ETHYL ALCOHOL PRODUCTION
Operation of the Texas A&M University ethyl alcohol plant is an interdisciplinary project with support from the Texas Agricultural Extension Service, Texas Agricultural Experiment Station, Center for Energy and Mineral Resources, The Texas A&M University System; and the Texas Energy Development Fund of the Texas Energy and Natural Resources Advisory Council.
Ethyl Alcohol Production

Henry O'Neal*

The Agricultural Engineering Department at Texas A&M University has been operating a research and demonstration ethyl alcohol production plant since January 1981 as part of an alternate energy program. The plant is located on the Texas A&M University West Campus at the Agricultural Engineering Research Shop and is representative of a small farm-scale facility.

Alcohol Production Steps

Corn and grain sorghum are the main feedstocks used for alcohol production at the Texas A&M plant. The steps in production vary depending on the brand of enzymes used. Each enzyme manufacturer has slightly different temperature and water requirements to fit the activity of a particular enzyme. Any enzyme may be used but should be used according to the manufacturer's recommendations. A combination of enzymes from two different manufacturers has worked well at the Texas A&M plant.

The following general production steps are the ones presently used and may change with future production experience.

1. The grain is ground in a hammermill with a 1/8-inch screen. The 350-gallon cooker-fermenter tanks normally handle a 12½ bushel batch.

2. The ground grain is added to and mixed with 150 gallons of water (12 gallons per bushel) at 120 degrees F. This begins the cooking process, during which the grain mixture or mash is constantly agitated. A liquefying enzyme (Taka-Therm by Miles Laboratories, Inc.) is added at the rate of 30 grams per 56 pounds of grain. The pH of the

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grain mash normally ranges from 6.0 to 6.4, which is within the optimum pH range of the liquefying enzyme (pH 5.5 to 7.0). The mash is then heated to 210 degrees F at a rate of about 1 degree per minute. The mash is held at this temperature for one hour. The heating and cooking is achieved by direct steam injection.

3. At the end of the cooking period, 62½ gallons of cold water (5 gallons per bushel of grain) are added to begin cooling the mash to a fermentation temperature of 98 degrees F. The cooling process includes running cold water through a water jacket on the outside of the cooker, reducing the temperature about 1 degree F per minute. The pH of the mash is lowered to 5.0 to 5.4 during the cooling process (at 100 to 120 degrees F) by adding sulfuric acid.

4. A saccharifying enzyme (Gasolase by Biocon Inc.) is added at the rate of 12 grams per 56 pounds of grain. Distiller's yeast or baker's yeast (or a half-and-half mixture) is added at the rate of 3 pounds per 1,000 gallons of mash or 1 pound per 300 gallons of mash. The enzyme and yeast are allowed to mix for 15 to 20 minutes before agitation is stopped.

5. The mash is then allowed to ferment at a temperature not to exceed 100 degrees F. In the Texas A&M plant, the cooker is also the fermenter. At temperatures of 94 to 98 degrees F, fermentation is complete in 2-3/4 to 3 days. The fermented mixture is known as beer.

6. The next step is to separate the ethyl alcohol from the beer using two 12-inch diameter plate distillation columns, each 20 feet in height. All of the fermented mash is put into the first column (beer column) with steam injected directly into the base of the column. A mixture of alcohol and water vapor is driven from the top of the beer column while grain and water residue (stillage) are removed from the bottom. The alcohol and
water vapor then enter the bottom of the second column (rectifying column) where alcohol vapor is driven off at the top and condensed to yield liquid alcohol. The normal production proof of the Texas A&M University plant is 182 to 184.

7. The solid grain residues are separated from the stillage in an auger de-watering press. These solid residues (distiller's grains) leave the de-watering press at about 65 percent moisture with a yield of about 8 pounds of residue (dry weight basis) per bushel of original grain. These residues contain 27 to 28 percent protein. After removal of the distiller's grains, about 8 to 9 pounds of grain residue remain as solubles in the water.

Plant Operation Data

The average yield at the Texas A&M plant, with corn and grain sorghum as the main feedstocks, is 2.6 gallons of 182- to 184-proof ethyl alcohol per bushel of corn or 2.5 gallons per bushel of grain sorghum. The equivalent for 200-proof alcohol would be 2.4 gallons per bushel of corn and 2.3 gallons per bushel of grain sorghum.

