405
7/17/81
T-5
(2)

Dr. 2841

DOE/CS/40352-T2

ENERGY CONSERVATION IN ETHANOL PRODUCTION FROM
RENEWABLE RESOURCES AND NON-PETROLEUM ENERGY SOURCES

MASTER

March 1981

Work Performed Under Contract No. AC01-80CS40352

CENTEC Corporation
Reston, Virginia

Dist-271
NTIS-23

U.S. Department of Energy

Solar Energy

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

"This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A04
Microfiche A01

ENERGY CONSERVATION
IN ETHANOL PRODUCTION
FROM RENEWABLE RESOURCES AND
NON-PETROLEUM ENERGY SOURCES

A report on the application of commercially proven energy conservation technologies to the production of ethanol and DDG from grains.

By CENTEC Corporation
Reston, Virginia

For A. Smith Bowman Distillery
Sunset Hills, Virginia

Under DOE Contract DE-AC01-80CS40352

March 1981

TABLE OF CONTENTS

	<u>Page</u>
SECTION 1 SUMMARY	1-1
SECTION 2 INTRODUCTION AND BACKGROUND	2-1
INTRODUCTION	2-1
BACKGROUND	2-2
SECTION 3 ENERGY CONSERVATION	3-1
OVERVIEW	3-1
MASH PREPARATION	3-1
MASH COOKING	3-4
FERMENTATION	3-16
DISTILLATION	3-19
DISTILLERS DRIED GRAIN PROCESS	3-33
COGENERATION	3-43
BIBLIOGRAPHY	B-1

SECTION 1

SUMMARY

The dry milling process for the conversion of grain to fuel ethanol has been reviewed for the application of energy conservation technology. The application of commercially proven energy conservation will reduce the energy consumption to 70,000 Btu per gallon, a reduction of 42 percent from a distilled spirits process.

This report outlines specific energy conservation technology applications and provides guidelines for the owner/engineer for fuel ethanol plants to consider in the selection on the basis of energy conservation economies of processing steps and equipment.

For the purposes of this study the process was divided into sections as shown in Figure 1-1. The energy consumed in each step was determined based on three sets of conditions:

- o A conventional distilled spirits process
- o A modern process incorporating commercially proven energy conservation
- o A second generation process incorporating advanced conservation technologies which have not yet been proven.

Figure 1-1. Steps in Fuel Ethanol Preparation

A summary of the results of these studies is shown in Figure 1-2. This figure shows the energy needed for each step of the process under each of the three conditions. The use of energy conservation technologies can make a significant reduction in the energy required for fuel alcohol production.

The application of advanced energy conservation technologies was also considered. Technologies which are near commercialization but which are not commercially proven were considered. These technologies can reduce energy consumption to 44,000 Btu per gallon, a reduction of 37 percent from a current technology energy efficient process.

This study considered the fuel energy input to an ethanol producing plant and is on the basis of a plant consuming coal and electricity. The figures do include energy loss in the combustion of coal (80 percent thermal efficiency) and assume the energy value of electricity as 10,000 Btu per kWh unless otherwise designated. The energy value of raw materials is not considered.

In a modern fuel ethanol plant using commercially proven technology, a large number of energy conservation technologies are included in the process. A limited number of conservation steps account for most of the energy saving. The major conservation steps are listed below:

- o Use of recycle hot water for mash preparation
- o Flash heat recovery in mash cooking

SUMMARY OF RESULTS

<u>Process Step</u>	<u>Btu/gallon</u>		
	<u>Spirits Process</u>	<u>Proven Conservation</u>	<u>Advanced Technology</u>
Mash Preparation	1,000	1,000	500
Mash Cooking	17,600	11,000	8,500
Fermentation	1,000	1,000	2,000
Distillation	59,000	35,000	25,000
DDG Processing	42,400	22,000	8,000
TOTAL	121,000	70,000	44,000

Figure 1-2. Comparison of Energy Consumption
Ethanol Energy Conservation Technologies

- o The preheat of the beer fed to distillation by heat exchange
- o The reuse of heat in distillation by cascading the distillation columns
- o The maximum use of evaporation in water removal to make the byproduct distiller's dried grains
- o The use of flue gas from the boiler for drying of the distiller's dried grains.

Several advanced technologies appear to be attractive and can make a significant reduction in the fuel energy consumption. Most of the technologies are in various stages of commercialization. These advanced technologies include:

- o The application of computer control systems to process control, equipment monitoring and energy management
- o The use of vacuum fermentation to increase the concentration of ethanol in the beer
- o The use of molecular sieves or zeolite vapor phase adsorbants to dehydrate 190 proof ethanol to 199+ proof ethanol
- o The use of high efficiency steam turbines to drive mechanical vapor recompressors in distillation, evaporation, and in vacuum fermentation.

The economics of co-generation of electricity on fuel ethanol plants was also studied. Co-generation of electricity was reviewed on the basis of generating high pressure superheated steam in a coal fired boiler. The steam is passed through a turbine-generator set exhausting at lower pressures suitable for process use. The added cost for installation of co-generation equipment in conjunction with a fuel ethanol plant gives a 15 percent DCF-ROR for a 4 million gallon per year plant to 35

percent for a 40 million gallon per year plant. Addition of co-generation equipment should be considered on all plants above 3 million gallons per year capacity.

