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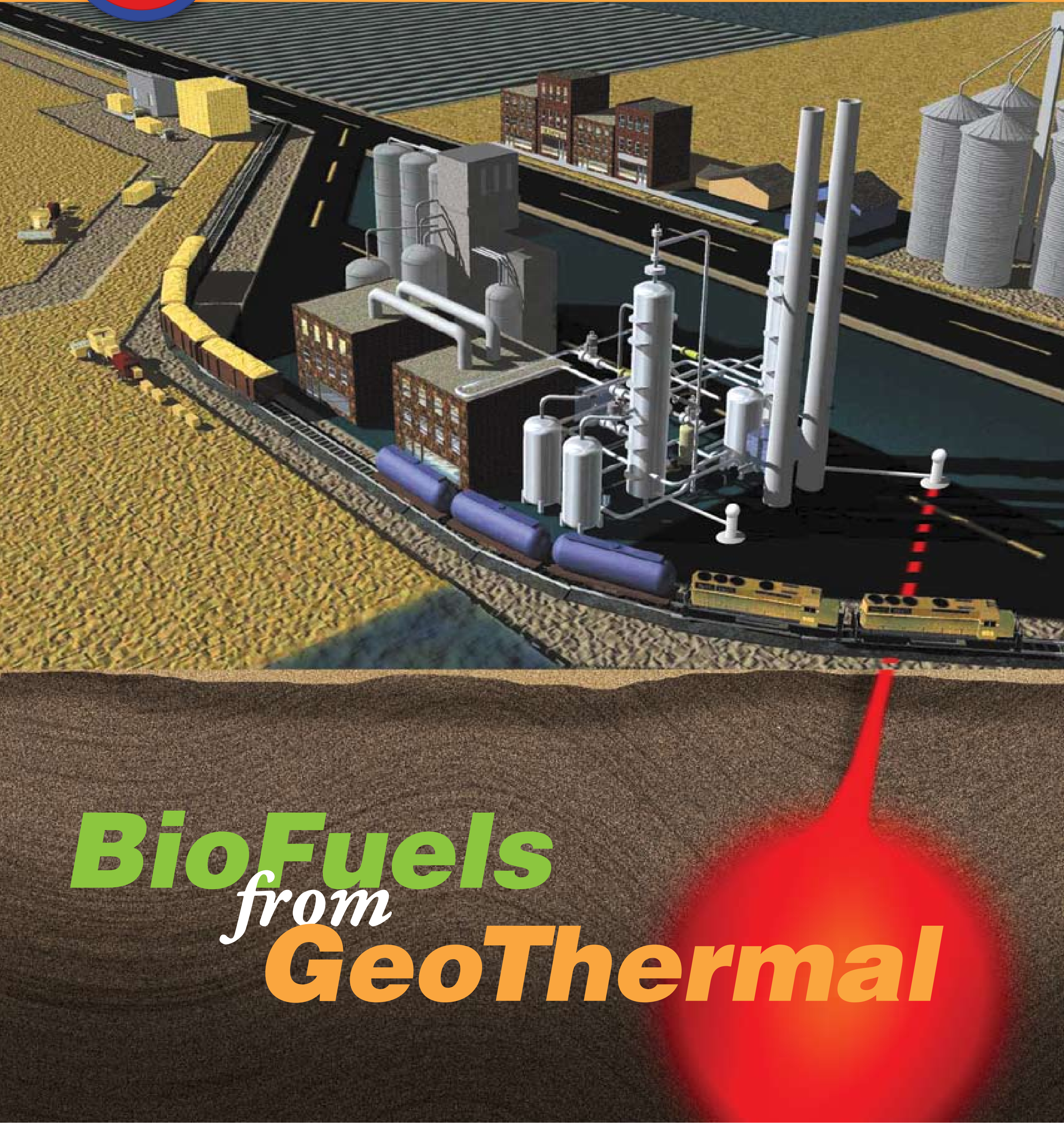

BioFuels from GeoThermal

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

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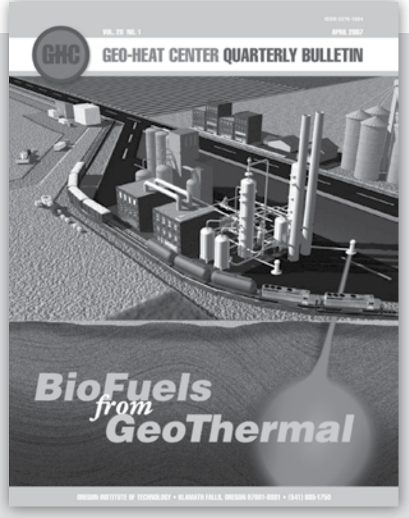

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BIOFUELS FROM GEOTHERMAL

The production of biofuels is a popular issue as it is a domestic product that reduces our dependency on imported fossil fuels for the transportation sector of our economy. Two types of biofuels are produced: ethanol and biodiesel, both of which are used as a blend with conventional fuels to power cars and trucks. The main controversy is the balance between energy input and energy output, as some reports contend that more energy is needed to produce the fuel as is produced from the fuel. The issue appears to be how you analyze the various energy inputs such as from fertilizer, growing the product, transporting it to market and the energy input in the refining process, as well as the benefits of the byproducts. Many of the steps require the use of fossil fuels, and thus, this is where geothermal energy can contribute, by replacing some of the energy input.

ETHANOL PRODUCTION

The Model T in 1908 was designed to either run on gasoline or ethanol; however, due to cheaper gasoline, it wasn't until the 1970s oil shock, that ethanol was of interest again. But, it wasn't until around 2000 that ethanol emerged as a substitute for methyl tertiary butyl either (MTBE), an oxygenate that reduced air pollution, but caused problems when it leaked into aquifers.

Today, corn is the major product used in ethanol production in the United States, with about 20% of the US production or 12 billion bushels of corn used annually. This increased demand is great for the farmers, as it has doubled the price of corn in one year to about $4.00 a bushel. This price, of course, affects cattle feed and then the cost of meat to consumers. To counter the use of corn, cellulosic ethanol is being investigated that comes from fibrous materials like corn husks and rice hulls, as well as fast-growing reedy crops that require little fertilizer or tending, such as switch grass and timber industry wastes.

Ethanol can be blended with gasoline as high as 85% ethanol to 15% gasoline, referred to as E-85, which is presently offered at about 1,000 gas stations in the United States. Only about 2.5 percent of the nation's cars are flexible fuel vehicles that can handle this mixture. Also, the energy content of ethanol is lower than gasoline, thus, it takes about 1.5 gallons of ethanol to drive as far as one gallon of gasoline. Despite all of these limitations, ethanol production is widely supported by Congress with few opponents.

BIODIESEL PRODUCTION

The idea of using vegetable oil for fuel has been around for a long time, as Rudolph Diesel, the inventor of the diesel engine, experimented with fuels such as peanut oil around the 1890s. However, due to the cheap and plentiful availability of petroleum distillates, commercial production of biodiesel in the United States did not being until the 1990s.

In the United States, the majority of biodiesel is made from soybean or canola oils, but is also made from waste sources such as used cooking oils or animal fats. In Europe, biodiesel is mainly produced from rape seed, which unfortunately, due to the high price has cut demand across the EU. More recently, interest has been in producing biodiesel from algae, some of which have over 50% oil content.

Since biodiesel is more expensive and has engine compatibility issues, it is mixed at 2% (B2) to 20% (B20) with conventional diesel. The use of biodiesel reduces hydrocarbons (CO_2) and particulate emissions; however increases nitrogen oxide emissions. At 100% biodiesel, CO_2 emissions are reduce by over 75%. Biodiesel is non-toxic and biodegrades four times faster than conventional diesel. Biodiesel does not flow as well as petroleum diesel in cold weather causing operating issues in colder climates. 100% biodiesel also tends to reduce fuel economy by about 11 percent.

ENERGY EFFICIENCY

Unfortunately, there are not uniform opinions on the efficiency and economics of biofuels production. A study by Cornell and the University of California Berkeley concluded that more energy was required to produce ethanol and biodiesel than was produced in it use. On the other hand, a study by NREL in the use of biodiesel with an urban bus concluded that biodiesel yields 3.2 units of fuel product energy for every unit of fossil energy consumed in its life cycle. A study from the University of Idaho which analyzed both of these reports, concluded that the answer was somewhere in between and that the value of the byproducts, such as animal feed, needs to be considered. In any event, the use of geothermal energy certainly will contribute to the energy balance and economics in the production of either fuels as described in the accompanying articles.

The Editor

REFERENCES:

"Is Ethanol the Answer?" by Marianne Lavelle and Bret Schulte, U.S. News & World Report, February 12, 2007, pp. 30-39.

"Biodiesel Energy Balance," by Jon Van Gerpen and Dev Shresthat, University of Idaho,

"Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus," by John Sheehan, Vince Camobreco, James Duffield, Michael, Graboski and Housein Shapouri, May 1998, National Renewable Energy Laboratory, Golden, CO

"Cornell Ecologist's Study Finds that Producing Ethanol and Biodiesel from Corn and other Crops is not Worth the Energy" by Susan Lang, Cornell University News Service, http://www.news.cornell.edu/stories/July 05/ethanol.toocostly.ssl.html.

GEOTHERMAL ENERGY UTILIZATION IN ETHANOL PRODUCTION

Andrew Chiasson, Geo-Heat Center

The Geo-Heat Center conducted an evaluation of using geothermal energy in ethanol production, funded and completed under a grant from Midwest Research Institute, National Renewable Energy Laboratory (NREL) Task Order No. KLDJ-5-55052-01. Presented here is a summary of the results of that study.

OVERVIEW OF ETHANOL USES AND PRODUCTION

Ethanol is also referred to as ethyl alcohol or grain alcohol. According to BBI International (2003), ethanol's primary uses in the U.S. are: as an octane extender for gasoline; as a clean-air gasoline additive in the form of an oxygenate; as a product to foster rural economic development; and as a domestic fuel source to aid in the reduction of U.S. dependence on imported oil. Ethanol blended fuels currently represent more than 12% of U.S. motor gasoline sales, and ethanol blends of up to 10% are approved under the warranties of all the major automobiles sold in the U.S.