The average natural gas, water and electricity requirements of the plant for the production of 182- to 184-proof ethyl alcohol are listed in the following sections. Also following is a plant process diagram.

Natural Gas Use

<table>
<thead>
<tr>
<th>Natural Gas Use per Gallon of Alcohol Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking</td>
</tr>
<tr>
<td>25 cubic feet</td>
</tr>
<tr>
<td>Distilling</td>
</tr>
<tr>
<td>45 cubic feet</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>70 cubic feet</td>
</tr>
</tbody>
</table>
This natural gas use is average for a production batch using 12 gallons of cooking water at 118 to 120 degrees F initially and an additional 5 gallons of cooling water per bushel of grain after cooking. Hot condenser water from a previous distillation is stored in tanks and used for cooking. Natural gas required for cooking increases 5 to 10 cubic feet per gallon of alcohol produced when the batch is started with cold water.

Using additional cooking and cooling water lowers the beer alcohol concentration and increases the amount of natural gas required for distillation by about 5 to 10 cubic feet per gallon of alcohol produced.

Water Use

<table>
<thead>
<tr>
<th>Process</th>
<th>Water Use per Gallon of Alcohol Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking</td>
<td></td>
</tr>
<tr>
<td>Added to grain</td>
<td>7 gallons</td>
</tr>
<tr>
<td>(17 gallons/bushel)</td>
<td></td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>25 gallons</td>
</tr>
<tr>
<td>(cooling water jacket)</td>
<td></td>
</tr>
<tr>
<td>Boiler</td>
<td>2 gallons</td>
</tr>
<tr>
<td>Distilling</td>
<td></td>
</tr>
<tr>
<td>Condenser cooling</td>
<td>5 gallons</td>
</tr>
<tr>
<td>Boiler</td>
<td>2 gallons</td>
</tr>
<tr>
<td>Total</td>
<td>41 gallons</td>
</tr>
</tbody>
</table>

At the Texas A&M plant, water used in the heat exchanger is disposed of as waste water. However, it could be stored, cooled, and used again as cooling water for the heat exchanger. Heat-exchanger water use was determined from the January through April production batches. Water use increased during summer months because of higher water temperatures. Also during hot weather, fermentation temperatures rise and cooling water is used in the heat exchanger to keep fermentation temperatures below 100 degrees F.
Cooling water in the condenser heats up as vaporized alcohol is condensed to liquid alcohol. This hot water is stored and used as cooking water in a successive batch. Condenser cooling-water use may also increase as water temperatures rise during hot weather.

Electricity Use

Average electricity use to produce 182- to 184-proof ethyl alcohol from corn and grain sorghum is 0.7 kilowatt hours per gallon of alcohol produced. This includes grinding grain and running all plant motors. Electricity for lighting in the plant building is not included.

Cooking and Distilling Logs

The following cooking and distilling logs show typical production batches for the Texas A&M plant.
COOLING WATER ADDED
ICORN AND LIQUEFYING ENZYME ADDED
SULPHURIC ACID ADDED
STOP HEAT EXCHANGER WATER SACCHARIFYING ENZYME AND YEAST ADDED
BEGIN HEAT EXCHANGER WATER FLOW
COOKING PERIOD
BEGIN HEATING WATER

TEMPERATURE (°F)

TIME (HRS.)

BATCH 29 COOKING AND FERMENTING LOG
Batch 29 Cooking and Fermenting Log (continued)

Corn

Natural gas used
   Cooking
   Boiler start up
   Total

Water used
   Cooking (12 gallons per bushel)
   Cooling (4 gallons per bushel)
   Heat exchanger (5.2 g.p.m. flow rate)
   Boiler
   Boiler start up
   Total

Fermenting time--69 hours

Maximum fermenting temperature--101° F.

Temperature at end of fermenting period--86° F.

