

Solar fuel alcohol distillation

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Contents

- 1 Introduction
- 2 History
- 3 Fuel vs. Food Controversy
- 4 Background
 - 4.1 Available sources of fuel substrates
 - 4.2 Hydrolysis
 - 4.3 Fermentation
 - 4.4 Distillation
- 5 High Grade Fuel from Low Technology
- 6 Build
 - 6.1 Materials
 - 6.2 Assembly
- 7 Operation
- 8 Future Work
- 9 References

Introduction

An abundance of clean, locally-produced, combustible fuel could dramatically improve the standard of living in parts of the developing world. This fuel could transport goods to markets, produce steam and electricity, heat homes, boil water and cook food, provide power for communication equipment and provide for better standards of education and health. With less reliance on dirtier fuels, there would be less air pollution indoors and out, less deforestation and erosion of soils. This report describes the simple engineering required to increase the efficiency of a solar still to produce low-cost, concentrated ethanol for fuel at the local, "micro" level, reliably and safely.

It should be noted that this project is for fuel-alcohol only, and not for human consumption, though the basic design principles could be applied to distillation of water or other liquids. It should also be noted that this is a theoretical design at this point and as such no prototyping or testing has been done, but the results of said testing will be posted when they are available.

History

Over the last two centuries, many systems for generating alcohol fuel (ethanol) from sugars and starches have been developed and inventors have demonstrated the utility of this fuel. The first alcohol-fuelled engine was an internal combustion engine, built in 1826 by Samuel Morey^[1]. Fifty years later, German engineer Nicholas Otto invented the four-stroke (Otto Cycle) internal combustion engine, using ethanol as its primary fuel. In the late 1800's, Henry Ford's Quadricycle ran on ethanol. He believed that alcohol was "the fuel of the future" and, in 1912, made his Model-T available with an ethanol engine. Farm equipment in Europe was developed using ethanol for fuel throughout the 20th century, increasing these countries' self-reliance. Disruptions to North American petroleum supplies from the Middle East began in the early 1970's and, in response to these supply problems, public policy has encouraged research and development into alternative fuels as a way to escape dependence on hostile suppliers.

In a report published by the National Center for Appropriate Technology in 1981, Bradley, Moody, Portch and Runnion created a summary of the common available technologies for producing alcohol fuels from sugars and starches^[2]. Since this time, technologies for alcohol fuel production have become increasingly complex, making them less available where cost and simplicity of design are important.

Fuel vs. Food Controversy

The desirability and ethics of ethanol production from materials which could serve as food is the subject of increasing controversy and debate. What is not debated, however, is the profound, positive effect on local economies, manufacturing, environments and standard of living the expanded use of these clean fuels could have in developing communities and nations. The ultimate answer to this debate may lie in the development of low-cost production of fuel-alcohol from cellulose and hemi-cellulose but, until this technology becomes more readily available and affordable, engineering may be able to bridge the gap between potential and real benefits using current knowledge.

Background

Available sources of fuel substrates

The conversion of sugars and grains and non-edible plant material (cellulose and hemi-cellulose) to ethanol is accomplished through the three-steps of hydrolysis, fermentation and distillation. A short description of these processes are offered here but a more detailed description of hydrolysis entitled "Starch hydrolysis for ethanol production." by G.B. Borglum of Myles Laboratories is available here (http://www.anl.gov/PCS/acsfuel/preprint%20archive/Files/25_4_SAN%20_0264.pdf) , while a good review of fermentation is found here (http://www.en.wikipedia.org/wiki/Ethanol_fermentation) . A particularly good article describing solar distillation can be found here.

Hydrolysis

Fruits, vegetables and grains, all sources of sugars and starches, are

boiled and agitated for 30 minutes to break down cell walls, releasing long-chain sugars. Inexpensive and commercially available alpha-amylase is added to the solution, as it cools, to hydrolyse these long-chain sugars to short-chain polysaccharides. Next, beta-amylase is added to this solution to reduce short-chain sugars to individual glucose molecules. This process is reasonable for remote and developing communities because the costs and requirements for this technology are small.

If non-edible plant cellulose and hemi-cellulose such as cane or corn stalks or wood fibre, amongst many others, are to be used, they are also boiled to release a variety of polysaccharides. At that point, more sophisticated chemicals in the form of cellulases, derived from various organisms, are used to convert these long-chained sugars to simple monosaccharides^[3]. These simple sugars include xylose, manose, galactose and pentose sugars, amongst others. Chemical hydrolysis of cellulose and hemi-cellulose by strong acids (H_2SO_4 , HCl) can also be used to expose sugars^[4].

