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Control System Based on Fuzzy Logic in Nutmeg Oil Distillation Process

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Abstract

The focus of this research is the application of electronic control on the distillation boiler of nutmeg oil. The control system is based on fuzzy logic and as the input parameter is temperature and vapor pressure. The temperature parameters are set in the range 80-120ºC, and the vapor pressure parameters are set in the range of 1-2.5 atmospheres. The output parameter is the time required in the distillation process. The optimal values of these input and output parameters are embedded in microcontroller based control. The control responds to the temperature and vapor pressure to select the gas flow rate at the distillation boiler. This experiment was conducted on a distillation system with a capacity of 25 kg of crushed dried nutmeg, manually and with control based on fuzzy logic. Conventional testing requires 6.90 kg of gas and applying fuzzy logic based control requires 5.50 kg of gas. The yield of nutmeg oil from the distillation process is 2.5 kg conventionally and 2.63 kg with fuzzy logic control. Based on the optimal time of 16 hours distillation process, there was a decrease of gas consumption by 20.3%.

Keywords: *distillation process, control system, fuzzy logic control, gas consumption*

1. Introduction

This research focused on distillation process that takes a long time to produce nutmeg oil. This long distillation process requires large energy consumption. The amount of energy used causes the production cost in the distillation process to be expensive and this greatly affects the profit of distillation business. Therefore, many studies and research have been conducted in relation to distillation systems including distillation of nutmeg oil. The focus of this research is on distillation boilers with the aim of reducing energy consumption in the distillation system.

One of the methods applied in the distillation process to obtain nutmeg oil is the steam boiler system method. Steam boiler method is one method that has the advantages of pressure and temperature exposure to improve performance to be more optimal, but this method has a weakness that is the decrease of oil quality if the pressure and temperature settings are not controlled. Therefore the aroma of nutmeg oil produced must remain of good quality by providing a controlled vapor pressure [1]-[3]. Pressure and temperature are the control parameters in the distillation process. The temperature setting is in the range of 80-120 ºC and the pressure setting in the 1-2.5 atmospheres range. Controlling the pressure and temperature on the appropriate steam boiler can speed up the distillation prsoses [4]. Therefore, the pressure and temperature need to be monitored continuously so that the distillation time becomes optimal and the quality of the nutmeg oil aroma remains good.

Distillation systems that are widely used in the process of distillation of nutmeg oil require enormous energy. This huge energy requirement is sufficient to use firewood as cheap and easy to obtain. Some also use oil and gas as an energy source in the distillation process. The weakness of the conventional oil nutmeg distillation system, the distillation process is monitored continuously, so require the operator always ready. Negligence can lead to decreased quality and production of nutmeg oil. Conventional nutmeg oil distillation takes 30-36 hours for one distillation. Long distillation times will increase production costs, especially fuel costs. The performance of conventional distillation times can be improved by controlling the pressure and temperature so that the distillation time decreases to 14 from 30 hours. With this decrease in distillation time will reduce the fuel usage of firewood [5]. The use of firewood can lead to a decrease in the quality of oil. Burn wood and fuel replacements with non-fuel gas fuels to maintain the quality of nutmeg oil and apply clean energy. CO2 emissions increase by 2.3%

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in 2013 and increase to 2.5% by 2014, one of the reasons is the use of energy from fossil fuels. The need for effective use of energy and the transfer of renewable energy utilization [6].

Control of the energy source in the distillation process can be done to reduce the condensation of the fuel. Such as controlling the flow of gas in the distillation stove. Control of gas flow for two positions ie. maximum flow and minimum flow can reduce gas consumption up to 14.7% of the system without control [7]. The use of fuel in boiler distillation can be saved up to 30%, if boiler system is optimized, that is by addition of control. A control method is required that optimizes energy use based on temperature, vapor pressure and time of distillation [8-11].

