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## Application of Automated Control For Reflux Hydrous Bioethanol Distiller

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### Abstract

*Hydrous ethanol, also known as azeotropic ethanol, is most concentrated grade of its kind that can be produced through simple distillation and is suitable for use as an alternative fuel. This study was conducted to develop an automated control of the heating system for reflux hydrous bioethanol distiller. Production processes were done for the evaluation of the system from fermentation of the sugarcane molasses, automation of the heating system and distillation. Both Application of Automated Control for Reflux Hydrous Bioethanol Distiller (AHED) and Existing Hydrous Bioethanol Distiller (EHED) were evaluated in terms of boiler and reflux head temperature, hydrous bioethanol yield, hydrous bioethanol purity and recovery, time of operation and energy consumption. AHED was compared to EHED in terms of hydrous bioethanol yield, hydrous bioethanol purity and recovery, time of operation, and energy consumption. AHED and EHED were not significantly different in terms of hydrous bioethanol yield, hydrous bioethanol purity and recovery, and time of operation but performed significantly different in terms of energy consumption. Cost analysis was performed in the study considering all the costs incurred throughout the whole production process and it was proven that the machine has economically feasible for the use of bioethanol production.*

**Keywords:** *automated distillation; distillate; ethanol; hydrous bioethanol; reflux hydrous bioethanol distiller*

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### INTRODUCTION

Several industries now consider ethanol to be a good fuel. Ethanol has been recognized as an important renewable and sustainable fuel source for modern industries; it can be used as a substitute for gasoline in

many internal combustion engines, and it can be mixed with gasoline in any concentration (Yang et al., 2012). To produce usable ethanol, the excess water content from the liquid wash must be extracted through the distillation process in order (Babu et al., 2013). Because of the formation of a low-boiling water-ethanol azeotrope, the final purity of the ethanol products is limited to 95 to 96 percent (Rousseau & James, 1987).

Bioethanol production has been the subject of numerous investigations in recent years because of a need for alternative energy, as it is being introduced on a large scale to several countries (Galbe et al., 2011), has many applications in several industries across the world (Shah et al., 2021), and the use of ethanol-blended fuels can reduce the exhaust emission of greenhouse gas, carbon monoxide (CO), volatile organic compounds (VOC) and particulates compared to the conventional gasoline or diesel (Hea et al., 2003).

Distillation is the most widely used separation operation in chemical industries; the great consumption of energy is the major disadvantage of this process that is unable to reach a high level of purity of bioethanol (Tgarguifa et al., 2017). One of the most important techniques to make distillation successful is temperature control. The temperature of the wash entering the fractionating column must be within the range of azeotrope point and boiling point of pure water. If wash temperature is too low, the ethanol will not evaporate. If its temperature is too high, the wash will overheat and the distillation will tend to fail as well (Griend & Lee, 1990). Thus, automation or automatic control has an important role in this process. Temperature controller will be a big help in regulating the heating system of the distiller to get the desired purity of the ethanol.

### **Statement of the Problem**

Bioethanol production has been the subject of numerous investigations in recent years because of a need for alternative energy. Some possible reasons are the unstable energy supply from oil producing countries and the adverse environmental impact of the use of fossil fuel as a source of energy. To lessen the dependency on foreign oil and the need to become more environmentally conscious due to climate change, it pushes people through the production of possible renewable energy source such as hydrous bioethanol. Most researches for fuel ethanol deals with the development and improvement of some apparatus necessary to attain desired purity with less energy consumption and minimal use of water. Distillation is the most widely used separation technique in bioethanol production. One disadvantage of the distillation process is the large energy requirement accounting for around 25 to 40 percent of the total energy usage. Distillation consumes a great deal of energy for providing heat to change liquid to vapor and large amounts of cool water to condense the vapor back to liquid at the condenser (Agrupis et al., 2014).

The existing bioethanol distiller of the Affiliated Renewable Energy Center (AREC) at Central Luzon State University (CLSU) is subject to numerous researches. One of the recommendations for the faster production of bioethanol is to have an equal distribution of heat running in the system that could also give a higher ethanol recovery and purity (Borromeo, 2016). The furnace used in the study was designed to be fed with any solid fuel, such as wood, which is responsible for the combustion of fuel to produce the required heat needed in the distillation process. Control of temperature was done by adding or limiting the amount of fuel to be fed in the furnace. The heat produced in this system is unmanageable due to manual feeding of wood. It also generates relative amount of pollution, intrinsic messiness, and can pose danger if left unattended. It causes unsafe conditions for the operators, as wood driven fires, it must be attended at all times to effectively guard against its danger. The needed heat in the furnace and the amount of water continuously running at the condenser, that serves as the coolant, are important in maintaining the needed temperature for the vaporization of bioethanol, which is 78.5°C. Hence, the study developed an automated control of the heating system for the production of hydrous bioethanol with less energy consumption.

