PID Control for Temperature and Motor Speed Based on PLC

Muhammad Faqihuddin Al-Andzar [a,1], Riky Dwi Puriyanto [b,2,*]

[a,b] Department of Electrical Engineering, Faculty of Industrial Technology, Ahmad Dahlan University
South Ringroad Street, Kragilan, Tamanan, Banguntapan, Bantul, Special Region of Yogyakarta 55191, Indonesia
[1] faqihuddin9@gmail.com [2] rikydp@ee.uad.ac.id*
* corresponding author

ARTICLE INFO

Article history
Received
Revised
Accepted

Keywords
Motor Control
Temperature Control
Biodiesel Reactor
PID
PLC

ABSTRACT

Transesterification process of used cooking oil to biodiesel need heating and mixing of ingredients and catalyst at temperature of 30-65°C and stirring speed of 700 rpm for 60 minutes. This research builds a prototype of biodiesel reactor control system to control those process automatically. The system is built using heater element, LM35DZ temperature sensor, DC motor to drive the stirrer, and rotary encoder sensor. PLC OMRON CP1E NA20DR-A is used as system controller by using PID algorithm. The results of this research shows that this system works well as expected. Test results of motor speed control shows, at 700 rpm set point this system gives stable response at 100 % Proportional band, 1,6 s Integral, and 0,2 derivative PID parameters, the system at this setting gives fast rise time and have small overshoot. Test result of temperature control shows, at 60°C set point this system works well at 1% proportional band, 400 s integral, and 0 s derivative PID parameters, the system at this setting gives fast rise time and stable steady state.

1. Introduction

Currently Indonesia still depending on fossil based fuel as energy source [1]. This makes right now and in the future Indonesian energy source will still be depending on the oils availability [1]. One of the way to reduce oils dependence is by developing environmental friendly fuels [2]. Indonesia has alternate energy source potency in great quantity. Some of them are biodesel and bioethanol that's made from plants [3]. Biofuels consumption as renewable energy in Indonesia as well as the world is still low [1]. The Indonesian government has established a policy which encourage biofuels development to optimize renewable energy supply in which increase usage of biofuel, such as President Instruction no. 1 year 2006 about supply and usage of biofuel as alternative fuel, and President Decision no. 26 year 2006 about the establishment and tasks of National Team of biofuel usage acceleration to reduce poverty and unemployment.

One of the biodiesel ingredients which is easy to obtain and affordable is used cooking oil [4]. The process of biodiesel production from used cooking oil uses transesterification method, which is reacting purificated used cooking oils with alcohol and catalyst by heating them at temperature of 30-65 °C while mixing them [5][6]. The optimal mixing speed is 100-700 rpm for 30-120 minute duration [7]. Both process of heating and mixing are very important because it determine the biodiesel quality, thus require to be controlled automatically and precisely [8].

Automatic control has been developed and used widely for many sectors. Technology development caused many sophisticated device that allow control system to be done automatically, safer, lower cost, and easier to use [9]. One of the devices is Programmable Logic Controller (PLC).

PLC is a device to control various production machinery according to the programming to achieve some objective [10].

PLC has been used widely within industrial environment to control complex production machinery [10]. Its role as control device has been satisfying many companies for it's easy to use, maintenance and quick repair. Knowledge of PLC is very important and it is utilization has been widely used. These things underlie the writer to design "Control System of Motor speed and Fluid Temperature At Biodiesel Reactor Based On PLC". The PLC used for this research is PLC OMRON CP1E NA20DR-A because it has PIDAT instruction which is easy to operate without the need to write mathematic formula to the ladder program. PID algorithm is used as the control method because of it's simplicity and has been widely used in industrial world [11]. Control automatization of mixing and heating is expected to be able to increase transesterification processing efficiency and improve biodiesel quality. Moreover, the easiness of operation can ensure safety of the machine operator [12].

This research is built using 12 VDC motor as mixer, rotary encoder sensor to measure motor speed, heater element, LM35DZ temperature sensor [13], and PLC as the system controller. The work principle of this system is to switch the heater on-off to maintain the temperature set points while maintain motor speed which stir the mixer [14]. The DC motor is coupled to rotary encoder sensor and the LM35DZ is within the fluids of biodiesel reactor.

