Increasing the Efficiency of Pitorro's Production

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Abstract *— Puerto Rico has produced Rum since early ages and is part of its culture. But the rum making process has been an irregular one since the process has been passed through generations and the persons who make it don't really know what's happening in terms of chemistry. Here, we constructed a reflux column system where the process of distillation is more robust, controlled, and efficient. In the end, the new automated systems' production doubled in the same period of time as in the traditional system. In addition, we managed to obtain a consistent high-quality product.*

Key Terms *— Automation, Distillation, Reflux Column, Rum.*

PROBLEM STATEMENT

Every country in the world has its own distilled spirit. Russia produces Vodka, North America produces Whiskey, Japan produces Sake, México produces Tequila, and the Caribbean produces Rum. Each of these spirits are differentiated by the source of sugar that is used for the fermentation. To produce Vodka they use starch like potatoes, for Whiskey is grains like corn or rye, for Sake is rice, for Tequila is agave, and for Rum is molasses. Now, all over the world there are people that produces these spirits illegally. Meaning that these spirits are produced without the Government's knowledge nor paying taxes. Here in Puerto Rico the "illegal" Rum produced is called Pitorro. I quoted the term "illegal" since in Puerto Rico it's legal to produce Pitorro in the months of November, December, and January, as long it's for personal consumption only.

Pitorro is known by many names like Cañita, Lágrima de monte (Mountain's tear), Pitrinche, among others, and has always retained its main characteristic, its clandestinity. In the beginning, it was the alcoholic beverage of slaves, farmers, and jíbaros that worked collecting sugar cane and in the sugar mills during the 17 and 18 centuries. It then spread to the whole population, making it very popular. Nowadays it is mainly consumed in the winter season since it has become a very strong Christmas custom. It is said that this is because Pitorro was used in the past by jíbaros to heat their bodies.

How is it produced? Well, like Rum, it is produced from molasses. The molasses are first diluted and mixed with yeast. Yeast ferments the molasses's sugars into alcohol and carbon dioxide, which is released to the air. Once the yeast has completed the fermentation, this "mash", which separates the alcohol from water. This first distillation will result in a liquid that is around 50 to 60% alcohol. It then is distilled up to 3 times, resulting in a liquid that is 80 to 90% alcohol.

Until now we basically have Rum since it is produced exactly like it. So, what makes Pitorro different from Rum? The difference is in its aging process. Rum is aged during years in American White Oak barrels that were previously used for aging bourbon whiskey. Pitorro is aged normally during one (1) year in fruits and precisely this is one of the factors that made it illegal. It is supposed to be aged in fruits only, but unfortunately, some uninformed people began to age it in unhealthy substances like raw meat, raw seafood like octopus, and even added human feces to the aging process. These practices obviously led to illness and maybe even deaths, forcing the government to prohibit its production. A very popular myth is that if you consume too much Pitorro you can go blind. Which is actually a myth for all other distilled spirits and is