## Objectives of the Study

The study developed and evaluated the performance of the automated control of the heating system for reflux hydrous bioethanol distiller. Specifically, this study aimed to:

1. develop an automated control of the heating system for reflux hydrous bioethanol distiller;
2. evaluate the following parameters: boiler temperature, reflux head temperature, hydrous bioethanol purity, hydrous bioethanol recovery and fuel consumption rate;
3. compare the existing hydrous bioethanol distiller to the automated distillation system reflux distiller in terms of hydrous bioethanol yield, hydrous bioethanol purity, hydrous bioethanol recovery, time of operation, and energy consumed; and
4. conduct cost analysis in using the device.

## Scope and Limitation of the Study

The study focused in utilizing baker's yeast fermented molasses as feedstock for the production of hydrous bioethanol. Sugarcane molasses was used because of its availability in the market and it was used for evaluation purposes only. Determination of sugar concentration followed the procedure of Lagan (2014). Although the distiller has a capacity of 150 liters, only 120 liters of feedstock was used in the distillation process because the fermenter drum that was used during fermentation process, has a capacity of 160 liters only and capable of fermenting 120 liters of broth and the remaining 40 liters served as space for gas. Readily available stainless-steel wool at the CLSU AREC was used as packing materials at the reflux column.

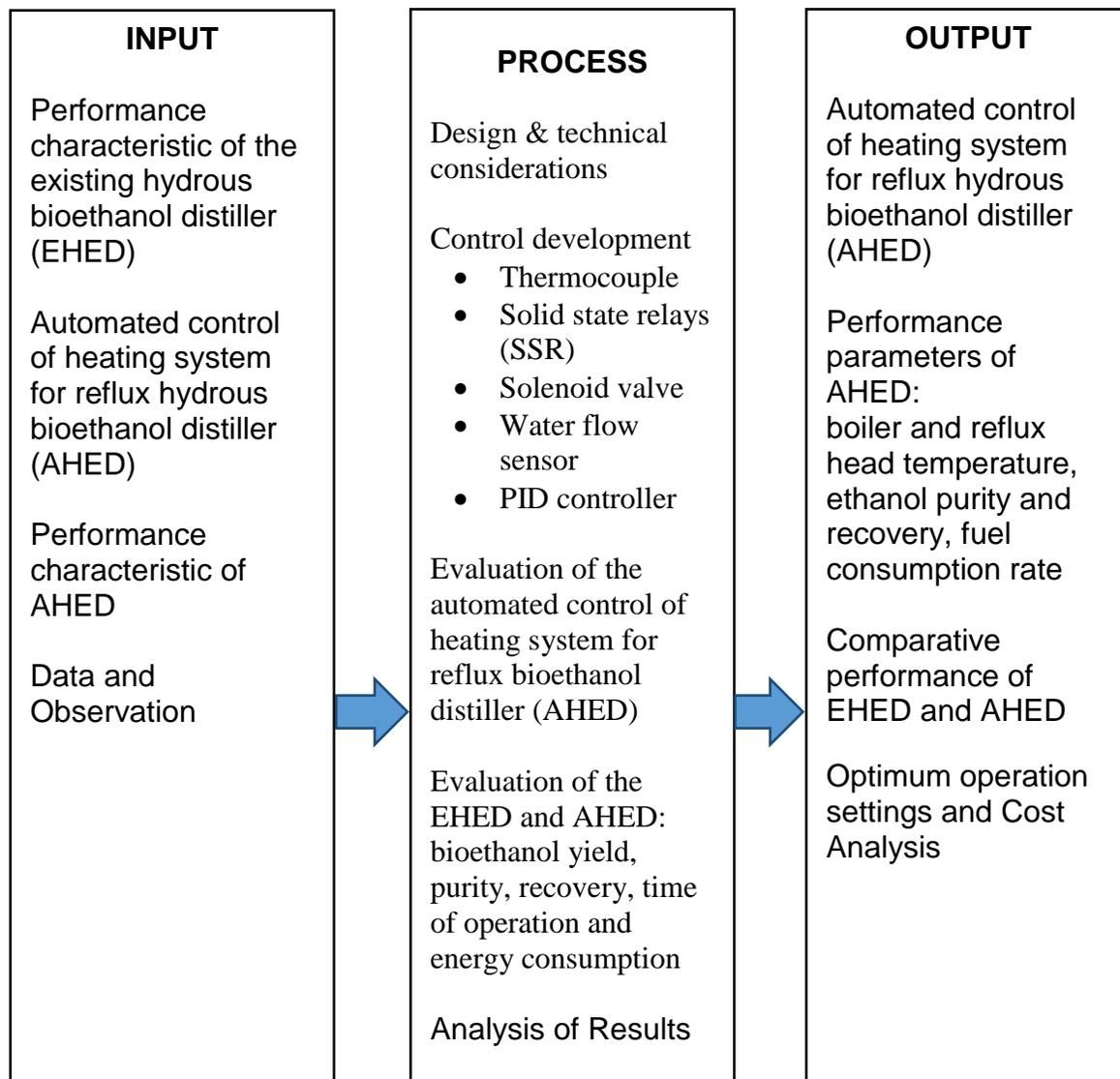
The study was limited to the automation of the heating system of reflux hydrous bioethanol distiller. The cooling system was limited to the specific flowrate of about 216.96 liters per hour suggested by Siano (2016). The automation of the heating system of the reflux hydrous bioethanol distiller was limited on the controlling of heat sources, such as the turning on and off of the LPG burner and the electric heater. The amount of heat needed to supply the boiler was controlled by means of proportional integral derivative control to maintain the temperature of 85°C to 95°C at the boiler.