2. Method

2.1. Hardware Design

Hardware design is made as block diagram. This design consist of 4 parts which is control system, sensor, actuator, and plant. Figure 1. shows the block diagram of the hardware design.

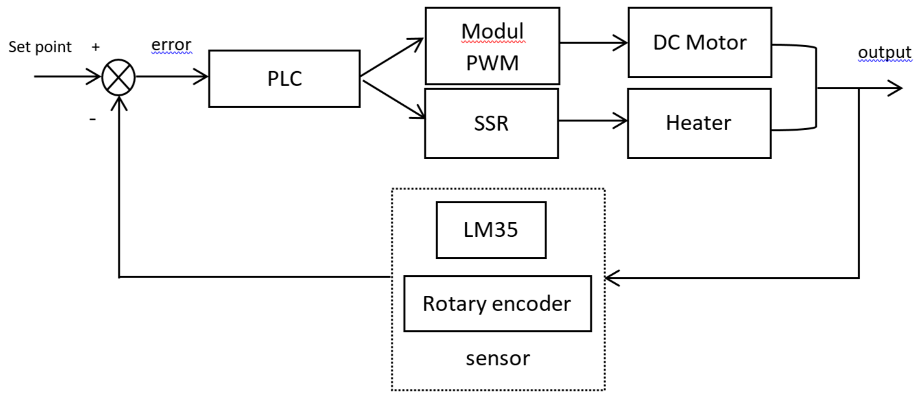

Fig. 1. Block diagram of hardware design

Control system in this design uses PLC OMRON CP1E NA20DR-A to calculate, process, and control input data form the sensors and give the output command to the actuators. The sensor which used to read the temperature is LM35DZ with amplified output and the sensor which used to read the motor speed is LPD3806-400BM rotary encoder. The sensor's reading result is processed with the set points by PID algorithm at PLC to produce output commands to the actuators. Figure 2. Shows the biodiesel reactor prototype design.

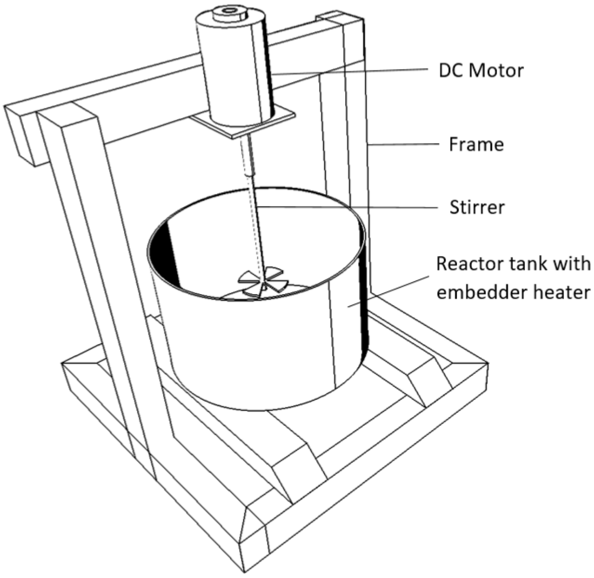

Fig. 2. Biodiesel reactor prototype design

The actuator used in this system is a heater element to increase temperature of the reactor tank and a DC motor which it's shaft is coupled to the stirrer. The heater element is switched on and off using solid state relay to maintain the set point. The DC motor speed controlled using Pulse Width Modulation (PWM) method which generated from a voltage to PWM converter circuit. This circuit converts voltage analog output form PLC to duty cycle percentage of PWM signal. PWM method is chosen because it can maintain tors

2.2. Program Design

Program design in this research consist of 3 sections which is temperature control design, motor speed control design, and Human Machine Interface (HMI) design. The temperature and motor speed control design was built using CX-Programmer and the HMI was built using CX-Designer. Figure 3. Shows the flowchart of the program design.