The fuzzy logic based control method has been widely applied such as temperature, pressure, position, speed system and other. Various systems have applied fuzzy logic as a controlling base to improve their performance. On a larger scale fuzzy logic-based controls have also been widely applied [12-16]. Application of controls based on fuzzy logic can improve the efficiency of energy consumption [17]. Based on the previous description that this research can speed up the distillation time so that the production cost of gas fuel cost can be decreased. The applied method is to the performance of the steam boiler using fuzzy logic control.

2. Research Method

2.1. Distillation System Design

In this research the design of distillation system of nutmeg oil is the mechanical design of distillation system and control system design. The design of a mechanical system comprises a refining boiler and a combustion, cooling and separator. The fuel for this distillation system uses LPG gas. The fuzzy logic based control system with pressure and temperature input parameters, while the output parameter is the distillation time and gas flow rate. The design of the fuzzy logic control system and the distillation of nutmeg oil are shown in Figure 1.

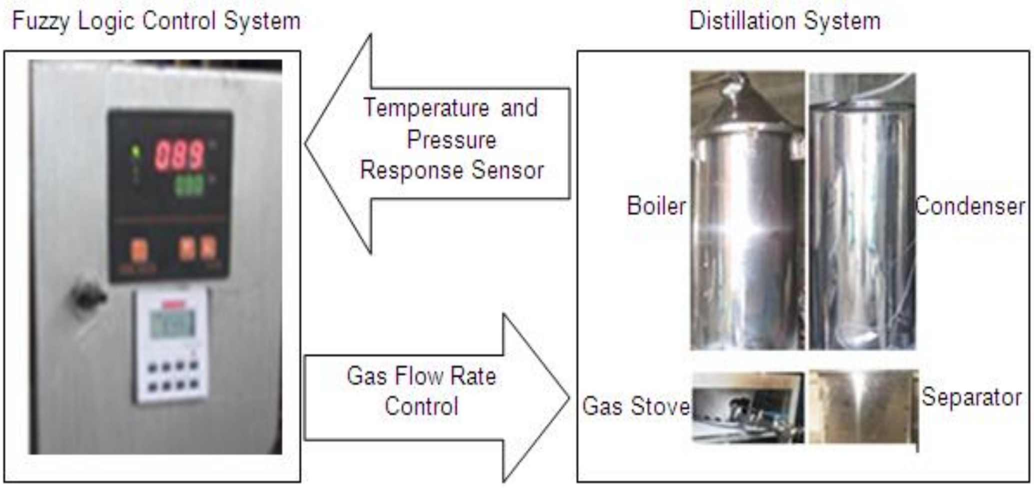


Figure 1. Distillation system design and fuzzy logic control

The fuzzy logic builds on the four steps of determining the fuzzy set, determining membership functions, setting rules and defuzzifications [18]. The design steps of fuzzy logic control on this distillation system are as follows:

a. The fuzzification process is designing crisp input consists of pressure and temperature. Crisp output consists of the time of distillation and gas flow rate. Crisp input and output as shown in Figure 2.
b. The design of membership function of the temperature input with the range 0-120ºC consists of three membership levels ie LOW, MEDIUM and HIGH as shown in Figure 3(a). The design of pressure membership functions with a range of 0-2.5 atmospheres comprises LOW, MIDDLE and HIGH as shown in Figure 3(b).