SECTION 2

INTRODUCTION AND BACKGROUND

INTRODUCTION

The national program to produce significant quantities of fuel ethanol is proceeding rapidly. Over 60 major plants are in various stages of planning, design and construction. These plants are in all areas of the country and use various raw materials.

The fermentation of biomass to produce ethanol can make a significant contribution to the United States supply of high grade liquid fuel and significantly reduce the import of oil. By 1985, the capacity to produce fuel ethanol in the United States is estimated to increase to 500-600 million gal/yr. By 2000, production could be as high as 11.5 billion gal/yr. These figures project a rapidly developing industry.

It is important that fuel economy be fully considered in the design and construction of fuel ethanol plants. Much of the technology for ethanol production comes from the beverage alcohol industry. In this industry tradition, the importance of taste and customer acceptance cause reluctance to change processes. Thus, an analytical study was done to examine fuel

conservation measures proven in industrial use and to report the economics of the technologies in fuel ethanol production. Beverage alcohol consumes about 121,000 Btu/gal, an energy efficient fuel ethanol plant will consume 70,000 Btu/gal. It is expected that the first generation of fuel ethanol plants will consume energy in this range. The large carefully designed and energy integrated plants will be at the lower number with smaller plants appreciably higher.

BACKGROUND

Process Description

Since most of the new fuel ethanol plants will be using a dry milling process using grains such as corn and milo, this process was selected for a study. The steps are shown in Figure 1-1. In the Energy Conservation section of this report each section is shown in sufficient detail to illustrate the technologies involved. The process is described here in general terms.

The process raw material is grain in the form of U.S. No. 2 dried corn which is kernels of corn removed from the cob and dried. The typical composition is shown in Figure 2-1. The starch portion of the grain is converted to sugar which is fermented to ethanol. The ethanol is separated by distillation. The residue called stillage is processed to remove water, producing a dry product called distiller's dried grains (DDG).

	<u>Weight %</u> <u>Dry Basis</u>	<u>Weight %</u> <u>Commodity</u>	<u>Pounds Per</u> <u>Bushel</u>
Starch	72.0	60.8	34.0
Protein	10.0	8.5	4.8
Oil	4.5	3.8	2.1
Fiber and Ash	13.5	11.4	6.4
Water	-	15.5	8.7
TOTAL	100.0	100.0	56.0

Figure 2-1. Typical Composition U.S. No. 2 Dried Corn

The products of the process are fuel ethanol and DDG. The fuel ethanol is mostly blended with gasoline for use as motor fuel. The DDG is used for animal feed where it has many desirable properties. The DDG is also suitable for human consumption when properly processed for that purpose.

For purposes of this study the process was divided into five steps, and each of the steps will be described below.

Process Steps

1. Mash Preparation
2. Mash Cooking
3. Fermentation
4. Distillation
5. Distiller's Dried Grains (DDG) Processing

Mash Preparation

The purpose of this step is to make a slurry of ground corn and water. The dry corn is ground to a powder usually in an impact mill. The powdered or pulverized corn is then mixed with water to form a mash. The grinding is required to put the corn in physical form so the starch can be brought into contact with water.

A major portion of the corn solids is insoluble and remains as suspended solids. Another portion is soluble, forming a solution with the water.

Mash Cooking

In this step the starch is converted into fermentable sugars, mostly dextrose, by the action of heat and enzymes. Chemically the process is one of hydrolysis as shown below:

The process is done in two steps. The first step does a preliminary breakdown of the starch and puts the starch into solution. An enzyme, alpha-amylase, with heat is used for this breakdown. The second step converts the liquefied starch (dextrin) to dextrose. A second enzyme, glucoamylase, is used for this reaction. The product of mash cooking is a slurry.

Fermentation

Fermentation converts the dextrose to ethanol and carbon dioxide. The reaction is accomplished by the action of a yeast, usually *saccharomyces cerevisiae*. The carbon dioxide formed is released to the atmosphere or to a recovery process. The product of fermentation is ethanol in a mash slurry commonly called beer.

In some processes, the suspended solids are removed before fermentation. In this case the beer is a solution containing a small fraction of suspended solids.

Distillation

The purpose of this step is to recover the ethanol in a concentrated form. It is usually done in two steps. The first step removes the ethanol from the beer in the form of a product

with about 6 percent water. The second step removes essentially all the water producing nearly anhydrous ethanol. The anhydrous ethanol is put into storage, mixed with gasoline and shipped for distribution.

The residual beer with the ethanol removed is now called stillage. The stillage is further processed to make DDG.

DDG Processing

The purpose of this step is to recover the valuable grain solids in the stillage. The product produced is distiller's dried grains. The processing steps involve separation of solids, evaporation of water from the liquid portion, and drying of the solids and concentrate from evaporation to form the DDG. The water removed is recycled, discharged to waste treatment, and discharged to the atmosphere in the dryer.

SECTION 3

ENERGY CONSERVATION

OVERVIEW

Each step of the fuel ethanol process from grain is discussed in this section. The process of each step is described and then the energy considerations are reviewed. The processing factors which must be controlled to reduce energy consumption are highlighted and guidance provided in their selection. Where significant investment is involved, economic comparisons of alternatives are made.

MASH PREPARATION

Process Description

A diagram of the mash preparation process is shown in Figure 3-1.

