Remote monitoring and control system for the energy self-sufficient bioethanol distiller

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Abstract. Mariano Marcos State University (MMSU) started the Bioethanol industry way back in 2008 and produced the first fuel-grade Hydrous Ethanol (95%) in the Philippines in 2012. Developments continued until the team developed Village-scale fuelwood fired 150 L and 850 L capacity Multi-Feedstock Bioethanol Distiller. Recently, the Village-Scale Bioethanol Industry established in Pamplona, Cagayan, produced more than 4000 L of 95% Ethanol from Nipa Sap last year. The output of the team was remarkable. Challenges encountered in monitoring operation protocols resulted in low efficiency, mainly because the distillers are situated about 4 hrs away from the University. With a low ethanol yield of 5-6 percent during the production last year, the team was challenged to develop a Remote Monitoring and Control System for the Distillers deployed in Cagayan. This study aims to automate the Bioethanol distiller to increase the yield of ethanol. Implementing IoT via web application for real-time monitoring and control, and integrating Photovoltaic cells for an energy self-sufficient Bioethanol Distiller. Results showed that it is functional and effective in controlling the kettle temperature, water pump, and the Bioethanol distiller's energy usage wirelessly and remotely through the MMSU i4.0 platform. It was observed that the ethanol yield is up to 8.39%. Furthermore, a better quality of the front and tail ethanol yield was achieved by implementing PID control.

1. Introduction

In response to the Biofuel Act of 2006, the Mariano Marcos State University started the biofuels project as early as 2008. In 2012, Agrupis et al. [1] developed a bioethanol distiller capable of producing fuel-grade Hydrous Ethanol (95%). Developments continued until the team developed Village-scale fuelwood fired 150 L and 850 L capacity Multi-Feedstock Bioethanol Distiller. This success paved the way for the Village Scale Bioethanol Project to produce a large volume of bioethanol from Nipa and to integrate Nipa farmers in the Bioethanol Industry vertically. The pilot bulk production of bioethanol funded by the Department of Energy and the Sugar Regulatory Authority in 2017 manifests the capability of the MMSU developed bioethanol distillers to produce a 95% fuel grade bioethanol.

There are four 850 L distillers at the site of the nipa community in Pamplona, Cagayan. These distillers, following the correct process, can produce 10,000 L of hydrous bioethanol in two-month time. However, the pilot production encountered some issues and concerns arising from the involvement of a community in a controlled condition for which they were not adequately prepared.
These issues and concerns translated into low efficiency of ethanol yield. The involvement of experienced sap collectors and distiller operators, who did not observe proper protocols but followed practices they were previously used to, lowered bioethanol yield efficiency. Also, during distillation, firewood as the source of heat cannot be easily regulated, especially if the operator does not follow protocols. Another challenging issue with the fuelwood powered distiller is the regulation of temperature. So, an energy self-sufficient distiller is necessary to ensure higher quality production of fuel-grade bioethanol. Besides, local people near the village distiller will have access to free electricity during the off-production season allocating the power consumption to other outputs rather than being consumed only by the distiller [2].

These challenges in monitoring the operation and implementing the protocols resulted in low production efficiency; mainly, the distillers are situated about 4 hrs away from the University. With a low ethanol yield of 5-6 percent during the pilot bulk production last year, the team was challenged to develop a Remote Monitoring and Control System [4][8][9][10] for the Distillers deployed in Cagayan.

Implementing IoT [5] through MQTT [6][7] protocol achieves remote monitoring and control through a single page application developed using different web technologies for the bioethanol distillery that was deployed in a remote community. One of the system's forms is to provide a unified graphical user interface to multiple users in different locations. Generally, the project aimed to develop a web application for the bioethanol distillery remote monitoring and control system. Specifically, it aimed to: (a) design the circuit of the actuators and sensors of the bioethanol distillery, (b) develop a web application using MongoDB, express, react, and node.js, (c) evaluate the functionality of the designed controller of the bioethanol distiller.

2. Methodology
2.1. Development Procedure

This study adopts a development research design deepened by descriptive data. Some aspects and contents need to be defined in detail; therefore, a descriptive method will be used. The study will adopt the development cycle below.

Figure 1 illustrates the system development flowchart, which shows the hardware design, fabrication, software development, system integration, and testing. The hardware design starts with identifying the load requirement composed of ten pieces of 1 kW electric heaters and one water pump at 1 hp rating. After knowing the load requirements, the controller’s feature was considered, then the computation of the necessary specifications of the solid-state relays that match the load requirements and can satisfy the desired characteristics, which is the PID mode of control. Next is the assessment of the system requirements, which will make the controller be IoT capable.