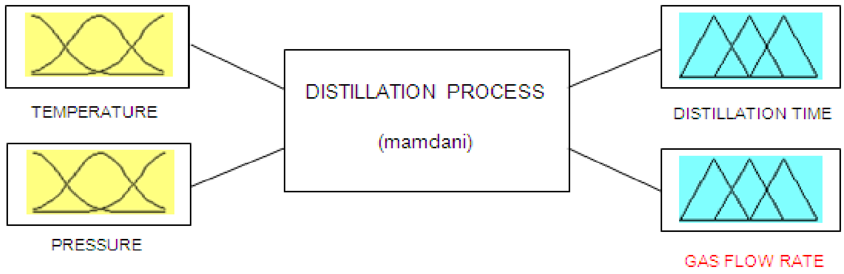
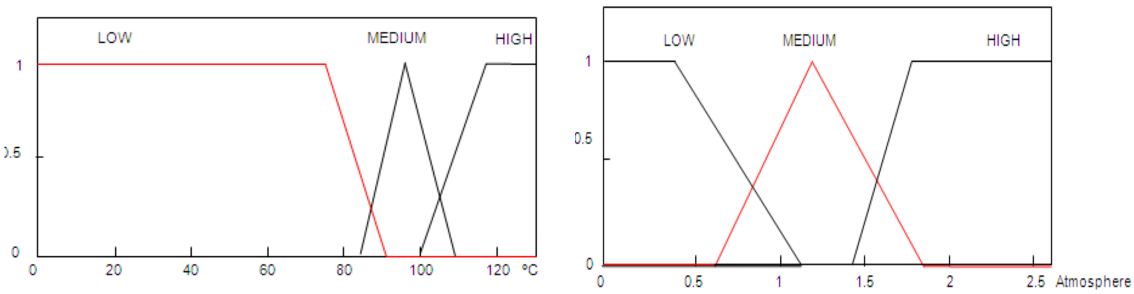


Figure 2. Crisp input and output design on fuzzy logic control



(a) (b)

Figure 3. The fuzzy membership function (a) temperature input (b) pressure input

The representation diagram of the fuzzy set of Figure 3 (a) corresponds to equation 1, 2, and 3.

$$\mu_{LOW}[x]=\begin{cases}1, & x\le 75\\ \frac{90-x}{90-75}, & 75<x<90\\ 0, & x\ge 90\end{cases} \quad (1)$$

$$\mu_{MEDIUM}[x]=\begin{cases}0, & x\le 85 \text{ or } x\ge 105\\ \frac{x-85}{95-85}, & 85<x<95\\ \frac{105-x}{105-95}, & 95<x<105\end{cases} \quad (2)$$

$$\mu_{HIGH}[x]=\begin{cases}0, & x\le 100\\ \frac{x-100}{110-100}, & 100<x<110\\ 1, & x\ge 110\end{cases} \quad (3)$$

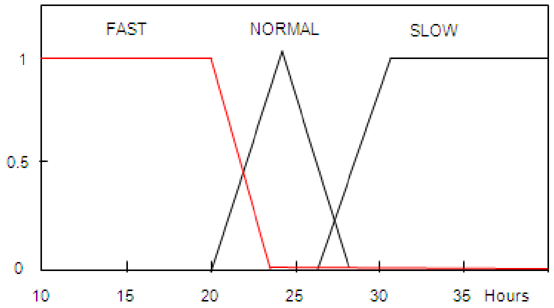
The representation diagram of the fuzzy set of Figure 3 (b) corresponds to equation 4, 5, and 6.

$$\mu_{LOW}[x]=\begin{cases}1 & x\le 0.4\\ \frac{0.9-x}{0.9-0.4}, & 0.4\le x\le 0.9\\ 0, & x\ge 0.9\end{cases} \quad (4)$$

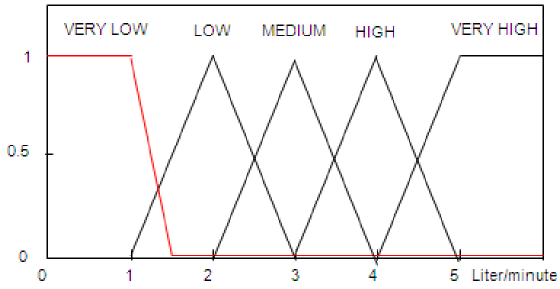
$$\mu_{MEDIUM}[x]=\begin{cases}0, & x\le 0.7 \text{ or } x\ge 1.8\\ \frac{x-1.3}{1.3-0.7}, & 0.7\le x\le 1.3\\ \frac{1.9-x}{1.9-1.3}, & 1.3\le x\le 1.9\end{cases} \quad (5)$$

$$\mu_{HIGH}[x]=\begin{cases}0, & x\leq 1.5\\ \frac{x-1.5}{2.0-1.5}, & 1.5\leq x\leq 2\\ 1, & x\geq 1.9\end{cases} \quad (6)$$

The design of the distillation membership function with a range of 16-36 hours consists of FAST, NORMAL and SLOW as shown in Figure 4(a). Design membership function with range 1-5 liter/minute VERY LOW, LOW, NORMAL, HIGH and VERY HIGH as shown in Figure 4(b).