The steps involved are:

- (1) Cleaning the grain to remove trash. A sifter or screen is used to remove large foreign objects and a magnet separator is used to remove magnetic metal.
- (2) Grinding to reduce the particle size. A hammer mill is used. This mill requires an air stream for proper operation.
- (3) Collecting the ground grain. A bag filter dust collector or a combination with a cyclone is used.
- (4) Weighing the grain. A weigh bin or weigh belt is commonly used. The weight is required to properly proportion the corn with the water, enzymes and brine.

Figure 3-1. Mash Preparation Process Diagram

- (5) Mixing the grain, water and other materials to form a mash.

Energy Considerations

There are two energy considerations in this step--grinding and the temperature of water used to mix with the ground corn to make up the mash.

Grinding is an important step in the fuel alcohol process. If the corn is not ground sufficiently fine, some starch passes through the process unchanged and the yield to alcohol is low. If the grind is too fine, the solid fermentation byproducts are difficult to remove and excessive energy is used in the processing.

The energy consumed in this portion of the process is electricity at about 0.13 kWh per gallon or about 1,000 Btu per gallon. While some systems of grinding are more efficient than others, energy consumption will not vary significantly for an equivalent grind.

The temperature of the water used to make up the corn mash is critical. Since the corn is heated in the next step, the higher the temperature of the water used in mash make up, the less heat is used in mash cooking. There is an upper limit, however. The mash must not be heated above 150°F or the starch will start to gel. A temperature of 140 to 145°F is a safe upper limit. A water temperature of 160 to 165°F will make a mash in usual concentrations at this temperature.

Since water at this temperature is available from the process, no energy consumption for this heat is consumed in the mash preparation step. The effect of water temperature on energy required in mash cooking is shown in Figure 3-2. Making a mash at 140°F saves 3300 Btu/gallon compared to using fresh water at 60°F.

The concentration of the mash affects the energy used in mash cooking and will be discussed in the mash cooking section.

Technology is available to use concentrations as high as 60 percent solids with extrusion equipment. This equipment seems to offer advantages for small plants (about one million gallons per year) but would appear to have a low return when applied to larger plants. Extrusion technology is discussed under mash cooking.

MASH COOKING

Process Description

The grains used for fuel ethanol production do not contain fermentable sugars. The function of the mash preparation process is to convert the starch in a grain to fermentable sugars. To accomplish this, the grain is processed through two major steps.

- o Liquefaction (cooking) - The slurry is cooked by direct steam injection and an enzyme is added to convert the insoluble starches to soluble compounds
- o Saccharification (conversion) - A second enzyme is added which completes the hydrolysis of the starches to fermentable sugars

Figure 3-2. Energy Saving from Use of Hot
Water in Mash Preparation

A flow diagram for the mash cooking process is illustrated in Figure 3-3. The mash is pumped through an ejector where it is heated to 280-300°F by direct injection of steam. The hot mash travels through a mash cooker which is essentially a plug flow reactor with a residence time of 1.5 to 5 minutes.

As the mash exits the cooker, it flashes to atmospheric pressure and enters the mash holdup tanks. Additional alpha-amylase is added. The mash is cooled to 180-205°F. Sufficient hydrolysis takes place in these tanks to liquefy the starch completely.

The large starch polymers at this point have been broken into shorter molecules called dextrans. The final reduction to fermentable sugars is accomplished in the last step called saccharification or conversion. Dilute sulphuric acid is added to the effluent from the vacuum flash tank to adjust the pH to 4.0 to 4.5. This is the optimal pH range for the glucoamylase enzyme which is added next. This mixture flows through the saccharifier to provide residence time. In many processes complete conversion to sugar is not necessary in this step as additional saccharification takes place during fermentation.

Various combinations and sequences of these steps may be employed. Low temperature heating may be employed before jet cooking, after jet cooking, or before and after jet cooking. Jet cooking can be eliminated from the process with only low temperature cooking. Longer times are used at lower temperatures.

Figure 3-3. Mash Cooking Process Diagram

Conventional spirits processing has involved high temperature jet cooking with cooling by flashing the mash to the atmosphere. Heat recovery was not used for several reasons. Parts of the cooking step were done batch-wise so that the step requiring heat was not being done at the time of the step releasing heat. High viscosities make heat exchangers inefficient. Effective instrument controls are required.

The use of a continuous process embodies the savings involved in the heat recovery steps and is a significant development in the economy of alcohol production. Continuous mash cooking is based on a number of technologies. Temperature stable alpha-amylase enzyme, which keeps viscosities in a moderate range, is an important item in this process. Also the use of equipment designed to handle the thick slurries, combined with modern instrumentation, are essential elements. A modern mash cooking system is a good example of applying technologies from the process industries to traditional alcohol process.

Work is continuing on enzymes and starch conversion systems. A combination of conditions to achieve a satisfactory conversion of starch to dexrins at temperatures below the boiling point may be developed. Such a system would have significant additional energy savings.

Energy Conservation

Energy conservation in mash cooking uses two technologies:

- o High solids concentrations using modern enzymes

o Flash steam heat recovery.

In small plants (less than 4 million gallons per year) the use of extrusion cooking allowing very high solids concentrations makes even greater reductions in energy but the system does not appear economical in larger plants.

Concentration of Mash

The total quantity of material that must be heated in mash cooking is the grain plus water. Thus, high concentrations of grain are desirable. The effect of concentration on the energy required for mash cooking is shown in Figure 3-4. Concentrations between 20 percent and 35 percent are used commercially. About half as much heat is required at 35 percent as at 20 percent.

