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Coffee Bean *Roasting* Machine with PD *(Proportional - Derivative)* Control System Arduino-Based

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Abstract— *Roasting coffee beans is a process to convert raw coffee beans into roasted coffee beans that have distinctive aroma and taste characteristics. The arduino-based automatic coffee bean roasting and cooling machine uses arduino due for data processing and processing and uses a 3.2 inch LCD touchscreen nextion to display data during the roasting process. The controller used is PD control with kp = 34.98 and Td = 9.5. For the preheating process in the roasting tube takes 40 minutes to reach the required temperature setpoint of 100 ° C, for the roasting and cooling process of coffee beans automatically with a weight of 5kg coffee beans requires 39 minutes for the level of light maturity, 56 minutes for the level medium maturity and 103 minutes for the level of dark maturity. While the time needed for the 5kg cooling process of coffee beans takes 25 minutes.*

Keywords— *Roasting; PD Controller; coffee beans; cooler.*

I. INTRODUCTION

Coffee is one of Indonesia's mainstay export commodities in agriculture, the fourth after cocoa, oil palm, and rubber [1]. According to the official website of the Ministry of Trade (Kemendag), the production result of Indonesian coffee farmers penetrated the United States market with export values reaching 138.8 in 2017 and 123.6 in 2018[2].

Indonesia is one of the largest coffee-producing countries in the world [3]. Madiun Regency, East Java, precisely in the Kandangan village, Kare district is one of the coffee-producing areas. The most famous types with their distinctive scent are Arabica and Robusta coffee. Coffee is distinguished by its taste and acidity after processing. This is influenced by natural factors where coffee is grown, such as soil type, soil height above sea level, plant groups, and the coffee cultivation process itself. One of the flavors and scents in coffee drinks was formed through the post-harvest process, namely roasting [4]. The level of maturity of coffee beans from roasting creates a variety of flavors and scents in coffee drinks, but currently, there is still little knowledge about how to properly roast coffee beans to produce quality coffee beans [5].

Roasting is a food ripening technique using fat or oil, whether naturally contained in food or not [7]. The minimum temperature for *roasting* is 150°C. While coffee *roasting* is the process of roasting *green beans* to a certain level of maturity. Roasted seeds will be ready for consumption after passing through the *first crack,* usually characterized by a sweet scent due to the caramelization process in the seeds [8]. In the coffee roasting process, temperature and time will affect the final result and taste of the coffee (Sesame Coffee).

The problem faced in the coffee bean roasting process for the Coffee Farmer Group in Kandangan, Kare, Madiun is that their machine does not have a cooling process that's used to lower the temperature of the coffee beans after going through the roasting process. So the farmers still do the cooling of coffee beans manually and the cooling process is carried out for a day and a night.

Based on these problems, "Coffee Bean Roasting Machine with PD (Proportional - Derivative) Control System Arduino-Based" was made. The working principle of this machine is to roast the coffee beans and lower the temperature of the coffee beans after the roasting process automatically. In the roasting process, it uses a PD (Proportional- Derivative) control system to regulate the motion of the servo motor on the gas valve and also uses three choices of coffee bean maturity levels, namely light, medium and dark with the heating temperature of the roasting tube which is determined based on testing and the time required for the roasting process varies based on the choice of the maturity level of the coffee beans selected and the weight of the coffee beans to be roasted. This PD control system works based on the temperature setpoint after the heating process and after the coffee beans enter the roasting tube and the actuator is controlled in the form of a servo motor on the gas valve to regulate gas pressure during the roasting process. After the roasting process is complete, the coffee beans come out of the roasting tube and into the cooling container. In this cooling system, it functions to lower the temperature of the coffee beans after the roasting process with the help of a fan in the cooling container while removing the rest of the coffee bean skin that is still attached during the roasting process [9]. This chine can accommodate as much as 2 to 5 kg of coffee beans. And it is hoped that this machine can be useful for coffee farmers because there is already a cooling process in this machine making it easier for farmers to cool the coffee beans after roasting.

II. METHODOLOGY

A. *Tools and Materials*

In the manufacture of "Coffee Bean Roasting Machine With-Based PD (Proportional – Derivative) Control System Arduino-Based" on a coffee bean roaster using the following tools:

- Arduino Due.