At the time of completion of this report, there are currently about 100 ethanol plants in the U.S., producing over 4.2 billion gallons of ethanol annually (www.bbiethanol.com/). Over 20 new plants are planned or are under construction, with an estimated combined annual production of over 1.1 billion gallons of ethanol. As of 2003, approximately 95% of the U.S. fuel ethanol was manufactured from corn (BBI International, 2003).

ETHANOL PRODUCTION PROCESS AND ENERGY REQUIREMENTS

Prior to examining the feasibility of utilizing geothermal energy in ethanol production, it is necessary to detail the process, along with the associated energy and temperature requirements at each step. First of all, there are two types of processes used to produce ethanol: wet-mill process and dry-mill process. In the wet-mill process, corn is soaked or steeped and then separated into its component parts, which are recovered prior to fermentation, and only the starch fraction is processed. In the dry milling process, corn is ground into flour (meal) and processed without separation of component parts. Wet-milling plants have much higher up-front costs and operating expenses than dry-milling plants, and thus are not as common. Consequently, this study only deals with dry-milling process plants.

There are basically eight steps in the dry-milling ethanol production process as summarized below and shown schematically in Figure 1.

1. Milling: The corn (or barley or wheat) is first processed through hammer mills, which grind it into a fine powder the industry refers to as "meal".
2. Cooking and Liquefaction: The meal is then mixed with water and enzymes, which passes through cookers where the starch is liquefied. Cooking is generally accomplished at temperatures of 150-180°F (65-80°C). The meal is exposed to a high temperature stage of 250-300°F (120-150°C) for a short period of time to reduce bacterial growth in the mash.
3. Saccharification: The process of saccharification involves transferring the mash from the cookers where it is cooled, and a secondary enzyme (glucoamylase) is added to convert the liquefied starch to fermentable sugars (dextrose).
4. Fermentation: Yeast is then added to the mash to ferment the sugars to ethanol and carbon dioxide. Using a continuous process, the fermenting mash will be allowed to flow, or cascade, through several fermenters until the mash is fully fermented. In a batch fermentation process, the mash stays in one fermenter for about 48 hours before the distillation process is started.

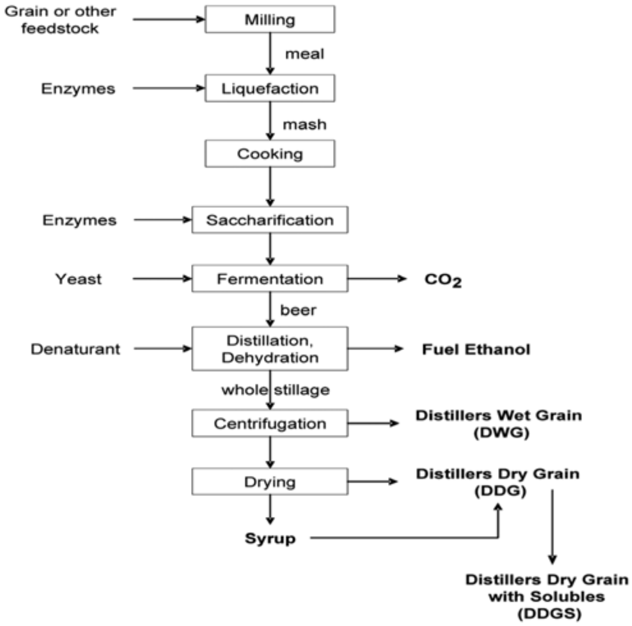


Figure 1. Process schematic of ethanol production using the dry milling process.

5. Distillation: The fermented mash, now called "beer," at this stage contains about 10% alcohol, as well as non-fermentable solids from the corn and the yeast cells. The mash is then pumped to the continuous flow, multi-column distillation system where the alcohol is removed from the solids and the water. Ethanol boils at a temperature of 173°F (78.3°C) at sea level pressure, allowing the distillation separation of the ethanol from water, which boils at 212°F (100°C) at sea level. The alcohol will leave

the top of the final column at about 95% purity (190 proof), and the residual mash, called stillage, gets transferred from the base of the column to the co-product processing area.

6. *Dehydration*: The alcohol from the top of the column is then passed through a dehydration system where the remaining water is removed. At this point, distillation has diminishing effect, and the remaining water must be removed chemically. Most commercial ethanol plants use a molecular sieve to capture the remaining water in the ethanol. The alcohol product at this stage is called anhydrous ethanol and is approximately 200 proof.

7. *Denaturing*: Ethanol to be used for fuel is then denatured with a small amount (2-5%) of a product (usually gasoline) to make it unfit for human consumption.

8. *Co-Products*: There are two main co-products created in the production of ethanol: carbon dioxide and distillers' grain. Carbon dioxide is given off in significant quantities during fermentation, and many ethanol plants collect this carbon dioxide, clean it of any residual alcohol, compress it, and sell it for use in carbonated beverages or in the flash freezing of meat. Distillers' grain is sold in two forms: distillers' wet grain (DWG) and distillers' dried grain (DDG). Both are high in protein and other nutrients, and are a highly valued livestock feed ingredient. DWG seems to be preferred by dairy and beef cattle (BBI International, 2003), but if a cattle feed lot is not within 100 miles of the ethanol plant, storage and transportation can become problematic. DDG requires a high amount of input energy to dry the grain to 10-12% moisture. The main advantage of DDG over DWG is better "flowability" and longer storage life. Some ethanol plants also create a "syrup" that contains some of the leftover materials, and can be sold as a separate product in addition to the distiller's grain, or combined with it to form so-called "distillers' dried grain with solubles" (DDGS).

According to BBI International (2003), about 85% of the ethanol plants in the U.S. use natural gas as a source of thermal energy. The remainder use propane, fuel oil, or coal. In general, about 20,000 to 40,000 Btu of energy is required to produce a gallon of ethanol and associated co-products. The highest energy requirements are needed when dry distillers grain (DDG) is a co-product. For comparison, the energy content of ethanol is about 85,000 Btu/gal.

Geothermal utilization opportunities exist in three stages of the production process: cooking, distillation, and drying of the distillers grain. In addition, geothermal energy could be used for space heating.

ECONOMIC ANALYSIS

For the economic analysis, an ethanol plant producing 10 million gallons of ethanol annually was considered. According to BBI International (2003) a small plant would be one producing about five million gallons per year. The fraction of the peak load met by geothermal energy was assumed at 75%, and the remaining 25% was assumed to be met by natural gas.

The peak heating load of the fictitious plant is estimated at 26.8 million Btu/hr and the annual heating requirement is approximately 3.0x1011 Btu (operating 350 days per year). The annual energy cost of a conventional ethanol plant using 100% natural gas is estimated at $3.22 million while the annual energy cost of the fictitious ethanol plant using 75% geothermal energy is estimated at $1.19 million.

Capital costs of the fictitious plant using geothermal energy included: design and engineering fees, land acquisition and construction of roads and services to a possibly remote location, exploratory drilling, and final well construction. The capital cost of a comparable conventional ethanol plant is estimated at $21.15 million, while the cost of an ethanol plant using geothermal energy is estimated at $25.72 million. Thus, the incremental cost of the geothermal ethanol scenario above the conventional is approximately $4.57 million or 21.6%

Annual costs considered include all costs associated with ethanol production. For this feasibility study, relative values were taken from BBI International (2003). For both plants, the greatest annual cost item is that associated with acquiring the feedstock (typically corn) and related chemicals and enzymes. For the conventional natural gas ethanol plant, energy costs account for 22.3% of total annual costs, while only 9.6% of the total annual cost is attributed to energy use in the 75% geothermal, 25% natural gas ethanol plant scenario. For the geothermal case, an additional well maintenance cost was assumed at $15,000, or 0.1% of the annual costs.

Annual income was estimated from relative values from BBI International (2003). Income is generated through sale of ethanol, CO_2, and some type of distillers grain. As described previously, the distillers grain is sold as animal feed and can be wet, dry, or mixed with solubles. For the ethanol plant scenario considered here, gross sales of $18.5 million are realized.

For the scenarios examined here, the conventional natural gas ethanol plant yields an annual profit before taxes of approximately $4.1 million, while the 75% geothermal, 25% natural gas ethanol plant yields an annual profit before taxes of approximately $6.1 million. This results in a pretax profit margin of $0.41/gal. for the conventional plant and $0.61/gal. for the geothermal scenario.

Thirty-year life-cycle economics were compared using present value comparison. Given the uncertainty of the cost of items, a sensitivity analysis was conducted in order to observe the effects of various cost items on the present value. The items varied in the sensitivity analysis were: natural gas costs, energy required per gallon of ethanol, fraction of energy provided by geothermal, geothermal initial costs, ethanol market price, feedstock price, and electricity costs. Results of the sensitivity analysis are shown in Figure 2. Present values are expressed as a ratio of the geothermal scenario to the conventional scenario. A discount rate of 8% was assumed.

A review of the data presented in Figure 2 shows that, for the base case described above, the geothermal case has a 54% greater present value than the conventional case. The most sensitive item to the present values is the ethanol selling price. As ethanol selling price is decreased, the ratio of the present value of the geothermal case to the conventional case rises dramatically as operating costs become very important. As the ethanol selling price is increased by up to 25%, the present value of the geothermal case relative to the conventional case decreases to about 1.2.

Following the market price for ethanol, the next most sensitive item on the project economics is the feedstock price. An increase in feedstock price of 10% increases the ratio of the present value of the geothermal case to the conventional case up to a value of 2.0. A further increase in the feedstock price up to 25% results in operating costs exceeding profits (and thus resulting in a negative present value) for the conventional case, while the geothermal case remains profitable. Lowering the feedstock price has a similar effect to lowering the natural gas price and the energy required per gallon of ethanol, the next most sensitive items.