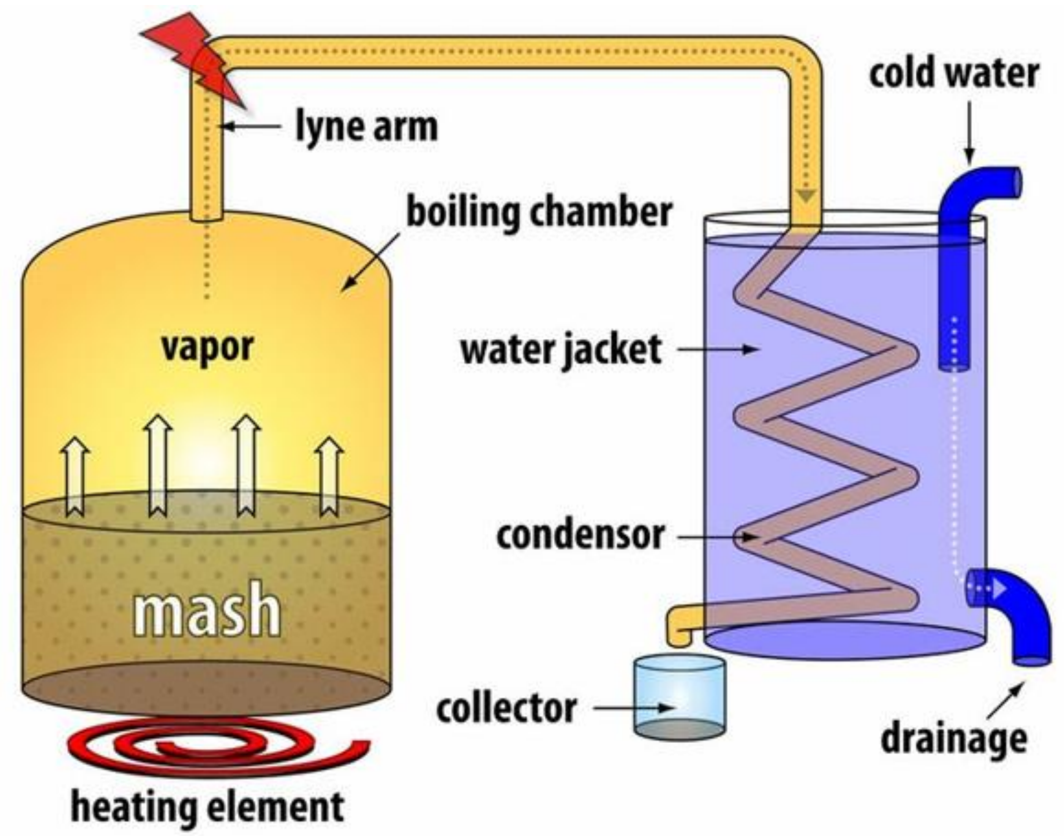

Figure 1
Traditional Pot Still [1]

believed that what causes it is the methanol present in the first part of the product.

Although Pitorro's production, distribution, and sales are illegal, it is currently made in Puerto Rico. Previously the term "illegal" was quoted since in Puerto Rico it's legal to produce Pitorro in the months of November, December, and January, as long it's for personal consumption only. The government has even permitted its production only for the distillers' own consumption for a charge of $100.

Research Description

This research will result in a distillation system that will allow to produce Pitorro in a safely manner and even allow the distiller to distill alcohol for fuel purposes.

Research Objectives

The purpose of this Thesis is to add controls, safety measures, and increase the efficiency of the distillation process. This will result in a process that is way more efficient in terms of quality, time, and costs.

Research Contributions

The main contribution will be demonstrating that alcohol distillation can be done safely efficiently and produce alcohol for fuel purposes. This can be further developed to obtain electricity for homes from an electric generator that can use alcohol as fuel.

Literature Review

Now, let's analyze the problems ***Figure 1*** shows the traditional equipment, known as a pot still, which is passed from generation to generation.

Heating Element

Traditionally, the heating element has been firewood, which has several problems. The main problem with firewood is that we cannot accurately control the temperature. It'll be either too hot or not hot enough to maintain the mash boiling. Having a temperature that is too high represents a waste of energy (rise in operating costs) and could possibly damage the final product since the mash will boil violently (causing mash to splash in the lyne arm and ending in the collector) and not giving the vapor a chance to separate the alcohol from the water. Also, it could represent a major safety issue since we could end with a pressure build up in the system, resulting in a vapor leak (loss of product and a dangerous potential for fire startup) and even an explosion.

Another main problem with firewood is the response time to meet the temperature change needs. Meaning that if we want to increase the temperature we would need to add firewood, wait for it to burn and finally have more fire, and if we need to decrease the temperature we would have to grab the burning firewood and take it away from the pot still. All of this represents an increase in operating time (added costs) and even a safety issue since we can easily get burned. Another health and even an environmental hazard of working with firewood would be the smoke [2].

Alcohol Percentage

When using the pot still system, we find that the end product's alcohol percentage or proof (another unit of measure for alcohol content) has an inversely proportional relation to the distilling time. Meaning that the first collected drops of alcohol will be the ones with the higher proof, and as time passes, and we continue to collect product (remove alcohol from the mash), the product proof decreases.

