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*Geothermal Energy Market Study
on the Atlantic Coastal Plain*

TECHNICAL FEASIBILITY OF USE OF EASTERN GEOTHERMAL ENERGY IN VACUUM DISTILLATION OF ETHANOL FUEL

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COLUMBIA, MD

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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COLUMBIA, MD
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PREFACE

The Johns Hopkins University Applied Physics Laboratory is designated as one of the technical assistance centers for the Division of Geothermal Energy, Department of Energy. This brief report, compiled by the Carltech Associates, P. O. Box 1203, Columbia, MD 21044, under subcontract, is typical of the type of assistance rendered. This study was intended to show the potential for ethanol distillation using a vacuum and modest temperature geothermal resources — typical of those located in the Eastern United States. It should be noted that it was not the intent of this study to evaluate the economics of vacuum distillation of ethanol using modest geothermal resources, or to explore cost-optimum column pressures with specific resource temperatures. These tasks are recommended for later analysis.

The appendix lists other technical assistance studies documented in letter or formal reports.

1. SUMMARY

The United States Department of Energy (U.S. DOE) is studying availability, economics, and uses of geothermal energy. These studies are being conducted to assure maximum cost-effective use of geothermal resources. The U.S. DOE is also aiding development of a viable ethanol fuel industry. One important point of the ethanol program is to encourage use of non-fossil fuels, such as geothermal energy, as process heat to manufacture ethanol. Geothermal waters available in the eastern United States tend to be lower in temperature (180°F or less) than those available in the western states (above 250°F). Technically feasible use of eastern geothermal energy for ethanol process heat requires use of technology that lowers ethanol process temperature requirements. Vacuum (subatmospheric) distillation is one such technology. This study, then, addresses technical feasibility of use of geothermal energy to provide process heat to ethanol distillation units operated at vacuum pressures.

We conducted this study by performing energy balances on conventional and vacuum ethanol processes of ten million gallons per year size. Energy and temperature requirements for these processes were obtained from the literature or were estimated (for process units or technologies not covered in available literature). Data on available temperature and energy of eastern geothermal resources was obtained from the literature. These data were compared to ethanol process requirements, assuming a 150°F geothermal resource temperature.

Conventional ethanol processes require temperatures of 221°F for mash cooking to 240°F for stripping. Fermentation, conducted at 90°F, is exothermic and requires no process heat. All temperature requirements except those for fermentation exceed assumed geothermal temperatures of 150°F. We assumed a 130 millimeter distillation pressure for the vacuum process. It

requires temperatures of 221°F for mash cooking and 140°F for distillation. Data indicate lower energy requirements for the vacuum ethanol process (30 million BTUs per hour) than for the conventional process (36 million BTUs per hour). Lower energy requirements result from improved process energy recovery.

Data examined in this study indicate feasible use of eastern geothermal heated waters (150°F) to provide process heat for vacuum (130 mm Hg) ethanol distillation units. Data indicate additional heat sources are needed to raise geothermal temperatures to the 220°F level required by mash cooking. Data also indicate potential savings in overall process energy use through use of vacuum distillation technology.

Further study is needed to confirm conclusions reached during this study. Additional work includes obtaining energy use data from vacuum ethanol distillation units currently operating in the 130 millimeter pressure range; economic analysis of different vacuum pressures to select an optimum; and operation of a pilot geothermally heated vacuum column to produce confirmatory process data.

2. INTRODUCTION

2.1 BACKGROUND

The United States Department of Energy (U.S. DOE) is currently conducting studies to establish the prevalence, energy yield potential, and economics of use of geothermal energy in the United States. This program is part of a national effort to achieve maximum use of renewable sources of energy. This effort has involved surveying potential geothermal resources in all parts of the United States. Studies^{26,30} have shown that geothermal resources in the eastern United States tend to be lower in temperature than western geothermal resources. Past studies^{27,31} also have surveyed economic uses for available geothermal resources. These uses include home heating, industrial space heating, and industrial process heating. One of these industrial process uses is to supply process heat for ethanol distillation.