## MATERIALS AND METHODS

### Conceptualization of the Study

The study was conceptualized considering the need for the modification of the heating system of the existing hydrous bioethanol distiller. Problems met from manual feeding of fuel were considered in the development of automated control for the distillation process in order to separate higher percentage of ethanol, and minimize the energy consumption.

The conceptual framework of the study followed the input-process-output (IPO) for the evaluation of the automated control of heating system for the reflux bioethanol distiller (Figure 1). The inputs that were considered in the design and technical stage were the materials needed for the automation of the heating system of the distiller: fabrication of furnace assembly, size of heating element for the boiler, controllers, sensors and signaling devices. Improvement of the heating system of the distiller would give an easy access in controlling the temperature needed by the apparatus to produce ethanol vapor. One of the most important techniques to make this system successful was temperature control. The temperature of the wash entering the fractionating column must be within the range between azeotrope point and boiling point of pure water. If wash temperature was too low, the ethanol would not evaporate. If its temperature is too high, the wash would overheat and the distillation would tend to fail as well.



**Figure 1.** Conceptual Framework

### **Automation of the Reflux Hydrous Bioethanol Distiller**

The development of automated control of heating system for reflux hydrous bioethanol distiller was composed of five main components: the furnace, boiler, the first and second condenser, and the arduino micro controller. The main component of the heating system included the furnace with LPG burner as the source of heat and the heating element placed inside the boiler. The source of water used to cool down the ethanol vapor was from the water supply of Central Luzon State University main line. A water flow meter was installed at the water inlet pipe to measure the amount of water running in the system and its actual flow was displayed at the flow meter LCD attached to the controller. A process controller (Arduino micro-controller) served as the controlling mechanism of the system. Temperature of the feedstock was set to its operating temperature. The solid state relays are connected to the heater and the controller. Those were designed to switch the on and off once the burner shut off. The needed amount of heat to boil the feedstock to produce ethanol vapor was controlled using the Arduino micro-controller with the proportional-integral-derivative control.

## Performance Test and Evaluation

Existing Hydrous Bioethanol Distiller (EHED) and Automated Control of the Heating System for Reflux Hydrous Bioethanol Distiller (AHED) were evaluated in terms of hydrous bioethanol yield (L), hydrous bioethanol purity (%), hydrous bioethanol recovery at 95% ETOH (%), time of operation (hrs), bottom and head flux temperatures, and energy consumption (kW-hr).