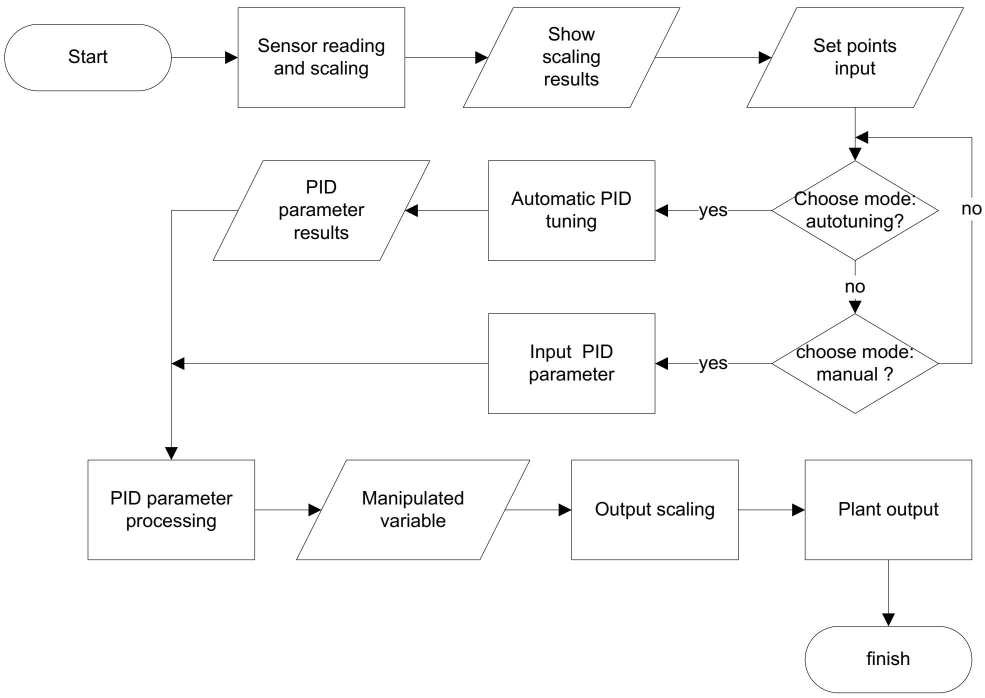

Fig. 3. Program's flowchart

The programs work steps begins with sensor readings of the temperature and motor speed. The readings value then is scaled so it can be shown as the real value at the HMI. Those real value of sensor readings is used as present value (PV) input for PIDAT instructions. The PID tuning can be done in manual mode and autotuning mode. The manual tuning is done by inputting set point, PID parameters and sampling time manually. The autotuning mode is done by inputting the setpoint and sampling time then activating the autotuning bit. The PIDAT instruction process these inputs and give manipulated variable (MV) which used as output commands.

2.3. Human Machine Interface (HMI) Design

HMI designed using CX-designer software. The HMI comprised of two pages, namely temperature control page and motor speed control page. Figure 4. Shows the designed temperature control interface page.