The viscosity of corn mash will vary from 100 cp to 10,000 cp depending on the temperature, concentration, holdup time, enzyme concentration, and back mixing. The design of a particular system must properly use these factors to control viscosity in operable ranges. Concentrations between 25 percent and 32 percent are currently being used in the design of fuel ethanol systems. As additional equipment is developed, concentrations between 32 and 40 percent may be developed.

The investment for increased cooking concentration involves small changes in equipment design and selection. In the ranges of plant size and concentration considered, there is little or no difference in the equipment cost for a concentrated system compared to one more dilute. Careful design of the equipment is

Figure 3-4. Energy Consumption in Mash Cooking as a Function of Mash Concentration

required. Good operating practice and control is needed to avoid swings in concentrations or temperature which can plug the system. Savings in fuel cost for a 5 percent increase in concentration in a heat efficient system are about \$0.007 per gallon at \$3.25 per million Btu or \$140,000 per year in a 20 million gallon per year plant.

Flash Heat Recovery

Flash heat recovery significantly reduces the heat required for cooking. When the mash is heated above the atmospheric boiling point (about 214°F), the heat above this level can be recovered by flashing off steam. The steam can be mostly consumed in heating the mash from 140°F to 200°F with a small portion used for other purposes such as boiler feed water preheat.

With recovery of the heat in the flashed steam, all systems which heat above the boiling point have about the same net energy consumption. The effect of flash heat recovery is shown by the two lines on Figure 3-1. As these lines show, flash heat recovery reduces the heat involved in mash cooking by about 40 percent.

When the mash exits the jet cooker, instead of flashing it directly to atmosphere, an intermediate step can be added where the mixture is flashed to low pressure steam. This step is illustrated in Figure 3-5. The steam produced by the low pressure flash is added back to the mash in a precooker which raises the temperature of the mash entering the high pressure

Figure 3-5. Energy Consumption in Mash Mixing as a Function of Mixing Water Temperature

steam jet cooker. A further flash to atmospheric pressure recovers additional heat. The heat available in the vacuum flash to 140°F is at such a low level that its recovery is not currently economical.

The additional investment required for flash recovery consists of a pressure flash vessel, larger steam lines, and instrumentation. The investment required as a function of plant capacity and the DCF-ROR is shown in Figure 3-6. Recovery of the flash steam has an excellent return even in small plants.

Extrusion

Extrusion cooking is commonly used to cook cereal grains for food processing. Its application to fuel ethanol production is straightforward, as shown in Figure 3-7. The ground corn is mixed with enough warm water to produce a thick slurry containing around 63 percent total solids. This slurry enters a live bottom surge bin (which has a residence time of one hour to insure that the meal is fully hydrated) and is then force fed into the extrusion screw. The screw is driven by a large electric motor which supplies the energy necessary to heat and pressurize the mash, supplemented with some steam injection. The effluent from the extruder will be at 60 percent total solids and 210°F.

The energy requirements for an extrusion process are compared with a flash steam recovery process below. Extrusion cooking requires 61 percent less energy than the steam process.

Figure 3-6. Economics of Including Flash Steam Heat Recovery in Mash Cooking

Figure 3-7. Extrusion Cooking Mash Preparation Process

Mash Cooking Energy
Extrusion Compared to Steam
Btu/gallon

	<u>Extrusion</u>	<u>Steam</u>
Electricity @ 10,000 Btu/kWh	3,800	300
Steam	2,100	9,400
TOTAL	5,900	9,700

The use of extrusion cooking is primarily limited at present to small (less than 4 million gallons per year) plants. The size of extrusion equipment is limited so that larger plants require multiple units and the economy of scale is lost. Figure 3-8 shows the installed cost and DCF-ROR for extrusion equipment at \$3.25 per million Btu steam cost and at several electrical costs. In the range studied, the DCF-ROR is small. In smaller plants there would be little or no added investment and extrusion cooking could be the process of choice.

FERMENTATION

Process Description

Fermentation in ethanol manufacture is accomplished by the action of yeast, generally saccharomyces cerevisiae. The yeast converts glucose to alcohol and carbon dioxide with the release of heat. The chemical reactions involved can be written as follows:

Fermentations are done by both batch and continuous processes. There are several continuous processes including several

Figure 3-8. Total Installed Cost and DCF-ROR for Extrusion as a Function of Plant Capacity and Electrical Cost

continuous stirred back-mixed fermenters in series and units with high yeast concentrations, high yeast recycle, and high production rates per unit of volume.

In batch fermentation the partially saccharified mash is placed in a large tank and inoculated with yeast. Some air and nutrients may be added for yeast growth. The temperature is controlled by circulation through a heat exchanger or by cooling coils. Carbon dioxide vapors are vented. The mixture is held for 40-72 hours where the fermentation is over 95 percent complete.

Energy Conservation

The energy required in fermentation is only for cooling to remove the heat of fermentation. The heat released in fermentation is about 1,700 Btu/gallon of alcohol produced. Since fermentation must take place at temperatures less than about 95°F (35°C) cooling can require a significant amount of equipment if a low temperature cooling water is not available. However, energy requirements are not great and no significant energy savings are made in fermentation.