The United States Department of Energy has a program underway to aid development of a viable ethanol fuel production industry. The program involves financial aid and technical assistance aid to potential ethanol producers. One requirement made by DOE of prospective recipients is that ethanol plants built must use "nonpetroleum" forms of energy for process heat. Geothermal energy is one such form of nonpetroleum energy.

The conventional fermentation process for the manufacture of ethanol or ethyl alcohol requires heat delivery at temperatures in the range of 250 to 350°F^{3,5} to maintain atmospheric distilling temperatures of 172 to 212°F. These temperatures exceed the available range of geothermal resource temperatures in the east. Vacuum stripping and distillation require lower temperatures to achieve the same degree of purification than does conventional (atmospheric) distillation. Thus, vacuum separation processes using eastern geothermal heat sources may be possible.

2.2 PURPOSE

The purpose of this project, then, is to investigate the technical feasibility of using eastern geothermal heated water to provide process heat for vacuum distillation of ethyl alcohol produced by fermentation. Technical feasibility assessment involves investigation of applicability of vacuum methods to reduce distillation temperature requirements. The following study addresses use of vacuum distillation to prepare ethanol and the feasibility of use of eastern geothermal heated water to supply the process heat needed for such ethanol production.

2.3 ORGANIZATION

This report is organized in the following manner: Section 1 presents a summary of the entire report. Section 3 presents the methodology that was used to reach conclusions regarding technical feasibility of use of eastern geothermal energy in vacuum distillation. Methodology discussed in section 3 includes methods used to obtain data from the literature, to prepare energy balances for conventional and vacuum distillation alcohol plants of 10 million gallons per year size. Section 3 also contains information on temperatures available from eastern geothermal resources. Section 4 contains results of performing vacuum and conventional energy balances and estimating temperature requirements, energy requirements, and other parameters that affect both conventional and vacuum distillative ethanol processes. Conclusions and recommendations regarding technical feasibility of the use of geothermal energy in vacuum ethanol production are presented in section 5. Section 6 contains the limitations of this study and presents a plan for future work. References are found in the Appendix.

3. METHODOLOGY

This section of our report presents the methodology used to conduct this study. In this section we describe

- the types of literature reviewed;
- types of data obtained from the literature;
- energy balances performed on both conventional and vacuum ethanol process units;
- methods used to assess temperatures and energy available from eastern geothermal resources; and the
- methodology used to compare energy requirements of ethanol production to energy available from geothermal resources.

3.1 LITERATURE REVIEW

During the course of this project, we made a limited literature search, reviewing data available from 31 different sources (see Appendix). These sources included textbooks, journal articles, and telephone conversations with knowledgeable individuals engaged in ethanol manufacture. We obtained data on process descriptions of conventional and vacuum ethanol distillation processes. We obtained energy and temperature requirement data for conventional and vacuum processes. We obtained data on vapor liquid equilibria for both conventional (atmospheric) and vacuum processes. Data on ethanol and geothermal energy was obtained from Mr. F. C. Paddison of the Johns Hopkins Applied Physics Laboratory.

Data on energy balance for conventional processes were available from references 3, 5, 13, 18, 21, and 22. We obtained a small amount of data on energy usage for vacuum processes from one source via personal communication with Dennis Day²⁴, a farmer who currently operates a vacuum distillation unit.

We obtained data on temperature requirements for conventional processes

from references 3, 4, 5, 13, 18, 21, and 22. Temperature requirements for vacuum processes were obtained from reference 24 and from vapor liquid equilibrium data^{10,11,12,13,14}. Data on process descriptions were obtained principally from standard texts.^{1,2,3,4}

Data on geothermal resources included several reports on the availability and characteristics of geothermal energy in the United States. These are included in references 26 through 31. These references characterize availability and projected availability of geothermal energy, both in terms of temperature and in terms of energy available for the eastern United States.

3.2 ENERGY BALANCES AND COMPARISONS

Carltech Associates used data on temperature and energy requirements for conventional and vacuum processes to perform energy balances on a single 10 million gallon per year ethanol plant. Data on energy requirements for vacuum distillation processes was scarce. We therefore used our conventional process energy balance as a basis and adjusted energy requirements for distillation based upon known temperature requirements.^{10,11,12,13,24}

We prepared tables and figures showing temperature and energy requirements of the ethanol processes by unit operation. (A process unit is a group of process equipment that is intended to perform a single function, such as distillation.)

