Application of Automatic Control System on Steam Boiler to Reduce Electric Power Consumption

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Abstract. This research focused on utilizing alternative energy sources in the nutmeg oil refining process. The purpose of this study is to obtain a more efficient energy source than fuel and gas energy sources in the steam boiler. The benefits of this research are reducing production costs, simplifying operations and reducing pollution in the distillation process. The method applied is to modify the steam boiler using an electrical energy source. Electric power consumption is based on the amount of temperature and pressure on the steam boiler. The desired temperature ranges from 100 °C - 120 °C, and the desired pressure is in the range of 1.0 - 2.0 bar. So that to maintain the temperature and pressure range is applied microcontroller-based electronic control. To improve the performance of the distillation system, the control works automatically. Testing on the steam boiler, by distilling as much as 20-25 kg of nutmeg in 16 hours. During this testing time, the electric power consumption decreased by 15%.

1. Introduction

The nutmeg oil refining process is still the focus of the research. One focus of research is to design a control method on a steam boiler. In this study, Steam boilers are used using electrical energy as a source of energy for heating. Electrical energy sources are selected taking into account their availability and control flexibility. Compared to other energy sources, such as fuelwood and heating gas in the steam boiler using electrical energy allows a decrease in energy costs. So that the production costs in the whole process become cheaper.

The nutmeg oil refining system can be done with several systems. One of the systems is the steam boiler method which is a distillation method with an excess vapor pressure that can be controlled so that the distillation process becomes optimal and can produce more quality yields [1], [2], [3].

Energy efficiency is very important because the process of nutmeg oil refining takes a long time in a span of 16-24 hours. The conventional method can last for 30 hours. Several control methods have been carried out on the steam boiler and an efficiency of 14.87% LPG gas is obtained for 16 hours of refining time [4]. Increased efficiency is obtained by improving the control method by applying the fuzzy logic method and obtaining an efficiency of 20.3% for 16 hours of refining time [5]. And the application of control to the distillation system using wood fuel can reduce refining time to 14 hours [6].

The parameter that becomes the benchmark in the steam boiler is temperature and pressure. The higher the temperature and pressure of steam in the steam boiler will accelerate the refining process, but can result in a decrease in the quality of the oil produced [7]. Therefore these two parameters need to be controlled in the allowed range. The permissible temperature range is 100-120 °C, and the permissible pressure is 1-2 bar [8].
Control of the steam boiler is done electronically so that it can accelerate in response to temperature and pressure from the sensor, perform processing and control the output, namely the selection of heating elements. Electronic controls are applied based on microcontrollers by considering more practical and competency. Intelligence-based control methods such as fuzzy logic can be applied [9], [10], [11]. This control method can improve the performance of steam boilers in energy savings.

2. Method
This research starts by designing a steam boiler control system, assembly and fabrication, and system testing.

2.1. Steam boiler control system design
This research is applied research that is applying control in the nutmeg oil refining process. The focus of this research is to add a microcontroller-based control system to the steam boiler. Block control system block diagram on the nutmeg oil refinery boiler is shown in figure 1.

![Figure 1. Block diagram of a steam boiler control system for nutmeg oil refining](image)

Referring to the block diagram in figure 1, the steam boiler control system of nutmeg oil refinery consists of three parts, namely:

- Arduino Uno R3 microcontroller with control parameter input settings via keypad type 4x4 matrix keypad stamp keyboard key switch Arduino push button, Control display using 20x4 LCD and Omron relay 12V, 8 pins, 8 feet. Arduino Uno R3 microcontroller is the control center of this control system. Setting and parameter settings are temperature settings, pressure settings and operating time settings done via the keypad. The parameter display is shown on the LCD.
• MAX6675 type K thermocouple temperature sensor and 500PSI sensor pressure transmitter, these two sensors are placed on the steam boiler. The response of the two sensors will be processed by the microcontroller to activate the heater.

• 1000 Watt and 750 Watt heating elements and these two heaters are energy sources for heating the steam boiler. The heater is controlled by the Arduino Uno R3 microcontroller.

