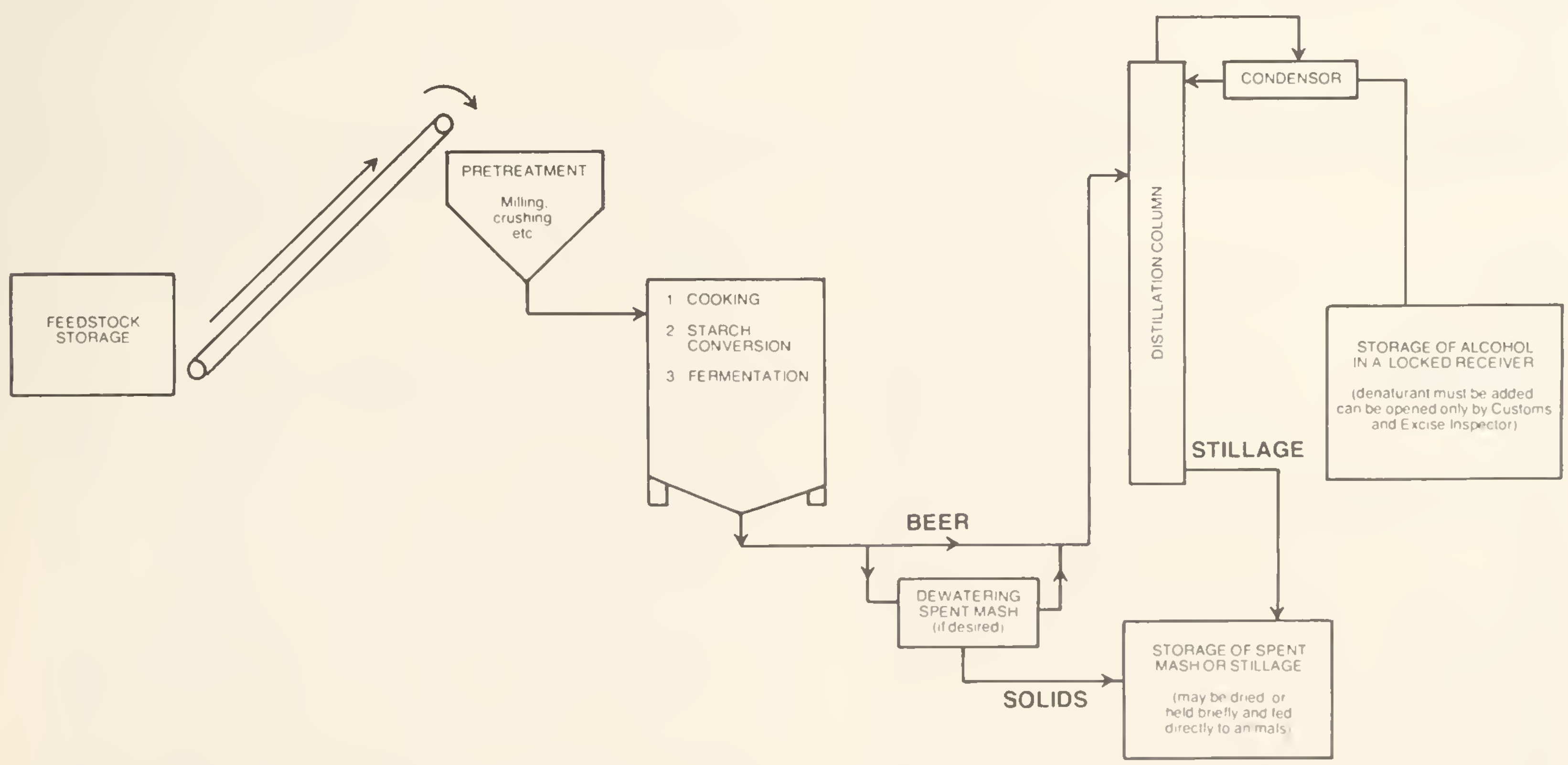

Figure 1. Simple flow diagram of one form of the process

this time or transfer the mixture "as is" to a distillation apparatus (still) where the alcohol is separated from the "whole stillage".