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- *Thermocouple k-type* and MAX6675 module.
- *Load Cell* Sensors and HX-711 module.
- Motor Servo dan *valve* gas.
- *Liquefied Petroleum Gas*.
- LCD Touchscreen.

B. System Block Diagram

The Block Diagram of a Coffee Bean Roasting Machine with an Arduino-Based PD (Proportional – Derivative) Control System is shown in Figure 1. as follows:

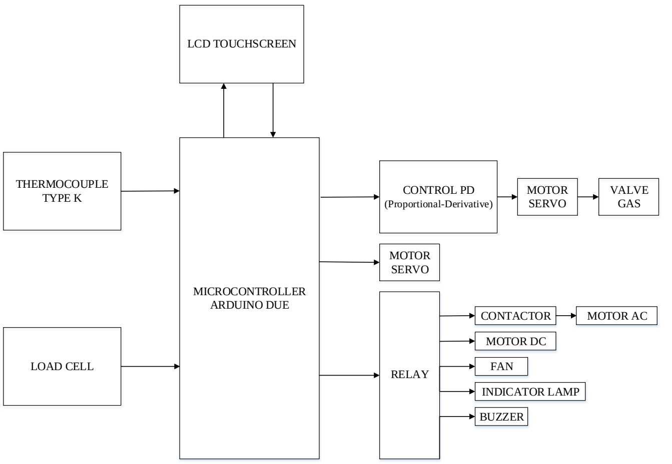


Fig. 1. Block Diagram System

The working principle of this automatic coffee roaster is that this tool will start to work when the tool starts to be given a voltage. The AC motor driving the roasting tube will rotate counterclockwise. When the start command is displayed on the LCD screen, the servo motor opens the gas cylinder valve to start the fire and heat the roasting tube. When the temperature in the roasting tube has reached the set point first, then choose the maturity level of the coffee beans (light, medium, and dark). After selecting the level of maturity of the coffee beans as desired, the coffee beans begin to enter the roasting tube. The capacity of the roasting tube is between 2 to 5 kg. After the coffee beans enter the roasting tube, the temperature in the roasting tube will drop. This is influenced by the temperature of the coffee beans themselves.

After the temperature in the roasting tube starts to rise again, the temperature will be stable until the roasting process is finished according to the time of the choice the level of maturity of the coffee beans, and the weight of the roasted coffee. After the timer runs for the desired time, the tube valve will close which causes the fire to die and stop the roasting process and the coffee beans enter the cooling container to lower the temperature of the coffee beans after roasting. When the roasting time is over, the AC motor driving the tube will rotate clockwise to remove the coffee beans that are in the roasting tube into the cooling container. The cooling case contains a fan and a DC motor for lowers the temperature of the coffee beans after roasting in the cooling tube. After the temperature of the coffee beans has dropped for a predetermined time (based on experiments), the whole system will stop and the beans will come out of the cooler. There is an indicator in the form of a buzzer sound and an indicator light that indicates the roasting and cooling process has been completed. During the process, the LCD screen will display a marker that the roasting process and the cooling process is in operation.

C. Flowchart

The flowchart in " Coffee Bean Roasting Machine with PD (Proportional - Derivative) Control System Arduino- Based " is divided into 2 parts, namely the coffee roasting system, and the coffee cooling system. For more details, see Figure 2. and Figure 3.