Why this does happen? First, to understand what is happening, we need to know the composition of the mash that we have in the boiler and its physical properties. To better explain the situation, we will assume that we have in the boiler 40 gallons of the fermentation process end product, which is basically 40 gallons composed of 85.0% water and 15.0% alcohol. That's a total of 6 gallons of alcohol.

$$Gallons\ of\ alcohol = 40\ gallons * 0.15 \\ = 6\ gallons$$

So, as we can see in ***Figure 2*** following the blue line, this mixture (15 Alcohol % By Volume) will boil and the vapor will have a composition (red line) of 62.2% alcohol and 37.8% water. This information can be confirmed on ***Table 1***.

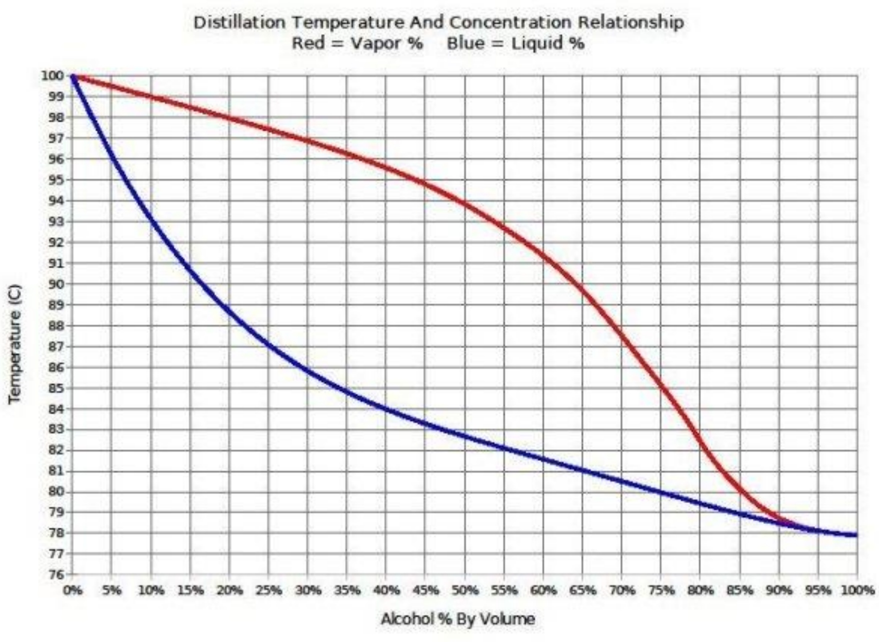

Figure 1

Liquid Alcohol Mixture Bubble Point and Vapor Alcohol Dew Point [3]

Table 1
Tabulated Data of Figure 2 [4]

Liquid Alcohol %	Vapor Alcohol %	Liquid Alcohol %	Vapor Alcohol %	Liquid Alcohol %	Vapor Alcohol %
97.0	96.9	**64.0**	82.5	**31.0**	74.0
96.0	96.0	**63.0**	82.3	**30.0**	73.6
95.0	95.1	**62.0**	82.0	**29.0**	73.1
94.0	94.3	**61.0**	81.8	**28.0**	72.6
93.0	93.6	**60.0**	81.6	**27.0**	72.1
92.0	92.9	**59.0**	81.4	**26.0**	71.5
91.0	92.2	**58.0**	81.2	**25.0**	70.9
90.0	91.6	**57.0**	81.0	**24.0**	70.3
89.0	91.0	**56.0**	80.8	**23.0**	69.7
88.0	90.5	**55.0**	80.6	**22.0**	69.0
87.0	90.0	**54.0**	80.4	**21.0**	68.2
86.0	89.5	**53.0**	80.2	**20.0**	67.4
85.0	89.1	**52.0**	80.0	**19.0**	66.6
84.0	88.6	**51.0**	79.8	**18.0**	65.7
83.0	88.2	**50.0**	79.6	**17.0**	64.6
82.0	87.9	**49.0**	79.4	**16.0**	63.5
81.0	87.5	**48.0**	79.2	**15.0**	62.2
80.0	87.1	**47.0**	79.0	**14.0**	60.8
79.0	86.8	**46.0**	78.8	**13.0**	59.3
78.0	86.5	**45.0**	78.6	**12.0**	57.5
77.0	86.1	**44.0**	78.4	**11.0**	55.4
76.0	85.8	**43.0**	78.1	**10.0**	53.1
75.0	85.5	**42.0**	77.9	**9.0**	50.5
74.0	85.2	**41.0**	77.6	**8.0**	47.4
73.0	84.9	**40.0**	77.3	**7.0**	43.9
72.0	84.6	**39.0**	77.0	**6.0**	39.9
71.0	84.3	**38.0**	76.7	**5.0**	35.3
70.0	84.1	**37.0**	76.4	**4.0**	30.1
69.0	83.8	**36.0**	76.0	**3.0**	24.0
68.0	83.5	**35.0**	75.7	**2.0**	17.1
67.0	83.3	**34.0**	75.3	**1.0**	9.1
66.0	83.0	**33.0**	74.9		
65.0	82.7	**32.0**	74.5		