7. The spent mash or stillage is either dried to prevent spoilage when stored, or fed directly to livestock as part of the feed ration. If fed directly, it can be partially dewatered (by centrifuge, filter press or other means) to reduce the amount of water consumed in the feed, although some soluble nutrients will be lost.

The major energy inputs for the process occur at the cooking and distillation stages (and for drying of stillage, if required). The fermentation creates some heat and, if the ambient temperature is high (e.g. a hot summer day), provide a cooling system.

POTENTIAL OPPORTUNITIES

On-farm production of alcohol can give some independence from traditional fuel sources. Though not commercially available in Canada, engines that run on 100% alcohol or mixtures of alcohol and water ("aquahol") are being developed. Some individuals have been successful at modifying gasoline and diesel engines to run on various combinations of fuel (gasoline or diesel), alcohol and water. Companies are developing conversion kits for existing engines. If it is economic to do so, you can mix up to 10% (perhaps even 20%) of anhydrous (water-free) alcohol produced on the farm with gasoline and use this in gasoline engines without major engine modification. The mixture ("gasohol") appears to cause no damage to the engine, although long-term effects are not precisely known. Alcohol can also provide a source of fuel to dry grain and to heat buildings, greenhouses, and water. However, it makes better sense to directly burn straw, stover or wood for such heating.

Low-cost steel or fiberglass rather than stainless steel may be used for some components of the alcohol production system to reduce capital costs. However, because of possible hazards and rapid wear due to corrosion, stainless steel is recommended for most of the components, especially the distillation apparatus. Many individuals will be capable of building some of the components themselves. Odor, clarity and the bitter taste of fusel oils (higher alcohols) are not concerns in fuel alcohol production.

When practical, crop residues (straw, stover) or wood may be used to fire a steam boiler for the distillery.

Unsold crop inventory, distressed grains and other low-quality produce such as potato culls may be used to produce alcohol.

On a cash crop/livestock farm, you may convert part of the crop to alcohol, and use the wet spent mash or stillage, that is high in protein, as livestock feed.

Cooperative development of a central alcohol production plant is a possible way to increase production and balance alcohol and feedstock supply versus alcohol demand, while lowering costs to individual producers. The cooperative or other business arrangement will let the producers hire a qualified person to operate the system, avoiding many, though not all, of the technical problems that will be encountered.

An integrated approach might be to produce alcohol in association with a methane digester using livestock wastes. Methane could supply some of the energy needed by the digester and the cooking/distillation operations. However, farm-scale methane (or anaerobic) digestion has not yet proven profitable in Canada.

Better cost-effective technologies for both the production and end-use of alcohol fuels are cur-

Table 1 Potential Alcohol Yield From Field Crops*

Crop	Yield (L/t)
Starch	680
Sugar	610
Spring wheat	380
Winter wheat	410
Oats	270
Barley	390
Mixed grains (west)	350
Mixed grains (east)	330
Rye	390
Corn	430
Buckwheat	350
Peas, beans	350
Potatoes	110
Field roots	30
Sugar beets	70

*Yield assumes a maximum theoretical conversion efficiency to alcohol of 95%. The efficiency on farms would more likely be 50 to 85%.

rently being developed. Whether these technologies will become applicable on the farm remains to be seen. Potential producers are faced with the decision to either build their alcohol plants now to take early advantage of farm-produced fuel, or to wait and take advantage of better technologies as they become commercially available.

POTENTIAL PROBLEMS AND OTHER CONSIDERATIONS

To date, there is little experience of on-farm production of alcohol. The United States program is still in its infancy. Although there is a large number of new suppliers of alcohol production equipment on the United States market, some are less than reputable. Before buying from any company, check their "track record" and guarantees thoroughly.