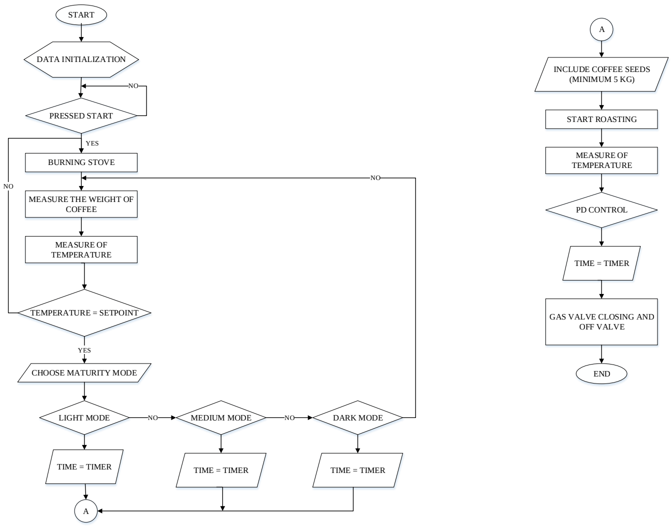


Fig. 2. Coffee Roasting System Flowchart

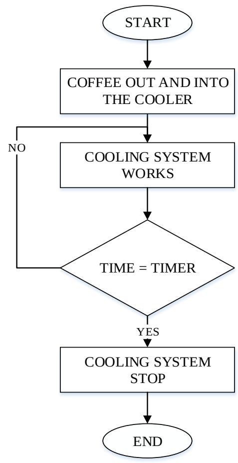
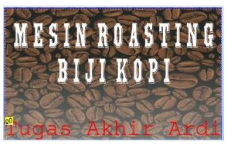


Fig. 3. Coffee Cooling System Flowchart

D. Flowchart Design

For interface design on the Touchscreen LCD, you can we see in figure 19.



(a)

(b)

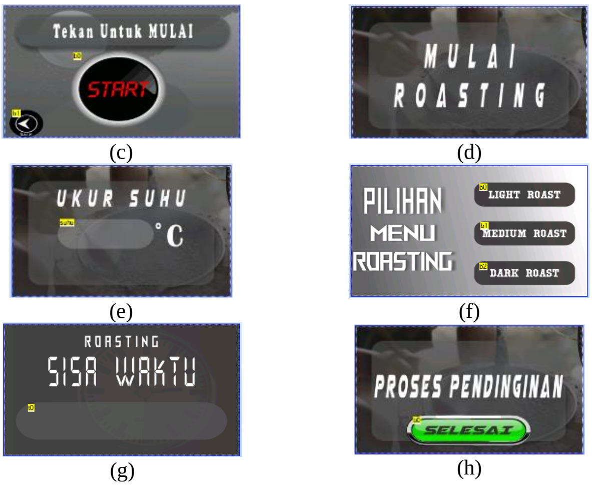


Fig. 4. (a). Initial view (b). Display when weighing coffee beans (c). Display to start *roasting* (d). Display indicating the *roasting* process has started (e). Display when measuring temperature (f). Display for selecting roasting mode options (g). Display when the timer process is running (h). Display when the cooling process is running

The explanation of each image above is as follows:

1. Initial view of the LCD Touchscreen as shown in Figure 4 (a).
2. Display when coffee beans are weighed with the Load sensor Cell as in Figure 4 (b).
3. The display for starting roasting where there is a "START" button which functions to start the heating process as shown in Figure 4 (c).
4. After pressing the start button, the LCD will display a page indicating the roasting process will begin as shown in Figure 4 (d).
5. Next on the interface screen will display the temperature value read by the Thermocouple sensor as in Figure 4(e). After temperature sensor reaches the setpoint, the LCD screen will move to the coffee bean maturity level selection page.
6. There are three menu options for the maturity level of beans according to different roasting times, namely light, medium and dark. The user will select the level of maturity of the coffee beans as desired by the user as shown in Figure 4 (f).
7. After selecting the maturity level of the coffee beans, the LCD screen will roasting according to the selected level of maturity as shown in Figure 4 (g) *roasting*
8. After the remaining time has finished running, the LCD screen will display a page indicating the cooling process is running. And there is a button that functions to stop the cooling process as shown in Figure 4 (h).

III. PID CONTROL

PD control (Proportional–Derivative) is a feedback mechanism controller that is usually used in industrial control systems. A PD controller continuously calculates the error value as the difference between the desired setpoint and the measured process variable.

