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Implementation of PID controller on Hohenheim tunnel dryer using Ziegler-Nichols Approach method

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Abstract

Hohenheim Tunnel Dryer has two heating mechanisms, namely the solar collectors and the greenhouse effect. Two outlet fans are used to remove moisture from drying as well as to lower the temperature in the drying chamber. Suppose the outlet fans are turned on continuously, the temperature in the drying room will not reach the optimal drying temperature, and vice versa if the outlet fans are not turned on, the drying temperature can exceed 60°C. Controlling these outlet fans manually is a very inconvenient thing and becomes an obstacle for accepting this drying technology by the farmers. Therefore, this study focused on the design of temperature control for the Hohenheim Tunnel Dryer by using a proportional integral derivative (PID) controller with an Arduino Nano microcontroller. It controls the fan outlet to obtain an optimal drying temperature so that the operation of this dryer becomes more accessible and more efficient. The temperature sensor used is DHT22. The tuning method chosen is the Ziegler – Nichols method, and the setpoint value is selected at 55, which is the optimum temperature for drying most agricultural products. The design, manufacture, and testing of the temperature control system on the Hohenheim tunnel dryer was successfully carried out without over shoot and steady state error so it can be concluded that the system has worked well.

Keywords:
Hohenheim Tunnel Dryer, Temperature Control, PID Controller, drying room, temperature sensor.

Nomenclature

K_p : Constant value of each Proportional
T_i : Time of Integral
T_d : Time of Derivative
T_C : Time constant
L : Delay time
$C(t)$: System stability value

Abbreviations

PID : Proportional Integral Derivative
PWM : Pulse Width Modulation

1. Introduction

The drying of agricultural products is a post-harvest process that consumes a large amount of energy. The drying process is something that can affect the quality of the product [1]. The purpose of drying foodstuffs is to allow for a more extended storage period with minimized packaging requirements and reduced shipping weight. The quality of a food product is assessed from the amount of physical and biochemical degradation during the dehydration process [2]. So far, people usually still use manualrying techniques and dry them directly under the sun. Still, this technique has many weaknesses, including requiring more energy, taking a long time, is easily contaminated, and impractical.

Currently, there are several drying technologies, as has been done by previous researchers [3, 4], using microwave heating technology for pliek-u drying. Several factors that affect drying need to be monitored during the drying process, such as temperature and humidity. The temperature and humidity in the drying process must meet the drying criteria to produce a quality product. Several researchers have made a drying system based on a microcontroller so that drying can be done automatically [5, 6]. The drying technology used in this research is the Hohenheim type tunnel dryer modified.

The Hohenheim Tunnel Dryer is made using two heating mechanisms, namely the solar collectors and the greenhouse effect. The solar collector is a heating system that uses the principle of maximum heat absorption by a black surface mounted under a transparent surface. The air entering through that can heat with the leading solar energy collected. In contrast, the greenhouse effect is a process where solar radiation is trapped in a room because a transparent surface covers it. This trapped solar radiation heats the air contained in the tunnel, which contributes some additional energy for drying process. This mechanism causes the temperature in the tunnel dryer to increase significantly compared to the ambient temperature. Previous researchers on Garcinia atroviridis drying have carried out drying using a solar drying system or solar heat [7].

Drying using the Hohenheim tunnel has been carried out by previous researchers on drying elephant ginger [8]. Still, when the drying process is carried out at a specific time, there is an increase in temperature to reach 62 °C, which will damage the quality of the dried product because it passes the optimal drying temperature for most agricultural products, which is around 50-60 °C. To avoid the temperature in the drying room exceeding 60 °C, the outlet fans are used as an actuator to lower the temperature in the drying chamber. However, suppose the outlet fans are turned on continuously, the temperature in the drying chamber does not reach the optimal drying temperature, which is below 50 °C. An automatic temperature control system is needed, which is expected to improve the performance of the Hohenheim tunnel dryer by controlling the outlet fans as the system output. So that the temperature in the drying chamber is stable at the optimal drying temperature.