Temperature and energy availability from eastern geothermal resources were obtained from the literature^{26,27,28,29,30,31} and were compared to tabulated requirements of both conventional and vacuum distillative ethanol processes. We assumed a geothermal resource temperature of 150°F. Findings were made and conclusions were drawn based on comparisons of tabulated energy and temperature requirements versus geothermal energy available.

4. RESULTS

4.1 COMPARISON OF ETHANOL PROCESS REQUIREMENTS WITH AVAILABLE GEOTHERMAL RESOURCES

Comparison of temperature and energy requirements of both conventional and vacuum distillative ethanol processes with geothermal energies are discussed in this section.

4.1.1 Introduction and Ethanol Process Description

The process for production of ethanol fuel by distillation of conventional grains consists of six (6) basic steps:

- Mash preparation or "cooking"
- Fermentation
- Stripping (sometimes called beer distillation)
- Distillation/rectification
- Alcohol dehydration
- Stillage drying

Mash cooking is a unit operation in which the grain to be fermented is raised to fairly high temperatures (350°F)^{1,3} in order to kill unwanted yeast, bacteria, etc. The mash may then be held for several hours at these high temperatures or at somewhat lower temperatures in enzymatic processes (210 to 250°F)³ in order to facilitate the breakdown of complex starch molecules into smaller, simpler sugar molecules. These are more readily fermented by yeast. Fermentation is a process step in which the mash is cooled to fermentation temperatures of 70 to 90°F ³ and yeast are allowed to grow. Often, yeast produce heat that must be removed from the fermentation vessel³ in order to assure optimum fermentation temperature. Fermented mash contains about 10 to 13 percent alcohol. This mash, then, is placed in the stripping column or beer still, which separates the water alcohol mixture from the

mash particles. Wet mash particles, called "stillage," leave the bottom of the stripping column. Stillage may be disposed of, or may be dried for sale as animal fodder called distillers dried grain (DDG).

The overhead product of the stripper is fed to the bottom of the distillation/rectification column. This column's purpose is to produce a high-grade ethanol overhead product. The bottoms of this column are returned to the beer still to recover the alcohol. In some plants stripping and distillation are combined in a single column. The overhead product of this column, the ethanol-water azeotrope, consists of 180° (90 percent) ethanol. Depending on the use of the product, the overhead product of the rectification column may be dehydrated to produce so-called "absolute ethanol." Dehydration is an operation in which a hydrocarbon such as benzene is mixed with the ethanol product. The water-hydrocarbon azeotrope boils overhead in the column and the pure ethanol product leaves as a bottom product.

This study does not address dehydration or preparation of DDG. There is controversy about whether dehydration of rectification column overhead is necessary.²⁴ Studies are currently underway to determine how much water removal is necessary²⁴ for efficient use of ethanol in various types of equipment.

Grain drying is believed to be an optional operation.^{1,4,5,21} Many distilleries dispose of distillers dried grain. DDG is dried only when there is a market. We assume that distilleries would produce DDG only if the market provided compensation for energy required to produce DDG. For this reason we will not address the production of distillers dried grain in this project.

4.1.2 Temperature Requirements

Temperature requirements were obtained from the literature for both conventional and vacuum processes. Conventional ethanol processes require the highest temperatures and large amounts of energy in the mash preparation operation (Exhibit 4-1). Mash cooking requires temperatures of 210 to 350°F, depending on the exact nature of the cooking process to be used.