Now, let's suppose that we removed one (1) gallon from this condensed vapor (62.0% alcohol and 38.0% water), which is equivalent to removing 0.620 gallons of alcohol.

$$Total\ alcohol\ removed = 1\ gallon * 0.620 = 0.620\ gallons\ of\ alcohol$$
$$Total\ water\ removed = 1\ gallons * 0.380 = 0.380\ gallons\ of\ water$$

We will now have in the boiler 39 gallons with a composition of 13.79% alcohol and 86.21% water.

$$Total\ alcohol = 6 - 0.620 = 5.380\ gallons$$

$$Alcohol\ Percentage = {5.380\ gallons\ of\ alcohol}/{39\ gallons} * 100 = 13.8\%\ alcohol$$

This new mixture will boil, and the vapor will be composed of 59.0% alcohol and 41.0% water and the process would continue like this. So, we can now see the pattern. As we continue to remove alcohol from the condensed vapor the percentage of alcohol will naturally decrease. To illustrate this, we can make a graph supposing that we retrieve a constant amount of 1 gallon per hour of distilling. This graph is illustrated in ***Figure 3***.

To do this simulation, I had to first take the data from ***Table 1*** and make a polynomial regression line in Microsoft Excel. This would allow me to know the exact vapor composition when we have a liquid alcohol percentage with one decimal place. To make it exact I had to do a polynomial equation to the ninth power. The exact equation is as follows:

$$\boldsymbol{y = 6.6087E^{-16}x^9 - 1.24144745E^{-12}x^8 + 5.0542768394E^{-10}x^7 - 9.554924205258E^{-8}x^6 + 1.016955312872030E^{-5}x^5 - 6.5514062240851100E^{-4}x^4 + 0.0261675786462708x^3 - 0.646038874956939x^2 + 9.713700838556x + 0.025143508128771}$$