There are several aspects of fermentation that effect the overall process and where future work to improve the process would be desirable.

o Ethanol concentration

As the concentration of alcohol in the fermentation solution becomes higher, the rate of fermentation decreases. Fermentation times of weeks or months can yield alcohol contents of 9-12 percent by weight, 12-15 percent by volume. Practical, economical fermentation

equipment will approach 8 percent by weight (10 percent by volume). The higher the fraction of alcohol produced, the less energy is required to separate and purify the alcohol. The energy required to purify a 12 percent alcohol solution is 75 percent of that required for an 8 percent solution. Yeast strains or fermentation techniques to produce higher concentrations of ethanol by fermentation seems highly desirable.

- o Fermentation temperature

Removing the heat evolved during fermentation requires large heat transfer surfaces because of the low temperature and because the solution involved can foul heat transfer surfaces. Fermentation at higher temperatures would significantly reduce cost and reduce the energy required for cooling. In practice, higher temperatures tend to reduce ethanol concentration.

Vacuum fermentation is a system which overcomes many of the problems in fermentation. A concentrated alcohol stream is produced by removal of the alcohol as a vapor. Cooling is accomplished by evaporation and condensation rather than direct heat exchange. The system is used with continuous fermentation. The compression of the carbon dioxide and ethanol vapors is a major problem in such a system. A reliable and efficient compression system is required to make this process commercial.

DISTILLATION

Process Description

The ethanol must be recovered from the solution obtained in fermentation. The product of fermentation is a solution of about 6.4 to 8.0 percent ethanol by weight. The solution also contains the soluble portion of the corn, byproducts of fermentation, and the insoluble portion of the corn if it has not been removed before fermentation.

For use in gasoline as a motor fuel nearly all the water must be removed to make the water concentration less than 0.8 percent by weight. In a laboratory the removal of water can be accomplished in a number of ways, but in large commercial practice, distillation is the only system in use.

In making alcohol for industrial use or for making beverage alcohol many of the fermentation byproducts present in small quantities must be removed. These materials are not significant in fuel ethanol.

The distillation is done in two steps as shown in Figure 3-9. The first step removes the ethanol from the fermentation solution and concentrates it to 90-95 percent ethanol. This first distillation column is commonly called the Stripper Rectifier Column. This first step is a conventional distillation.

The second step removes the remaining water. The second still is commonly called the Dehydrator Column. To remove the water from the ethanol an entrainer is used. A large number of materials can be used as an entrainer but those with significant commercial use are benzene and diethylether. The entrainer boils the water off overhead where it is condensed. Since the water is insoluble in the entrainer, it forms a separate layer which is removed in a decanter. The entrainer is stripped from the ethanol in the bottom of the dehydrator column. The anhydrous ethanol product is withdrawn from the bottom of the column. Only minor quantities of entrainer are used.

Figure 3-9. Ethanol Distillation Process Diagram

Energy Conservation

The major portion of the energy used in ethanol manufacture is consumed in distillation. Energy conservation techniques play a major role in reducing energy in distillation. These steps primarily are for feed preheat heat exchange and heat reuse by the cascading of the two distillation columns. These two items are discussed below.

Feed Preheat

The stream to be distilled must be heated to the boiling point before distillation can begin. The stream is starting at about 90°F and must be heated to between 208 and 238°F depending on the pressure used in the first stripper-rectifier column. This heat is about 13,000 Btu/gallon of alcohol. If supplied by consuming steam, the sensible heat nearly doubles the heat required for the stripper-rectifier column.

This heat can be supported by heat exchange with other hot streams in the process. Two systems are shown in Figures 3-10 and 3-11. Both systems involve heat exchange with the column bottoms. Figure 3-10 illustrates direct heat exchange. The column bottoms which are hot are used in a heat exchanger to heat the incoming feed.

\ In Figure 3-11, a system is shown where the hot column bottoms are flashed to form steam which is used to heat the feed. The steam flash system has an advantage in that the water flashed off saves on evaporation later in the process. The direct heat

Figure 3-10. Distillation Feed Preheat With Heat Exchange

Figure 3-11. Distillation Feed Preheat With Flash Steam

exchange is applicable to small plants, whereas the flash system is applicable to large plants. The investment and DCF-ROR is shown in Figure 3-12.

At the lower plant capacities less than 10 million GPY direct heat exchange with the column bottoms gives the highest DCF-ROR. At higher capacities the flasher system gives higher returns. In all cases, the return on the heat exchange equipment is excellent and feed preheat is a highly desirable feature to include in plant design.

Heat Reuse

There are several systems which have been devised to reduce the energy required in distillation. The physical properties of the materials involved and the requirements of the separation are significant factors in adapting these systems to a particular case.

In the ethanol separation the atmospheric boiling point of the distillate condensing in the first column is essentially the same as the boiling point of the bottoms product from the first column. With a slight increase in pressure on the first distillation column, the condensing temperature is higher than the reboiler temperature in the second column. Thus the vapor from the first column can be used to supply the heat required for the second column.

Figure 3-12. Distillation Feed Preheat Economics

The heat required for the dehydration step is about 75 percent of that required for the Stripper-Rectifier. Thus a major reduction in energy is achieved by the use of the vapors condensing vapors from the first column to drive the reboiler on the second column. The system is illustrated in Figure 3-13.

The economics of this operation are excellent. The investment needed for cascading the distillation columns is about the same as that needed for an alternate system using steam to drive the reboiler and cooling water for all of the condensing. Thus the DCF-ROR is infinite. Only in plants of about one million gallons per year capacity or less would this type of system become uneconomical.

There are other reuse energy systems where the vapors from distillation can be used to drive the thin stillage evaporators. This system uses the column vapor to provide the heat for a multiple effect evaporator system. The system is illustrated in Figure 3-14. The savings in energy are about the same as the column cascading system.