The next most sensitive items to the present value ratio, each having a nearly identical impact, are the natural gas price and the energy required per gallon of ethanol. Increasing each by 25% increases the ratio of the present value of the geothermal case to the conventional case to about 2.2. Decreasing these items by 25% has less of an impact, lowering the ratio of the present value of the geothermal case to the conventional case increases to about 1.25.

The next most sensitive item to the present value ratio is the initial geothermal cost, followed closely by the fraction of energy provided by geothermal. As the initial geothermal cost is decreased by 25%, the ratio of the present value of the geothermal case to the conventional case increases to about 1.8. Conversely, as the initial geothermal cost is increased by up to 25%, the ratio of the present value of the geothermal case to the conventional case decreases to about 1.25. When the fraction of energy provided by geothermal is increased by 25% (i.e. up to 93.75%), the ratio of the present value of the geothermal case to the conventional case increases to about 1.76. When the fraction of energy provided by geothermal is decreased by 25% (i.e. down to 56.25%), the ratio of the present value of the geothermal case to the conventional case decreases to about 1.35. The project economics are relatively insensitive to the electricity cost.

SOME POTENTIAL BARRIERS TO GEOTHERMAL UTILIZATION IN ETHANOL PRODUCTION

Although the economics of utilization of geothermal energy can be quite attractive in ethanol production, some barriers to implementation have been identified. One of these is geothermal resource location. If the resource is far from ethanol markets and byproducts markets and/or remote from transportation infrastructure, economics of an ethanol project could become prohibitive. Another challenge in the use of geothermal energy in ethanol production is in the necessary plant design modifications. The majority of ethanol plants use low-temperature steam in their process, but geothermal fluids may be two-phase or single phase liquid, depending on the resource temperatures and pressures.

This will require selection of different heat transfer equipment and modifications to the plant process design (relative to conventional), and will likely incur more design time and cost that may become prohibitive.

Finally, there could be some opportunities in ethanol plants for waste heat recovery that can negatively impact the economics of geothermal energy utilization. This might be the case where thermal oxidation is the best means of destruction of regulated volatile organic emissions and/or odors that could otherwise be released into the atmosphere. Thermal oxidation of air pollutants typically requires destruction temperatures over 1,000˚F, resulting in a significant amount of waste heat available for recovery and use in the ethanol production process.

Although some barriers do exist in further development of geothermal utilization in ethanol production, there are some advancements being made as well, particularly with regard to the use of lower temperature resources. New technologies in ethanol production are evolving through research that has been aimed at low-temperature, low-energy chemical process of extracting ethanol from many different types of organic materials.

CONCLUDING SUMMARY

A hypothetical ethanol plant using a dry-milling process was considered for a feasibility study, producing 10 million gallons of ethanol on an annual basis. The energy fraction considered was 75% geothermal and 25% natural gas.

Some specific results of this study are as follows:

- According to BBI International (2003), about 85% of the ethanol plants in the U.S. use natural gas as a source of thermal energy. The remainder use propane, fuel oil, or coal. In general, about 25,000 Btu of energy is required to produce a gallon of ethanol, and the associated dry distillers grain requires an additional 12,700 Btu.
- As of 2003, approximately 95% of U.S. fuel ethanol was manufactured from corn.

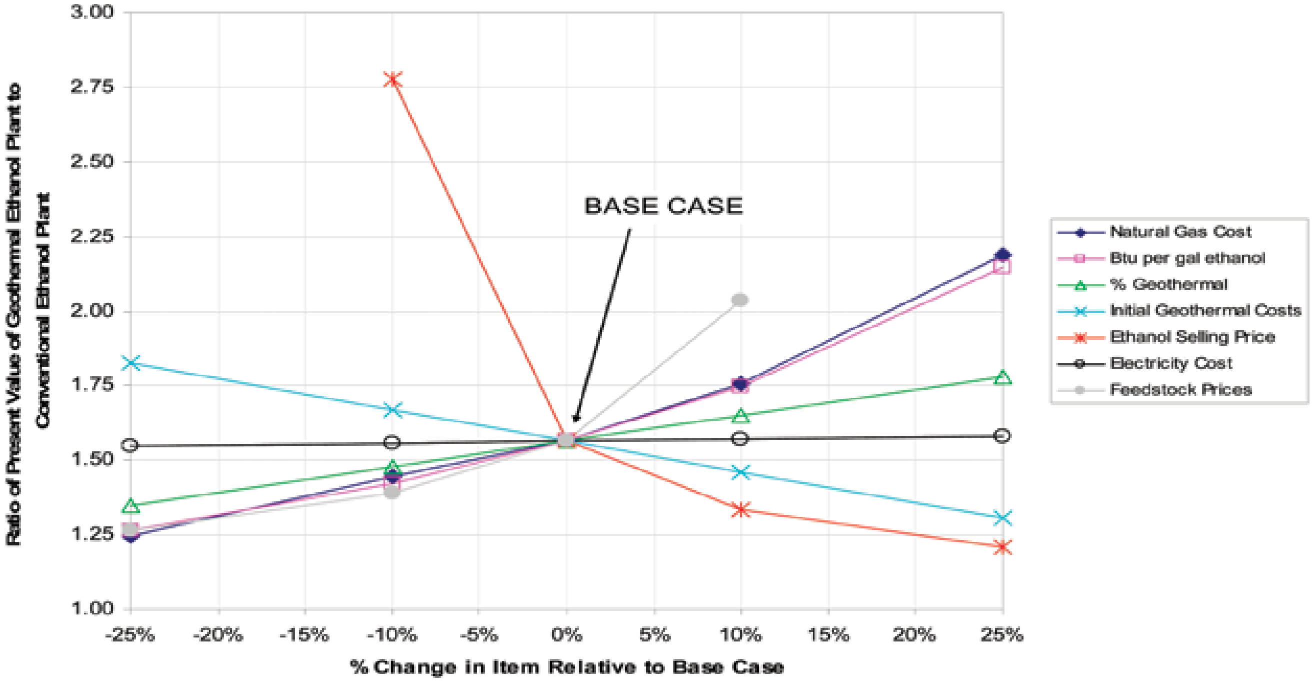


Figure 2. Sensitivity analysis of various cost items on the present value of a geothermal ethanol plant relative to a conventional natural gas ethanol plant.

- Geothermal utilization opportunities exist in three stages of the production process: cooking, distillation, and drying of the distillers grain. In addition, geothermal energy could be used for space heating.
- Cooking is generally accomplished at temperatures of 150-180˚F (65-80˚C). The meal is exposed to a high temperature stage of 250-300˚F (120-150˚C) for a short period of time to reduce bacterial growth in the mash.
- Distillation occurs at temperatures between the boiling point of ethanol (173˚F (78.3˚C) at sea level pressure) and the boiling point of water (212˚F (100˚C) at sea level).
- Grain drying occurs at temperatures exceeding the boiling point of water
- For the base case examined here, the incremental cost of the 75% geothermal plant above the conventional is approximately $4.57 million or 21.6%.
- The estimated annual energy savings with the 75% geothermal plant is $2.03 million or 63.2%. Energy costs account for 22.3% of total annual costs for the conventional plant, while only 9.6% of the total annual cost is attributed to energy use in the 75% geothermal plant.
- The conventional ethanol plant yields an annual profit before taxes of approximately $4.1 million, while the 75% geothermal plant yields an annual profit before taxes of approximately $6.1 million. This results in a pre-tax profit margin of $0.41/gal. for the conventional plant and $0.61/gal. for the geothermal scenario.
- The present value of a 30-year life-cycle of the 75% geothermal plant is 1.54 times greater than the conventional plant.
- A sensitivity analysis of cost items on the present value, shows that project economics are most sensitive to: ethanol selling price, feedstock price, natural gas price, energy required per gallon of ethanol, initial geothermal cost, and fraction of energy provided by geothermal. Project economics are relatively insensitive to electricity cost.
- Some barriers to further development of geothermal energy utilization in ethanol production include: distance of the geothermal resource from markets and/or infrastructure; plant design modifications to account for two-phase or single-phase liquid geothermal fluids; and other waste heat recovery opportunities at an ethanol plant.
- New technologies in ethanol production are emerging that require lower temperature and lower energy per gallon, expanding possibilities for low-temperature geothermal energy utilization.

REFERENCES

BBI International, 2003. Ethanol Plant Development Handbook, 4th Ed. BBI International. Cotopaxi, CO.

GREENFUELS OF OREGON: GEOTHERMAL ENERGY UTILIZATION IN BIODIESEL PRODUCTION

Andrew Chiasson, Geo-Heat Center

INTRODUCTION

Greenfuels of Oregon is undertaking a new venture in the Klamath Basin to produce biodiesel using geothermal energy. The facility is currently under construction, but the production process is set up to make use of geothermal energy in the biodiesel process.

THE GEOTHERMAL RESOURCE AND DISTRIBUTION SYSTEM

The Greenfuels of Oregon biodiesel production facility is located on the "Liskey Ranch" (Figure 1), a Known Geothermal Resource Area (KGRA) that has seen a long history of geothermal energy usage since the 1970s. Current uses of geothermal energy on the Liskey Ranch include space heating, greenhouse heating, aquaculture pond heating, and now biodiesel production.

The geothermal resource has been described by Laskin (1978) and Lund (1994). The area is located near the northwest edge of the Basin and Range geological province, and thus the occurrence of geothermal water is controlled by geologic faults along the front of the Klamath Hills. These faults allow groundwater which has circulated to great depths to rise upward into shallower aquifers where it can be tapped by water wells. Groundwater temperatures available for utilization are on the order of 190 to 210˚F, and wells on the property can produce geothermal water at several hundreds of gallons per minute.

THE GREENFUELS OF OREGON GEOTHERMAL SYSTEM

Greenfuels of Oregon makes extensive use of their geothermal resource for many heating purposes. Uses of geothermal energy include radiant floor space heating of the biodiesel production building, in addition to use in the production of biodiesel itself. From the biodiesel facility, the geothermal water is cascaded to greenhouses when various organic vegetables are grown, and to an aquaculture operation.

WHAT IS BIODIESEL?