Capital cost estimates for alcohol production facilities including fermenter, still, crushing apparatus, and storage are not firmly established. For a 100-900 L/day operation, the capital cost will range from a minimum of $10 000 for a manual facility to more than $100 000 for a completely automated operation. In addition to the interest paid on capital, you must consider the loss in revenue from not selling that portion of crop that goes into alcohol production, plus the additional costs of depreciation, operation, energy inputs, chemicals, enzymes, insurance, licensing, bonding, management time and labor. Feeding the wet spent mash to livestock will offset some of the costs. The farm is a business operation, so that other opportunities for investment, labor, time and feedstock play an important role in the decision to produce alcohol. *Do not begin alcohol production as a business venture on the farm without a great deal of economic planning.*

In determining the size of operation for a particular farm, you must answer three basic questions:

1. How much alcohol fuel can the farm use?
2. How much fuel can be produced from available feedstocks?
3. Are there enough animals on the farm or nearby that can use the spent mash byproduct as feed?

Credit may be difficult to obtain since lending agencies have no experience in financing small-scale farm distilleries. This is because of uncertainties about finding markets for surplus denatured fuel-grade alcohol, as well as about the technology of production and end-use in existing farm equipment. The economic risk is not well defined.

Experience in the United States has shown that learning to produce alcohol can be expensive and frustrating. Unexpected technical difficulties can arise with both fermentation and distillation. For example, "bad" fermentation batches are sometimes encountered. Soluble proteins and solids in the beer will foul up the trays in the distillation column so that periodic cleaning (every 2 or 3 days) will be required. Accidental spills of unfermented or spent mash increase the possibility that the fermentation will be contaminated by unwanted organisms. Good housekeeping is of extreme importance. The farmer who has done his homework properly will be best able to overcome these obstacles. Therefore, try to obtain some knowledge of chemistry, engineering, microbiology and plumbing.

Under present legislation, alcohol must be collected in a "locked receiver" which can only be opened by a customs and excise inspector. The alcohol must also be denatured (made undrinkable) by adding a prescribed chemical if it is to be exempt from excise duty. A distiller's license ($250/year) is required as well as a surety bond for a minimum of $200 000. (This type of bond costs $500/year.) Changes in this legislation to reduce the bonding and licensing requirements for experimental fuel-grade alcohol production are presently being considered. Additional information can be obtained from the regional directors, Customs and Excise, that are listed in the back of this publication.

It takes more actual energy to produce alcohol than we get back when we burn the alcohol. On the farm, however, this "negative energy balance" turns out to be very favorable if only gasoline and diesel, the very fuels that alcohol would replace, are counted as energy inputs. Furthermore, the use of low-value feedstocks (surplus or distressed produce, culls, etc.), crop residues or wood to produce energy for cooking and distillation help make the balance even more favorable.

A word of caution: Unsold surplus crops may not be relied upon every year. If crop prices rise, alcohol becomes in effect more expensive to produce. A continuous supply of feedstock and crop residues for a yearlong operation requires proper handling and storage facilities, an additional capital investment. Crop residues can only be collected from the fields within allowable limits for soil management and protection. Also to be considered are the extra capital, time, labor, and fuel required to collect residues.

Feeding wet spent mash or stillage to livestock is obviously a valuable economic opportunity. Also, the amount of energy saved by not drying this byproduct is significant. In general, a mature cow can daily consume the stillage byproduct from 4.5 L of alcohol production (feeder calf, from 3.2 L; pig, from 1.8 L; chicken, from 0.2 L). However, wet spent mash spoils and loses nutrients quickly, and must be fed to livestock within a day or two. Therefore, it should be produced in daily amounts no greater than can be fed to the animals. Because of the unique taste of spent mash, high-production animals may go "off feed" if it is fed intermittently. Refrigeration or added preservatives (these have not yet been defined) would help alleviate these problems. Whole stillage (10% solids) can be fed directly without partial dewatering, but in general,

