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Water bath sonicator integrated with PID-based temperature controller for flavonoid extraction

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ABSTRACT

In this research, water bath sonicator was fabricated to extract bioactive compound of plants material using sound energy (ultrasonic waves) and heater. The bioactive compound, flavonoid, has high sensitivity to temperature and extraction time and previous research stated best treatment with combination of 45˚C and 20 minutes. Therefore, fabricated water bath sonicator was equipped with proportional integral derivative (PID) based temperature controller and timer. Based on a calculation using the Ziegler-Nichols tuning method, Kp, Ki, Kd parameters are 16.59, 0.0279, and 2463.6, respectively. The experimental result shows that the PID controller can perform as design specification with overshoot 1.39%, error steady-state 0.688% and settling time 37.2 minutes. Furthermore, it was proven that the PID controller has contribution to extract more flavonoid.

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1. INTRODUCTION

Flavonoid is a useful natural substance which can be found in plants (fruits, flowers, vegetables, roots, grains, bark, stems, and tea). It is a needful bioactive compound for various applications, such as medicinal, pharmaceutical, and cosmetic [1-3]. Soursop leaf (*Annona muricata L*) has a very potent antioxidant ability which can be associated with flavonoid [4-8]. There are several techniques to extract flavonoid from soursop leaf. Ultrasound-Assisted Extraction (UAE) is reported as one of the techniques [9, 10].

Previous research about the influence of temperature and time on flavonoid extraction was conducted. The research was done for soursop leaf using ultrasonic with temperatures of 35˚C, 45˚C, 55˚C during 10, 20, 30 minutes. Combination of the temperatures and the times for flavonoid extraction were set manually. There are 9 combinations and each combination experiment was done 2 times, so that 18 samples were provided. The results confirmed that the best combination is the one with a temperature of 45˚C and 20 minutes [11].

Generally, the temperature controls are used in industry and divided into constant temperature heating mode and uniform velocity temperature control mode [12-14]. Temperature control can be realized using fuzzy control [15] or others. Combination of proportional, integral, and derivative controllers can also be used for temperature controller, such as Proportional-Integral (P-I) or Integral-Proportional (I-P) controllers [16]. Furthermore, some parameters (K_p, T_i, T_d) must be tuned when the controllers will be used, especially for Proportional Integral Derivative (PID) controller [17-20].

Tuning of PID controller parameters is essential due to the various applications. Different tuning methods, such as Ziegler-Nichols, Cohen-Coon, Chien-Hrones Reswick, and optimum tuning methods, can produce different responses [21]. In a research paper [22], several PID controller tuning methods like Ziegler-Nichols, Chien-Hrones-Reswic, and Chien et al. were evaluated in open-loop test. The result stated that the Ziegler-Nichols method gives the best rise times, settling times, and smaller integral absolute error (IAE). However, other research papers and applications may state a different conclusion. The Ziegler-Nichols method is not only used for temperature controller but also other applications, such as speed control of DC motor [23].

In this paper, design of soursop leaf extraction for flavonoid using water bath sonicator is proposed. The sonicator is integrated with the Ziegler-Nichols tuned PID controller and timer to control the temperature of 45˚C during 20 minutes automatically. Furthermore, this paper presents research method in section 2. Section 3 describes experiment result and analysis. Finally, section 4 concludes this study.

2. RESEARCH METHOD

This research was conducted based on several specifications. Block diagram of the system is shown in Figure 1. This research needs 2 preparations, i.e. hardware preparation and software preparation. The hardware preparation consists of detail explanation about the used components and working of the setup. While the software preparation discusses the design of timer and PI and PID controllers applied to the controller.