The Alternative Fuels Data Center of the U.S. Department of Energy defines biodiesel as a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant greases. Biodiesel is safe, biodegradable, and reduces air pollutants such as particulates, carbon monoxide, hydrocarbons, and air toxins. Blends of 20% biodiesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines; however, users should consult their OEM (Original Equipment Manufacturer) and engine warranty statement. Biodiesel can also be used in its pure form (B100), but it may require certain engine modifications to avoid maintenance and performance problems and may not be suitable for wintertime use.

THE BIODIESEL PRODUCTION PROCESS

The general formula for making biodiesel is:

alcohol + vegetable oil or fat + heat + lye catalyst ➔ biodiesel

The production process to be used by Greenfuels of Oregon is shown schematically in Figure 2. The process starts with some type of feedstock for the organic oil. Greenfuels of Oregon is currently set up for processing canola or soy beans with equipment shown in Figure 3 and 4.

The next stage of the process is to mix the organic vegetable oil with methanol and a sodium monoxide catalyst in the reactor, which is a 600-gallon tank. Heat is also added to the reactor through geothermal water at approximately 180˚F

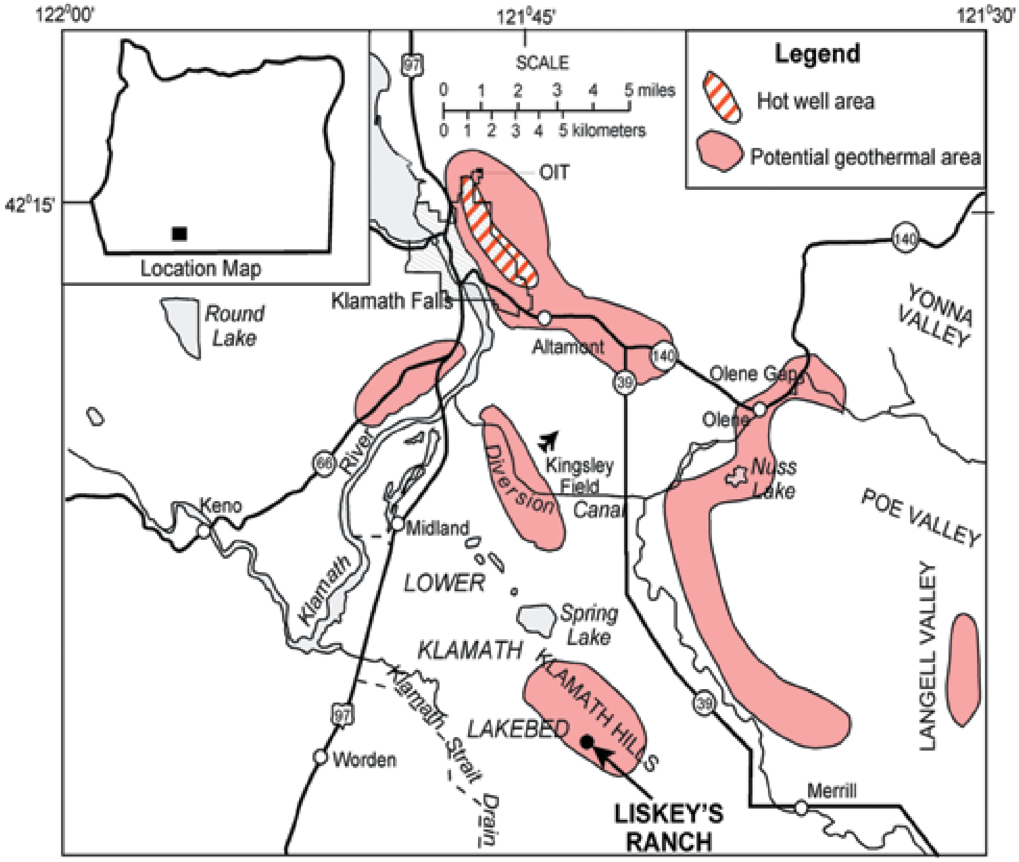


Figure 1. Location map of "Liskey Ranch".

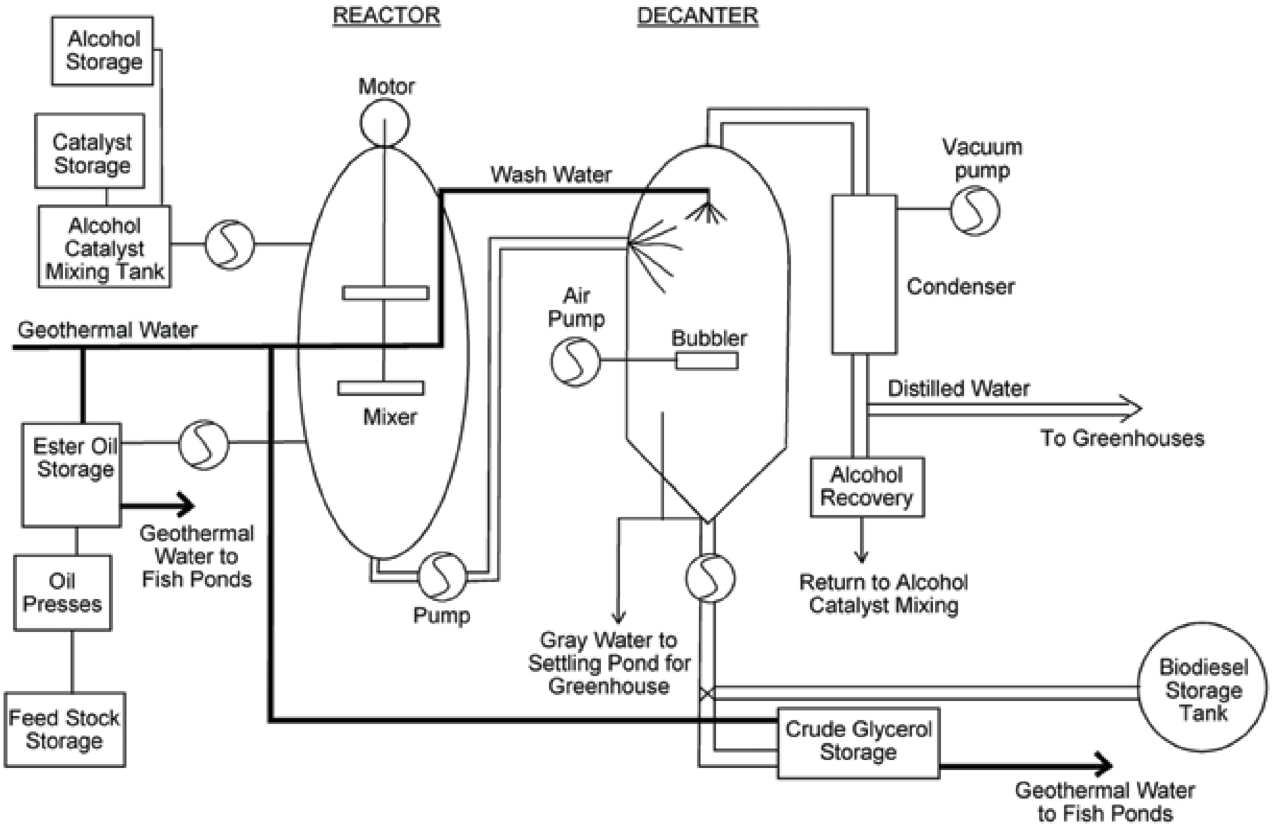


Figure 2. Schematic drawing of the biodiesel production process at Greenfuels of Oregon.

This process is formally called "transesterification" and occurs for approximately 30 minutes.

The mixture is then pumped to the decanter where geothermal water is used to "wash" and separate the finished biodiesel product from other materials. Distilled water and alcohol are recovered by vacuum pumping the decanter and then recondensing the vapors.

Geothermal gray-water is routed to settling ponds and then used in the greenhouses. Crude glycerol is a byproduct of the process. A photograph of the biodiesel production equipment is shown in Figure 5.

The biodiesel production target for Greenfuels of Oregon is about 1,500 gallons per day, but the actual production will depend upon feedstock availability. Most of the biodiesel is planned to be sold locally.

Figure 3. Feedstock grain storage silos.

Figure 4. Photograph of equipment for feedstock grinding.

CONCLUDING SUMMARY

Greenfuels of Oregon is undertaking a new use of geothermal energy in the Klamath Basin: production of biodiesel. In addition, geothermal energy will also be used for space heating of the building, and the geothermal water will be cascaded for use in greenhouse and aquaculture pond heating.

Figure 5. Photograph of the biodiesel production equipment.

There is on-going controversy in scientific literature about the energy balance of biodiesel production. In other words, there is a recurring question of whether it takes more energy to produce biodiesel than the energy that the biodiesel fuel produces. The Greenfuels of Oregon project in the Klamath Basin certainly requires a further examination of this question, and this will be the subject of future bulletin articles.

ACKNOWLEDGEMENTS

The Geo-Heat Center wishes to thank Rick Walsh for providing the information for this article, and Katja Winkler for providing the photographs of the equipment.