In this study, there are several literatures used related to temperature control. The method used is to design a dryer model using temperature control with the PID controller method to obtain good drying performance because it can achieve and be able to maintain the temperature at the specified value in a relatively fast time, such as rotary dryer [9-11]. In comparison to the PID controller, the use of fuzzy controller had been studied on indirect solar dryer [12], and other dryer types [13-17]. The objective of this to apply the PID controller on the Hohenheim Tunnel Dryer in order to improve its performance.

2. Research Methods

2.1 Hohenheim tunnel dryer.

The Hohenheim dryer is a tunnel-type dryer that utilizes solar energy to heat the air. The Hohenheim Tunnel Dryer consists of several parts, including a collector, drying chamber, solar panel, and fan motor [8]. As in Fig. 1 is the hohenheim tunnel dryer modified in Aceh. We installed four DC fans 12 V 0.2 A with a diameter of 12 cm to circulate the inlet and outlet air at a speed of 2 m/s during the drying process. A 20 WP solar panels installed to generate electricity.

Fig. 1. Hohenheim tunnel dryer modified in Aceh.

2.2 PID controller.

The PID control system functions to control a plant to achieve specific stability by tuning its control parameters. In general, industrial controllers used today are PID controllers or modified PID controllers, as previous studies [21, 22] were used optimal PID controllers for speed control of mobile robots and in electro-hydraulic servo systems. Since most PID controllers are system-adapted, there are many types of tuning of the PID itself. In addition, automatic tuning methods have also been developed, and some PID controllers may have automated tuning capabilities, as in previous studies [23, 25], which used the self-tuning method. Modified forms of PID control, such as I-PD and multi-degrees-of-freedom PID control, are currently used in the industry [18].

The usefulness of PID control lies in its application to most control systems. In particular, as in the block diagram of the PID control system i.e Fig. 2.

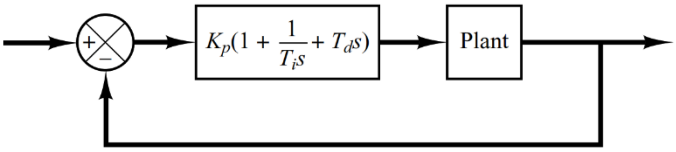

Fig. 2. PID control system block diagram [18].

If the mathematical model of the plant is unknown, therefore the system cannot be analyzed directly, so a PID controller is used. In the field of process control systems, it is well known that basic and modified PID control schemes have proven their usefulness in many specific situations. However, in certain situations, the control scheme may not provide optimal control. The PID control equation can be seen as follows eq. (1)[19].

$$G_c(s) = K_p(1 + \frac{1}{T_i s} + T_d s) \tag{1}$$

2.3 Tuning Ziegler-Nichols method.

Suppose the plant is very complex where the mathematical model is not easy to obtain. In that case, analytical or computational methods are not possible, as in the case of the Hohenheim Tunnel, which does not have a mathematical model. Then an experiment was carried out in tuning the PID Controller. The Ziegler–Nichols tuning method is advantageous if the mathematical model of the plant is unknown.

First, we must obtain the value for the effective pause. Then, the time required in decimal minutes until a visible rate of change is observed, and the value of N (PV slope at the point of the maximum rate of change) by providing a step input to the system to produce the resulting graph output an S-shaped curve [19].

The S-shaped curve has the characteristics of having two constants, the delay time L and the time constant Tc. These two constants can be obtained by giving a tangent to the inflection point of the S-shaped curve and determining the intersection of the line with the t-axis and *c(t)* = *K*, as in Fig. 3 based on Ziegler–Nichols tuning rule based on step response from plan in Table 1 [18].

