Design and Implementation of Temperature Controller for a Vacuum Distiller

M. Aziz Muslim, Goegoes Dwi N., Ahmad Salmi F., Akhbar Prachaessardhi R.
Departement of Electrical Engineering
Brawijaya University
Malang, Indonesia
muh_aziz@ub.ac.id, goegoesdn@ub.ac.id

***Abstract*—This paper proposed design and implementation of temperature controller for a vacuum distiller. The distiller is aimed to provide distillation process of bioethanol in nearly vacuum condition. Due to varying vacuum pressure, temperature have to be controlled by manipulating AC voltage to heating elements. Two arduino based control strategies have been implemented, PID control and Fuzzy Logic control. Control command from the controller was translated to AC drive using TRIAC based dimmer circuit. Experimental results show that fuzzy logic controllers have better performance in controlling temperature of vacuum distiller**

Keywords—temperature control; PID control; fuzzy logic control; vacuum distiller

I. Introduction

Since world stock of the fossil fuel is getting run out, exploration of alternative fuels getting more intense [1]. Bioethanol is a prospective alternative to gasoline [1-4]. The process of bioethanol production starts from fermentation of sugar-contained base material, e.g molasses. The result of this process is 7% -10% bioethanol. Distillation process is then performed to produce bioethanol at higher level [5-8]. Because of azeotrope phenomenon [6][8], levels of distilled bioethanol can not reach pure bioethanol. Purification is then usually done by dehydration proces using water absorbent. This process takes up to 2-3 days [9]. As an alternative method is to perform distillation under nearly vacuum conditions. In vacuum conditions, azeotrope formation can be avoided so that enable production of pure bioethanol [10]. However, reducing pressure will also reducing boiling point of bioethanol and water as well, makes difference of boiling points between the two smaller. Hence, precise control of temperature is necessary for successful distillation.

Due to difficulties in providing precise control and economical aspect, vacuum distillation were not used industry. Since no recent publication found, this study want to solve this challenging problem. Standard guideline in laboratory scale vacuum distiller were reported in [11-13]. The main manipulated variable is temperature. The temperature is controlled by regulating incoming voltage to the heater. Since it needs high heater power, DC voltage is not appropriate to be used. Given AC voltage as the input, it would require a special strategy for manipulating the voltage so that the temperature can be controlled. On-off control strategy has been used in our previous study [14], however the results were unsatisfactory. In this paper, a TRIAC based dimming circuit is proposed for temperature control of vacuum distiller. Although output of TRIAC has nonlinearity, what we need is actually a trigger signal, which is effectively provided by TRIAC. This dimming circuit is controlled by a fuzzy logic controller. For performance comparison, a PID based dimming circuit is also proposed. It is hope that the proposed control schema can improve performance of vaccuum distiller.

The rest of this paper is organized as follows. Section 2 describes experimental setup, control system design, and data acquisition. Experimental data, and its analysis describes in Section 3. And finally, Section 4 concludes the whole works.

II. Research Methods and Experimental Setup

Experiments were done using vacuum distiller apparatus developed in our previous study [14]. The apparatus comprises of a distillation tube, heater set, condensation tube and cooling water basin. Fig. 1. depicts position of each parts in vacuum distiller used in this study.

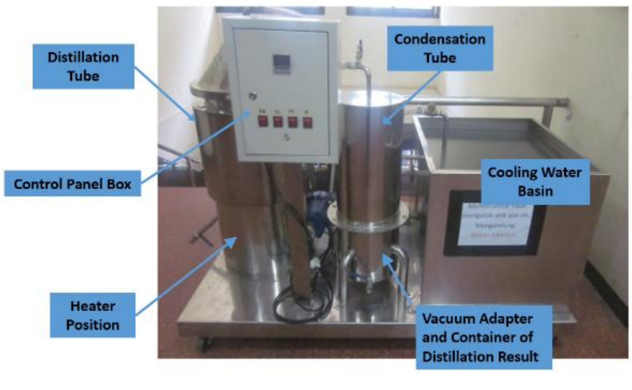

Fig. 1. Vacuum distiller used in this study

A. Experimental Procedure

Raw material for distillation was solution of 70% alkohol. This raw material was choosen since our focus only in developing a control strategy for vacuum distillation, not on the resulting product (bioethanol).

The experiments were conduct as follows. Temperature final set point is 66°C while set point of vacuum pressure is 0.5 atm. Temperature set point is increased gradually from 50°C, 57°C, 61°C, and 66°C to provide smooth temperature change.