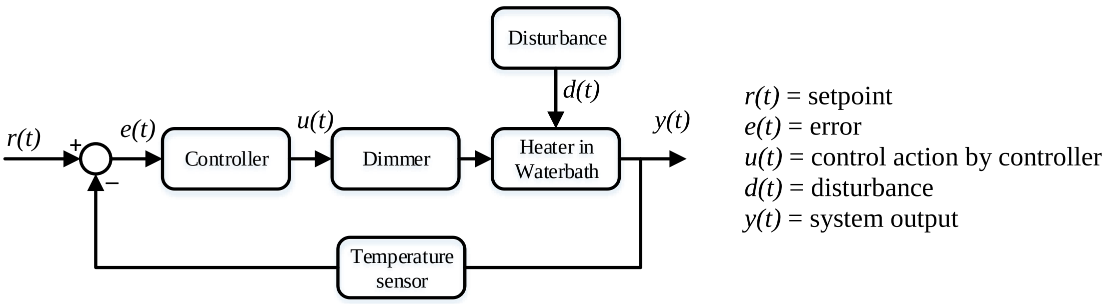

Figure 1. Block diagram of the proposed system

2.1. Hardware preparation

The water bath sonicator used in this research is shown in Figure 2. A temperature sensor DS18B20 was employed, providing a feedback signal to the system. In order to increase the temperature of water in the water bath, 500 watt heater was installed. An AC dimmer is used to control power supply of the heater. A 6 volt high torque DC motor was used to stir and flatten the water temperature in the water bath. Ultrasonic devices were used to make cavitation in the water bath. Inside the control unit, there is microcontroller Arduino Uno as the controller. LCD was installed to display temperature and timer. The quantity of water used in the designed water bath is 6 liters. When it is turned ON, the stirring motor operates. And then, it is followed with the temperature sensor. Normally, the used water has temperature less than 45˚C (setpoint entered to control unit). Therefore, the heater is then turned ON. After that, PI and PID controllers are applied in control unit to make the measured temperature same as setpoint. When it reaches 45˚C, ultrasonic devices are turned ON for flavonoid extraction during 20 minutes, while keep maintaining the temperature. User may monitor through the LCD. After 20 minutes, the heater, the ultrasonic devices, and the stirring motor are turned OFF.

2.2. Software preparation

Software preparation is focused on the controller (see Figure 1). In this research, microcontroller Arduino UNO runs the flowchart shown in Figure 3. The timer and setpoint achievement using the PID controller are the essential parts. The timer was easily realized by the microcontroller feature, delay timer. Furthermore, the design specification of the PID controller is determined by the response that must have error steady-state and overshoot of less than 2% and 5%, respectively. Setpoint used in this research is the temperature of 45˚C. Performance of PI and PID controllers are compared using the setpoint. Better performance controller must be used for the water bath sonicator.

The arduino UNO runs PI and PID controllers during realizing "present value = setpoint" (see Figure 3). A PI controller can be stated as follow

$$u(t) = K_p.e(t) + K_i \int e(t)dt \quad (1)$$

while a PID has an additional term

$$u(t) = K_p.e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (2)$$

In (1) and (2), $u(t)$ is a control action provided by controller while K_p, $K_{i,}$ and K_d are proportional gain, integral gain, and derivative gain, respectively. In order to achieve design specification, the PID controller must be tuned to achieve performance specification. The first Ziegler–Nichols method was used for tuning of PI and PID controller following reference [24]. A tangent line generated on the step response of the open-loop system is the basis for obtaining the parameters of the PID controller. An open-loop step response of the water bath sonicator is depicted in Figure 4. From the figure, delay time (*L*) and time constant (*T*) were obtained. The *L* and *T* have the value of 297s and 4107s, respectively. Following Ziegler–Nichols first method mentioned in reference [24], proportional gain (*Kp*), integral time (*Ti*), derivative time (*Td*) of PID controller were determined as 16.59, 594, 148.5, respectively. Based on the values, integral gain (*Ki*) and derivative gain (*Kd*) can be calculated as follow.

$$Ki = \frac{Kp}{Ti} = \frac{16.59}{594} = 0.0279 \quad (3)$$

$$\text{Kd} = \text{Kp x Td} = 16.59 \text{ x } 148.5 = 2463.6 \quad (4)$$

In order to compare the PID controller performance, PI controller must also be tuned. By calculating with the same method, the values of *Kp* and *Ti* are 12.44 and 990, respectively. Using the values, *Ki* can be calculated as follow.