OPTIONS

DIESEL ENGINE (compression ignition)

- Diesohol in unmodified engine. Impractical as diesohol contains anhydrous alcohol, which is very expensive to produce on the farm.
- Emulsified blends of diesel fuel and alcohol or aquahol in slightly modified engine. Ontario Research Foundation is testing a system.
- Dual injection of diesel fuel and alcohol or aquahol into the intake air stream of turbocharged diesels. Requires modification of injection system. Under development in Sweden.
- Separate injection of diesel fuel and aquahol into the intake air stream of turbocharged diesels. Requires slight modification. Conversiom kits for turbocharged tractors are available in the United States.
- Aquahol used alone in diesel engine converted to spark ignition. Conversion kits are not available, but individuals might be able to do it at some risk to the engine.
- Straight alcohol or aquahol used in unmodified engine. Impractical until way found to raise alcohol's cetane rating.

GASOLINE ENGINE (spark ignition)

- Gasohol in unmodified engine. Impractical as gasohol contains anhydrous alcohol. which is very expensive to produce on the farm.
- Emulsified blend of gasoline and aquahol in slightly modified engine. Ontario Research Foundation is developing this.
- Straight alcohol or aquahol in slightly modified engine. There is some risk to the engine.

ALCOHOL ENGINE

- Specially designed engine that uses straight alcohol or aquahol. Developed elsewhere, these are not commercially available in Canada.

Figure 2. Use of alcohol in engines

water should not exceed four times the solids intake in the total ration. This varies according to type and weight of animal. Spent mash, if it's a byproduct of the fermentation of moldy grains, should not be fed to animals. It contains the original toxins (i.e. poisons) of the moldy grains.

USE OF ALCOHOL IN ENGINES

Figure 2 shows some of the options for alcohol fuel use. "Diesohol" (a mixture of alcohol and diesel fuel) is impractical for farm use. Alcohol and diesel fuel do not mix unless both fuels are virtually water-free, and are kept that way. Though not as critical as diesohol, "gasohol" (alcohol and gasoline) will tolerate only a small amount of water before the mixture separates into two phases. This problem becomes especially critical during cold weather. Distillation can produce alcohol up to 95.6% pure, but removing the remaining 4.4% water requires additional energy inputs plus a major capital investment. Though not commercially available, new techniques are being developed that use much less energy.

To combat the phase separation problem when water is present, a number of interesting possibilities are under development. These include chemical additives, emulsification of aquahol and diesel fuel or gasoline just before injection, separate injection of aquahol and diesel fuel into diesel engines, and carbureting aquahol into the turbocharger air intake of diesels. None of these techniques are commercially available in Canada. One United States company has developed conversion kits (about $1000) for a number of turbocharged diesel tractors; however, long-term effects on the engines are not yet known.

Total replacement of gasoline or diesel with aquahol in farm vehicles is a desirable option for those wishing complete self-sufficiency in liquid fuels. Specially designed engines that run on aquahol have been developed in Brazil and elsewhere, but are not available in Canada. Gasoline engines (spark ignition) can run on aquahol (80% alcohol/20% water) after a "do-it-yourself" modification. Alcohol's cetane rating is too low to be used in a diesel engine (compression ignition) although a number of chemical additives that raise the cetane rating have been tested experimentally. Diesels can, however, run on aquahol when converted to a spark ignition system.

The engine modifications described above have been presented in a simplified fashion. The cost of modification ranges from $300 to $3000. The risks to operators, equipment, and engine warranties are unknown.

POTENTIAL HAZARDS

Health

Toxic vapors may escape from the fermenter, still or storage container. Ethers, from the distillation column, are powerful narcotics and in large doses can cause death. Continued exposure to small concentrations is relatively harmless but may cause thirst, fatigue and loss of appetite. Although exposure to high concentrations of ethanol vapor is not likely to cause death, continued inhalation will produce a narcotic effect, as well as headaches and irritation to the eyes, nose and throat. Many of the chemicals used in the process or as denaturants are corrosive, poisonous or may cause cancer. Carbon dioxide is given off in large quantities during fermentation. It is heavier than air, so that without proper ventilation it could build up in the building and cause asphyxiation. Higher than normal concentrations of carbon dioxide cause the heart rate to increase and may be dangerous to people with heart problems.