Fermentation usually requires removal heat and is conducted at temperatures of between 70 and 90°F²¹. The first operation that separates alcohol from process solids is the stripping operation. Stripping requires temperatures in the range of 150 to 240°F^{4,21,22}. These very high temperatures are required since the feed to the stripper is quite high in water (90 weight percent). High temperatures are required to evaporate this water. Distillation/rectification requires a somewhat narrower range of temperatures (175 to 195°F)^{21,22}. Bottoms of the rectification column are fairly high in alcohol and the overhead product of this column is fairly strong (90 percent) ethanol. Occasionally these column temperatures are designed to be higher. Columns are maintained at a slight positive pressure in order to avoid losses of ethanol. *subjected to*

Temperature requirements for mash cooking and fermentation are unaffected by distillation pressure.³ Rates of microbial death depend principally on the external temperature^{2,3}. Similarly, mash cooking is performed to break down starch into simple mono and disaccharides. Cooking is also dependent only on temperature and not on ambient pressure.^{1,2} Fermentation depends on ambient temperature, nutrient level, and on the presence of foreign bacteria, viruses, and toxins. It is independent of the ambient pressure.

Temperature requirements for stripping and distillation units are highly sensitive to column pressure. These range from 101°F for the highest temperature observed (nearly pure water) at 50 millimeters pressure to 212°F for the highest temperature observed at 760 millimeters.¹⁰ Other distillation temperatures show similar sensitivity. Even more dramatic results are found in the distillation/rectification section. Rectification overhead temperatures range from 175°F for the 90 percent ethanol overhead of an atmospheric column to 70°F for the 96 percent ethanol overhead of a column operated at 50 millimeters pressure.¹⁰

A pressure of 130 millimeters was chosen for the 10 million gallon per year example presented in Exhibit 4-2. This temperature was chosen for two (2) reasons.

- The highest temperature observed at 130 millimeters is 140°F, which is 10° lower than the 150°F geothermal temperature assumed for this project.
- A farm-scale plant is currently operating at this pressure and in this temperature range.²⁴

Temperature requirements for this process range from a high temperature of 221°F for mash cooking to 140°F for distillation (Exhibit 4-2).

4.1.3 Energy Requirements

Energy requirements for both conventional and vacuum ethanol processes are discussed in this section. These balances were obtained from the literature for conventional processes. Vacuum process energies are based on conventional energies and ^{are} adjusted using vacuum temperature requirements obtained from the literature.

Energy requirements for conventional processes are represented in a drawing in Exhibit 4-1. This exhibit is a 10 million gallon a year ethanol product plant that produces 180 proof ethanol as an overhead product. Energy requirements for conventional processes range from 5.25 million BTUs per hour for mash cooking to 22 million BTUs per hour for stripping and distillation. Miscellaneous energy uses account for about nine (9) million BTUs per hour (for electricity equivalents). A conventional ethanol plant has about 36 million BTUs per hour total energy use. Exhibit 4-1 shows that the principal area of energy use is in the stripping and distillation areas. This area's temperature requirements are sensitive to pressure, which can in turn affect energy use.

Vacuum energy requirements, as well as temperature requirements for a 10 million gallon per year ethanol plant, are presented in Exhibit 4-2. The drawing presented in this exhibit shows that temperatures and energy use are lower in the vacuum process. The same amount of water is evaporated in both processes. Lower distillation temperatures allow use of additional energy-saving devices such as food/product heat exchange, heat pumps and recovery of heat of fermentation. These additional energy recoveries compensate for 3 million BTUs per hour of additional energy required to maintain the vacuum. Mash cooking and fermentation energies do not change for the vacuum process,

EXHIBIT 4-1
CONVENTIONAL ETHANOL PLANT
10 MILLION GALLONS PER YEAR

Legend and Notes

CW - Cold Water (80°F)

STM - Steam (250°F minimum)

ATH - Atmospheric Pressure

ETOH - Ethyl Alcohol

MM - 10⁶

mm - Millimeters

1. Miscellaneous Energy Uses: 8.77 MMBTU/HR

2. Denotes Negative Energy Use - Energy Removal

EXHIBIT 4-2
VACUUM ETHANOL PLANT
10 MILLION GALLONS PER YEAR

Legend and Notes

- CW - Cold Water (80°F)
 STM - Steam (250°F minimum)
 ATM - Atmospheric Pressure
 ETOH - Ethyl Alcohol
 MM - 10⁶
 mm - Millimeters
 1. Miscellaneous Energy Uses: 11.92 MMBTU/HR
 2. Denotes Negative Energy Use - Energy Removal
 3. Geothermal Water - 150°F
 4. Circle Denotes Heat Exchanger
 Jagged Line Indicates Tube Flow
 5. Arrow Indicates Condenser (arrow down)
 or Reboiler (arrow up)
 6. Heat Pump - Coefficient of Performance: 4
 7. Heat Pump - Coefficient of Performance: 2