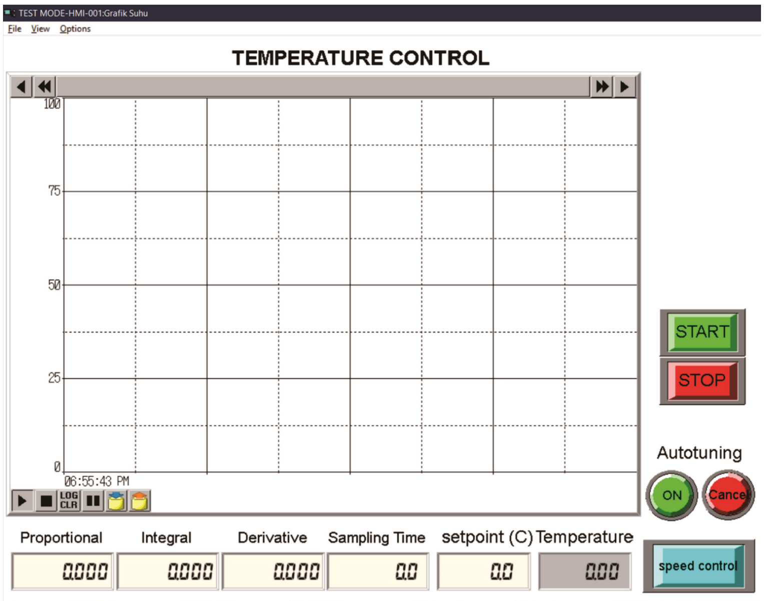

Fig. 4. Temperature control interface page

This page is used to monitor the temperature the sensor reads, input the value required such as set point, PID parameters, sampling time, and activate the autotuning mode. The control process also starts and stops from this page. The graphic shows curves which can be used to observe the system response. Furthermore, it has data log feature to save the temperature reads in the csv. file Format. Figure 5. Shows the motor speed control interface page.

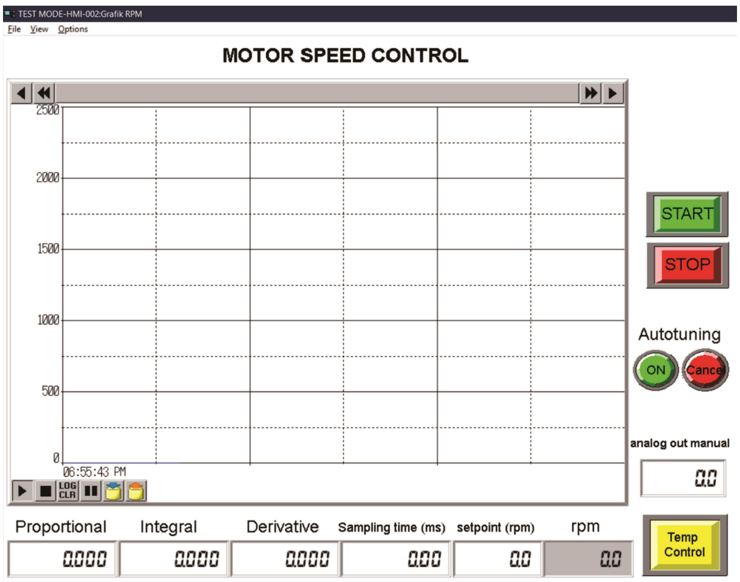

Fig. 5. Motor speed control interface page

Similar to temperature control page, this page is used to monitor the motor speed reads by the sensor, input set point, PID parameters, sampling time, activate the autotuning mode, starts and stops the control process. This page has feature to give manual analog output command to the motor.

Unlike the usual PID constant such as proportional constant (Kp), integral constant (Ki), and derivative constant (Kd), PIDAT instructions uses PID parameters such as proportional band (PB), Integral Time (Tik), and Derivative time (Tdk). Proportional band equation is:

$$PB = 100 / K_P \tag{1}$$

With:
PB = Proportional band (%)
K_P = proportional constant
While integral time (Tik) equation is:

$$K_I = K_P / Tik \tag{2}$$

with :
K_I = integral constant
K_P = proportional constant
Tik = integral time (s)
And *derivative* time (Tdk) equation is:

$$K_D = K_P \times Tdk \tag{3}$$

K_d = derivative constant
K_p = proportional constant
Tdk = derivative time (s)

3. Results and Discussion

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

3.1. Motor Speed Control Testing

Motor speed control testing is done in order to find out whether the system built is working as expected that is to control DC motor speed using PID method. This testing is done at the motor which drive the stirrer stirring 500 ml used cooking oil while being heated inside the reactor. Set point is given at 700 rpm with sampling period of 100 ms. The testing results are shown in figure 6.