Fermentation

If the solution contains simple glucose, brewer's yeast (*Saccharomyces cerevisiae*) is added and the solution is agitated to oxygenate it for ten to twenty minutes, initiating the budding of the yeast. *Saccharomyces* will ferment glucose in oxygen but will do this more completely in anaerobic conditions. The solution is isolated from the air, and CO_2 and ethanol are produced. As was discussed under hydrolysis, if sugars other than glucose (those derived from cellulose and hemi-cellulose) are present, other enzymes are required. Xylose is the predominant monosaccharide from cellulosic hydrolysis, therefore, beta-D-xylosidases are commonly used^[5]. The introduction of organisms that produce these enzymes in anaerobic conditions, results in the production of a variety of by-products, primarily, but not exclusively, CO_2 and ethanol.

The ethanol in the "beer" produced in either process will increase in concentration until the sugars in the solution are exhausted or the ethanol concentration exceeds the tolerances of the organisms being used for fermentation and they are killed. This usually occurs above

14%. Most fermentation processes will use a hydrometer to guide the decision as to when to extract the fermented product, usually at concentrations of 10 to 12% so that new substrate can be added, diluting the concentration and allowing the process to continue without killing the essential organisms.

Distillation

Ethanol is miscible in water and the solution can be concentrated by distillation to levels where it can function as a fuel, a mixture of 50% or greater. The potential of the solution to be used as fuel increases as the concentration increases. Because alcohol and water become an azeotrope at an ethanol concentration of about 95%, distillation to this concentration is the ideal, as controlling the pressure inside the still is beyond the scope of this design.

Ethanol will separate from the mixture when the temperature of the vaporizing chamber reaches the boiling point of the ethanol, (a table of evaporation temperatures can be found in Table 1). The temperature of

evaporation for the ethanol-water solution will be between the boiling point of ethanol and that of water, dependent on the concentration of the solution.

Stills that are capable of producing highly concentrated ethanol do so by remaining at the boiling temperature of pure ethanol.

Table 1 - Boiling point of 95% ethanol vs. altitude

Altitude (ft)	Boiling point of 95% ethanol (°C)
0	78.1
500	77.3
1000	77.1
1500	76.7
2000	76.2
2500	75.7
3000	75.2

3500	74.7
4500	73.8
5000	73.3
6000	72.4
7000	71.4
8000	70.4
9000	69.4
10 000	68.4
15 000	63.5

High Grade Fuel from Low Technology

Solar stills are minimally sophisticated devices that employ solar energy to separate ethanol from the water in the solution. Short-wave, UV

radiation penetrates the glass on the face of the still, hits the dark surface of the evaporation wick and is converted to longer-wave radiation, becoming trapped in the still and heating it (green-house effect). The ethanol vapor rises from the evaporation pad, contacts the glass on the front of the still, condenses and collects in a concentration exceeding that of the original solution. Initially, the still will warm to the boiling point of the ethanol and the majority of the distillation will take place relatively quickly, but as the ethanol is extracted and the composition of the water mixture changes, the temperature inside the still will increase, eventually reaching a point where some of the mixture will begin to boil. In practice, this results in a concentration of close to 60% from an initial batch of 10% ethanol solution. Further distillation runs will eventually yield a 95% solution.

Build

While the design has not been tested as of yet, the still in this project should, in theory, work as both a batch and continuous still. It also provides the option for an actively controlled air vent to be added to help control the internal temperature. Figure 1 below shows the still's

basic design and proposed dimensions. The internal dimensions were chosen based on the requirement of the still to be able to process a batch size of 1 Litre. Based on standard diameter plastic pipes and what were deemed reasonable dimensions for construction, an optimal pipe diameter and length were chosen to be 3 inches and 20 inches respectively, and as such internal dimensions measure 20" x 20" x 4.5".



Figure 1:
Dimmensioned
sketch of still.

Materials

- Materials for sides (suggested: 4.5" x 3/4" wood or otherwise)
- Material to make angled base piece (use end cut of side material)
- Material to make vent cover (use end cut of side material)
- Material to cover the back-plate of the still (1/4" plywood or equivalent)
- Burlap or other dark wicking material
- Two 3" inner diameter, 20" long pieces of PVC pipe
- Two screws
- Two bolts and corresponding drill bit for mounting the still to a stand
- One piece of Plexiglass large enough to cover the box's front face
- 1/16" Drill bit or equivalent for making holes in the PVC pipe
- 1/4" Drill bit for making vent holes.
- Black paint (optional)
- Stand material (not covered in this project).