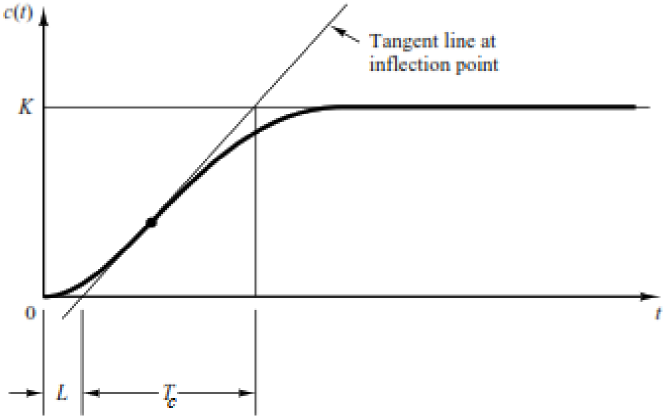

Fig. 3. Ziegler-Nichols tuning method [19].

Table 1. Ziegler-Nichols tuning rules based on the plant step response [18]

Controller Types	K_p	T_i	T_d
P	$\frac{Tc}{L}$	∞	0
PI	$0{,}9\frac{Tc}{L}$	$\frac{L}{0{,}3}$	0
PID	$1{,}2\frac{Tc}{L}$	$2L$	$0{,}5L$

2.4 Methodology and implementation.

Furthermore, the process carried out during the study is explained, starting from data collection, the PID tuning process, the application of PID to the system, and system analysis, as shown in Fig. 4.

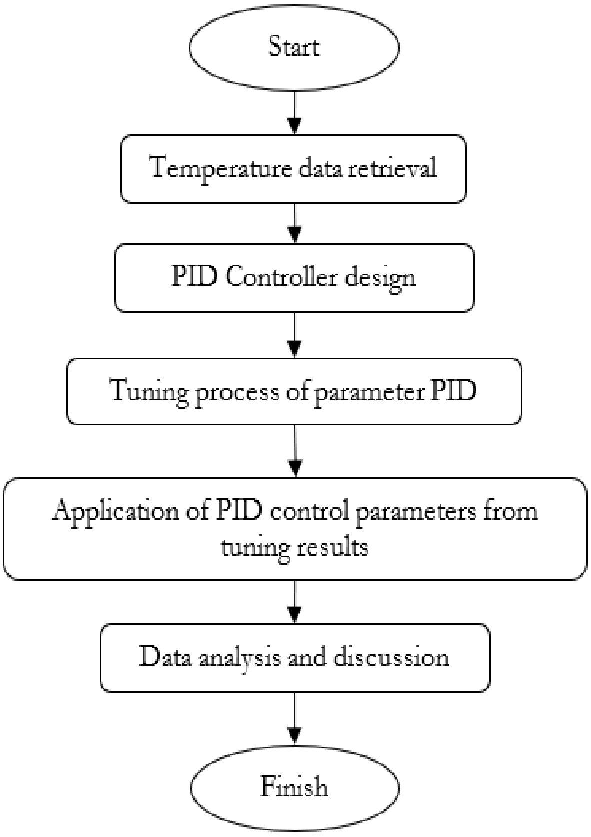

Fig. 4. Research Method

2.4.1 Hardware design

At the hardware design stage, we applied the PID controller design on the Hohenheim tunnel dryer. Also, we implemented The PID controller assembly using the Arduino Nano Atmega328 microcontroller as the PID control center to control the temperature in the plant. The description of Fig. 5 is as follows:

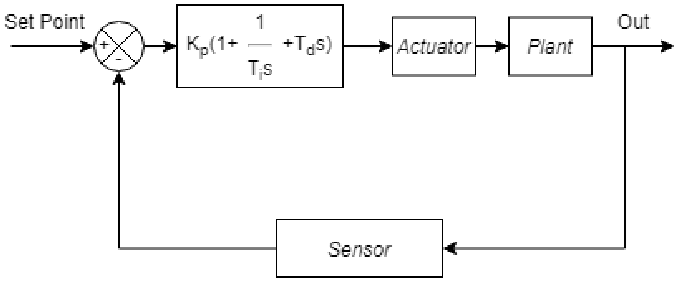

Fig. 5. Block system diagram

1. Actuator is an output controlled by a PID operator. In this case, the actuator are two outlet fans.
2. Plants are objects controlled by the PID controller. In this case, the plant is the Hohenheim Tunnel dryer.
3. Sensor is a device that detects changes in magnitude and functions as feedback on the PID controller. In this case, the quantity question is the temperature in the Hohenheim Tunnel dryer, which is read by the DHT22 sensor.