as these steps are pressure independent. The distillation process energy decreases to 13 BTUs per hour. Miscellaneous energies increase to 12 million BTUs per hour from nine (9). Thus, the vacuum ethanol process uses less energy than does the conventional process because of lower absolute temperatures.

4.1.4 Comparison of Ethanol Process Requirements with Available Geothermal Resources

Tabulated energy requirements for 10 million gallon per year conventional and vacuum ethanol plants are presented by process unit (Exhibit 4-3). Data on available geothermal temperatures and energies are also presented. Available geothermal temperatures of 150°F are lower than conventional and vacuum mash cooking requirements of 221°F. Fermentation requires heat removal in both processes and does not need geothermal process heat. Stripping and distillation require 197 to 240°F distillation temperatures in conventional processes. This temperature exceeds the available 150°F geothermal temperature. Vacuum stripping and distillation requires temperatures of 135 to 140°F. These temperatures are 10°F lower than available geothermal temperatures. A 10°F temperature difference allows satisfactory heat transfer to conduct distillation operations. Thus, geothermal temperatures of 150°F are suitable for distillation process heat, but require energy additions (about five (5) million BTUs per hour in a 10 million gallon per year plant) for use in mash cooking.

4.2 OTHER CONSIDERATIONS

One consideration that is a matter of concern to potential geothermal users is fouling. Some geothermal heated water may contain fairly large amounts of dissolved solids and scaling chemicals such as carbonates and sulfates. Scaling can be an economic problem, requiring special equipment to be designed for scaling service. The heat transfer units required in ethanol production processes can be designed for scaling service and present no feasibility problems. They are, however, more expensive than conventional equipment and may present an economic attractiveness problem.

Conventional ethanol processes are often operated with an additional step called dehydration. Depending on the end use of the ethanol, the 90 percent

EXHIBIT 4-3

COMPARISON OF ETHANOL PROCESS REQUIREMENTS WITH GEOTHERMAL AVAILABILITY

Energy Requirements

Column Pressure	760 mm Hg		130 mm Hg		Geothermal Availability				
	High Temperature °F	Energy Use MM BTU/HR	High Temperature °F	Energy Use MM BTU/HR	Temperature °F		Enthalpy BTU/LB		LBS/HR Required
Process Unit					Inlet	Outlet	Inlet	Outlet (3)	
Mash cooking	221	5.25	221	5.25	150	250 ¹	117.89	1046.11	5385
Fermentation	90	(3.55)	90	(3.55)	---	---	---	---	---
Stripping	240	22.0	140		150	145	117.89	112.89	2.64x10 ⁶ (4)
Distillation/ Rectification	197		135	13.2	---	---			
Miscellaneous ²	---	8.77	---	11.92	2	2			
TOTAL	---	36.02	---	30.37					

Notes to EXHIBIT 4-3

1. Needs additional energy to preheat geothermal water to 250°F.
2. Uses electricity.
3. Assumes geothermal water, available at 150°F, preheated to 250°F steam.
4. Equivalent to 7.74 million gallons per day.

ethanol overhead product (obtained at atmospheric pressure) is distilled with a hydrocarbon dehydration agent to produce a bottoms product of absolute (100 percent) ethanol. Ethanol forms a constant-boiling mixture or azeotrope with water. Changes in pressure affect the composition of the ethanol-water azeotrope.^{10,12,13} As pressures decrease, the percentage of alcohol in the ethanol-water azeotrope increases. The ethanol-water azeotrope at atmospheric pressure consists of 90 percent ethanol; the azeotrope at 50 millimeters is more than 96 percent ethyl alcohol. This result is important since use of vacuum distillation may eliminate the need for a hydrocarbon dehydration column, thus significantly lowering overall energy use for preparation of fuel-grade ethanol.