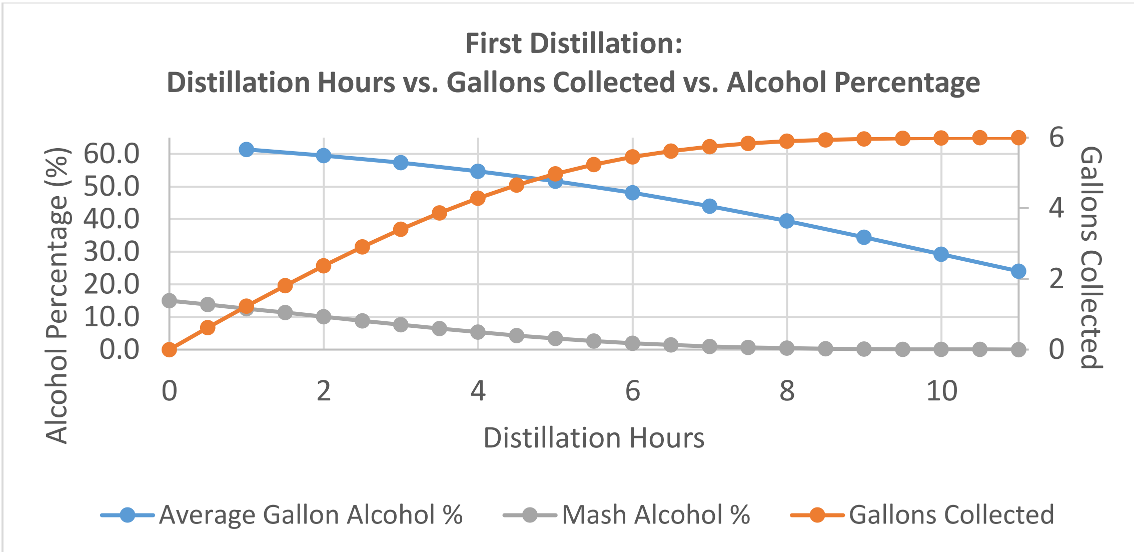

Figure 2
First Batch Distillation Illustration

By analyzing the information in ***Figure 3***, we can conclude that the energy and time invested in collecting the last gallon will not be a cost-effective activity. This is because we will be investing 5 labor hours to collect around a gallon of alcohol of less than 40% alcohol. So, taking this into consideration, we would collect the first 5 gallons of product and repeat this process another 3 times. Assuming that all 4 distillation runs results in exactly the same 5 gallons with the same corresponding alcohol percentages, we would end with 20 gallons composed of 56.9% alcohol and 52.0% water. This was calculated as follows:

$$Alcohol\ Percentage = \frac{(0.614 + 0.595 + 0.573 + 0.547 + 0.516)}{5} x100$$
$$= 56.9\%$$

By distilling this new batch of 20 gallons we would obtain something as shown in ***Figure 4***.

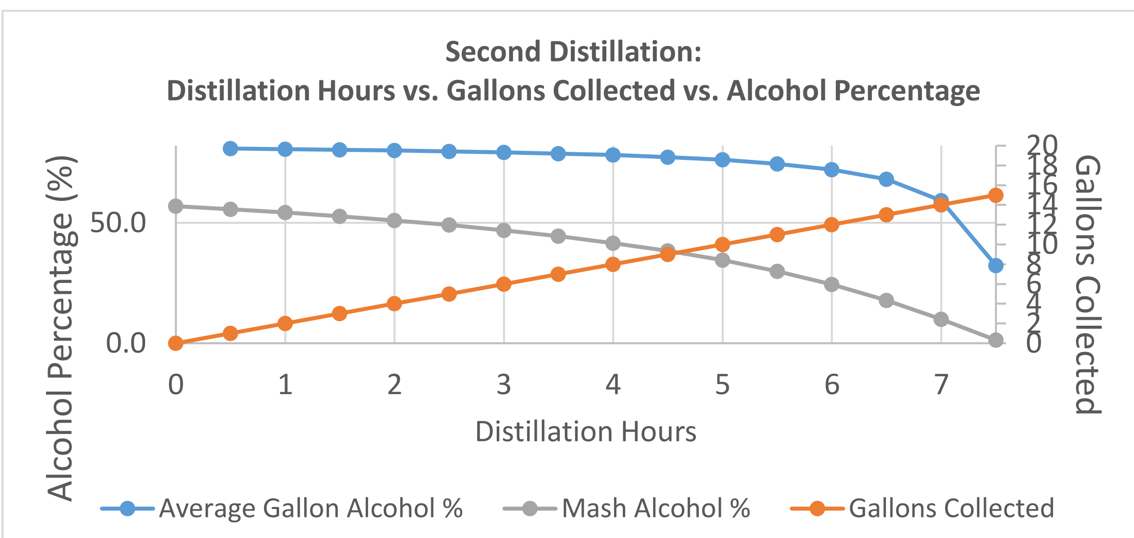

Figure 3
Second Batch Distillation Illustration (Comprised of 4 First Batch Distillations)