Fire and Explosion

Ethers, the first products to come off the distillation apparatus, are easily ignited and are very dangerous fire and explosion hazards. Alcohol is readily ignited and, in certain mixtures with air, is potentially explosive if exposed to a flame or strong spark. Alcohol also burns with a nearly invisible flame so that a fire may go undetected until severe damage has been done. Fortunately, alcohol fires can be extinguished with water. Caution must also be exercised when using other flammable chemicals in the process.

Safety Precautions and Regulations

An alcohol production or storage facility that is enclosed in a building is defined as a hazardous area. Always consult with provincial officials and comply to provincial safety codes. The two important codes in each province are modeled after the Canadian Electric Code and the National Fire Code.

To prevent accidents, have adequate ventilation to remove hazardous vapors. Ethers should be drawn off at source and vented to the outside. You may wish to install gas detectors and a warning system as added safety precautions.

Remove from the area all potential sources of ignition such as open flames, exposed parts of electrical equipment or installations (e.g. resistance space heaters), and any other potential source of spark. Where it is necessary to have electrical equipment or installations in the area, use only approved equipment. Other guidelines and regulations for hazardous locations are given by the provincial electric safety codes for items such as lighting fixtures, receptacles, switches, special wiring methods, and seals for electrical conduits and motors. Also, follow regulations on the safe storage of alcohols set by the national, provincial or local fire codes.

If the process uses steam under pressure, check the "Boiler and Pressure Vessels Act" in your province; this will set specific standards for equipment construction. Although some provinces have exempted boiler and pressure vessels used for agricultural purposes from their jurisdiction, inquire nevertheless to ensure that you have taken adequate safety measures.

DEFINITION OF TERMS

Alcohol - in this bulletin, refers to ethanol, CH_3CH_2OH, (other names: ethyl alcohol, grain spirits). Other alcohols include methanol, butanol, propanol, etc.

Anhydrous alcohol - refers to water-free (less than 0.5% water) alcohol. Distillation produces 95.6% alcohol, at which point an azeotrope (or azeotropic mixture) is formed. Further distillation will not remove any more water unless benzene or other chemicals are added to "break the azeotrope". There are also other techniques being developed to remove the remaining 4.4% water.

Aquahol - a generic name for mixtures of alcohol and water. The water content could range from 1 to 50% depending on the requirements of the particular engine.

Azeotrope - a mixture of two components (e.g. 95.6% ethanol/4.4% water) which can be boiled away without further change in alcohol concentration in either the vapor or liquid portion.

Beer - the fermented broth that consists of water, alcohol, and small amounts of ethers and assorted alcohols.

Cetane rating - (cetane number) a measure of a fuel's ease of self ignition. Diesel fuel, with a high cetane rating, is suitable for compression ignition engines, while alcohol and gasoline, with low cetane ratings are not suitable (see also octane rating).

Dewatering - the separation of free water from the solids portion of spent mash or whole stillage (by screening, centrifuge, filter press or other means). The remaining solids portion is a wet cake that still contains 50 to 80% moisture.

Diesohol - a mixture of diesel fuel and anhydrous alcohol. Both components must be free of water to remain stable as a blend.

Emulsification - is the mixing of two fluids that do not dissolve in each other (e.g. oil and water, diesel and aquahol, gasoline and aquahol). The result is an emulsion where one fluid is dispersed in very fine droplets in the other fluid.

Enzyme - a protein found internally or secreted externally by living cells or organisms (yeast, bacteria, fungi) which is, in effect, a highly specific catalyst for biochemical reactions such as the conversion of starch to sugar.