The system of cascading the Stripper-Rectifier Column with the thin stillage evaporators does not supply heat for the dehydration column. If a low energy dehydration system such as the use of molecular sieves is developed, then the cascading with evaporation becomes of major importance and an advance system with low energy consumption is possible.

Figure 3-13. Distillation Vapor Reuse Cascading Distillation Columns

Vapor Recompression

Vapor recompression can also be used to provide heat for the distillation columns. In this system the overhead vapors of the column are compressed. The compressed vapors are condensed in the reboiler of the column and provide the heat for driving the column. The system is illustrated in Figure 3-15.

The economics of vapor recompression depend on

- o The amount of compression required to raise the condensing temperature to drive the reboiler
- o The ratio of steam to electrical energy cost
- o The investment

In the stripper-rectifier column the properties of the materials require a ratio of compressor discharge to feed of 3.6. This system then delivers 8 Btu of condensing energy for each Btu of electrical energy put in to drive the compressor. In the case of ethanol two compressors must be installed one for each column. In the overall ethanol system one Btu of electrical energy replaces 4.6 Btu of steam energy.

If the ratio of the cost of energy in the form of electricity to the cost of energy in the form of steam is less than 4.6, the use of vapor recompression will show savings in fuel. When maintenance, depreciation, and return on investment are considered, a lower ratio is needed to provide a significant return on investment. The ratio of electrical to steam cost to show a 10 percent after tax DCF-ROR is shown in Figure 3-16.

Figure 3-15. Vapor Recompression for Distillation

Figure 3-16. Vapor Recompression for Distillation Economics Compared to Heat Reuse

The economics for the use of vapor recompression may be improved significantly if the compressor is driven by a high efficiency steam turbine rather than an electric motor and where the discharge steam is consumed in the process. Sufficient detail of such a system is not presently available for economic evaluation. The combination of high efficiency turbines with high efficiency compressors for use in ethanol distillation could make significant reductions. A study of this advanced technology could yield significant energy savings.

DISTILLERS DRIED GRAIN PROCESS

Process Description

The various grains which are used to produce alcohol contain many compounds which are not changed by the ethanol process. After the fermented beer goes through the stripper column where the ethanol is removed, the still bottoms or whole stillage, still contain protein, oil, fiber, ash, yeast solids, and small amounts of sugar which were not fermented. These items have significant food value, but the whole stillage contains only 10-12 percent total solids. In this wet form the material will spoil rapidly, and there are many problems associated with feeding wet stillage to livestock. Therefore, most large ethanol plants have equipment which dries the stillage, making a product known as DDG (distillers dried grains) or DDGS (distillers dried grains with solubles). DDG usually contains 8-10 percent moisture, has good storage properties, and can be transported much more efficiently than whole stillage.

Most DDG facilities use three basic unit operations to remove the water.

- o Mechanical Dewatering -- A centrifuge or press separates a large portion of the insoluble solids producing a cake and a thin liquor stream containing mostly soluble material
- o Evaporation -- The thin liquor is processed through evaporators which remove part of the water and produce a concentrate
- o Drying -- The dewatered cake is mixed with the evaporator product and fed to a dryer which removes the remaining water and produces a 10 percent moisture product.

A flow diagram for a typical DDG process is shown in Figure 3-17. Whole stillage from the stripper column is pumped to a centrifuge which makes the first cut. A dewatered cake at 30 percent solids is transported to the dryer, and the thin stillage at 8 percent solids is pumped to a holding tank. The thin stillage from the holding tank is split into two streams. Almost 40 percent is recycled back to the mash preparation section and the remainder is pumped to the evaporators.

The evaporator uses steam from a boiler to concentrate the thin stillage and produce a 50 percent solids product. A typical multiple effect evaporator system will remove four pounds of water for every pound of steam consumed.

The evaporator concentrate combines with the centrifuge cake to form a dryer feed with 40 percent total solids. Heat is supplied to the dryer, a flue gas either from a burner or from the plant boiler. The final product is a dried granular substance containing 10 percent moisture (90 percent solids).

Figure 3-17. Distillers Dried Grains (DDG) Process Diagram

Energy Conserving

The conservation of energy in DDG processing involves three technologies:

1. The use of mechanical dewatering screws or presses to remove additional water from the solids before drying.
2. The use of mechanical vapor recompression to preconcentrate stillage before evaporation.
3. The use of flue gas from the plant steam boiler to supply most of the heat for drying.

Additional Mechanical Dewatering

Multiple effect evaporators require less energy than dryers to remove a given amount of water. For the centrifuge case described, the evaporator is handling 70 percent of the water removal and the dryer 30 percent. One method of saving energy is to shift an even larger portion of the evaporation load to the multiple effect evaporators. This can be done by adding a press after the centrifuge, as shown in Figure 3-18.

If the press were to increase the total solids of the press cake from 30 percent to 40 percent, then the evaporator would remove 80 percent of the water and the dryer 20 percent.

The economics of adding this press are favorable. Figure 3-19 shows the total installed cost and payback for a press as a function of plant size. A press for a 20 million gallons per year plant would cost about \$250,000, and the discounted cash flow (DCF) rate of return would be 79 percent. Even for small plants (4 MM gal/yr) the DCF rate of return is over 40 percent.

Figure 3-18. Additional Mechanical Dewatering

Figure 3-19. Economics of Adding a Press to Achieve 40 WT% Total Solids Cake Dryness.