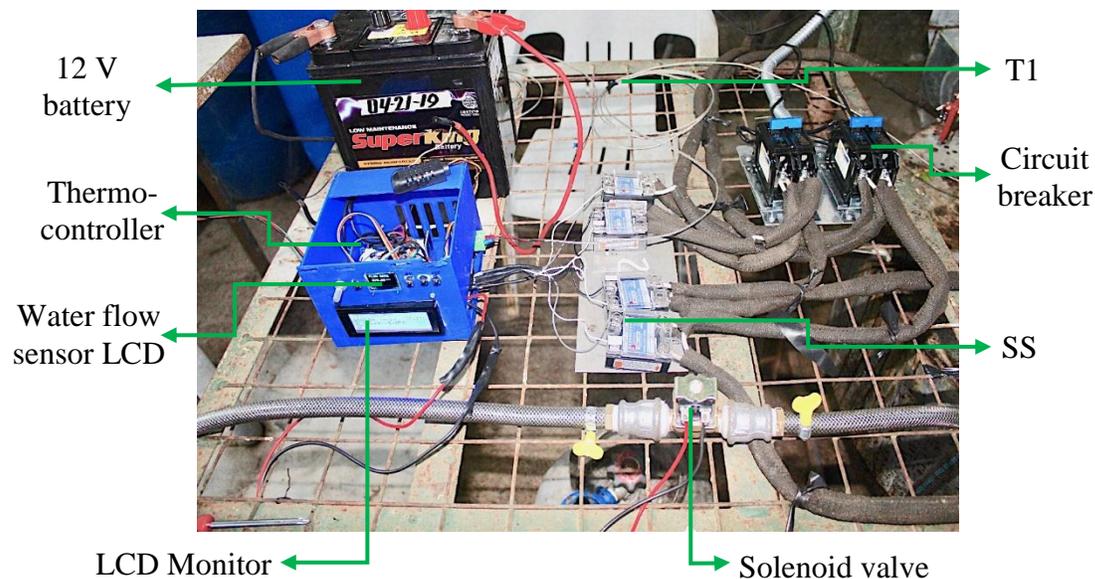
## Cost Analysis

The cost analysis included the calculations of annual cost of operation: fixed and variable costs, break-even point, cost of distillation (₱/l) and payback period, in case the machine shall be used for custom service operation.

## FINDINGS

### Automated Control of the Heating System for Reflux Hydrous Bioethanol Distiller

Automated Control of the Heating System for Reflux Hydrous Bioethanol Distiller (AHED) was exactly the developed version of the Existing Hydrous Bioethanol Distiller (EHED) available at AREC Compound, CLSU. It was developed to regulate and control heat distribution inside the boiler during distillation process which could produce hydrous bioethanol at lower energy requirement and cost. The machine's major components are the following: (1) boiler with 150L capacity; (2) reflux column; (3) primary and secondary condenser; (4) water inlet and outlet; (5) heating elements; (6) LPG tank and burner assembly; and (7) micro-controller system which includes sensors for water flow rate, LPG, and temperature. EHED consisted only of first four components while the last three were the modified parts of now called AHED. Figure 2 shows the developed heating system of the reflux hydrous bioethanol distiller, it was developed to maintain the needed temperature of the feedstock to produce hydrous bioethanol with low energy consumption at short period of time.



**Figure 2.** Heating system of the reflux hydrous bioethanol distiller

## Comparison between EHED and AHED

Performance characteristics of the Existing Hydrous Bioethanol Distiller (EHED) and Automated Control of the Heating System for Reflux Hydrous Bioethanol Distiller (AHED) were compared in the context of hydrous bioethanol yield (L), hydrous bioethanol purity (%), hydrous bioethanol recovery at 95% ETOH (%), time of operation (hrs), bottom and head flux temperatures, and energy consumption (kW-hr).

The mean hydrous bioethanol yield of EHED was 14.33 liters while AHED produced 16 liters. Result showed that the hydrous bioethanol yield of EHED did not significantly differ with AHED. Though the comparison was said to be statistically the same, the difference of 1.67 liters per batch of 120 liters feedstock implies an improvement in hydrous bioethanol yield brought by AHED which conforms to the competitiveness of the process and commercial viability of the technology according to the study of Agrupis et al.(2014).

The highest purity recorded for both EHED and AHED were 94.05 and 94.67 while the lowest were 90.73 and 86.43 percent, respectively. The purity of the produced hydrous bioethanol was decreasing over time same as the study of Borrromeo (2016) that when the production of hydrous bioethanol reached its peak, the ethanol purity dropped. However, the result shows that hydrous bioethanol purity for EHED did not significantly differ with AHED.

In the one-sample t-test analysis of the hydrous bioethanol recovery at 95% ETOH of EHED having 11.74 liters when compared to AHED having 14.42 liters were statistically the same. Even though the two were statistically the same, their difference of 8.25% justified that AHED can yield 2.68 liters more per batch than EHED; a very considerable amount for a village level distillation system.

AHED had just operated for 4.71 hours against 6.06 hours of EHED yet produced a total of 14.42 compared with only 11.74 liters for EHED. A 1.64 hours difference yielded AHED of 2.68 liters more. The result of the independent sample t-test performed to determine whether the time of operation for EHED and AHED differed. Result showed that the length of distillation for EHED did not significantly differ with AHED at 5% level of significance. However, a time difference of 1.35 hours was more than enough for the operator to take enough break or rest or do some other important things for the day. Six days of 8-hour operation for manual distillation would save the operator of AHED an equivalent of one day. The scenario was technically different giving advantage in favor of AHED.