Fig. 6 shows the main components of the PID controller, namely the Arduino Nano Atmega328 as the central controller, 2 DHT22 sensors as feedback on the PID controller, and two outlet fans, which are controlled using a MOSFET as a controlled system output. In contrast, the supporting components are the MicroSD module as a data logger to store temperature data, LCD display the temperature data and PID controller output, and RTC DS3231 as a time and date module for data logger purposes.

2.4.2 Software design

The software design in this study uses the C++ programming language which is supported by the Arduino Nano microcontroller Fig. 7 shows a software algorithm whose flow starts from several stages, namely the setpoint value, control constant, and temperature input, then produces the expected output value using the PID control method. We adjust the setpoint value at 55 °C. Then, the controlling constant is obtained from the tuning results using the Ziegler – Nichols's method. The temperature input is gained from the temperature reading in the drying room using the DHT22 sensor. The output generated from the PID controller is a PWM value to control the outlet fan using a MOSFET so that the fan will remove the hot air contained in the drying room.

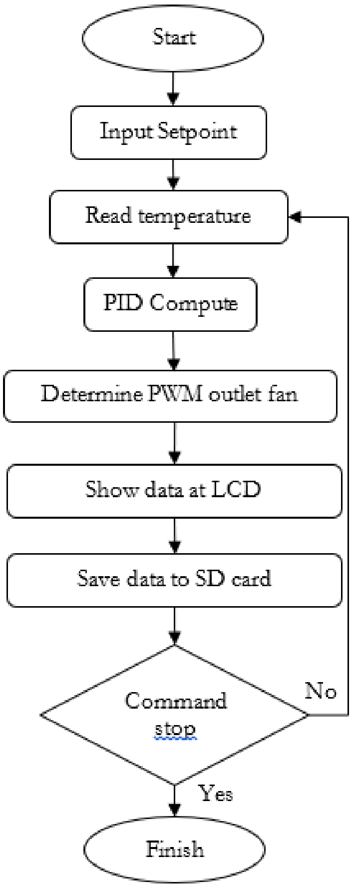

Fig. 7. Software Algorithm

Thus, the temperature in the drying chamber is stable at 55 °C. The Ziegler-Nichols tuning process is carried out in the following steps:

1. Step one: Obtaining open-loop data. The open-loop temperature data is obtained by turning on the outlet fans until the dryer