Mechanical Vapor Recompression (MVR)

Incorporation of mechanical vapor compressors into the evaporation process is shown in Figure 3-20. MVR replaces thermal energy (steam) with electrical energy which drives the vapor compressor. In general, MVR evaporators in ethanol plants will require only 36 Btu of electrical energy for each pound of evaporation, whereas a normal four effect evaporator would require 250 Btu/lb.

The thin stillage from the centrifuge is first introduced to the MVR preconcentrator where 88 percent of the total water is evaporated. The hot vapors from the MVR compressor supply the heat required for evaporation. Normally the evaporator design is a falling film type with internal recirculation. The water vapor which is evaporated and subsequently separated in a vapor/liquid separator is piped directly back to the suction side of the compressor where it is boosted from approximately atmospheric pressure to about 22 psia. The process vapors are compressed from saturated steam conditions, to a higher pressure, temperature, and enthalpy.

The concentrated soluble stream emerges from the MVR preconcentrator at 30 percent total solids. This stream is then introduced to a steam heated one or two effect evaporator where additional water is removed and a final concentrate is produced at 50 percent total solids. The concentrated stream is then mixed with the press cake (or solids from the centrifuge) prior to the dryer.

Figure 3-20. Mechanical Vapor Recompression (MVR)
in Thin Stillage Evaporation

The economics of utilizing mechanical vapor recompression type evaporators with thermal finishers may be favorable depending on the plant size as shown on Figure 3-21 which is based on steam at \$3.25/M lb and electricity at \$0.05/kWh. For example, a four million gal/yr plant processing DDG would only have an 8.5 percent DCF rate of return by using an MVR vapor compressor over a 4 effect evaporator. The differential in the total installed costs would be \$165,000. Larger plants generate higher DCF rates of return due to the relatively lower cost of higher capacity units. At plant capacities of 20 and 40 MM gal/yr, the resulting DCF rates of return would be 36 and 45 percent respectively for incrementally higher investments of \$210,000 and \$360,000.

Boiler Flue Gas

The use of boiler flue gas makes a major reduction in the energy required for drying. Drying of DDG in rotary kiln dryer is usually done with flue gas generated in a burner connected to the dryer. A major portion of this gas can be replaced with flue gas from the plant's steam boiler. There is no change in the dryer except for a slightly larger dryer.

The flue gas from the plant boiler can supply about 70 percent of the heat required to dry the DDG. This reduction is about 7,600 Btu/gallon of ethanol or a saving of about \$0.02/gallon.

Figure 3-21. Economics of Using Mechanical Vapor Recompression

COGENERATION

Cogeneration, the simultaneous production of thermal energy (steam) and electricity, is an effective technique to reduce energy cost. Cogeneration produces electricity at about 35 percent of the energy per kilowatt hour as used in a modern electrical generating plant. Since the system can be applied to most types of ethanol plants, it has been considered separately and no credit has been taken for cogeneration in estimating energy consumption to produce ethanol. If cogeneration is included, energy consumption is reduced 7-10 percent.

In the cogeneration system studied, superheated steam at 750°F and 600 psig is produced in the plant steam boiler. The steam is passed through a turbine to drive an electric generator. The steam is exhausted from the turbine at 50 psig and a portion also extracted at 150 psig. All of the exhaust steam is used in the ethanol plant. The electric generator is synchronized with the power company with any slight excess of power above plant consumption sold to the utility company.

The following information was used to determine the economic viability of the coal-fired cogeneration system:

- o Define system characteristics (i.e., for an extraction turbine)
- o Select system to meet plant's energy needs (i.e., size to meet thermal requirements)
- o Determine supplemental energy requirements or available excess energy
- o Determine system capital and operating and maintenance costs

- o Determine incremental costs (i.e., differential between cogeneration and baseline conventional system)
- o Define allowable investment tax credit
- o Develop economic algorithm (i.e., discounted cash flow)
- o Establish economic parameters
 - Buyback rate
 - Standby rate
 - Electricity price
 - Coal price
 - Depreciation schedule
- o Determine after-tax incremental return on investment

A summary of the system characteristics is given in Figure 3-22. The economic analysis is shown in Figure 3-23. An after-tax DCF-ROR of 15-35 percent can be achieved on the incremental investment required for the turbine, generator and higher pressure boiler. Careful consideration should be given to including cogeneration in any coal-fired steam system for an ethanol production facility.

Cogeneration Systems Characteristics

Plant Size	Throttle Pressure (psig)	Total Steam (10 ³ lbs/hr)	Electrical Output (mW)	Excess Electricity (mW)	Capital Cost (10 ⁶)	Incremental Capital Cost (10 ⁶)	Incremental O&M (10 ⁶)
4 MM gal/yr	600	22	0.75	0.10	2.5	1.0	0.05
20 MM gal/yr	600	109	3.75	0.50	10.0	2.3	0.13
40 MM gal/yr	600	218	7.75	1.25	17.2	4.2	0.17

Figure 3-22. Cogeneration Systems Characteristics
for Varying Plant Sizes

Note: Coal Price: 1.8\$/mm Btu
 Electricity Price: [5¢/kWh]
 Buyback Price: 50%
 Standby: 100% @50¢/kW

Figure 3-23. After Tax Incremental DCF-ROR as a Function of Ethanol Plant Size for Coal-Fired Cogeneration Systems (Extraction Turbine - 150/50)