(a)



(b)

Figure 4. The fuzzy membership function output (a) time of distillation (b) gas flow rate

The representation diagram of the fuzzy set of Figure 4(a) corresponds to equation 7, 8, and 9.

$$\mu_{FAST}[x]=\begin{cases}1 & x\leq 20\\ \frac{24-x}{24-20}, & 20\leq x\leq 2\\ 0, & x\geq 24\end{cases} \quad (7)$$

$$\mu_{NORMAL}[x]=\begin{cases}0, & x\leq 20 \text{ or } x\geq 28\\ \frac{x-24}{24-20}, & 20\leq x\leq 24\\ \frac{28-x}{28-24}, & 24\leq x\leq 28\end{cases} \quad (8)$$

$$\mu_{SLOW}[x]=\begin{cases}0, & x\leq 26\\ \frac{x-26}{31-26}, & 2.5\leq x\leq 3\\ 1, & x\geq 31\end{cases} \quad (9)$$

The representation diagram of the fuzzy set of Figure 4(b) corresponds to equation 10-14.

$$\mu_{VERY\ LOW}[x]=\begin{cases}1 & x\leq 1\\ \frac{1.5-x}{1.5-1}, & 1\leq x\leq 1.5\\ 0, & x\geq 1.5\end{cases} \quad (10)$$

$$\mu_{LOW}[x]=\begin{cases}0, & x\leq 1 \text{ or } x\geq 3\\ \frac{x-1}{2-1}, & 1\leq x\leq 2\\ \frac{3-x}{3-2}, & 2\leq x\leq 3\end{cases} \quad (11)$$

$$\mu_{NORMALI}[x] = \begin{cases} 0, & x \le 2 \text{ or } x \ge 4 \\ \frac{x-2}{3-2}, & 2 \le x \le 3 \\ \frac{4-x}{4-3}, & 3 \le x \le 4 \end{cases} \quad (12)$$

$$\mu_{HIGH}[x] = \begin{cases} 0, & x \le 3 \text{ or } x \ge 5 \\ \frac{x-3}{4-3}, & 3 \le x \le 4 \\ \frac{5-x}{5-4}, & 4 \le x \le 5 \end{cases} \quad (13)$$

$$\mu_{VERY\ HIGH}[x] = \begin{cases} 0, & x \le 4 \\ \frac{x-4}{5-4}, & 4 \le x \le 5 \\ 1, & x \ge 5 \end{cases} \quad (14)$$

c. The design of the rule base is based on the function of temperature and pressure membership. And the rules used to obtain the distillation time and gas flow rate as shown in Tables 1 and 2.

Table 1. Rule Matrix Time of Distillation

Temperature / Pressure	Time of Distillation LOW	MEDIUM	HIGH
LOW	SLOW	SLOW	NORMAL
MEDIUM	SLOW	NORMAL	FAST
HIGH	SLOW	FAST	FAST

Table 2. Rule Matrix of Gas Flow Rate

Temperature / Pressure	Gas Flow Rate LOW	MEDIUM	HIGH
LOW	VERY HIGH	VERY HIGH	HIGH
MEDIUM	VERY HIGH	NORMAL	LOW
HIGH	HIGH	LOW	VERY LOW

d. Defuzzification process, i.e. all rules in the rule base is done, the defuzzification result as shown in Tables 3 and 4.