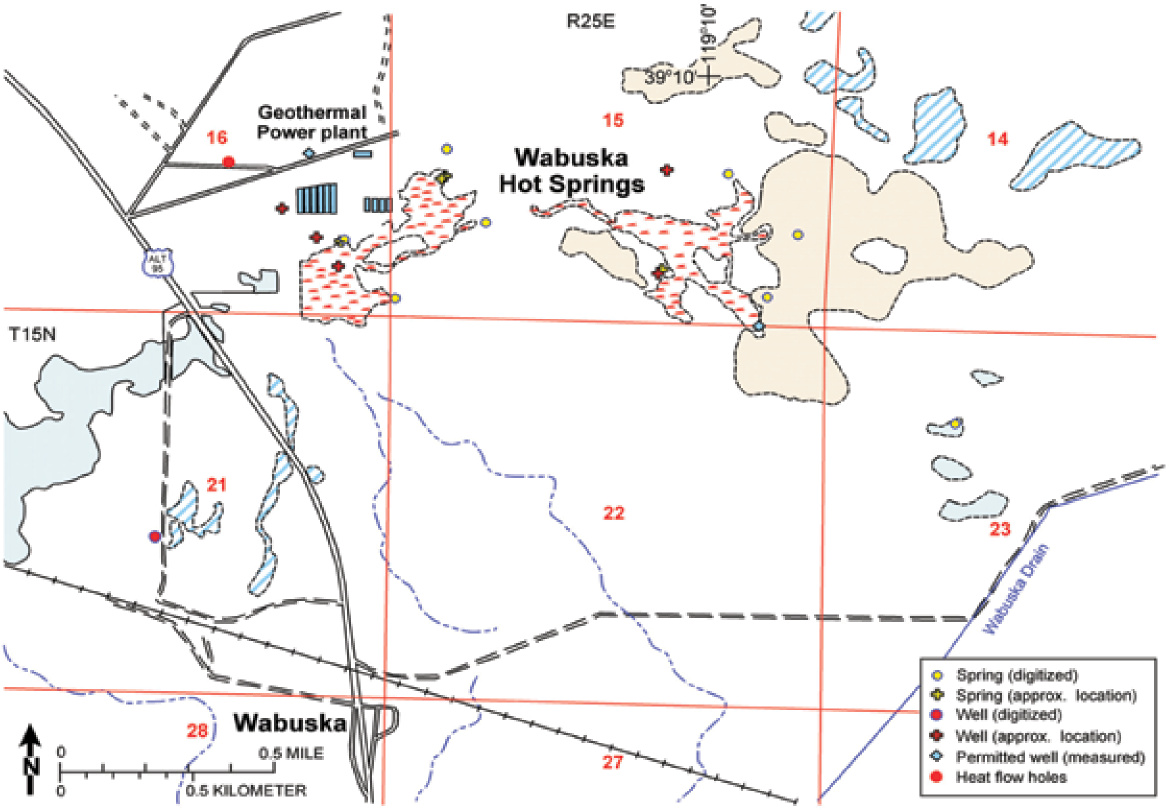
REFERENCES

Laskin, S., 1978. Klamath Greenhouses. Geo-Heat Utilization Center Quarterly Bulletin, July 1978, Oregon Institute of Technology, Klamath Falls, Oregon.

Lund, J., 1994. Agriculture & Aquaculture Cascading the Geothermal Way. Geo-Heat Center Quarterly Bulletin, November 1994, Oregon Institute of Technology, Klamath Falls, Oregon.

GEOTHERMAL POWER GENERATION AND BIODIESEL PRODUCTION IN WABUSKA, NEVADA

Claude Sapp, Infinifuel Biodiesel, Dayton, NV



INTRODUCTION

Wabuska (wuh-BUHS-kuh) is a very small unincorporated village in Lyon County, Nevada. The population is 150. It is in the Walker River Basin, on the north end of the Mason Valley, 10 miles north of Yerington, the Lyon County seat. The elevation is 4300 feet. The town is on Highway 95A, and a Union Pacific rail line crosses the highway at Wabuska.

The history of Wabuska (the Washoe Indian term for white grass) started in the 1870's when the settlement served as a coach and freight stop for travelers and shipments of supplies going to the booming mining towns of Nevada, including Aurora, Goldfield, and Bodie, California. By 1881 the town was a stop on the newly constructed Carson and Colorado railroad. Southern Pacific Rail purchased the rail line around 1900, and soon after copper was discovered in the Mason Valley, increasing freight and passenger traffic through Wabuska until the decline of mining throughout Nevada in the 1920's.

While Nevada mining operations drove the development of Wabuska in the late 19th and early 20th centuries, Wabuska today is in a predominantly agricultural area. Current local industry includes hay and alfalfa, cattle and sheep, and dairy. The only notable current non-agricultural business and industry in Wabuska includes a plastics fabricator (AES Industries), Linda's Old Wabuska Bar, Homestretch Geothermal and Infinifuel Biodiesel.

There are hot springs in and near Wabuska, and the 20th century saw a few businesses that sought to utilize the hot water. Probably in response to the oil shock of the 70's, in 1981 TAD's Enterprises built a 400,000 gallons per year ethanol plant in Wabuska, hoping to rail in corn as the feedstock. The plant was operational for a few years, and had an old geothermal well that supplied heat for the ethanol process. The owners commissioned a feasibility study performed by the Geo-Heat Center (GHC), to assess the financial impact of expanded use of the geothermal resource, looking for improvements that would lead to cost savings, including electrical power generation.

Subsequent to the GHC study, Wabuska became home to the first geothermal power production unit in Nevada. In 1984, Wabuska I went online, an Ormat binary power production unit. This was followed by Wabuska II in 1987, another Ormat unit. While the ethanol plant was decommissioned by the mid 1980's and then mothballed for decades, geothermal power production continues today, and has been operational in Wabuska almost continuously since going online. Homestretch Geothermal currently operates the geothermal facility.

Figure 1. 2MW geothermal power plant that provides electricity for the biodiesel plant.

GEOLOGY AND HYDROLOGY

The Wabuska geothermal area is located at the margin of Mason Valley, where both the valley margin and the thermal springs coincide with a northeast-striking zone of faults referred to as the Wabuska lineament (Stewart, 1988). Some faults are associated with the lineament cut Pleistocene units (Sawyer and Sawyer, 1999). Production is apparently from Quaternary gravels and sands; geothermal fluid may circulate along faults related to the Wabuska lineament as well as an unconformity above Mesozoic metasedimentary rocks possibly present at depth (Nevada Bureau of Mines and Geology, 2006).

Table 1. Water Chemistry

	mg/L		mg/L
Al	0.08	K	19.83
As	0.05	Na	300.67
B	0.02	Cl	63.40
Ba	1.09	F	9.47
Ca	42.17	SO_4	447.00
Cu	0.02	pH	7.39
Fe	0.02	TDS	1107.67
Mg	0.28	Hardness	106.33

Constituents with concentrations in excess of water quality criteria are arsenic (As), boron (B), copper (Cu), fluoride (F), sulfate (SO4) and TDS (Nevada Division of Environmental Protection Fact Sheet 2003 – 2005).

LOCATION AND DESCRIPTION

Homestretch Geothermal operates the facility at 15 Julian Lane in Wabuska, NV (39° 09' 40" N, 119° 11' 00" W, T15N R25E S15SW¼ and S16SE¼).

Homestretch Geothermal owns 500 acres fee simple along with the geothermal rights and 8500 acre feet of water rights. The majority of the land is undeveloped, but expansion plans include the development and sale of an industrial park served by geothermal utilities on the property.

GEOTHERMAL WELLS & DISCHARGE WATER

The resource consists of two wells referred to as Production Well #1 (PW#1) and Production Well #2 (PW#2), each less than 500 feet deep. PW#1 was drilled in 1959 and was first used as the water and heat supply for a large hydroponic vegetable business. In 1984, Tad's Enterprises who then owned the property and resource built the first geothermal power plant to ever sell power in Nevada. They utilized the flow from PW#1 for the brine to power the binary Rankine cycle generator and then used the discharge brine to provide the cooling water.

The original temperature of the resource was 220ºF. The flow rate of the well was 750 gpm. The original well is still producing 750 gpm at 218ºF 48 years later, and the well has produced water continuously at least 97% of the entire past 20 years. Flow has not diminished at all. The water level in the well while pumping is regularly monitored and only fluctuates minimally from season to season but remains constant year to year. In May 2003, Homestretch Geothermal had the well televised while it was down for a pump change-out. The televising revealed that the original casing is still in excellent condition even though it is 48 years old.

Production Well #2 was drilled in 1986 by TAD's Enterprises and a second power generation unit was built and put on line that year. PW#2 also started with a temperature of 220ºF. It also, 20 years later, continues to produce water at 218ºF. It originally was set up to pump 800 gpm. In May of 2003 Homestretch Geothermal also had PW#2 televised and the casing was in perfect condition. Every aspect of the well design showed to be excellent. Another flow test was conducted by Homestretch Geothermal and the well produced 2,200 gpm for 48 hours with very little draw down on the well and no apparent affect on PW#1. The well currently produces 2,800 gpm with virtually no change in temperature, flow or draw down.

Currently, PW#1 is off-line, and has not been pumped for two years. PW#2 is flowing 2,800gpm at 218ºF, and is running the two original power production units, and a third unit that was added by Homestretch Geothermal. Plans for expanded production include drilling a third well in 2007 and putting four more power production units online.

One unique fact about Wabuska is that geothermal water is not reinjected after passing through power generation. It is the only geothermal site in Nevada that is not required by the State to reinject, so the water simply passes through ponds to cool off. Water exits the geothermal units at 180ºF, and is pumped to two 400' x 125' cooling ponds. Each pond has 110 spray nozzles three feet above the pond surface that the hot water sprays through to air cool and settle in the pond. Water exits the ponds, and then drains onto property to leech back into the soil.

Figure 2. Spray pond.

POWER PRODUCTION & OPERATIONS

Homestretch Geothermal purchased the two power production units TAD's installed in the 1980's, and in 2002 added a third power production unit that is producing power today. There are four more power production units staged on property that are offline. Once drilling of the third well on property is complete, these last four units will be brought online. Each of the seven units is rated at 800kW.

Current total power production from the three units averages 1.2MW, throughout the year. Peak production in the winter is about 1.4MW, and in the warmer summer months electrical generation dips to about 1.1MW. The plant service requirement is 290kW, so a net of approximately 910kW is sold back to Sierra Pacific Power Company and put back on the grid, connected via a 24.9kV line. The current electricity is purchased under the terms of a 30 year power purchase agreement (PPA) that was entered into with Sierra Pacific in 1985, with purchase rates in the range of $0.06/kWh. Another PPA is being negotiated for the planned capacity increase and additional electrical generation expected to come online this year.