Ethanol - see alcohol.

Gasohol - a registered trademark of Nebraska that refers to a mixture of 10% anhydrous alcohol and 90% unleaded gasoline. It has also become a generic term for other blends of gasoline and anhydrous alcohol.

Mash - a slurry of feedstock and water.

Microorganism - refers to any microscopic organism such as yeast, bacteria, fungi, antinomycete, etc.

Octane rating - (octane number) a measure of a fuel's resistance to self ignition, hence a measure as well of the antiknock properties of the fuel. Whereas diesel fuel has a low octane rating, gasoline and alcohol have high octane ratings and are suitable for spark ignition engines.

pH - a measure of acidity, where pH 1 is very acid, pH 7 is neutral, and pH 14 is very alkali.

Phase separation - when water is added to gasohol or diesohol, the alcohol/water mix separates from the gasoline or diesel fuel and settles to the bottom of the tank.

Spent mash - the residual "slop" of unfermented matter plus the microbial cell mass that has accumulated during fermentation. If the spent mash (and beer) is transferred directly to the distillation apparatus (where the alcohol is removed), the residual slop is now called "whole stillage" (or stillage), a suspension of less than 10% solids in water containing dissolved proteins.

Sterilize - to ensure that all unwanted microorganisms in the mash are killed before yeast is added. Since the mash will give microorganisms more protection from heat treatment than plain water, simply boiling the mash for 15 minutes may not be sufficient. Chemicals used to sterilize the mash can also prevent growth of the alcohol-producing yeast. *Note:* It is not necessary to sterilize the mash; however, it does minimize fermentation problems.

Stillage - see spent mash.

REGIONAL DIRECTORS OF CUSTOMS AND EXCISE

Information on the production and control requirements for alcohol may be obtained from any of the following:

Regional Director, Halifax,
R. Young,
Halifax Insurance Bldg.,
5670 Spring Garden Road,
P.O. Box 1658,
Halifax, Nova Scotia
B3J 2Z8 (902) 426-2143

Regional Director, Quebec,
P. Gagnon,
2815 Laurier Blvd.,
P.O. Box 9664,
Ste Foy Station,
Quebec, Quebec
G1V 4C2 (418) 694-3853

Regional Director, Montreal,
P.V. Bartolini,
Customs House,
400 Youville Square,
P.O. Box 6092,
Montreal, Quebec
H3C 3H3 (514) 283-6023

Regional Director, Ottawa,
R.J. McCloskey,
9th Floor, S.B.I. Bldg.,
Billings Bridge Plaza,
P.O. Box 8257,
Ottawa, Ontario
K1G 3H7 (613) 998-3538

Regional Director, Toronto,
L.E. Rainboth,
4th Floor,
25 St. Clair Ave. E.,
P.O. Box 100, Stn. "Q",
Toronto, Ontario
M4T 2L7 (416) 966-6380

Regional Director, Hamilton,
R. Davie,
Suite 840, Stelco Tower,
100 King St. W.,
P.O. Box 588,
Hamilton, Ontario
L8N 3K7 (416) 523-2325

Regional Director, London,
L.J. Kluger,
457 Richmond Street,
Dominion Public Bldg.,
3rd Floor,
P.O. Box 5548, Terminal "A",
London, Ontario
N6A 4R3 (519) 679-4145

Regional Director, Winnipeg,
D. Fulton,
13th Floor,
Royal Bank Bldg.,
220 Portage Ave.,
Winnipeg, Manitoba
R3C 0A5 (204) 949-2972

Regional Director, Calgary,
C. Taylor,
Federal Building,
220-4th Avenue, South-East,
P.O. Box 2525, Station "M",
Calgary, Alberta
T2P 3B7 (403) 231-5669

Regional Director, Vancouver,
J.F.E. Heembrock,
460 Nanaimo Street,
P.O. Box 69090, Station "K",
Vancouver, British Columbia
V5K 4X2 (604) 666-3803

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