Assembly

Cut and assemble the four sides of the box such that the box is square

1.0 and the inner dimensions measure 20" x 20" x 4.5". Cut and fit the back plate to the sides. Cut and install the slanted base piece such that it has a height of less than 1" on one end, slopes to no height at the other and is the full thickness of the box. Paint the inside faces of the sides, bottom and back-plate black if possible.

2.0 Cut one piece of PVC pipe in half along its length and install in the box approximately 1" from the bottom and tightly pressed against the back plate. Seal around all three edges contacting the box if possible (caulking, tape etc.). This will be the mixture collection trough.

3.0 Attach the wicking material to the back-plate. cover from the top of the box to inside the collection trough. The fluid to be distilled will either soak down or wick up this material depending on the method being used to operate the still.

- | | |
|-----|---|
| 4.0 | Drill small ($\sim 1/16''$), evenly spaced ($\sim 1''$ interval) holes in the remaining whole PVC pipe piece and install in the top of the still with the holes facing directly downward when the still is tilted at its optimal angle. Seal around the ends of the pipe if possible. |
| 5.0 | Find the center mass of the box and install bolts to allow the still to be mounted to a stand and tilted to the appropriate angle to receive the maximum amount of sun. |
| 6.0 | Drill three holes. One that aligns with the center of the full pipe piece; one that aligns with the lowest point in the mixture collection trough when the box is set at its optimal angle to the sun; and one in the bottom corner of the back-plate, such that any fluid running down the angled base-piece will flow out through this hole. Install plumbing fittings and seal edges of PVC if possible. |
| | If an active temperature-control system is desired, drill venting holes the side of the box as shown in figure 6 and then cover with the vent cover, as seen in figure 7. This will allow the disc to spin either opening or closing the holes while keeping the disk balanced about the rotation. |

axis. Using a temperature sensor/controller chip such as the Aniomagi temperature learning sensor (\$4.80/chip when bought in quantities over 100) in conjunction with either a 3V battery or an equivalent solar panel and a small electric motor mounted outside the box to spin the vent cover. Place two small screws at the desired stop-points for the disk, also seen in figure 6, allowing either a vent-open or closed position.

7.0 The temperature learning sensor allows for simple calibration, and therefore a carefully temperature controlled probe could be placed in contact with the sensor with the calibration temperature based on the elevation at which the still was being used. The Aniomagic sensor has three possible outputs, one for when the temperature is below the setpoint (vents closed), temperature at setpoint (do nothing), temperature above setpoint (reverse motor polarity to open vents).

This control system could also be used with a small fan to aid in the cooling of the chamber. Furthermore, a passive control system could be designed to control the temperature in the evaporation chamber by

using the expansion and contraction of a fluid to actuate venting, or to regulate the flow of alcohol/water mixture into the still. Regulating the temperature through flow rate would use the heat capacity of the ethanol mixture to control the internal temperature. This system would allow more fluid in when the temperature was too high, and would restrict the input flow as temperature decreased. If carefully calibrated this system could temperature-regulate a continuous flow solar still with no external energy consumption.

8.0 Secure the Plexiglass panel to the front of the still and seal if possible

Operation

If the still is being operated using a batch of fluid, fill either the top pipe or the collection trough with 10% ethanol/water solution. Depending on where the fluid is input, it will soak down or wick up the material on the back-plate, which gives it a much greater area to evaporate from. The ethanol will begin to evaporate as the still heats up and it will condense on the Plexiglas. Once condensed, the ethanol will run down to the slanted base-piece where it can be collected via the hole in the back of the still and either used directly if the concentration is correct, or reprocessed if not. If the top pipe was filled with the batch, or if the still is being used in a continuous distillation process, the fluid in the collection trough can be collected for reprocessing, cascaded into a second still, or discarded.

Future Work

Future work for this project includes prototyping and field testing the unit starting with a 10% ethanol-water mixture. Once a baseline of the unit's distillation efficiency is obtained, the active temperature-control system should be tested. Once the ability of the still to be temperature controlled is demonstrated, a true passive temperature-control system should be designed, built and field-tested. Another addition to the project should be to create picture instructions for non-english speaking users.

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