BIBLIOGRAPHY

Energy Conservation in Ethanol Production From Renewable Resources and Non-Petroleum Energy Sources

1. Black, C., "Distillation Modeling of Ethanol Recovery and Dehydration Processes for Ethanol and Gasohol," Chemical Engineering Progress, 76(9):78-85, 1980.
2. California Energy Commission, The Production of Ethanol from Agricultural Waste - An Economic Evaluation. NTIS No. PB-292 552. January 1979. (Prepared by University of California, Davis) 27 p.
3. Chiang, Tze I. and Robert L. Collins, Fuel Alcohol Production in Georgia: A Preliminary Study. Project E120-210. Georgia Institute of Technology, Atlanta, May 1980. 35 p.
4. Cysewski, Gerald R. and Charles R. Wilke, "Process Design and Economic Studies of Alternative Fermentation Methods for the Production of Ethanol." In: Biotechnology and Bioengineering, Vol. 20, Wiley, New York, 1978, pp 1421-1444.
5. Gregor, Harry P. and Thomas W. Jeffries, Ethanollic Fuels from Renewable Resources in the Solar Age. NTIS No. PB-295 645. Columbia University, New York, 1979, 23 p.
6. Ozarks Regional Commission and Kansas Energy Office, Small-Scale Ethanol Production for Gasohol. April 1980. (Prepared by Development Planning and Research Associates, Inc.) 180 p.
7. U.S. Congress, Office of Technology Assessment, Gasohol: A Technical Memorandum. U.S. GPO S/N 052-003-00706-1. September 1979. 71 p.
8. U.S. Department of Energy, Alcohol Production from Agricultural and Forestry Residues. NTIS No. ANL/EES-TM-88. May 1980. (Prepared by Argonne National Laboratory) 48 p.
9. U.S. Department of Energy, Carbohydrate Crops as a Renewable Resource for Fuels Production, Volume 2: Identification of Key Policy Issues, Alternatives, and Implications Relating Energy from Biomass. NTIS No. BMI-2031 (Vol. 2). May 1979. (Prepared by Battelle, Columbus Laboratories) 68 p.
10. U.S. Department of Energy, Energy Conservation in Distillation. NTIS No. DOE/CS/4431-T2. May 1980. (Prepared by Radian Corporation) 48 p.
11. U.S. Department of Energy, First Annual Report to Congress on the Use of Alcohol in Motor Fuels. NTIS No. DOE/CS-0165. April 1980. 56 p.

12. U.S. Department of Energy, Fuel from Farms - A Guide to Small Scale Ethanol Production. NTIS No. SERI/SP-451-519. February 1980. (Prepared by Solar Energy Research Institute.) 160 p.
13. U.S. Department of Energy, Grain Motor Fuel Alcohol: Technical and Economic Assessment Study. U.S. GPO S/N 061-000-00308-8. June 1979. (Prepared by Raphael Katzen Associates.) 344 p.
14. U.S. Department of Energy, A Guide to Commercial-Scale Ethanol Production and Financing. NTIS No. SERI/SP-751-877. November 1980. (Prepared by Solar Energy Research Institute.) 305 p.
15. U.S. Department of Energy, Rapid Ethanol Production Via Fermentation, NTIS No. LBL-10219. November 1979. (Prepared by Lawrence Berkeley Laboratory, University of California.) 28 p.
16. U.S. Department of Energy, Raw Materials Evaluation and Process Development Studies for Conversion of Biomass to Sugars and Ethanol. NTIS No. LBL-7847. June 1978. (Prepared by Lawrence Berkeley Laboratory, University of California.) 39 p.
17. U.S. Department of Energy, The Report of the Alcohol Fuels Policy Review. NTIS No. DOE/PE-0012. June 1979. 119 P.
18. U.S. Department of Energy, Technology and Economics of Conversion of Cellulose (Wood) and Corn Starch to Sugars, Alcohol and Yeast. NTIS No. C00-5007-1. August 1978. (Prepared by Bernard Wolnak and Associates.) 249 p.
19. U.S. Department of Energy, Western European Energy Conservation Technologies for Evaporators. NTIS No. DOE/CS/5172-T1. 1980. (Prepared by CENTEC Corporation.) 28 p.
20. U.S. Energy Research and Development Administration, Fermentation Kinetics and Process Economics for the Production of Ethanol. NTIS No. LBL-4480. No date. (Prepared by Lawrence Berkeley Laboratory, University of California.) 288 p.
21. U.S. Energy Research and Development Administration, Summary of ERDA/MITRE Workshop on Energy Conservation in Unit Operations. MITRE Technical Report No. MTR-7205. May 1976. (Prepared by MITRE Corporation.) 79 p.

22. U.S. Environmental Protection Agency, Source Test and Evaluation Report: Alcohol Synthesis Facility for Gasohol Production. January 1980. (Prepared by Radian Corporation.) 215 p.
23. U.S. National Alcohol Fuels Commission and U.S. Department of Energy, Energy Balances in the Production and End-Use of Alcohols Derived from Biomass: A Fuels-Specific Comparative Analysis of Alternative Ethanol Production Cycles. October 1980. (Prepared by TRW.) 125 p.
24. U.S. National Alcohol Fuels Commission, Farm and Cooperative Alcohol Plant Study: Technical and Economic Assessment as a Commercial Venture. October 1980. (Prepared by Raphael Katzen Associates.)