5. CONCLUSIONS AND RECOMMENDATIONS

In this section we discuss conclusions that we have drawn based upon results presented in section 4. The conclusions presented in this section address the issues of overall and unit-by-unit technical feasibility of use of eastern geothermal energy in vacuum process units:

- Overall, with use of other forms of energy to provide higher temperatures for mash cooking, eastern geothermal energy can feasibly be used as a heat input for all unit processes in the vacuum ethanol process.
- Mash cooking is pressure independent and requires temperatures in excess of 220°F. Thus, additional heat must be provided for feasible geothermal use.
- Fermentation requires heat removal and does not use geothermal or other heat sources.
- The vacuum distillation operation requires highest temperatures of about 140°F. This temperature can be achieved by 150°F geothermal temperatures and allows for a sufficient temperature difference in the reboiler.
- Vacuum distillation results in lower energy use because of increased energy recovery.

6. LIMITATIONS AND FUTURE WORK

This section discusses limitations of the methodology used in the conduct of this study and future work that would be necessary to address those limitations.

6.1 LIMITATIONS

Analyses conducted in the course of this study show that demonstration status is high for the use of western geothermal energy as a heat source for farm-scale ethanol production. Data obtained during this study indicate that vacuum units are currently in operation that operate in the feasible range for use of eastern geothermal resources. These vacuum units use fossil fuel or solar energy as process heat. Thus, conclusions drawn in this study should be verified by construction and operation of a pilot plant that uses eastern geothermal energy to heat a vacuum column.

We assumed a column pressure of 130 millimeters in conducting this project. There are several economic tradeoffs that can be made by operating columns at different pressures. It is not obvious at this point that 130 millimeters pressure is the optimum point of operation for a vacuum system. Further studies should be done to establish the optimum pressure for operation of a vacuum column to produce ethanol fuel.

Energy requirements and the energy balance for a vacuum system were calculated. The method used was to factor data obtained for conventional energy requirements. We feel that this method produces a realistic projection of energy requirements for a vacuum ethanol plant. However, energy requirements reported in the literature for conventional processes were based on measurements of actual energy use. Similar data should be gathered for vacuum units to confirm conclusions reached in this study.

6.2 FUTURE WORK

Future work on this effort will consist of efforts designed to address limitations identified in the conduct of this study. Additional effort is needed to analyze the economic attractiveness of construction and operation of vacuum ethanol processes. Additional data should be obtained from operating vacuum distillation units, such as that operated by Dennis Day of Iowa, to confirm energy estimates presented. Furthermore, we recommend that operation of a pilot vacuum unit be investigated.

These additional studies will serve to verify the attractiveness of use of eastern geothermal energy as a potential heat source for farm-scale vacuum ethanol plants.

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APPENDIX

Other Geothermal Technical Assistance Studies

- *1. "The Crisfield, Maryland Well and Geothermal Energy," JHU/APL Letter Report CQO-2544 (12 November 1979).
- *2. "Technical Assistance -- Mariculture Industry on the Eastern Shore of Maryland," JHU/APL Letter Report CQO-2828 (18 February 1980).
- *3. "Report of Technical Assistance for Columbia LNG Corp.," JHU/APL Letter Report CQO-2850 (28 March 1980).
4. "Technical Assistance Report No. 4, Geothermal Space Heating, Pittsville Middle/Elementary School, Pittsville, Maryland," JHU/APL Report QM-80-101 (June 1980).
5. "Technical Assistance Report No. 5, Geothermal Space Heating, Naval Air Rework Facility, Norfolk, Virginia," JHU/APL Report QM-80-102 (June 1980).
6. "Technical Assistance Report No. 6, Geothermal Space Heating and Air Conditioning, McGuire Air Force Base, New Jersey," JHU/APL Report QM-80-190 (December 1980).

*Presented in paper "Technical Assistance -- Hydrothermal Resource Application in the Eastern United States," GRC 1980 Proceedings, Vol. 4; also reported in "Papers Presented -- Geothermal Resources Council, 1980 Annual Meeting," JHU/APL Report QM-80-134 (October 1980).

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