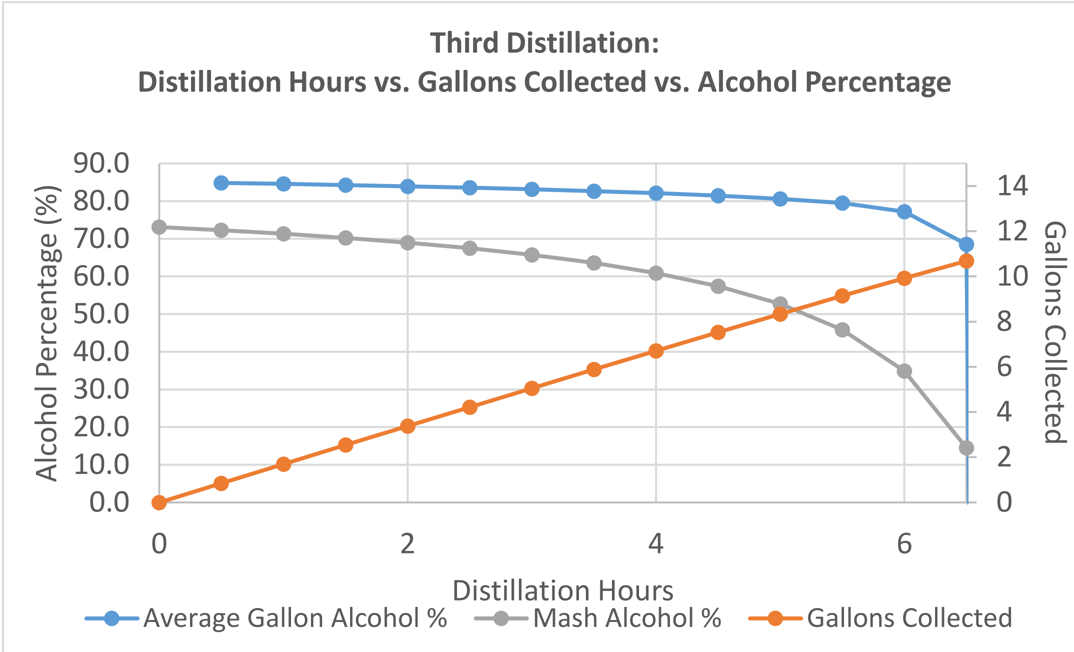

Figure 4
Third Batch Distillation Illustration (Comprised of the Second Batch Distillation Results)

In this second distillation we can see that the last 5 gallons do not contain a significant amount of alcohol and we can consider stopping the distillation once the gallon 15 is collected. These 15 gallons can then go to a third distillation. This distillation is illustrated in ***Figure 5***. These 15 gallons would have an average alcohol percent of 73.1%.

Finally, here we can see that we obtained 10 gallons of good alcohol. Gallons 11 through 15 would not be cost effective because they would mostly be composed of water.

Table 2
Traditional System Costs

Material	Individual Cost ($)	Quantity Used	Total Cost ($)
Molasses	12.5	12	150
Propane Gas	15.0	6	90
Labor	7.25 per hour	33	239.25
Costs Grand Total ($)			479.25
Costs per Gallon ($)			47.92
Costs per Liter ($)			12.66

We can now understand the end product's alcohol percentage (proof) has an inversely proportional relation to the distilling time. We can also see the great effort and time invested to obtain 10 gallons of good alcohol. In terms of costs we can calculate what the cost of producing a gallon is. Knowing the following production costs in ***Table 2***.

Here we can conclude that the cost of producing a gallon of good alcohol is $47.92.

METHODOLOGY

What we are going to do in this work is implement a system that distill Pitorro more efficiently and cost effective while adding some controls and safety measures. The first change would be the system we are going to change the distillation equipment. Instead of a pot still as in ***Figure 1*** we are going to implement a reflux column still like the one in ***Figure 6***.

Jeff King in his book [1] describes this system as: "This type of column is a popular choice among hobbyists. Instead of a regular tube leading to the lyne arm, the reflux still has a larger column, packed with an inert material. This material can be anything from stones to marbles but raschig rings (small ceramic rings) are most commonly used".