$$Ki = \frac{Kp}{Ti} = \frac{12.44}{990} = 0.01256 \quad (5)$$

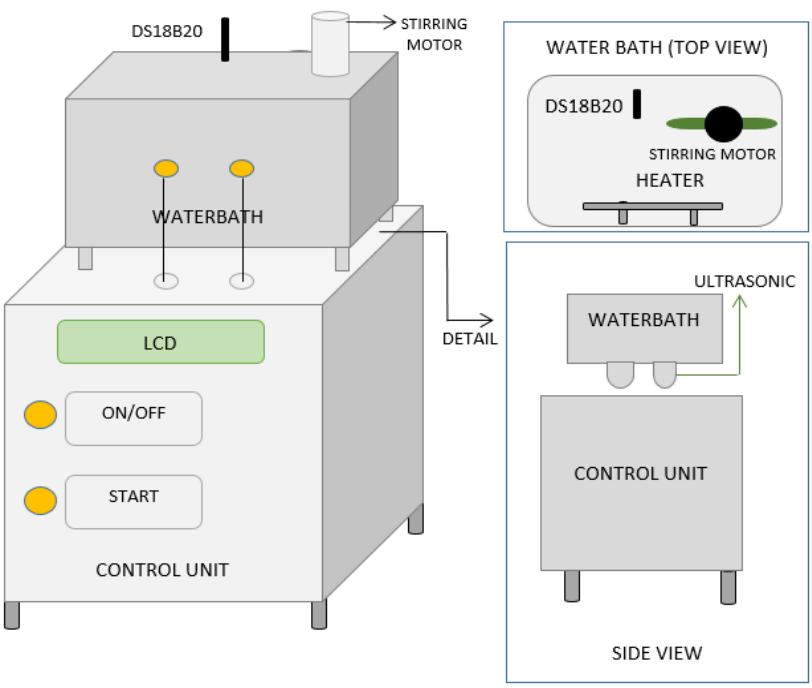

Figure 2. The setup of water bath sonicator

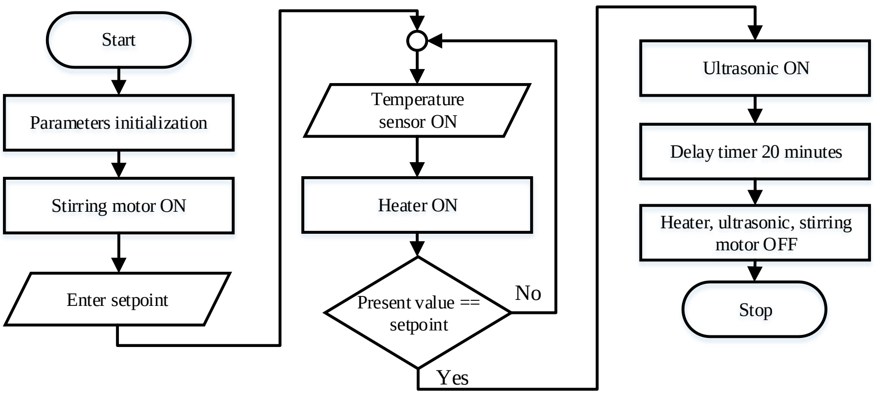

Figure 3. Flowchart of microcontroller

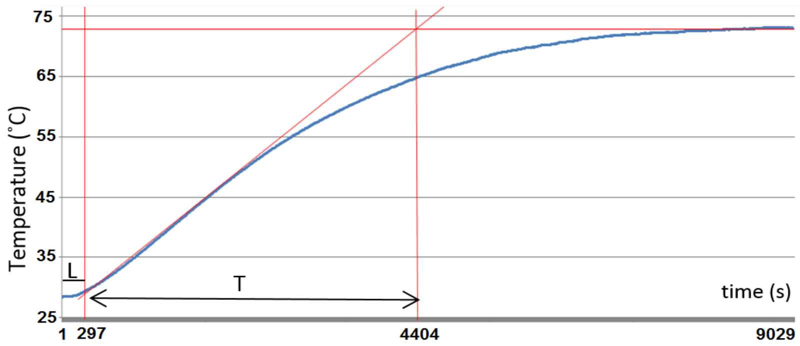

Figure 4. Open-loop response

3. RESULTS AND ANALYSIS

In this section, experimental results are presented. The experiment is focused on the implementation of the temperature controller. Performance of the PI controller is compared with a PID controller. Then, the better performance one is used for the experiment of overall extraction system to confirm the effectiveness of temperature control.

3.1. Experiment of controllers without disturbance

In this experiment, setpoint is 45˚C. Response of the PI and PID controllers are shown in Figures 5 and 6, respectively. Overshoot, error steady state, and settling time are summarized in Table 1. Both controllers have overshoot and error steady state which achieve the design specification. However, settling time of the PID controller is shorter than the PI one. Since settling time is the most important parameter for this system, PID controller suitable for this purpose.

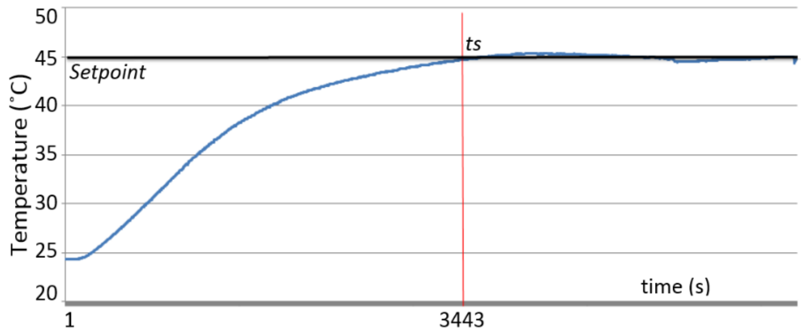

Figure 5. Response of PI controller (without disturbance)