B. Control System Design

Fig. 2. shows general control schema for vacuum distiller. Temperature sensor (PT100) provide feedback signal refer to actual temperature inside distillation tube. Based on difference between desired temperature and actual temperature, controller provide control signal for dimming circuit. Furthermore, dimming circuit provides controlled signal to the heater. Detail explanation follows.

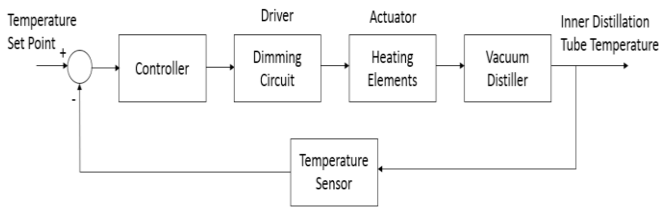

Fig. 2. General control schema

1) Controller

Two controllers were used in experiments, PID controller and Fuzzy Logic Controller. Parameters of PID controller is developed based on Ziegler Nichols I. While fuzzy logic controller is a fuzzy Mamdani developed heuristically.

2) Dimming Circuit

Fig. 3 shows dimmer circuit used in this research. This circuitry also contain TRIAC trigger circuit and Zero Cross Detector circuit.

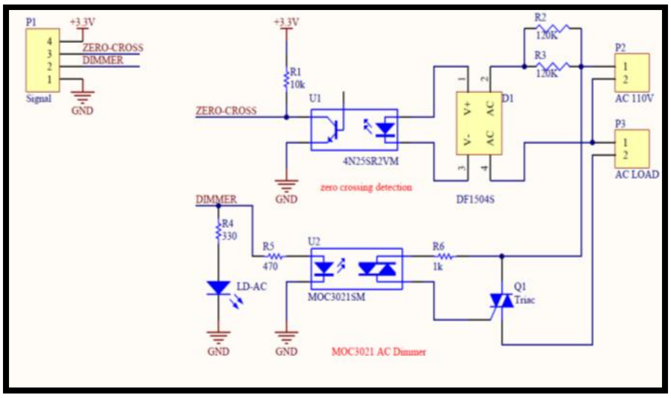

Fig. 3. Dimmer circuit

III. Experimental Results and Analysis

A. Experimental Results using PID Controller

Parameters of PID controller are determined based on open loop response in Fig. 4. Accoding to Table 1, the resulting PID parameters are Kp = 11.61, Ki = 0.01161 and Kd = 0. Figure 5 shows system performance using selected parameters of PID controller. The maximum overshoot was small enough (2.63%) but the settling time was big enough (around 6000 seconds).

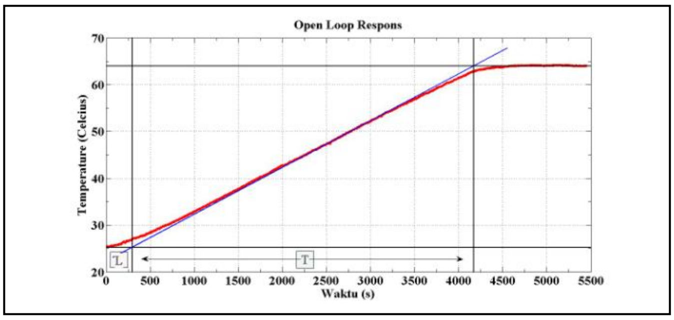

Fig. 4. Open loop response

Table 1.Determination of PID controller parameters using Niegler Nichols I

Controller	K_p	T_i	T_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	$2L$	$0.5L$

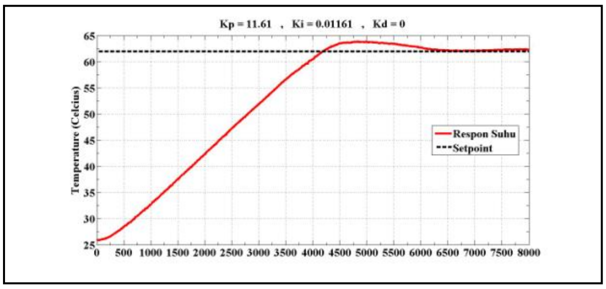

Fig. 5. Response of vacuum distiller using PID controller

B. Experimental Results using Fuzzy Logic Controller

The fuzzy logic controller used in this study has 2 inputs, i.e. temperature error (*error*) and difference of error (*delta error*), and 1 output, i.e. dimming level command for the dimming circuit. Fig. 6 and Fig.7 show fuzzy set definition for