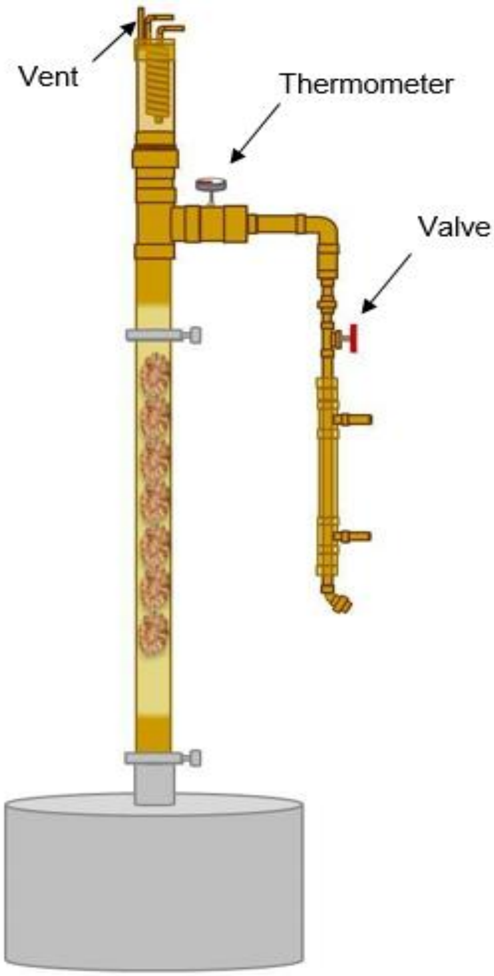

Figure 5
Basic Design of a Column Still [5]

Above this part of the column, on the top, is the condenser, where vapors pass through and those vapors condense on contact. The cooling tubes add another reflux element and help this still produce a final product with higher alcohol content.

Because of the added reflux elements, most of the alcohol vapor will condense on one of these inert materials and drip back into the boiling chamber. This means that the vapor that does reach the condenser will be much higher in alcohol content than that from a pot still.

So, a reflux still is good for making neutral spirits, such as vodka, gin, and rum. The real advantage is that you can "detune" the still by removing the packing material. With the packing material removed and the cooling tubes bypassed, it will operate just like a traditional pot still." [1].

Heating Element

To resolve the heating element problem, I'm going to use liquid propane instead of firewood. This will allow me to reduce the health and environmental hazard problem.

I can also add another solenoid valve with a digital controller but instead of using a thermometer I can use a pressure sensor, so if the system gets a pressure build up it will shut the burner off.

Alcohol Percentage

To resolve the alcohol percentage problem, I will substitute the valve shown in ***Figure 6*** with a solenoid valve. This valve will be controlled by a digital temperature controller, which will monitor the temperature where the thermometer in ***Figure 6*** is placed.

The digital temperature controller will allow me to set the valve to a certain temperature. This valve will allow me to block the exit of alcohol from the still, forcing it to go back to the boiler. This is known as full reflux and the alcohol that goes through the column again will be redistilled, resulting in a higher alcohol percentage in the output. This action will allow me to get an end product with a high alcohol percentage and save the second and third distillations. The production of good alcohol will be reduced to only one distillation. This will result in huge time and materials savings, which will directly reduce the production costs.

EXPERIMENT AND RESULTS

To perform this experiment, we changed from firewood to liquid propane as a safety measure. In addition, we constructed a system as described in the Alcohol Percentage section above. We then loaded the system with a mash of approximately 15% alcohol. We calibrated the temperature controller to open the solenoid valve at 80 °C. This temperature would yield liquid alcohol at 85% alcohol as ***Table 1*** indicates.

To validate this experiment, we did it 3 times measuring the alcohol percentage every 15 minutes as allowed by the system. The results are in ***Table 3***.

Table 3
Alcohol Percentage Results per Run

Measurement #	Run Number		
	1	2	3
1	90	91	91
2	88	90	90
3	84	86	84
4	86	85	86
5	83	83	85
6	86	84	84
7	84	86	85
8	85	85	83
9	81	82	83
10	84	81	86
11	86	85	85
12	82	86	84
13	84	84	87
14	83	83	85
15	84	85	84
16	85	84	86
17	84	84	84
18	84	84	87
19	85	85	85
20	N/A	83	N/A
21		82	