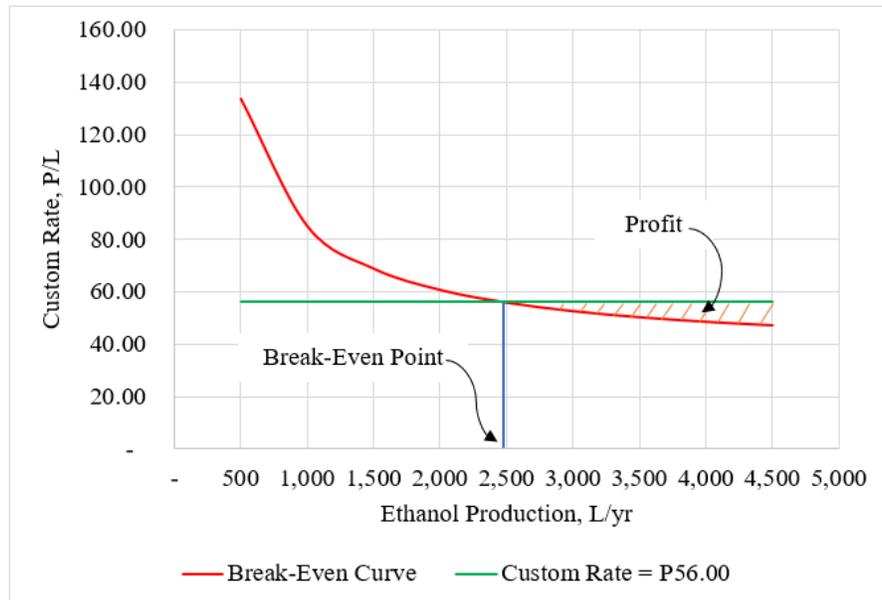
Bottom temperature reached the range of 95.0 and 103.50°C for manual while automated one had 92.77 and 97.23°C. The average bottom temperature was 97.85°C and 95.5°C for EHED and AHED, respectively. Reflux head temperature gave the optimum distillation result at 78.5°C. Surprisingly, the graph showed contradicting direction with AHED going upward. The average temperature was 78.22 and 79.08°C for EHED and AHED, respectively. The latter had 0.58°C higher than the optimum yet produced higher hydrous bioethanol recovery.

EHED consumed 37.52kW-hr which was higher by 19.89kW-hr than AHED with only 17.63kW-hr. As for the ratio of energy consumed per liter of hydrous bioethanol recovered with 95% ETOH, AHED had higher energy utilization efficiency consuming only 1.22kW-hr far below 3.2kW-hr per liter for EHED. Result showed that the energy consumption for EHED significantly differed with AHED. This implies a significant cost reduction per batch of distillation process using AHED.

## Cost Analysis

Initial cost of investment (IC), ₱185,000.00; percentage for salvage value, 10% of IC; machine's lifespan, 5 years; interest, 12.5%; power, 3.0kW; time of operation per day, 6 hours; capacity (feedstock), 150 liters; capacity (hydrous bioethanol at 95% purity), 14.42 liters; and distillation rate, and efficiency of

3.06 L/hr and 78.54% were used in determining total fixed and variable costs, break-even point, payback period, annual profit, and return on investment. With the machine's ₱48,608.75 fixed cost, ₱110.91 per hour variable cost, and 3.06 L/hr capacity; break-even was computed to be a bulk of 2,460.60 liters which will require 7,095.37 liters of sugarcane molasses. Breakeven curve is shown in Figure 2 implying its inverse relationship with the increasing number of ethanol produced. Shaded region shows the profit of the machine with respect to ₱56 custom rate per liter of ethanol produced with 95% ETOH.



**Figure 3.** Break-even curve of AHED

## CONCLUSIONS

The automation control of the heating system for reflux hydrous bioethanol distiller was developed for the production of hydrous bioethanol. As the temperature of the boiler increases the temperature of the reflux head also increases. The operational temperature at the bottom needs to be maintained between the range of 85°C to 95°C in order to meet temperature of 78.5°C that is the condensation of the ethanol. Performances of the EHED and AHED have comparable performance in terms of ethanol purity and recovery and time of operation except for energy consumption. The economic analysis on the production of bioethanol showed that it is financially viable.

## RECOMMENDATIONS

The automated control of heating system for reflux hydrous bioethanol distiller is recommended for all types of feedstock to minimize the energy consumption of the distillation process. To complete the automation system of the reflux hydrous bioethanol distiller, the automation of the cooling system must be included.

## ACKNOWLEDGEMENTS

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