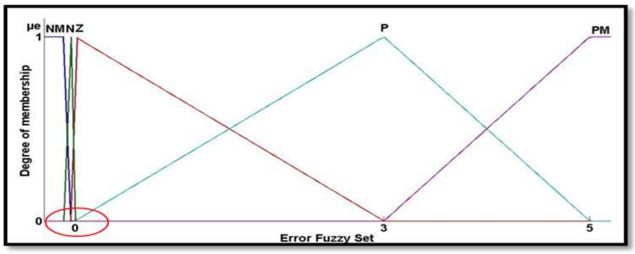

Fig. 6. Error fuzzy set

the inputs. Initially, membership function of both input were set to uniform triangular. Non uniform shape of the triangular error fuzzy set (Fig. 6) was the results of fuzzy set parameter tuning. For simplicity, fuzzy singleton was choosen for the output.Fig. 8 shows fuzzy set of the output.

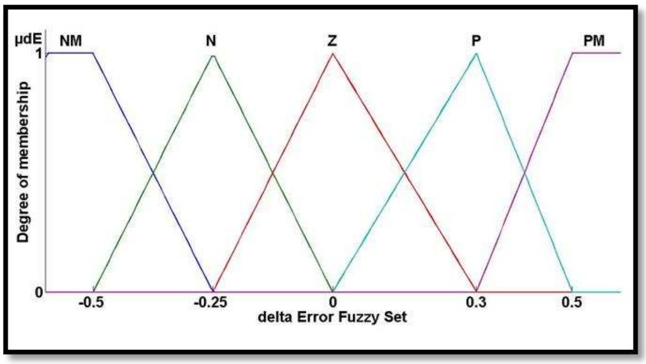

Fig. 7. Delta error fuzzy set

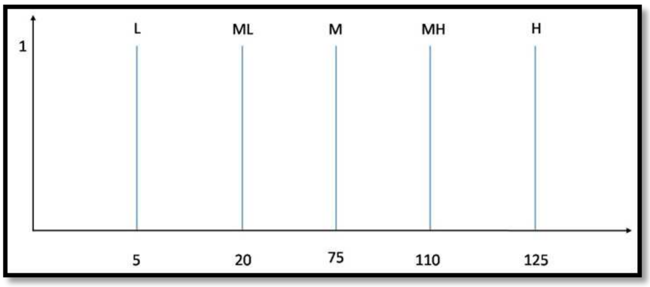

Fig. 8. Fuzzy set of the output (dimming level)

The most important part of a fuzzy system is fuzzy rule definition. In this study, fuzzy rules were determined experimentally using heuristic approach. Table 2 shows the complete fuzzy rules. Furthermore, Mini-Mamdani inference rule and weighted average defuzzyfication were employed in this study. Due to simplicity, an Arduino Mega 2560 board (Fig. 9) was used to implement fuzzy system.

Table 2. Fuzzy rules

e / de	NM	N	Z	P	PM
NM	H	H	H	MH	M
N	H	M	M	M	ML
Z	H	ML	M	MH	L
P	MH	M	ML	L	L
PM	M	ML	L	L	L

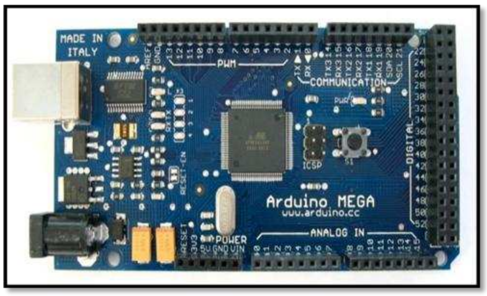

Fig. 9 Arduino Mega 2560 module

Fig.10 shows inner temperature of distillation tube by using fuzzy logic controller. There is no overshoot perceived and settling time is relatively shorter (5400 seconds) comparing to that of PID controller.