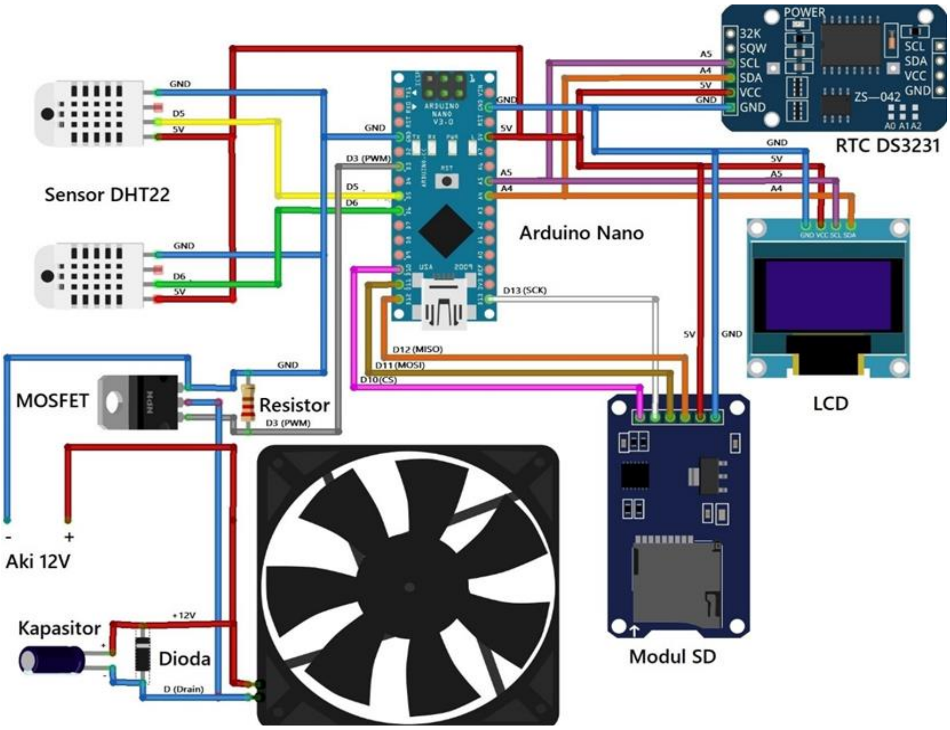

Fig. 6. System circuit

reaches the peak value of stability. The data is then converted into the graphical form using MATLAB.

2. Second step: Extracting the values of L and Tc. From the open-loop graph then given a tangent line on the S-shaped curve as in Fig. 3 so that the values of L and Tc are obtained.
3. Third step: Calculating the values of *Kp*, *Ti*, and *Td*. The values of L and Tc are substituted for the PID controller type in table 1 so that the values of *Kp*, *Ti*, and Td are obtained.
4. Fourth step: Applying *Kp*, *Ti*, and *Td* values to the PID controller. The three values are applied to the Arduino microcontroller.

2.4.3 Equipment used

The equipment we used in this study can be seen in Table 2, while the materials used can be seen in Table 3.

Table 2. Equipment used

No	Equipment	Number
1	Computer	1 pc
2	Tool-set	1 set
3	Multimeter	1 pc
4	Solder dan lead	1 pc
5	*Software* Arduino IDE	1 pc
6	*Software* MATLAB R2016b	1 pc

Table 3. Consumables

No	Material	Number
1	Micro controller Arduino Nano ATmega328	1 pc
2	Sensor DHT22	2 pc
3	Fan DC 12V 0.2A	2 pc
4	MOSFET IRLB3034	1 pc
5	Module MicroSD	1 pc
6	LCD I2C	1 pc
7	RTC DS3231	1 pc
8	Resistor 10K Ohm	1 pc
9	Capacitor 220 uF	1 pc
10	Diode 1 A	1 pc
11	PCB Board	1 pc
12	Connecting cable	1 set

2.4.4 Data analysis

After the PID controller is applied to the Hohenheim tunnel dryer, the system is run, and the output data from the system is displayed in MATLAB for analysis. In addition, the values of rise time, overshoot, error steady state, and recovery time are also analyzed.

2.4.5 Sensor testing

At the sensor testing stage, a comparison is made between the DHT22 temperature and humidity sensor readings with a more accurate measurement tool, the HTC meter sensor. At this stage, the results of the percentage of sensor error and the level of accuracy of the sensor are obtained using the following eq. (2).

$$\text{Error (\%)} = \left[\frac{\text{T HTC meter} - \text{T } \mathit{sensor}}{\text{T HTC meter}}\right] \text{ x } 100\ \% \qquad (2)$$

2.4.6 Moisture testing

At the humidity testing stage, it is carried out to pay attention to the effect of air humidity due to an increase in air temperature in the drying room.

2.4.7 System testing with disturbance

In the testing phase of the PID controller with disturbances, testing is carried out on the disturbed system (disturbance) so that the time required for the system to return to a steady state is obtained.

2.4.8 System testing using PID controller

At the stage of testing the system using a PID controller, testing using a MOSFET can produce PWM output to control the fan outlet by the PID controller command contained in the Arduino Nano Atmega328 microcontroller so that it is stable at the setpoint value.