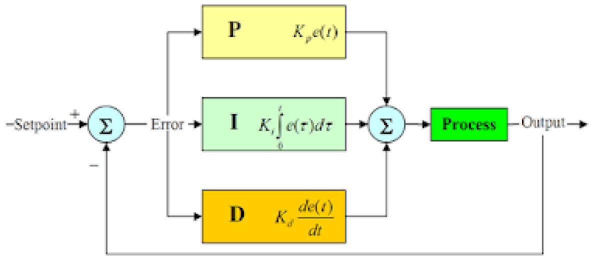


Fig. 5. Block Diagram of PID

The PD (Proportional-Derivative) control components that I use include:

A. Proportional Control

Control P if G(s) = kp, where k is a constant. If u=G(s)•e, then u=Kp•e, where Kp is a Proportional Constant. Kp acts as a gain (amplifier) only without giving a dynamic effect to the controller's performance. The use of P control is quite capable of improving the transient response, especially the rise time and settling time [6]. The proportional controller has an output that is proportional to the magnitude of the error signal (the difference between the desired quantity and the actual value).

B. Derivative Control

The output of the differential controller has properties similar to that of a derivative operation. Sudden changes in controller input will result in very large and rapid changes. Sudden changes in controller input will result in very large and rapid changes. When the input does not change, the controller output also does not change, while if the input signal changes suddenly and increases (in the form of a step function), the output produces an impulse signal. If the input signal changes slowly (a ramp function), the output is a step function whose magnitude is strongly influenced by the rising speed of the ramp function and the constant factor Kd. The control signal u generated by control D can be expressed as G(s)=s•Kd. From the above equation, it appears that the property of control D is in the context of "speed" or the rate of error. With these properties it can be used to improve transient responses by predicting the error that will occur. Derivative control only changes when there is a change in error so that when there is a static error this control will not react, this also causes the Derivative controller cannot be used alone.

The PD (Proportional-Derivative) control used to control the gas valve during the roasting process is so that when the temperature has reached the set point of 185˚C, these Kp and Kd values can maintain the temperature of the roasting process until the coffee beans are ripe according to the selected maturity level. This PD control uses the temperature setpoint from the Thermocouple type k temperature sensor and the output is an angle from the servo motor to control the motion of the gas valve so that the temperature of the roasting tube is maintained according to the setpoint until the roasting process is complete.

IV. RESULTS AND ANALYSIS

A. Testing The Temperature System Response by PD Control Method

This test aims to determine the response of the temperature system in the plant. After testing, the following data were obtained. The data is presented in the form of a graph.

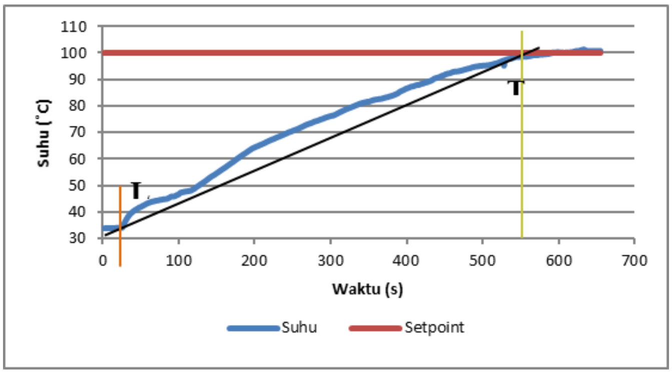


Fig. 6. Graph of Plant Open Loop Temperature

In this test, the transfer function was obtained experimentally by using the process reaction curve method using the first Zieghler – Nichol rule. The transfer function is the characterization of the tool into a formula, where the formula is a digital form of the characteristics of the tool being made.

Based on the figure, it shows that the plant's output is the temperature which continuously increases every time until it reaches a steady state. Then by using Zieghler Nichol's rule, the first method uses a guide line to determine two constants, namely the time delay (L) and the time constant (T). From the figure, it can be seen that the reaction curve increases after a time delay (L). The intersection of the tangent with the abscissa axis is the time delay (L) and the intersection with the maximum line is the time constant (T) measured from the point of delay time (L). So that we get the following data:

L = 19 S
T = 554 S
Setpoint = 100 ˚C

B. Temperature System Response Test

After getting the value of the delay time (L), time constant (T) and also the temperature setpoint. The next step is to determine the value of the PID constant, using the first rule Zieghler Nichol reaction curve graph, then tuning the PID constant, according to the rules of the Zieghler Nichol PID tuning parameter table by calculating the values of the Kp, Ti and Td parameters as follows :

TABLE I. Tuning Constant Zieghler Nichol First PID.