2.2. Manufacturing steam boiler control system in the refining system

The control system and distillation system in this study are the two systems that are the focus of testing. Manufacturing results of the control system are integrated into the steam boiler and steam boiler integrated with the cooling system and separator into a nutmeg oil refining system with automatic control. The automatic refining system of the research results as shown in figure 2.

![Figure 2. Distillation systems with automatic control](image)

2.3. Testing procedure

Testing of the steam control system is carried out after manufacturing the control subsystem on the steam boiler, condenser and separator are integrated. The test was carried out by distilling as much as 15 kg of dried nutmeg that had been ground and the test lasted for 16 hours. The treatment for cooling is by flowing cold water at a rate of 4 liters/minute, the temperature in the coolant is in the range of 30ºC-40ºC. The testing procedure for the nutmeg oil refiner with automatic control is shown in the flow diagram in figure 3.
Figure 3. Flowchart of refining system testing procedures with automatic control
Based on the flow chart in figure 3, the energy requirements of the steam boiler of nutmeg oil refinery are filled with two heaters with a power of 1000 W and 750 W. During the time of distillation both of these heaters are on and off based on the response of the temperature sensor and pressure sensors placed on the steam boiler. With the second arrangement of this heater, the consumption of electrical power in the steam boiler will decrease if the temperature and pressure on the steam boiler have reached the maximum limit that has been set, i.e. 120ºC for temperature and 2.0 bars for pressure.

To compare the need for electric power consumption in a refining system with automatic control and not using automatic control, comparative testing is carried out in the same treatment. Testing on a system without control is done by turning off the control system so that monitoring is carried out by temperature and pressure by manually measuring the temperature and pressure.

3. Result
The test data generated in this study are the calibration temperature and pressure data on the steam boiler and the data of electric power consumption of the refining system using a control system and not using a control system.

3.1. Testing the temperature and pressure calibration of the steam boiler
Measurement calibration is done to get valid results. Temperature and pressure calibration in the steam boiler is carried out using digital temperature and pressure measuring devices. The values obtained from this measurement are included in the temperature and pressure settings on the Arduino microcontroller-based Uno R3 control system. Test results of the calibration of temperature and pressure as shown in table 1.

| Test number | Digital thermometer and Digital pressure | Display on LCD |
|-------------|----------------------------------------|----------------|
|             | Temperature sensor response (ºC) | Pressure (bar) | Temperature sensor response (ºC) | Pressure (bar) |
| 1           | 50                                     | 0.5            | 50                                     | 0.5            |
| 2           | 60                                     | 0.6            | 60                                     | 0.6            |
| 3           | 80                                     | 0.7            | 80                                     | 0.7            |
| 4           | 90                                     | 0.9            | 90                                     | 0.9            |
| 5           | 100                                    | 1.1            | 100                                    | 1.1            |
| 6           | 110                                    | 1.6            | 110                                    | 1.6            |
| 7           | 120                                    | 2.0            | 120                                    | 2.0            |

3.2. Testing the electrical power consumption of the refining system
The testing of steam boiler control systems with energy sources derived from electrical power carried out for 16 hours. Testing is done by automatic control. Data only tests as shown in table 2.

Referring to table 2, heater 1000 W and 750 W are installed on the steam boiler automatically on and off based on the response of temperature and pressure of steam from temperature sensors and pressure sensors mounted on the steam boiler. Control settings are based on the program embedded in the Arduino Uno R3 microcontroller. Both heaters will turn off if the temperature reaches 120 ºC and the pressure reaches 2 bars. Then the heater 1000 W will be off and the heater 750 W will be on. If the temperature and pressure decrease to 100 ºC and the pressure decreases to 1.3 bar then both heaters will be on again. And if the temperature and pressure decrease at 110 ºC and the pressure at 1.6 bar then the 1000 W heater will be on.
Table 2. Electric power consumption of steam boilers with automatic control for 16 hours of operation.