Operation and maintenance is performed by a staff of two persons. The units operate mostly unattended and automatically, with an estimated 98% runtime. Should the units fail or shutdown, the service panel identifies the problem to be fixed, and an emergency diesel generator provides startup power for the facility after problems have been fixed. Routine maintenance costs average approximately $60,000 per year excluding salary. In 2006, routine and emergency maintenance included replacing a well pump, cleaning condensers, cleaning out heat exchanger tubing, rebuilding the turbine in unit #1, and replacing two iso-pentane pumps. The only extended downtime the plant has ever experienced was between 1996 and 1998. The plant was shutdown in 1996 due to the unavailability of Freon 114, the working fluid in the power units. The units were converted to iso-pentane in 1998, and resumed regular operations.

BIODIESEL PLANT

In 2006, Homestretch Geothermal and Infinifuel Biodiesel entered into an agreement to form Infinifuel Wabuska, a company that would retrofit the decommissioned ethanol plant on property in order to produce biodiesel. The goal was to produce a liquid renewable fuel using renewable energy for the heat and electricity used in biodiesel production, and in so doing, build the world's first geothermal biodiesel plant.

The biodiesel facility is a 3,600 sq. ft. building housing two reactor processors (7,000 and 4,000 gallons), and eight 7,600 gallon wash tanks in two banks of four. Though current production is under 1.0 million gpy, capacity of the plant is between 4-5 million gpy of biodiesel. Additional storage tanks are outside, the whole system is stainless steel, and all is connected by stainless steel piping and approximately 200 connected HP of motors and pumps.

The raw material needed for biodiesel is vegetable oil and alcohol. Current production is from used vegetable oil collected from local restaurants, with additional oil coming from a grease collector in California. The alcohol used is methanol, and this is the only petroleum product directly used in the process. In order to be more "green" Infinifuel has entered into discussion with a company that recycles medical waste, their byproduct being methanol. If this methanol from a recycled product is used in Wabuska, Infinifuel may run the only liquid fuel plant in the world that does not use petroleum products. To further efficiency, Infinifuel is planning to use the two distillation towers from the old ethanol facility to recover unused methanol from the biodiesel production process. Distillation is an energy intensive process, but geothermal makes it much more economic to pursue.

Infinifuel has also partnered with the University of Nevada Reno (UNR) and Desert Research Institute (DRI) to investigate the feasibility of growing oil crops in Nevada as an alternative to the predominant dirt crops, hay and alfalfa.

Figure 3. Grain silo, methanol recovery towers, tank farm.

Figure 4. Biodiesel processors and wash tanks are in the building to the left.

Figure 5. Algae research ponds.

Nevada farmers have been receptive to the idea, accepting crops like crambe, flax, and sunflower as rotation crops that improve the soil and use less water than hay or alfalfa. As Wabuska is in a ripe agricultural valley and there is much land proximate to the geothermal and biodiesel plants to cultivate, Infinifuel can experiment with oil crops in partnership with UNR and DRI.

Algae is also being investigated as an oil crop. In the 1980's the Department of Energy's Renewable Fuels Lab did research on algae to determine if it was feasible to extract oil from algae to produce biodiesel. Their findings generally supported the concept. One point to consider was that they were proposing to grow algae in the western deserts where land and sunlight are abundant, but where temperatures could drop at night providing a less than ideal environment for algae to grow. The lack of a system to regulate temperature was considered a hurdle, but the geothermal at Wabuska gives Infinifuel, UNR, and DRI the means to keep a constant and ideal temperature for algae research and production. The researchers at UNR are perfecting an oil extraction process for the algae that is based on heating the oil out of the algae, eliminating the need for mechanical or chemical extraction. The extraction process is efficient at 200ºF, a perfect temperature for the resource at Wabuska. While there is also a grain storage silo and a hammer mill at the Wabuska facility for mechanical oil extraction, the oil extraction process using heat alone is an example of how we are searching for every way to make use of the geothermal resource onsite.

CONCLUSION

Though Wabuska is a sleepy little village where there are more sheep than persons, exciting things are being done there with geothermal water. It has a long history of direct and indirect geothermal use, and is notable as being the site of the first geothermal electricity production in the State of Nevada. In the past, geothermal was used in numerous businesses in Wabuska, from growing hot house tomatoes to distilling ethanol. Recently we have added to the history, producing biodiesel using geothermal for the heat and electricity needed in the biodiesel plant. The future looks promising. As our academic research partners are looking for ways to expand renewable energy production in Nevada, Wabuska may turn into an important field research center. Hopefully, others may benefit from our experience as well.

REFERENCES

Sawyer, J.E., and Sawyer, T.L., compilers, 1999, Fault number 1665, Unnamed faults west of Desert Mountains, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, http://earthquakes.usgs.gov/regional/qfaults, accessed 2/27/07.

Stewart, J.H., 1988, Tectonics of the Walker Lane belt, western Great Basin: Mesozoic and Cenozoic deformation in a zone of shear, in Ernst, W.G., Metamorphism and crustal evolution of the western United States, Rubey volume VII: Prentice Hall, Englewood Cliffs, N.J., p. 683-713.

Nevada Bureau of Mines and Geology (NBMG), 2006, Wabuska Hot Springs (TAD's Enterprises): Nevada Bureau of Mines and Geology website http://www.nbmg.unr.edu/geothermal/site.php?sid=Wabuska Hot Springs, accessed 2/27/07.

DESIGN OF A GEOTHERMAL ENERGY DRYER FOR BEANS AND GRAINS DRYING IN KAMOJANG GEOTHERMAL FIELD, INDONESIA

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ABSTRACT

Indonesia is a country rich in geothermal energy. Of approximately 20,000 MWe energy potential, only about 850 MW has been utilized for electricity purposes. There are not many direct utilization activities for various purposes that have been implemented. This paper discusses a design of a geothermal dryer for beans and grains drying that will be implemented in Kamojang geothermal field, West Java, Indonesia. Geothermal fluid waste from a Kamojang well of approximately 160˚C will be used to supply the equipment. The heat will be extracted to produce a room drying temperature, for which coffee bean will be used as an experimental grain to be dried. A tube-bank heat exchanger has been designed, consisting of 1-meter-staggered pipes of 2-inches (50.1-mm) outer diameter. An air blower from one side produces air flow of varying velocities to flow heated air into a drying room on the other side. With a geothermal fluid flow containing a heat transfer rate of 1000 W and various air flow velocities of 4 to 9 m/s, the HE design could produce an output drying temperature of 45.48 to 40.64˚C and drying energy (heat) produced in the drying room of about 41.0 to 68.0 kW/m length of the heat exchanger. Depending on the bean's humidity, the drying time has to be set accordingly.

INTRODUCTION

Indonesia is a country having many volcanoes and rich in geothermal energy. There are at least 177 volcanic centers that are spread over volcanic belts of 7000 km along the Indonesian islands. From that many centers, there is at least 20,000 MWe-equivalent from geothermal energy resources contained in the volcanic areas. Islands in which geothermal energy can be found are Sumatera, Java, Nusa Tenggara, Sulawesi, and Maluku.

By now, only about 850 MW of that much energy potency has been utilized for electricity power generation. The rest has not been utilized optimally. Among the fields that have been developed are Kamojang, Darajat, Gunung Salak, Patuha, Wayang Windu, Dieng, Lahendong, and Sibayak. Electricity has been produced from those major fields. Unfortunately, there is only limited direct utilization of geothermal energy in those fields as well as in other undeveloped ones.

Meanwhile, in the geothermal fields that have been developed and utilized such as Kamojang, Dieng, Darajat, Gunung Salak, etc, there have been production geothermal wells that already have depleted pressure, temperature, and production rate thus unable to supply the existing electric power plants. Such wells have been modified to re-injection or monitoring wells. There are also waste geothermal fluids from electric power plants that are usually re-injected into the reservoir to maintain the life of the geothermal reservoir. The heat contained in the fluids can still be extracted to supply equipment or engines for producing fresh water steam, to supply heating or drying equipment for sterilization of growing media, drying agricultural and husbandry products and other direct utilizations.

The existence of geothermal energy resources that is commonly found in mountainous and inland regions has its own benefit. In Indonesian mountainous and inland regions there are found agricultural, plantation, and forestry areas in which their products require processes such as drying, preservation, heating, sterilization, pasteurization, etc. The agricultural and plantation product processing requiring heat are for examples: rice, coffee, and tea drying, potato seeding, mushroom cultivation, milk pasteurization, etc.

To initiate direct utilization of geothermal energy, the Agency for the Assessment and Applied Technology (BPPT), has been doing research in that field since 1999-2000. The first effort was a research in geothermal energy utilization for sterilization of mushroom growing media in Kamojang geothermal field. The research was a success and is now planned to continue to commercial scale. The research presently continues to design a geothermal dryer for beans and grains. This paper discusses such design to see the technical feasibility if the equipment will be built (Sumotarto et al., 2000)(Sumotarto, 2001).

METHODOLOGY & DESIGN OF EQUIPMENT

Traditionally, grains and beans drying in Indonesia have been done by heating the products under sunshine (solar drying). The products will be influenced by seasonal and weather changes, thus making the drying process un-continuous. This will result in cracking, fracturing, and imperfect drying products.

To improve the process, drying has to be done continuously, requiring continuous heat supply. This can be reached by using continuous energy resource supply such as geothermal fluid flows.

EQUIPMENT DESIGN

The dryer used in this research will be made of a fluid-air heat exchanger to produce hot air that will be blown into a drying room filled with trays of grains or beans. Figures 1 – 4 show the design of the equipment. The waste geothermal fluid is flowed into a bank of steel pipes, and air is blown outside the pipes to extract heat from geothermal fluids inside the tubes for the drying process.