Kp	Ti	Td
$1{,}2 \; x \; \frac{T}{L}$	$2 \; x \; L$	$0{,}5 \; x \; L$
$1{,}2 \; x \; \frac{554}{19}$	$2 \; x \; 19$	$0{,}5 \; x \; 19$
34,98	38	9,5

After getting the PID constant through the Zieghler Nichol calculation the first method, the next step is to implement the PID by entering the PID parameter values that have been obtained into the program, then uploading the program to the Arduino Due microcontroller. The following is a graph of the results of testing the PD control method on the servo to regulate the temperature at the plant.

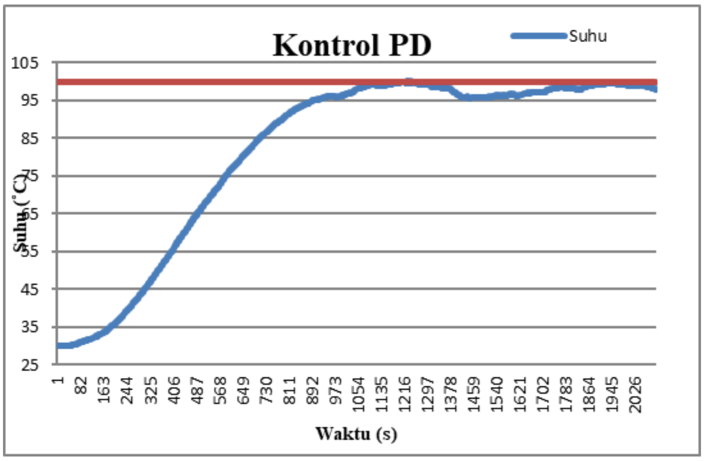


Fig. 7. Graph of PD Control Method Test Results

Based on the results of the PD servo control test to regulate the temperature in the roasting tube, the system performance is obtained as follows:

a) td (delay time) is the time interval when the temperature has not changed to rise, based on the tests carried out td is 34 seconds.
b) ts (settling time) is the time required for the system to reach the final value when it is in a steady state. Based on the test ts is 2029 S. Settling Time is obtained when the temperature has reached 74%.
c) Steady State error is the difference between the set point and the desired final value, after the system reaches its steady state.

$$v\%\,E = \left|\frac{Setpoint - Preset\ Value}{Setpoint}\right| x\ 100\%$$

$$\%E = \left|\frac{100 - 101{,}42}{100}\right| x\ 100\%$$

$$\%\,E = 0{,}0142\ x\ 100\%$$

$$\%E = 1{,}42\%$$

When the plant is running using PD control, the time needed to reach the setpoint can be faster. The time needed to reach the setpoint when using the PD control is 20 minutes. In addition, when the temperature reaches the setpoint or is more than the setpoint, the servo will slowly close to make the temperature in the roasting tube stay at the setpoint. Why use PD control? Because by using this PD control, we can speed up the heating time of the roasting tube and also speed up the roasting time. In addition, the authors use this PD control because the PD control has the advantage that it is easy to tune the control parameters.

C. Testing of Roasting Time Based on the Selection of Coffee Bean Murability

This test aims to determine the roasting time based on the choice of coffee bean maturity level (Light, Medium and

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Dark). This test is still done manually to determine the roasting time of each choice of coffee bean maturity level. The following are the results of the roasting time test based on the choice of the level of maturity of the coffee beans:

– *Light*

TABLE II. Light Roasting Time Test Result.

Picture	Heating Time	*Roasting* Time	Coffee Bean Weight
	35 minutes (100 ˚C)	- 18 minutes - 39 minutes	- 500 g - 5 kg

– *Medium*

TABLE III. Medium Roasting Time Test Result.

Picture	Heating Time	*Roasting* Time	Coffee Bean Weight
	35 minutes (100 ˚C)	- 23 minutes - 56 minutes	- 500 g - 5 kg

– *Dark*

TABLE IV. Dark Roasting Time Test Result.