| Temperature (°C) | Pressure (bar) | Heater 1 (1000 Watt) | Heater 2 (750 Watt) | Operating time (hour) |
|------------------|----------------|----------------------|---------------------|----------------------|
| 40               | 0.4            | 1000                 | 750                 | 1                    |
| 70               | 0.7            | 1000                 | 750                 | 1                    |
| 85               | 0.9            | 1000                 | 750                 | 1                    |
| 100              | 1.2            | 1000                 | 750                 | 1                    |
| 110              | 1.6            | 1000                 | 750                 | 1                    |
| 120              | 2.0            | 1000                 | 750                 | 1                    |
| 110              | 1.6            | 0                    | 750                 | 0.5                  |
| 100              | 1.3            | 1000                 | 750                 | 0.5                  |
| 120              | 2.0            | 1000                 | 750                 | 0.5                  |
| 110              | 1.9            | 0                    | 750                 | 1                    |
| 100              | 1.6            | 1000                 | 0                   | 1                    |
| 105              | 1.6            | 1000                 | 0                   | 1                    |
| 110              | 1.7            | 1000                 | 750                 | 1                    |
| 120              | 2.0            | 1000                 | 750                 | 1                    |
| 110              | 1.7            | 0                    | 750                 | 0.5                  |
| 100              | 1.5            | 1000                 | 0                   | 0.5                  |
| 115              | 1.8            | 1000                 | 750                 | 1                    |
| 110              | 1.6            | 0                    | 750                 | 1                    |
| 100              | 1.3            | 1000                 | 750                 | 0.5                  |

Testing steam boiler nutmeg oil refining is done by not activating the control system. Testing is done for 16 hours. Monitoring temperature and pressure is done manually. Test results as shown in table 3.

Table 3. Electric power consumption of a steam boiler without automatic control for 16 hours of operation.

| Temperature (°C) | Pressure (bar) | Heater 1 (1000 Watt) | Heater 2 (750 Watt) | Operating time (hour) |
|------------------|----------------|----------------------|---------------------|----------------------|
| 40               | 0.4            | 1000                 | 750                 | 2.0                  |
| 70               | 0.7            | 1000                 | 750                 | 2.0                  |
| 85               | 0.9            | 1000                 | 750                 | 1.5                  |
| 100              | 1.2            | 1000                 | 750                 | 1.5                  |
| 110              | 1.6            | 1000                 | 750                 | 1.5                  |
| 120              | 2.0            | 1000                 | 750                 | 7.5                  |
Comparison of electrical power consumption in the steam boiler for 16 hours of operating time with control and without automatic control is shown in table 4.

**Table 4.** Comparison of electric boiler steam power consumption with and without automatic control for 16 hours of operation.

| Electric power consumption in the steam boiler with automatic control | consumption of electric power in the steam boiler without automatic control |
|---|---|
| Heater 1 (1000 Watt) | Heater 2 (750 Watt) | Operating time (hour) | Heater 1 (1000 Watt) | Heater 2 (750 Watt) | Operating time (hour) |
| 1000 | 750 | 10.5 | 1000 | 750 | 16.0 |
| 1000 | 0 | 2.5 | 1000 | 0 | 0 |
| 0 | 750 | 3.0 | 0 | 750 | 0 |

Based on table 4, testing the steam boiler by activating automatic control shows heater 1000 W and 750 W, on for 10.5 hours. The 1000 W heater is on for 2.5 hours and the heater is 750 W on for 3.0 hours. So, that the electricity consumption for 16 hours of operation is 23,750 Watt hours.

And the electric power consumption in the steam boiler with automatic control in the off position is a 1000 W heater and a 750 W heater on for 16 hours. The electrical power consumed by the steam boiler is 28,000 Watt hours.

Comparison of electric power consumption steam boiler with automatic control and steam boiler without control is 23750/28000 or 0.85. So, that the efficiency of electric power consumption from both tests is 15%.

4. **Conclusion**

The addition of an automatic control system on steam boilers of nutmeg oil refining results in a decrease in electric power consumption by Watt hour, this is an efficiency of 15% when compared to power consumption without control. Another advantage is the quality of nutmeg oil distillation by applying a clean distillation process. The power involved in the refining process is small, and only requires one operator in operation.

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