Table 3. Rule Viewer Time of Distillation

No	Temperature Set Point (^{o}C)	Pressure Set Point (atmosphere)	Output Distillation Time (Hour)
1	90	1	30
2	100	1.5	24
3	120	2.5	16

Table 4. Rule Viewer of Gas Flow Rate

No	Temperature Set Point (^{o}C)	Pressure Set Point (atmosphere)	Gas Flow (Liter/min)
1	85	0.9	5
2	90	1.0	4
3	100	1,5	3
4	110	2.0	2
5	120	2.5	1

Based on the simulation of matlab software, the optimum distillation time is 16 hours as shown in Table 3. And based on the optimum time it is designed the control system to determine the gas flow rate in the distillation process as shown in Table 4. Further designed arduino uno R3 based control circuit. Temperature sensor using thermocouple MAX6675K type and pressure sensor using pressure transmitter 500PSI. The gas flow rate is controlled according to the YF-S201 type flow sensor response, where it works to increase and decrease the gas flow rate by 1-5 Liters/minute, in which the gas flow rate is obtained based on the working frequency. Therefore, the temperature and pressure response in the form of voltage needs to be changed into the framework of frequency. From this temperature and pressure response, the gas flow rate to the stove as a boiler heat source is controlled by the microcontroller. Setting input and output parameters can be done through keypad and display temperature and pressure displayed on 7-segment. The design of block diagram of fuzzy logic control system is shown in Figure 5.

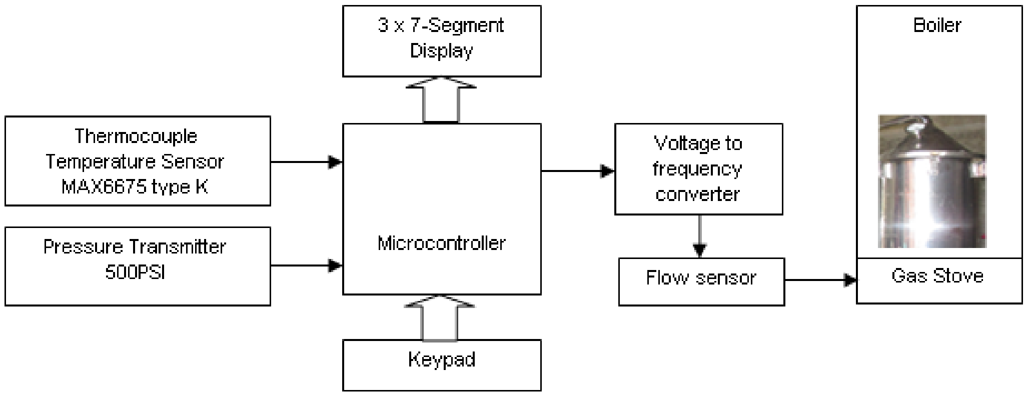


Figure 5. The design of block diagram of fuzzy logic control system

2.2. Manufacturing Distillation System

The manufacturing of distillation system of nutmeg oil consists of two systems: distillation system and control system. The distillation system consists of boilers and gas stoves, condensers and separators. This distillation system with a steam boiler with a capacity of 25 kg of nutmeg, 30 liters of water capacity at one time distillation. And the control system is built using arduino uno R3 microcontroller. Control is to regulate the flow rate of gas flowing into the gas stove with 5 positions ranging from 1-5 liters/minute. The gas flow rate is based on the pressure and temperature response on the distillation boiler. The fabrication results are shown in Figure 6.

Figure 6. Manufacturing of nutmeg distillation systems

2.3. Testing Procedure

In this research, the system test is done manually and using fuzzy logic based control. Treatment of the system when testing is the same ie; the materials tested were 25 kg of dry nutmeg, fruit basket at 50 cm high position, 30 liters of steam boiler water. The water flow rate at the condenser is 4 L/min and the temperature at the condenser is kept in the range of 30-40 ºC. This test is performed in order to obtain gas consumption data and measure the yield of nutmeg oil produced in both test methods. The flowchart of the test procedure, manually and controlled on this system is shown in Figure 7.