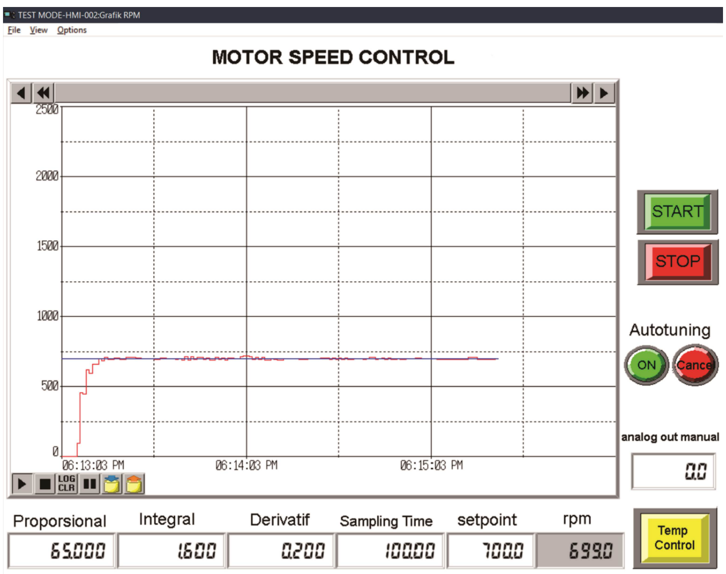

Fig. 6. Motor speed control testing result

Various testings is done by giving some variations to the proportional band and the results is shown in table 1.

Table 1. Motor speed control testing results

No.	PID Parameter			Average error (%)	Deviation standart (rpm)
	Proportional band (%)	*Tik (s)*	*Tdk (s)*		
1.	45	1,6	0,2	44,52	45,44
2.	50	1,6	0,2	6,09	16,45
3.	55	1,6	0,2	9,42	10,06
4.	60	1,6	0,2	0,7	3,86
5.	65	1,6	0,2	0,68	4,12

From the testing results above, motor speed control gives the most stable system response at the PID parameter of P= 65%; Tik= 1,6s; Tdk= 0,2s; with rise time = 10 sec, peak time = 11 sec, maximum overshoot = 1 rpm, settling time = 13 sec, and error steady state = 4,78 rpm.

3.2. Temperature Control Testing

Temperature control testing is done to find out wether the system built can work as intended which is to control temperature using PID control method. The testing is done by heating while stirring 500 ml used cooking oil inside the reactor at 700 rpm stirring speed. Set point value is given at 60 °C with 500 ms sampling time. Figure 7. shows the testing result.

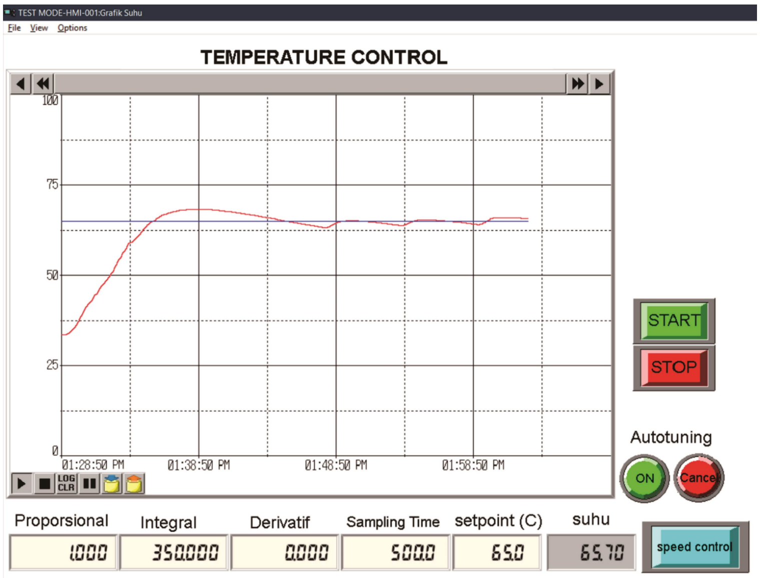

Fig. 7. Temperature control testing result

Various integral time is given and the results is shown in table 2.

Table 2. Temperature control testing results

No.	PID Parameter			Average error (%)	Deviation standard (°C)
	Proportional band (%)	*Tik (s)*	*Tdk (s)*		
1.	1	200	0	7,66	3,83
2.	1	250	0	6,04	3,25
3.	1	300	0	9,33	4,866
4.	1	350	0	1,87	1,114
5.	1	400	0	1,5	0,664

From the test results above, temperature control give the most stable system response at PID parameter of P= 1%; Tik= 400s; Tdk= 0s; with rise time = 377 sec, peak time = 531 sec, maximum overshoot = 2°C, settling time = 1095 sec, and error steady state = 0,98 °C.