The software development comprises of MongoDB, Express, React, and Node.js to develop a web application through

![Figure 1. System Development Flowchart](image-url)
control of the distillery. The hardware and software will properly be evaluated before system integration. In the actual setup, several testing has been done until the result is acceptable.

2.2 Testing and Gathering Procedure

The controlling and monitoring of the energy self-sufficient bioethanol distiller was evaluated on-site and remotely. The evaluation was done by determining the success rate of the controlled actuators and sensors. It was computed by dividing the number of successful attempts (N) by the total number of trials (T), multiplied by 100 percent.

\[
\text{Success Rate} = \left( \frac{N}{T} \right) \times 100
\]

where \(N\)=Number of successful attempts; \(T\)=Total number of trials

Ten trials were done to represent the various state of the temperature sensors, heater, and cooling water pump.

Also, the effectiveness of the controller was evaluated. Three trials were observed with collected sap and fermented during rainy days, four trials were observed with sap collected and fermented following the method of Nipa farmers, and three trials observed following the MMSU protocol on sap collection and fermentation. Gathered data were analyzed statistically using a simple mean.

3. Results and Discussion

The aim to control the distiller effectively and make the design cost-effective. The ten electric heaters at a 1 kW rating were grouped by twos and assigned to a solid-state relay (SSR). Hence, each SSR rated at 40 A controls two pieces of 1 kW electric heater. An SSR was also used to control the 1 hp water pump. The SSR was chosen over mechanical relays to implement a PID mode of control [3]. With the PID mode of control, regulation of temperature can be quickly achieved. Two K-type thermocouples were placed in the kettle and condenser. The instrumentation amplifier was added beside a 16-bit Analog-to-Digital Converter for the esp32 Microcontroller unit. The MCU connects to the internet through Wi-Fi.

The system architecture of the developed remote monitoring and control system of the distillery is shown in figure 2. The distillery consists of actuators and sensors that were used for monitoring and control. The temperature sensor was placed in different parts of the distillery, and the actuators were used in controlling the cooling water pump and the kettle. The frontend involves the graphical user interface of the web application. The web application can be viewed on desktops, laptops, tablets, and smartphones. The backend comprises of web server, MQTT broker, and database server. The web application is hosted in a cloud server; data from the distillation will pass through the MQTT server and displayed on the web application. Designing the Application Programming Interface (API) [11] needs to consider the endpoint route checklist. The checklist is paired to the number of functions in the application, which is used to create, update, and delete data to the database; for the contents type, matching the content types provides easier data parsing, extraction, and processing data in the frontend.
Figure 2. System Architecture

Figure 3 above is the Graphic User Interface (GUI) of the remote monitoring and control system. Controlling the heater through a proportional-integral-derivative (PID) [3] mechanism and showing the pump status and current real-time values of the kettle and condenser temperatures, those parameters were displayed for monitoring purposes and further analyses of the ethanol distillation to ensure high-quality production. Also, the temperature profiles in the condenser and the kettle provide comprehensive information to students and learners on how ethanol distillation processes take place for better learning experiences.

The IoT integration was done through the MQTT protocol and transported data through WebSockets. The MQTT client was bundled in the application's frontend component to receive and send data with the end-to-end communication model. Notably, the MQTT protocol was used over WebSockets with the publish and subscribe technique.
Figure 4. Records view of the system

The GUI portion shown above in Figure 4 contains the history of usage and a summary of the production. The summary can be filtered per week, month, and year. Each batch is tabulated in a paginated form for compact viewing; Users can search, view, download, and print the excel file for reporting.

On another note, monitoring and control systems need to maintain data security and exclusivity. By placing the cloud server in the NBERIC building, we can properly safeguard our data.

Table 1. Summary of the test result on the developed Remote Monitoring and Control Systems features for the energy self-sufficient bioethanol distiller.

| Items | Device               | Test Step  | Success Rate |
|-------|----------------------|------------|--------------|
| 1     | Heater               | ON/OFF/SET | 100%         |
| 2     | Pump                 | ON/OFF     | 100%         |
| 3     | Kettle Temperature   | READ       | 100%         |
| 4     | Condenser Temperature| READ       | 100%         |

Table 1 shows that the developed Remote Monitoring and Control Systems for energy self-sufficient bioethanol distiller can control the heater using PID control and the pump switching status remotely through the developed web application. Also, monitoring the kettle temperature and the condenser was being observed in the application.
Table 2. Summary of the test result on the performance of the energy self-sufficient bioethanol distiller.