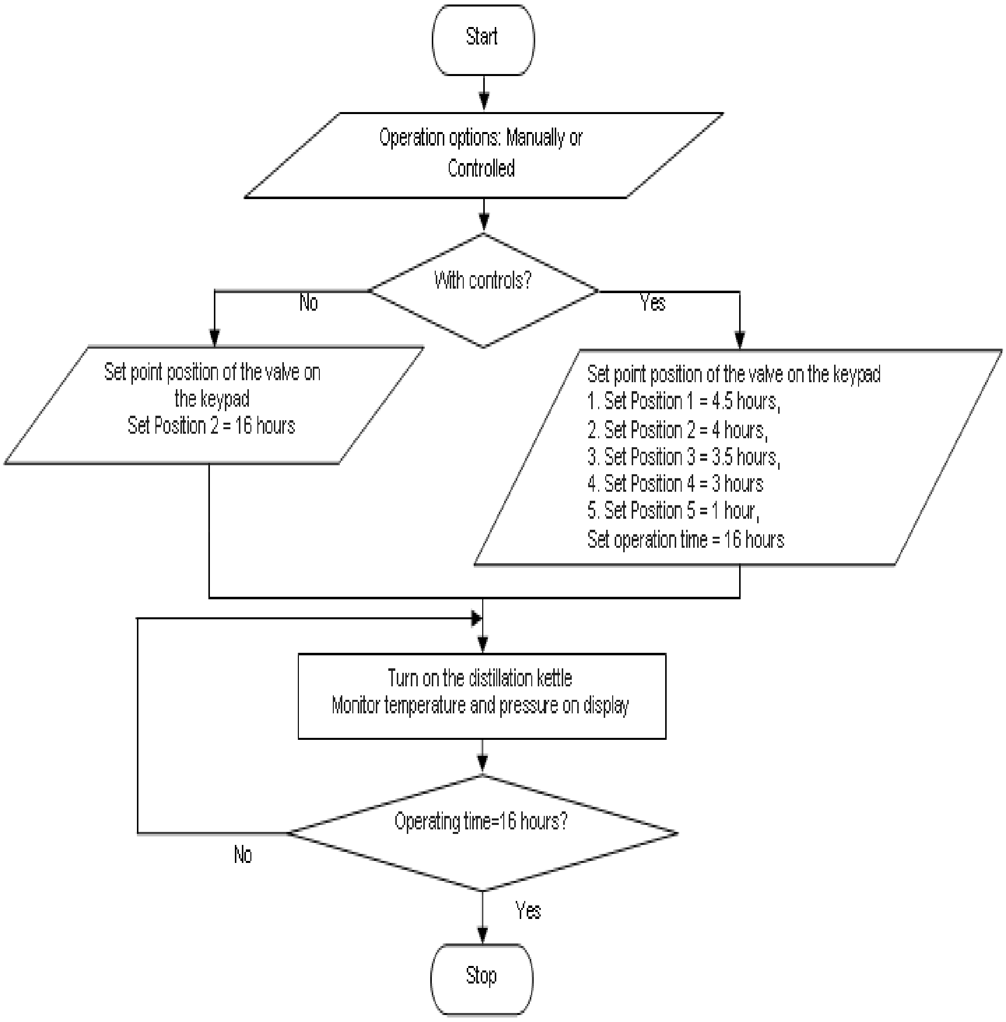


Figure 7. Flowchart testing of nutmeg oil distillation system

3. Results and Analysis

The data of test result in the research consist of data of test result of control system and data of test result of distillation system as a whole.

3.1. Testing Result of Fuzzy Logic Control System

The first control system test is done by calibrating the sensor ie pressure and temperature sensor. Test results are displayed on 7-segment. The test results data as shown in Table 5. This table shows that the pressure and temperature sensors in the boiler steam have worked in accordance with reference data by reference. And to strengthen the accuracy of the test data, the temperature and pressure pointing apparatus of the thermometer and the analogue manometer is added, and the result is that the temperature and pressure must be equal.

The position of the gas flow valve and the response acting on the response of the pressure and temperature sensors are shown in Table 6. Based on Table 6, the position of valve 1 for the pressure of 0.9 atmospheres and the temperature of 85ºC resulted in a gas flow rate of 5 liters/min. The position of valve 2 for the pressure of 1.0 atmosphere and the temperature of 90ºC produces a gas flow rate of 4 liters/minute of gas flow. The position of valve 3 for the pressure of 1.5 atmospheres and the temperature of 100ºC produces a gas flow rate of 3 liters/min. The position of valve 4 for the pressure of 2.0 atmospheres and the temperature of 110ºC produces a gas flow rate of 2 liters/minute. The position of valve 5 for the pressure of 2.5 atmospheres and the temperature of 120^0C produces a gas flow rate of 1 liter/min.