Picture	Heating Time	*Roasting* Time	Coffee Bean Weight
	35 minutes (100 ˚C)	- 35 minutes -103 minutes	- 500 g - 5 kg

In this test, the roasting tube heating process takes ± 20 minutes with a temperature setpoint of 100 C. In this test, 500 grams and 5000 grams (5 kg) of coffee beans were used. It can be seen that the darker the roasted coffee, the longer it will take for the roasting process itself. For the time required for each choice of maturity level of coffee beans with a coffee weight of 500 grams, namely Light with a time of 18 minutes with a roasting temperature of 100 C, Medium with a time of 23 minutes with a roasting temperature of 100 C, and Dark with a time of 35 minutes with a roasting temperature. 100 C. As for the time required for each choice of maturity level of coffee beans with a coffee weight of 5000 grams (5 kg), namely Light with a time of 39 minutes with a roasting temperature of 100 C, Medium with a time of 56 minutes with a roasting temperature of 100 C, and Dark with a roasting time of 100 C. 103 minutes with roasting temperature 100 ˚C. 100 C. When the coffee is put into the roasting tube, the temperature in the roasting tube drops by about ±84 degrees. The difference in roasting time is long between roasting 500 grams and 5000 grams of coffee beans because the air temperature in the roasting tube will also decrease if the weight of coffee is added too much. This is because if the temperature in the tube drops and there are many coffee beans in the tube, it will take a long time to raise the temperature in the tube because it is influenced by the temperature of the coffee beans themselves. The following is a comparison of the color of the coffee beans starting from before roasting until it is roasted according to the choice of coffee bean maturity level as shown in Figure 8.

Fig. 8. Color Comparison of Coffee Beans

D. Cooling Time Test

This test aims to determine the cooling time of coffee beans after the coffee beans come out of the roasting tube. This test is still done manually to determine the cooling time until the temperature reaches room temperature. The following are the results of testing the coffee bean cooling time to the appropriate temperature (room temperature) :

Fig. 9. Coffee Bean Cooling Test Results

The following table shows the results of the coffee bean cooling test based on the choice of the maturity level of the coffee beans selected during the roasting process.

TABLE V. Coffee Bean Cooling Test Result.

No	Maturity level	First Temperature	Last Temperature	Time Required
1.	*Light*	133 ˚C	33 ˚C	12 minutes
2.	*Medium*	161 ˚C	33 ˚C	14 minutes
3.	*Dark*	180 ˚C	33 ˚C	18 minutes
4.	*Dark*	147 ˚C	33 ˚C	25 minutes

Based on the test data that has been carried out, the data obtained for the time required for the cooling process varies, apart from the dc fan which functions to speed up the cooling process and several other factors that influence the cooling process of coffee beans, these factors include time the cooling process, between the day, afternoon, or night will require different times depending on the ambient air temperature and also the environmental conditions around where the cooling process is carried out, these conditions are in the form of air temperature and also the wind around the equipment used. But basically for the cooling process, each choice of coffee bean maturity level has a different cooling time. Because when the coffee comes out of the roasting tube , the temperature of the coffee beans also varies according to how long the beans have been roasted.

V. CONCLUSION

Conclusions from several experiments and studies that have been carried out are found that:

1. This roasting machine works using PD control. This PD control is used to adjust the opening and closing of the servo motor that mounted on the gas valve which functions to regulate the size of the fire during the roasting process.
2. To set the PD value on this machine, we use the Zieghler Nichol method, the first rule is to find the PID constant value from the open loop experiment (to determine the temperature setpoint of the machine).
3. Roasting time for each choice of maturity level, is determined based on experiments that have been carried out on the weight of coffee beans 500 grams and 5 kg (5000 grams) which we pay attention to based on the stopwatch.
4. The time needed when using PD control and without using PD control is very visible difference. When using PD control the time required to reach the setpoint is faster than without using PD control. This can affect the heating time of the roasting tube and the time of the roasting process.
5. Because the cooling here is not only assisted by a DC fan attached to the cooler, it also depends on the ambient wind conditions. This is because when the experiment was carried out outside.

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