4. Conclusion

This Research has successfully design and build a prototype system of motor speed control and fluid temperature of biodiesel reactor based on PLC by using PID algorithm using PLC OMRON CP1E NA20DR-A. This research has also successfully implement PID control method in manual mode for motor speed control and temperature control. The test results shows that motor speed control gives stable system response at Proportional band = 65%; integral time (Tik) =1,6 s; derivative time (Tdk) =0,2 s with error steady state 4,78 rpm. The test reslts also shows that fluid temperature control gives stable system response with low overshoot at Proportional band =1 %; integral time (Tik) = 400 s; derivative time (Tdk) = 0 s with *error steady state* 0,98 ^{o}C.

References

[1] A. Kharina, C. Malins, and S. Searle, "Biofuels policy in Indonesia: overview and status report," *Int. Counc. Clean Transp. Washington, DC, USA*, no. August, p. 14, 2016.

[2] F. Harahap, S. Silveira, and D. Khatiwada, "Cost competitiveness of palm oil biodiesel production in Indonesia," *Energy*, pp. 62–72, 2019.

[3] I. S. Tulliza, E. Hartulistiyoso, D. Kusdiana, and A. H. Tambunan, "Characteristics of Palm Oil Biodiesel Produced with a Static Mixing Reactor," *Int. J. Oil Palm*, vol. 1, no. 2, pp. 50–57, 2018.

[4] A. Kharina, S. Searle, D. Rachmadini, and A. A. Kurniawan, "THE POTENTIAL ECONOMIC , HEALTH AND GREENHOUSE GAS BENEFITS OF INCORPORATING USED COOKING OIL INTO INDONESIA ' S BIODIESEL," no. September, 2018.

[5] S. Unni K, Z. Yaakob, M. Pudukudy, M. Mohammed, and B. N. Narayanan, "Single step production of biodiesel from used cooking oil," *Proc. 2013 Int. Renew. Sustain. Energy Conf. IRSEC 2013*, pp. 461–464, 2013.

[6] M. Fangrui and H. Milford, "Biodiesel production: A review," *Bioresour. Technol.*, vol. 70, no. 1, pp. 1–15, 1999.

[7] J. M. Fonseca, J. G. Teleken, V. de Cinque Almeida, and C. da Silva, "Biodiesel from waste frying oils: Methods of production and purification," *Energy Convers. Manag.*, vol. 184, no. January, pp. 205–218, 2019.

[8] E. K. Okoye, C. P. C. Edeh, C. O. Ezumezu, and E. C. Ejiogu, "Biodiesel production from used cooking oil using controlled reactor plant," *IEEE AFRICON Conf.*, pp. 1–4, 2013.

[9] A. A. A. Rahim, M. H. M. Shah, I. S. A. Halim, and S. L. M. Hassan, "Programmable Logic Controller (PLC) for polymer mixing tank," *ISCAIE 2012 - 2012 IEEE Symp. Comput. Appl. Ind. Electron.*, no. Iscaie, pp. 136–141, 2012.

[10] E. R. Alphonsus and M. O. Abdullah, "A review on the applications of programmable logic controllers (PLCs)," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 1185–1205, 2016.

[11] S. Al Yusuf, "Development of PLC and SCADA based Integrated Thermal Control System with Self / Auto-tuning Feature," *2018 Cond. Monit. Diagnosis*, pp. 1–6, 1922.

[12] R. E. Samin, L. M. Jie, and M. A. Zawawi, "PID implementation of heating tank in mini automation plant using programmable logic controller (PLC)," *InECCE 2011 - Int. Conf. Electr. Control Comput. Eng.*, pp. 515–519, 2011.

[13] G. Rata and M. Rata, "Temperature control solution with PLC," *Proc. 2016 Int. Conf. Expo. Electr. Power Eng. EPE 2016*, no. Epe, pp. 571–575, 2016.

[14] S. Gulpanich, V. Krongratana, A. Srimuang, V. Tipsuwanporn, and N. Wongvanich, "PLC-based industrial temperature controller with different response times," *Int. Conf. Control. Autom. Syst.*, vol. 2017-Octob, no. Iccas, pp. 522–527, 2017.