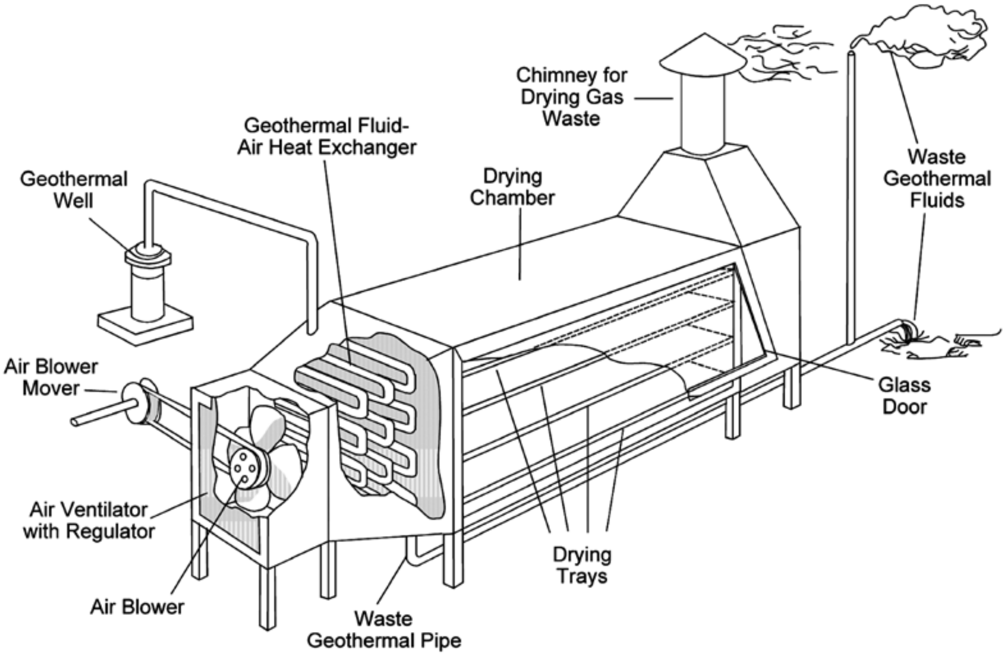

Figure 1. 3D view of the geothermal dryer design for drying grains and beans.

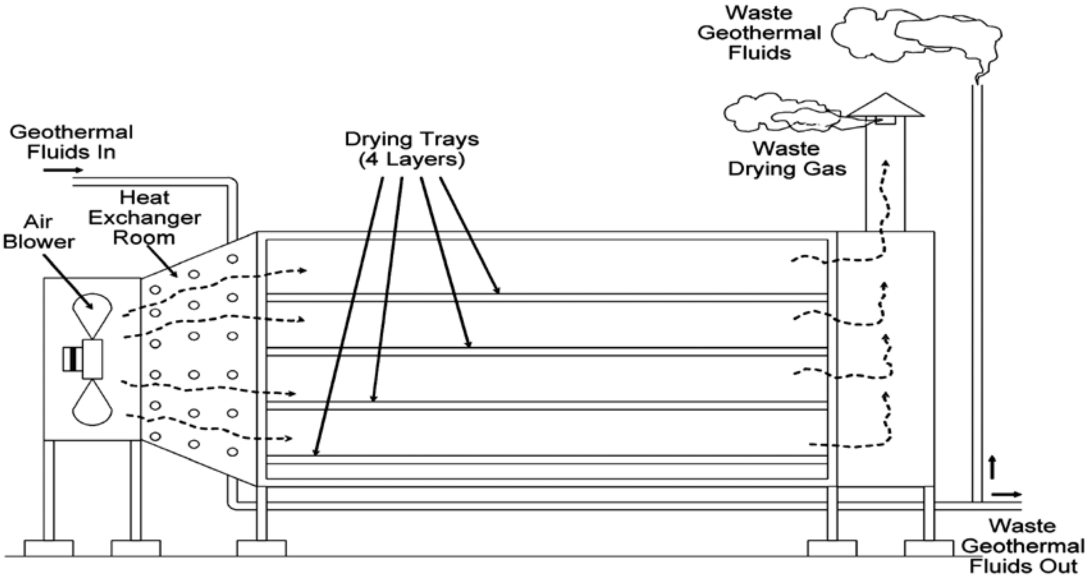

Figure 2. Longitudinal cross section of the geothermal dryer

The equipment does not use a drying belt to save energy for moving the belt. Instead, the beans and grains are placed on trays in the drying room. The only moving part is an air blower that can be designed to move by geothermal energy (pressure), while its heat content is used for the heat exchanger. The air blower is placed on one side of the heat exchanger while the drying room is on the other side.

The drying duration depends on the original humidity of the products. By doing several drying experiments, an ideal drying time can be found for which the product is perfectly dried. The dryer is designed as simple to assist the technical feasibility of geothermal energy direct utilization. If the drying is proven to be feasible, then the technology and design can be improved while the scale can be increased to meet a commercial project.

HEAT & ENERGY EQUATIONS

The energy balance equations governing the heat exchanger can be modeled in two parts. The first part is heat transfer from the geothermal fluids inside the tubes to the outer side of the tubes, and the second part govern the heat transfer process outside the tubes into the drying room. Figure 3 shows the first part of energy (heat) transfer and, figure 4 shows the second part.

Calculation of energy transfer in this part is performed when the equipment is in operation with steady state energy

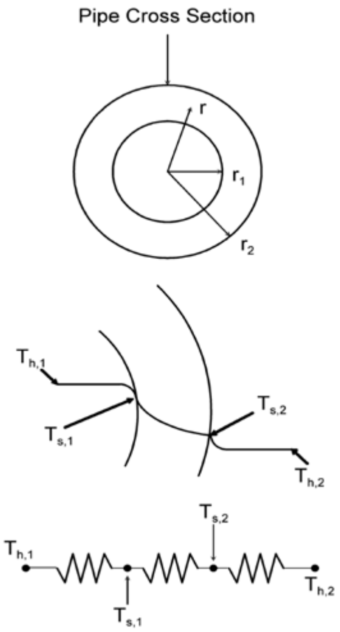

Figure 3. Heat transfer across the heat exchanger pipes.

transfer (heat flow). The calculation is based on phenomena where energy (heat) flows across a cylindrical pipe (Figure 3). Outside the heat exchanger the air is assumed to flow convectional into the drying room. There is assumed no other mode of heat flows i.e. radiation, because of the high speed of convection air current.

PART I:

For simple calculation, this part can be modeled as one-dimensional radial heat flow. If there is no energy generation in the equipment, heat transfer equation governing the system is

$$\frac{1}{r}\frac{d}{dr}\left(kr\frac{dT}{dr}\right)=0 \qquad (1)$$

According to Fourier's Law, energy (heat) flow rate by conduction through solid cylindrical surface can be expressed as

$$q_r=-kA\frac{dT}{dr}=-k(2\pi rL)\frac{dT}{dr} \qquad (2)$$

where $A=2\pi rL$= area of the surface normal to the direction of heat transfer. The heat transfer rate q_r , not heat transfer flux q_r", is a constant value in radial direction.

Equation (1) can be integrated twice to find a general solution

$$T(r)=C_1\ln r+C_2 \qquad (3)$$

With boundary conditions: T(r1) = Ts,1 and T(r2) = Ts,2 (Figure 4), C1 and C2 can be found as

$$C_1=\frac{T_{s,1}-T_{s,2}}{\ln(r_1/r_2)} \quad \text{and} \quad C_2=T_{s,2}-\left(\frac{T_{s,1}-T_{s,2}}{\ln(r_1/r_2)}\right)\ln r_2$$

Substituting C1 and C2 back to Equation (1) results in a general equation of temperature for the system as follows

$$T(r)=\frac{T_{s,1}-T_{s,2}}{\ln(r_1/r_2)}\ln\left(\frac{r}{r_2}\right)+T_{s,2} \qquad (4)$$

Note: Temperature distribution for a system associated with radial conduction heat flow through a cylindrical surface is in the form of logarithmic, not linear such as on a flat wall of similar condition.

Further, substitution of Equation (4) into Equation (2) results in a general equation of heat rate as follows

$$q_r=\frac{2\pi Lk(T_{s,1}-T_{s,2})}{\ln(r_2/r_1)} \qquad (5)$$

where

$R_{t(cond)}=\dfrac{\ln(r_2/r_1)}{2\pi Lk}$ is also called *Thermal Resistance.*

The heat flow from the center of the tube to the inside wall of the tube and from the outer side of the tube into the open air is a convection flow. For the whole system from $T_{\infty,1}$ -> $T_{s,1}$ -> $T_{s,2}$ -> $T_{\infty,2}$, the heat flow rate equation (5) can be formulated as

$$q_r=\frac{T_{\infty,1}-T_{\infty,2}}{\dfrac{1}{2\pi r_1Lh_1}+\dfrac{\ln(r_2/r_1)}{2\pi kL}+\dfrac{1}{2\pi r_2Lh_2}} \qquad (6)$$

which can also be expressed in heat rate equations for each portion of the entire flow as

$$q_{r,1}=2\pi r_1Lh_1(T_{\infty,1}-T_{s,1}) \qquad (6.a)$$

$$q_{r,2}=\frac{T_{s,1}-T_{s,2}}{\ln(r_2/r_1)}2\pi Lk \qquad (6.b)$$

and

$$q_{r,3}=2\pi r_2Lh_2(T_{s,2}-T_{\infty,2}) \qquad (6.c)$$

where

q = heat transfer rate [W]

r = pipe radius [m]

L = pipe length [m]

T = temperature [K] or [C]

k = thermal conductivity [W/m.K]

h = convection heat transfer coefficient [W/m^2.K]

Those three equations (6.a, 6.b, and 6.c) can be used to calculate $T_{s,1}$ and $T_{s,2}$ because $q_r = q_{r,1} = q_{r,2} = q_{r,3}$.

PART II:

As heat leaves the outer side of the pipes the governing equations can be modeled as an air convection flow through a bank of tubes (Figure 4). The tube rows in this heat exchanger are staggered in the direction of *fluid velocity (V)*. The configuration is characterized by the *tube diameter (D)* and by the *transverse pitch (S_T)* and *longitudinal pitch (S_L)* measured between tube centers. Flow conditions within the bank are dominated by boundary layer separation effects and by wake interactions, which in turn influence convection heat transfer. Incropera et.al (1985), describes such phenomena with the following equations.