3. Results and Discussion.

The results of the prototype design have been made and then applied to the Hohenheim tunnel dryer, which uses the DHT22 sensor as the system input, the fan outlet as the output, and the microcontroller as the PID control center. A DHT22 sensor is installed in the prototype to detect the temperature in the drying chamber as system input and a MOSFET to control the fan outlet as a system output. All components are connected to the Atmega328 microcontroller as the central PID controller of the system.

Fig. 8 results from installing a PID controller on a Hohenheim tunnel dryer. About 2 DHT22 sensors are placed in the drying room with a distance of 1m between the two sensors so that the microcontroller takes the average value of both sensors. The outlet fans on the Hohenheim tunnel dryer are connected to the MOSFET in the prototype so that the PID can control its operation.

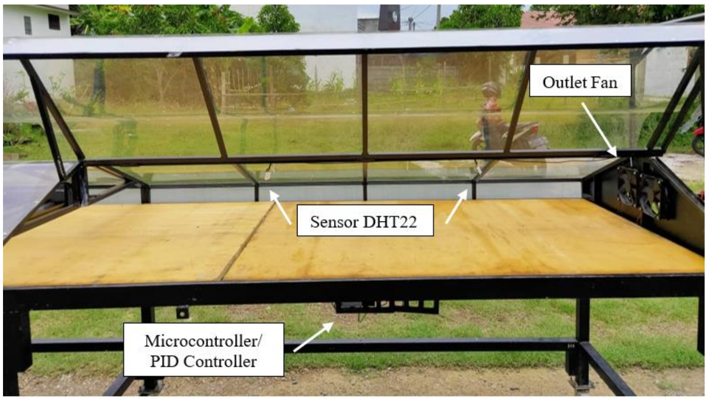

Fig. 8. Hohenheim tunnel dryer with PID controller

3.1 Determination of PID parameters.

The PID controller uses Proportional (P), Integral (I), and Derivative (D) constants to control the outlet fans so that the system is stable at the setpoint value. We apply a PID tuning process to determine the PID constant value that is suitable for the Hohenheim tunnel dryer. In this study, the Ziegler-Nichols tuning method was used from the open-loop temperature data obtained from the experiment.

The open-loop temperature data obtained from the drying chamber is then converted into a graph in MATLAB, and the Ziegler-Nichols tuning process is carried out by providing tangent value to an S-shaped curve, as shown in Fig. 9.

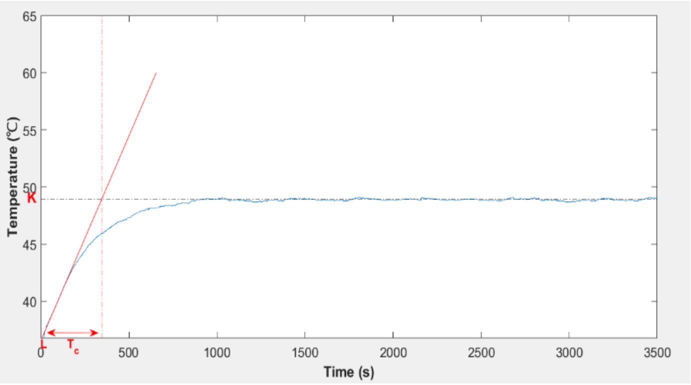

Fig. 9. The result of tuning Ziegler-Nichols

From the graph in Fig. 9, the values of L=5 and Tc=339.6 are obtained. Using the PID controller type in table 1, the appropriate PID controller parameters for the Hohenheim tunnel dryer system are obtained, namely Kp = 81.504, Ti = 10, and Td = 2.5. By substituting Ki=Kp/Ti and Kd= Kp x Td, we get the Proportional constant KP = 81.504, Integral constant KI = 8.1504, and derivative constant KD = 203.76, which is given to Arduino Nano as system PID controller.