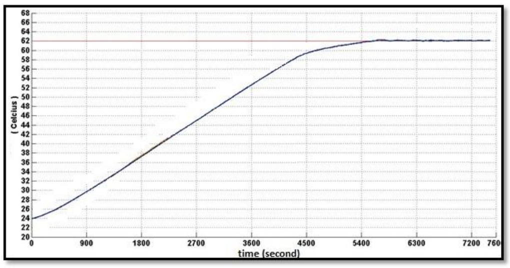

Fig. 10. Control performance of fuzzy logic controller

From the control point of view, since control purpose is to provide certain temperature without overshoot, these result are very good. But unfortunately, distillation results are still out of expectation. The maximum bioethanol concentration is 88%, which is still far from our expectation of producing pure (100%) bioethanol. Table II summarized best result from the experiments.

Table 2. Performance Summary

Control Stategy	% Overshoot	Settling time (sec)	% Bioethanol
PID	2.63%	6000	88%
Fuzzy Logic	0%	5400	88%

Concerning to the bioethanol concentration issue, we argue that since temperature and pressure are two dependent variables, control strategy should be made for temperature and vaccuum pressure in integrated manner. This will left for further study.

IV. CONCLUSION

In this paper, temperature control system for a vacuum distiller has been developed. Two control strategies has been proposed and compared, namely PID controller and fuzzy logic controller. These control strategis were implemented using Arduino Mega 2560 board. Output of the controllers then provide dimming level/value to a dimmer circuit. This circuit then supplied corresponding signal to the heater as an actuator for the system. From the performace comparison of output temperature (temperature inside the distillation tube), fuzzy logic controller has superior results in the sense of overshoot and settling time.

ACKNOWLEDGMENT

This research is funded by Directorate General of Higher Education, Ministry of Education and Culture, from DIPA Universitas Brawijaya No. DIPA-023.04.2.414989/2013, Desember 5th, 2012, under contract number 295/SK/2013 June 12th, 2013

REFERENCES

[1] Stevens, Don, 2004, Biofuels for Transport, IEA Bioenergy: T39: 2004: 01

[2] Paul, A., Tiwari, A., C., 2011, "Analyzing The Performance of SI Engine Fueled with Biofuel-Unleaded Gasoline Blends," International Journal of Wind and Renewable Energy, 1(1):1-9.

[3] Kheiralla, A., F., El-Awad, M., M., Hassan, M., Y., Hussen, M., A., Hind, I., 2012, "Experimental Determination of Fuel Properties of Ethanol/Gasoline Blends as Bio-fuel for SI Engine," Int. Conf. on Mechanical, Automobile and Robot Engineering (ICMAR 2012), Penang, Malaysia, pp. 244-249.

[4] Farkade, H., S., Pathre, A., P., 2012, "Experimental Investigation of metanol, etanol and Butanol Blends with Gasoline on SI Engine," International Journal of Emerging Technology and Advanced Engineering, 2(4):205-215.

[5] Ali, M., N., Mohd, M., K., Mohiudin, M., 2011, "Etahanol Fuel Production Through Microbial Extracellular Enzymatic Hydrolysis and Fermentation krom Renewable Agrobased Cellulosic Waste," International Journal of Pharma and Bio Science, 2(2):B321-B331.

[6] Dias, M.,O., S., Ensinas, A., V., Nebra, S., A., Filho, R., M., Rossel, C., E., V., Maciel, M., R., W., 2009, "Production of Bioethanol and Other Bio-based Materials from Sugarcane Bagasse: Integration to Conventional Bioethanol Production Process," Chemical Engineering Research and Design, 87:1206-1216

[7] Bamforth, C., W., 2005, Food, Fermentation and Micro-organism, Oxford, Blackwell Science.

[8] Wyman, C.E., 1996, Handbook on Bioethanol: Production and Utilization, Washington, DC, Taylor & Francis.

[9] Gil, I., D., Uyazan, A., M., Aguilar, J., L., Rodriguez, G., Caicedo, L., A., 2008, "Separation of Ethanol and Water By Extractive Distillation with Salt and Solvent as Entrainer: Process Simulation," Brazilian Journal of Chemical Engineering, 25(01):207-215.

[10] Ackland, Toni, 2012, Home Distillation of Alcohol, accessed from http://homedistiller.org on March 17th 2013

[11] Nixon, M., Mc. Gaw, 2001, The Compleat Distiller, Auckland, The Amphora Society

[12] Anonim, 1999, Buiding a Home Distillation Apparatus, Small Still Engineering, LLC

[13] Anonim, 2003, Ethanol Plant Development Handbook, Colorado, BBI International

[14] Muslim, M., A., Nusantoro, G.,D., "Design and Development of Vacuum Distiller for Bioethanol Production," Proceeding of NETS 2013 International Conferece, 2013