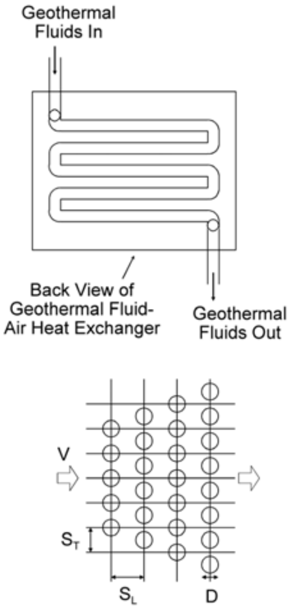

Figure 4. Heat exchanger pipes lay-out.

The amount of heat transfer can be calculated by, first calculating the air-side Nusselt number as:

$$\overline{Nu}_D = C\,\mathrm{Re}_{D,\max}^{m}\,\mathrm{Pr}^{0.36}\left(\frac{\mathrm{Pr}_\infty}{\mathrm{Pr}_s}\right)^{1/4} \qquad (7)$$

where

$$\mathrm{Re}_{D,\max} = \frac{V_{\max} D}{\nu} \qquad (8)$$

ν = kinematics viscosity of the air [m^2/s].
Pr = Prandtl number

C and *m* are constants that depend on tube configuration (tabulated in table 1 (Howell and Buckius, 1987)).

The *Reynolds number ($Re_{D,max}$)* for the foregoing correlations is based on the *maximum fluid velocity (V_{max})* occurring within the tube bank. For the staggered configuration, the maximum velocity may occur at either the transverse plane or the diagonal plane. If the rows are placed such that

$$S_D = \left[S_L^2 + (S_T/2)^2\right]^{1/2} > (S_T + D)/2 \text{ , then}$$

$$V_{\max} = \frac{S_T}{S_T - D} V \qquad (9.a)$$

Otherwise,

$$V_{\max} = \frac{S_T}{2(S_D - D)} V \qquad (9.b)$$

The average convection *heat transfer coefficient (h)* can be calculated using the following equation

$$\bar{h} = \overline{Nu}_D \frac{k}{D} \qquad (10)$$

where

k = gas (air) thermal conductivity [W/m.K].

The heated air temperature produced from the heat exchanger can be calculated using a log-mean temperature difference

$$\Delta T_{lm} = \frac{(T_s - T_i) - (T_s - T_o)}{\ln\left(\dfrac{T_s - T_i}{T_s - T_o}\right)} \qquad (11)$$

where T_i and T_o are temperatures of the fluid as it enters (T_i) and leaves (T_o) the bank, respectively and T_s is the temperature of the tube outside surface. The outlet temperature T_o, which is needed to determine ΔT_{lm} may be estimated from

$$\frac{T_s - T_o}{T_s - T_i} = \exp\left(-\frac{\pi D N \bar{h}}{\rho V N_T S_T c_p}\right) \qquad (12)$$

where

ρ = air mass density [kg/m^3]
c_p = gas (air) specific heat at constant pressure[J/kg.K]
N = total number of tubes in the bank, and
N_T = number of tubes in the transverse plane

Finally, the heat transfer rate per unit length of the tubes may be computed from

$$q' = N\left(\bar{h}\pi D \Delta T_{lm}\right) \qquad (13)$$

where

q' = heat transfer rate per unit length [kW/m]

SIMULATION AND RESULTS

Using the equations described in the above section, it can be determined the relation between the *air flow velocity (V)* produced by the air blower and the *drying temperature (T_o)*. Depending on the drying temperatures that are specific to each product, the *air flow velocity (V)* can be adjusted accordingly. The calculation and simulation are conducted as follows:

1. Write a computer program for the calculation according to the equations described in previous sections.
2. Prepare parameters and constants needed in the calculation such as geothermal fluid temperature inside the tube, drying temperature required, heat transfer coefficients, etc. Table 1 shows parameter and constants needed for the calculation.

3. Using the proper data and calculation procedure, it can be calculated the parameter needed for the drying process.
4. Tables and figures showing various relations can be made according to the calculation results.

Table 1. Parameters used in the simulation and calculation of the geothermal drying equipment for grains and beans.

Parameters		Unit
Geothermal Fluid heat convection coefficient (h_1)	5000	$W/m^2.K$
Heat Exchanger pipe thermal conductivity (k)	10	W/m.K
Air heat convection coefficient (h_2)	15	$W/m^2.K$
Geothermal Fluid temperature	160	^0C
HE Input Temperature (T_i)	20	^0C
HE transverse pitch (S_T)and longitudinal pitch (S_L)	0.08, 0.11	m
Air kinematics viscosity (ν)	15.2678 $*10^{-6}$	m^2/s
Gas (air) thermal conductivity (k_{air})	0.0263	W/m.K
Air mass density (ρ)	1.1614	kg/m^3
Constants in Nusselt number calculation (C&m)	0.330430629 , 0.6	-
Gas (air) specific heat at constant pressure (c_p)	1.007	J/kg.K
Total number of tubes in the HE bank (N)	26	-
HE number of tubes in the transverse plane (N_T)	6	-
HE pipe diameter and total length	0.0501, 29.3	m

Using the above simulation procedure it is found that at a geothermal fluid temperature of 160˚C, there can be calculated various heat transfer rate and drying temperature at various air flow velocity produced from the air blower. Tables 2, 3 and 4 show the results of the calculations and the relations between air flow velocity to heat transfer rate and drying temperature.

Table 2 shows that at various geothermal fluid flows with *heat transfer rate (q_r)* of between 1000 to 6000W, the outside surface temperature of the heat exchanger pipes would reach as high as 159.93 to 159.60˚C. Further, Table 3 shows that at the above various heat transfer rate, the output *temperature (T_o)* of the HE would reach 45.48 to 45.44˚C, from which we can have enough temperature for drying purposes. It can be seen here that varying geothermal heat transfer rate does not result in significant range of outside temperature of the HE pipes and output temperature of the HE in the drying room. Therefore, it is enough to pick one value of the geothermal heat transfer rate to be used for sensitivity analysis of the other governing parameters i.e. *air flow rate (V)* from the blower.

Further, by picking a fixed heat transfer rate of 1000W, which results in outside surface temperature of the HE pipes of 159.93˚C, it can be seen in Table 4 that for various air flow velocities from the air blower of between 4 to 9 m/s, the drying temperature would vary between 45.48 to 40.64˚C, which will produce a drying heat transfer rate of 41.0 to 68.0 kW per meter length of the HE.

Table 2. Relationship between geothermal heat flow rate (q_r[W]) inside the HE tubes and inside and outside pipe surface temperature (T_{s1},T_{s2}[C]) and air temperature ($T_{\infty 2}$[C]) for a constant geothermal fluid temperature ($T_{\infty 1}$[C]) of 160 [C].

q_r	T_{s1}	T_{s2}	$T_{\infty 2}$
1000	159.95	159.93	145.48
2000	159.91	159.87	130.96
3000	159.86	159.80	116.45
4000	159.82	159.73	101.93
5000	159.77	159.66	87.41
6000	159.73	159.60	72.89

Table 3. Output (drying) temperature (T_o[C]) and heat transfer rate per length of HE (q_{rate}[kW/m]) at various outside surface temperature of the HE (T_{s2}[C]).

T_{s2}	T_o	q_{rate}
159.93	45.48	41.50
159.87	45.47	41.48
159.8	45.46	41.46
159.73	45.45	41.44
159.66	45.44	41.42
159.6	45.44	41.40

Table 4. Output (drying) temperature (T_o[C]) and heat transfer rate per length of the HE (q_{rate}[kW/m]) at various air flow rate (V[m/s]) from the air blower for a constant geothermal heat flow rate (q_r[W]) of 1000 [W] and a constant surface temperature of the HE pipes (T_s[C]) of 159.93 [C].

V	T_o	q_{rate}
4	45.48	41.50
5	44.01	47.74
6	42.89	53.52
7	41.99	58.92
8	41.26	64.03
9	40.64	68.90

CONCLUSIONS

From the design of the geothermal drying equipment and equations model needed for the design there can be calculated various parameters needed for the drying process. From the calculation and simulation performed in this research it can be concluded the following:

- The drying equipment designed in this research uses a heat exchanger that can be modeled as staggered pipes bank in which fresh air from the atmosphere is flowed through the heat exchanger using an air blower into a drying room filled with trays of products to be dried.
- The equations governing the heat exchanger design can be modeled into two parts. The first part is heat transfer from geothermal fluids inside the pipes to the outer side of the pipe where heat is transferred through convection and conduction modes. The second part is heat transfer from the outer side of the pipe into the drying room where heat is mainly transferred by (forced) convection mode.
- Depending on the product being dried, the drying temperature can be set to find a proper air flow velocity from the air blower. In this experiment, calculation is performed to compute various heat transfer rate and air flow velocity for varying drying temperature using a fixed geothermal fluids temperature of 160˚C.
- Calculation of the experiment using a fixed geothermal fluid flow with a heat transfer rate of 1000W with various air flow velocities of 4 to 9 m/s results in an output drying temperature of 45.48 to 40.64˚C, a temperature range enough for drying purposes, with drying energy (heat) produced in the drying room of about 41.50 to 68.90 kW/m length of the heat exchanger.
- From the simulations performed in the experiments shows that the most important parameters to govern the drying temperature are, among others, geothermal fluid temperature, geothermal fluid flow rate which determines geothermal heat transfer rate, and air flow velocity from the blower.
- This research has to be followed up with more detail experiments and calculations in order to find a complete and thorough design of the equipment that can work optimally.

REFERENCES

Howell, J.R. & Buckius, R.O.: Fundamentals of Engineering Thermodynamics, McGraw-Hill Book Co., 1987, 697 p.

Incropera, F.P. & De Witt, D.P.: Fundamentals of Heat and Mass Transfer, 2nd Ed., John Wiley & Sons, 1985, 802 p.

Sumotarto, U., Surana, T., and Lasman, F., (2000) Utilization of Geothermal Energy for Mushroom Growing, Presented at the 4th INAGA Annual Conference, Jakarta, 25-26 January 2000.

Sumotarto, U.: Problems in Direct Utilization of Geothermal Energy in Kamojang Geothermal Field, Indonesia. Presented at the INAGA Annual Conference, Yogyakarta, 2001.

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