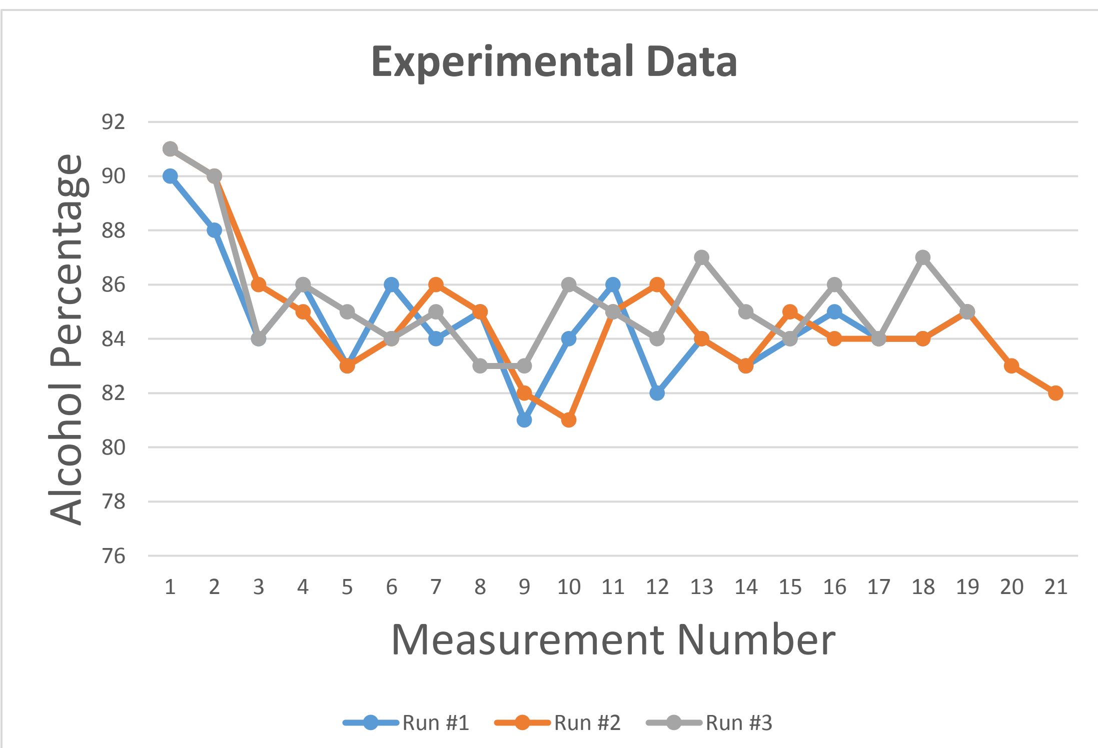

Figure 6
Data Obtained During Experiment

Discussion of Results and Conclusion

As we can observe in ***Figure 7***, the experiment was successful. It maintained the alcohol percentage through the whole distillation in all 3 experimental runs. The down side to this system was that we intended to take measurements every 15 minutes as discussed in the Methodology section, but it was not possible. At first, the system would open the valve 2 or 3 time within the 15 minutes, but eventually the system took over 15 minutes to open the valve. This discrepancy made us to make measurements whenever possible and then wait 15 minutes at minimum to take the next measurement.

Overall, the system did demonstrate that it is more efficiently. The average distillation time was 8 hours. Meaning that four batches would be completed in approximately 32 hours of distillation and resulting in 20 gallons of alcohol with an average of 85% alcohol. Resulting in a total cost of $22.10 per gallon or $5.84 per liter.

Finally, we can now conclude that the process was successfully controlled. The new system permitted to obtain the double amount of good alcohol while doing it in the same period of time. Cutting the production cost by half.

Future Suggestions

To add efficiency to the system we could add a solenoid valve to the propane supply line. This valve will be controlled by a digital temperature controller, which will monitor the temperature from a thermometer in the boiler. With this equipment I can set the valve opening and closing, so when the temperature gets too high, it will allow more gas flow to the burner and adjust the mash temperature.

This will allow us to reduce the amount of gas used, reducing the production costs, and will serve as a safety measure. If the temperature gets too high it will reduce or shut off the gas flow.

Another suggestion would be to a flow meter on the output valve. That way we could know what the actual alcohol percentage of the mash is at all times and further tune up the amount of gas needed to boil the mash.

References

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