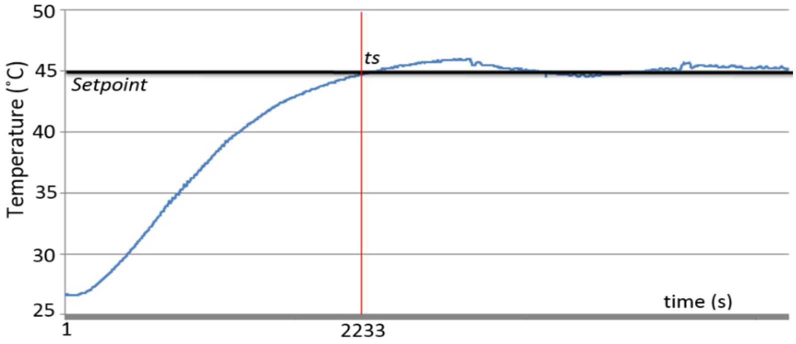

Figure 6. The response of PID controller (without disturbance)

Table 1. Responses summary (without disturbance)

Controllers	Overshoot	Error steady state	Settling time
PI	0.823%	0.13%	57.4 min.
PID	1.39%	0.688%	37.2 min.

3.2. Experiment of controllers with disturbance

Using same setpoint, disturbance is applied through 1.5 liters water reduction and addition. Analysis is focused on recovery time (t_r) which is started when disturbance is given (t_0). Response of the PI and PID controllers are shown in Figures 7 and 8, respectively. The t_r of the PI and PID controllers are 55.6 and 33.9 minutes, respectively. Therefore, the t_r of the PID controller is shorter than the PI one. On the presence of disturbance, the purpose of the controller is to make recovery time as soon as possible. Hence, PID controller is more suitable for this purpose.

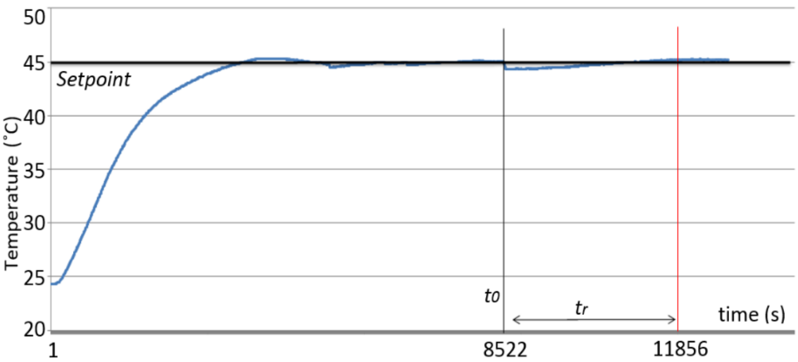

Figure 7. Response of PI controller (with disturbance)

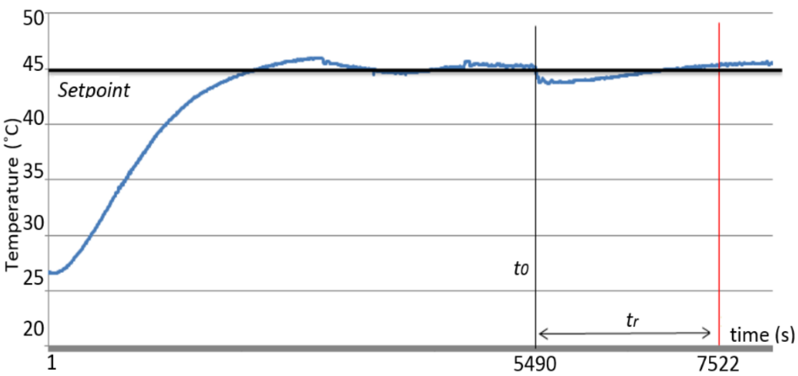

Figure 8. The response of PID controller (with disturbance)

3.2. The experiment of the overall extraction system

Since the PID controller has a shorter settling time, the overall extraction system is examined with a PID controller. Soursop leaves were extracted by the water bath sonicator with 45˚C during 20 minutes, and the result was examined by using the colorimetric method to measure the total flavonoid, as mentioned in reference [25]. Samples were taken for the extraction using PID controller (automatic extraction) and without controller (manual extraction). The extraction result can be seen in Table 2. With the same sample concentration, the automatic extraction produced more flavonoid than the manual one. Eventhough there is overshoot during disturbance applied, the automatic one is still better than the manual one.

Table 2. Flavonoid extraction result

Samples	Sample concentration (μ/ml)	Total flavonoid QE(mg/g extract)
Automatic extraction	1000	229.7879
Manual extraction	1000	214.4848

4. CONCLUSION

In this paper, fabrication and experimental evaluation of water bath sonicator with a PID-based temperature controller and timer have been reported. The PID controller can accomplish design specification and be proven to be suitable for the ultrasonic-assisted extraction. Finally, the automatic extraction has more total flavonoid than manual one. In the future, other tuning method or control method with less overshoot will be applied to get more total flavonoid. Then the effect of the overshoot on total flavonoid can be reported.

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