Table 5. Calibration Pressure and Temperature Sensor on the Steam Boiler

No	Temperature on analogue thermometer (ºC)	Pressure on analogue manometer (atmosphere)	Display on 7-segment Temperature sensor response (ºC)	Display on 7-segment Pressure (atmosphere)
1	60	0.6	60	0.6
2	80	0.7	80	0,7
3	90	0.9	90	0.9
4	100	1.0	100	1.0
5	105	1.5	105	1.5
6	110	2.0	110	2.0

Table 6. The Position of the Flow Gas Valve is based on the Pressure and Temperature

Position of gas flow valve	Temperature (ºC)	Pressure (atmosphere)	Gas Flow Rate (Liter/min)
1	85	0.9	5.0
2	90	1.0	4.0
3	100	1,5	3.0
4	110	2.0	2.0
5	120	2.5	1.0

3.2. Testing Result of Distillation System Performace

The system performance test of the distillation time is shown in Table 7. Based on this table, the overall distillation time is 16 hours. During this distillation time, the position of the gas flow valve changes according to the temperature and pressure response of the steam boiler. This change of flow valve position causes the gas flow rate to change. The gas flow valve at the first operation is at position 1 (gas flow rate 5 liters/min) and lasts for 4.5 hours. Gas flow position changed to position 2 (4 liters/minute) for 4 hours. Position the valve at position 3 (3 liters/min) for 3.5 hours. In the 4th position (2 liters/min) operate for 2.0 hours. And the gas flow position moves to position 5 (1 liter/min) for 1.0 hours.

Table 7. Performance Fuzzy Logic Control to Distillation Time

Position of gas flow valve	Temperature (ºC)	Vapor Pressure (atmosphere)	Opreation Time (Hour)
1	85	0.9	4.5
2	90	1.0	4.0
3	100	1.5	3.5
4	110	2.0	3.0
5	120	2.5	1.0

Tables 8 and 9 shows that with a 16 hours operating time, the amount of LPG gas used is 5.5 kg and 6.9 kg. Based on the test results, the nutmeg oil produced in the distillation process for 16 hours was 2.63 kg with fuzzy and 2.5 kg logic control without the control of 25 kg of dried nutmeg which was distilled. Compared with the conventional system gas consumption during 16 hours distillation time decreased gas consumption by 1.4 kg or 20.3%.

Table 8. The USE of Gas Fuel in the Distillation System by Controlling Fuzzy Logic Based

Gas Flow Rate (Liter/min)	Temperature (^oC)	Vapor Pressure (atmosphere)	Opreation Time (hour)	Fuel gas mass (kg)
5	80	0.9	4.5	2.78
4	90	1.0	4.0	1.73
3	100	1.5	3.5	0.73
2	110	2.0	3.0	0.25
1	120	2.5	1.0	0.03

Table 9. The use of gas fuel in an uncontrolled distillation system

Gas Flow Rate (Liter/min)	Temperature (ºC)	Vapor Pressure (atmosphere)	Opreation Time (hour)	Fuel gas mass (kg)
4	90	1.0	16	6.6

4. Conclusion

The distillation system of nutmeg oil requires distillation time in the range of 24 to 30 hours. In this study, a non-controlled distillation system for 16 hours of testing required 6.9 kg of LPG gas. The refining system with fuzzy logic-based controls for 16 hours of testing consumes 5.50 kg of LPG gas. So there is a decrease in LPG gas consumption by 1.38 kg or 20.3%. Measurement of nutmeg yield during the test of 25 kg of distended nutmeg was 2.5 kg (10%) for the non-controlled system and 2.63 kg (10.5%) in the distillation system with fuzzy logic-based controls and increase in yield of 0.13 kg (0.5%).

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