| Trials | The volume of Fermented Nipa Sap Distilled (L) | Percent Ethanol Yield* (V/V) | Average Percent of Ethanol Yield |
|--------|-----------------------------------------------|-----------------------------|---------------------------------|
| 1      | 150\textsuperscript{a}                       | 5.05                        |                                 |
| 2      | 155\textsuperscript{a}                       | 5.32                        |                                 |
| 3      | 150\textsuperscript{a}                       | 5.54                        | 5.30                            |
| 4      | 150\textsuperscript{b}                       | 5.66                        |                                 |
| 5      | 150\textsuperscript{b}                       | 6.18                        |                                 |
| 6      | 150\textsuperscript{b}                       | 6.06                        |                                 |
| 7      | 150\textsuperscript{b}                       | 7.14                        | 6.26                            |
| 8      | 150\textsuperscript{c}                       | 8.39                        |                                 |
| 9      | 150\textsuperscript{c}                       | 8.23                        |                                 |
| 10     | 137\textsuperscript{c}                       | 7.81                        | 8.14                            |

\*Collection and fermentation of sap were done during rainy days and without MMSU supervision.
\textsuperscript{a}Collection and fermentation of sap were done during good weather conditions using the traditional method by the Nipa farmers.
\textsuperscript{b}Collection and fermentation of sap were done during good weather conditions and following the protocol developed by MMSU.

The distiller was evaluated using collected and fermented sap during rainy days and good weather conditions. Observations were also made following the MMSU fermentation protocol and not following it. The result of these observations is shown in table 2. During the rainy days before the Flood at Pamplona, Cagayan, three trials were conducted, resulting in more than 5% ethanol yield. The result was expected since the collected sap was diluted with rainwater, and the protocol developed at MMSU was not observed. During good weather conditions, another four trials were conducted. The average percent ethanol yield is 6.26% and slightly higher than the yield during rainy days. Trials 8-10 were done following the MMSU protocol and resulted in an 8.14% average. The percent ethanol yield is quite promising.

The first two sets of observations validated the earlier observation on the ethanol yield, which is 5-6% during the pilot bulk production of bioethanol at Pamplona, Cagayan. Comparing the yield of firewood powered distiller with that of the automated energy self-sufficient distiller, without following the MMSU protocol, the yield understudy is far better in performance. The yield is much better if the MMSU protocol is observed. The percent ethanol yield can be as high as 8.39%. The percentage yield is so far the highest observed yield in producing bioethanol using Nipa sap.

Table 3. Evaluation of input and output energy around the distillation unit.

|                    | Total Energy | Energy Per Liter |
|--------------------|--------------|------------------|
| Input Energy, MJ   | 189.07 MJ    | 14.11 MJ         |
| Energy from Controller, MJ | 0.02 MJ    |                  |
| The energy of ethanol produced | 266.526 MJ | 19.89 MJ         |

The energy ratio of the system was 1.41 MJ of ethanol produced per MJ of net energy input. The total energy consumed in the system was 14.11 MJ of inputs per liter of ethanol produced. The obtained ratio between the ethanol's energy and the energy input during the production is greater than 1. It indicates that higher energy is produced than the energy required, which is desired in the study.
Table 4. The effect of IoT in the yield and energy value of ethanol product

|                      | Average % Ethanol Yield* v/v | Ethanol Volume (L) | Bioethanol Fuel Energy |
|----------------------|-------------------------------|-------------------|------------------------|
| Traditional without IoT | 5.50                          | 8.25              | 173.49 MJ              |
| With IoT             | 6.58                          | 9.87              | 207.56 MJ              |

*Percent ethanol yield is calculated based on the ratio of the volume of ethanol produced and the volume of feedstock, which is the fermented nipa sap.

The heating value of the traditional distillation without the help of IoT is lower than the distillation with the service of IoT with a difference of 34.07 MJ, which is equivalent to 9.46 kWh of fuel energy. The value is much larger than the IoT controller's energy consumption, which is 0.02 MJ only, as shown in table 3. Thus, integrating the Remote Monitoring and Control System to the Energy Self-Sufficient Distiller will improve the distillation ethanol yield.

Usually, the front and tail of ethanol yield is somewhat odorous and has a low concentration. With the developed system under study, a better quality of the front and tail ethanol yield was observed by implementing a PID control.

The web application developed to monitor and control the heater, pump, kettle temperature, and condenser was installed in the bioethanol distiller. The web application was a great help in remote areas wherein various bioethanol distillers were deployed. The need to have a good quality bioethanol yield, data acquisition, and system control on the bioethanol production provides assurance and better production management. The researchers have conducted manual testing, functionality testing, white box testing, black-box testing, and acceptability testing. All the testing results showed favorable implications for overall performance and acceptability to the user with a 100% success rate.

4. Conclusion

Implementing IoT via web application for real-time monitoring and control helped attain ethanol yield up to 8.39%. Results showed that it is functional and effective in controlling the kettle temperature, water pump, and bioethanol distiller's energy usage wirelessly and remotely through the MMSU i4.0 platform. A better quality of the front and tail ethanol yield was achieved by implementing the PID control.

5. References

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