682 pounds--12.2 bushels

Meter measures in increments of 100 cubic feet
1000 cubic feet--33 cubic feet per gallon of alcohol produced
1100 cubic feet

146 gallons
49 gallons
787 gallons--25.7 gallons per gallon of alcohol produced
51 gallons--1.7 gallons per gallon of alcohol produced
12 gallons
1045 gallons
START STILL WARM UP
START BEER FEED
START ALCOHOL FLOW TO STORAGE

FERMENTER EMPTY
STOP ALCOHOL FLOW TO STORAGE

STILL SHUT DOWN
Batch 29 Distilling Log (continued)

Corn

Beer

Alcohol into storage tank

Alcohol (still clean out)

Total alcohol produced

Corn production rate

Distilling time (30.6 gallons alcohol)

Average distilling rate

Natural gas used

Distilling (30.6 gallons alcohol)
Still warm up and clean out
Total

Water used
Condenser (30.6 gallons alcohol)
Boiler (30.6 gallons alcohol)
Still warm up and clean up
Total

682 pounds—12.2 bushels

281 gallons

30.6 gallons at 183 proof

4.8 gallons at 38 proof—1.0 gallon at 183 proof

31.6 gallons at 183 proof

2.6 gallons per bushel at 183 proof—2.4 gallons per bushel at 200 proof equivalent

3 hours—03 minutes

10 gallons per hour

Meter measures in increments of 100 cubic feet

1200 cubic feet—39 cubic feet per gallon of alcohol produced

600 cubic feet

1800 cubic feet

199 gallons—6.5 gallons per gallon of alcohol produced

73 gallons—2.4 gallons per gallon of alcohol produced

262 gallons

534 gallons
COOKING PERIOD

COOLING WATER ADDED

BEGIN HEAT EXCHANGER WATER FLOW

SULPHURIC ACID ADDED

STOP HEAT EXCHANGER WATER

SACCHARIFYING ENZYME AND YEAST ADDED

TEMPERATURE (°F)

TIME (HRS.)

BATCH 30 COOKING AND FERMENTING LOG
### Batch 30 Cooking and Fermenting Log (continued)

#### Corn

<table>
<thead>
<tr>
<th>Natural gas used</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking</td>
<td></td>
</tr>
<tr>
<td>Boiler start up</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water used</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking (12 gallons per bushel)</td>
<td></td>
</tr>
<tr>
<td>Cooling (5 gallons per bushel)</td>
<td></td>
</tr>
<tr>
<td>Heat exchanger (6.7 g.p.m. flow rate)</td>
<td></td>
</tr>
<tr>
<td>Boiler</td>
<td></td>
</tr>
<tr>
<td>Boiler start up</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

#### Fermenting time--68 hours

- Maximum fermenting temperature--99°F.
- Temperature at end of fermenting period--86°F.

<table>
<thead>
<tr>
<th>689 pounds--12.3 bushels</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Meter measures in increments of 100 cubic feet</td>
<td></td>
</tr>
<tr>
<td>800 cubic feet--26 cubic feet per gallon of alcohol produced</td>
<td></td>
</tr>
<tr>
<td>148 gallons</td>
<td></td>
</tr>
<tr>
<td>62 gallons</td>
<td></td>
</tr>
<tr>
<td>837 gallons--27.4 gallons per gallon of alcohol produced</td>
<td></td>
</tr>
<tr>
<td>35 gallons--1.1 gallons per gallon of alcohol produced</td>
<td></td>
</tr>
<tr>
<td>12 gallons</td>
<td></td>
</tr>
<tr>
<td>1094 gallons</td>
<td></td>
</tr>
</tbody>
</table>
BATCH 30 DISTILLING LOG
Batch 30 Distilling Log (continued)

Corn

Beer

Alcohol into storage tank

Alcohol (still clean out)

Total alcohol produced

Corn production

Distilling time (30.6 gallons alcohol)

Average distilling rate

Natural gas used

Distilling (30.6 gallons alcohol)

Still warm up and clean out

Total

Water used

Condenser (30.6 gallons alcohol)

Boiler (30.6 gallons alcohol)

Still warm up and clean up

Total

689 pounds 12.3 bushels

285 gallons

30.6 gallons at 183 proof

7.4 gallons at 39 proof--1.6 gallons at 183 proof

32.2 gallons at 183 proof

2.6 gallons per bushel at 183 proof--2.4 gallons per bushel at 200 proof equivalent

3 hours-08 minutes

9.8 gallons per hour

Meter measures in increments of 100 cubic feet

1400 cubic feet--46 cubic feet per gallon of alcohol produced

600 cubic feet

2000 cubic feet

202 gallons--6.6 gallons per gallon of alcohol produced

70 gallons--2.3 gallons per gallon of alcohol produced

318 gallons

590 gallons
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