3.2 DHT22 sensor testing.

DHT22 temperature sensor testing is done by comparing the results of temperature measurements produced by the DHT22 sensor and the temperature measuring device used in the drying system, namely the HTC meter. The test was carried out at the measuring point in the Hohenheim tunnel drying chamber using the equation (2).

Table 4 shows the test results of the first DHT22 sensor. We did the test at different temperatures. The test results show that the highest percentage of error produced is 1.96 %, with an average error value of 1.49 %.

Table 4. Comparison between HTC meter and DHT22 first sensor

Temperature of HTC meter (°C)	Temperature sensor 1 (°C)	Error (%)
36,3	36,0	0,83 %
35,8	36,4	1,68 %
35,7	36,4	1,96 %
Mean		1,49 %

Table 5. Comparison between HTC meter and DHT22 second sensor

Temperature of HTC meter (°C)	Temperature sensor 2 (°C)	Error (%)
36,3	36,2	0,28 %
36,4	36,3	0,27 %
36,3	36,4	0,28 %
Mean		0,277 %

Table 5 presents the test results of the second DHT22 sensor, where the highest percentage of error produced is 0.28 %, with an average error of 0.277 %. Therefore, from the results of the percentage error of the two sensors, it can be concluded that the sensor is running well with a low error rate, which is below 2 %.

3.3 Humidity test.

We conducted a humidity test to see the effect of increasing temperature on air humidity in the Hohenheim tunnel dryer room. We do this by measuring the temperature and humidity at the beginning of placing the Hohenheim tunnel dryer in the sun until it reaches the maximum temperature of the dryer.

As highlighted, Fig. 10 shows the results of the humidity test in the drying chamber with an increase in temperature for 60 minutes.

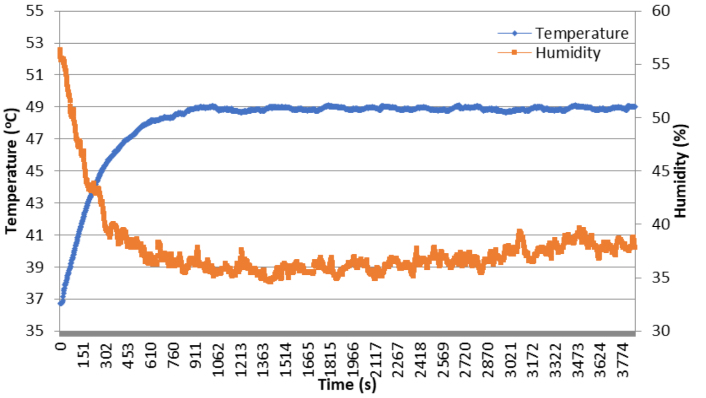

Fig. 10. Result of temperature and humidity in Hohenheim tunnel dryer

We get the initial humidity value from the sensor readings at a temperature of 36.75 °C, which is 56.3 %, and decreases until it reaches an average humidity of 37.2 % at temperatures above 40 °C. We conclude that temperature can affect air humidity; that is, the higher the temperature, the lower the humidity in the drying chamber.

3.4 System testing with PID controller.

This test was carried out by looking at the response of the Hohenheim tunnel dryer system with a PID controller in the absence of dried material (empty drying). We do the test to see if the drying works well after being given a PID controller. Proportional constant KP = 81.504, Integral constant KI = 8.1504 and Derivative constant KD = 203.76 then implemented to the microcontroller with final temperature value or setpoint 55,0. From the implementation of the PID control parameters, the system response is generated, as shown in Fig. 11.

Fig. 11 determines the response results of drying chamber temperature after being given a PID controller for 60 minutes. The initial temperature is 36 °C and then reaches the set point of 55 °C in 15 minutes 24 seconds. Also, it shows that the system does not experience overshoot, and there is no stable error. Thus, it proved that the PID controller from the Ziegler-Nichols tuning control parameters is running well. Based on the calculations on the graph, the rise time value of the temperature response using the PID controller is approximately 9 minutes.

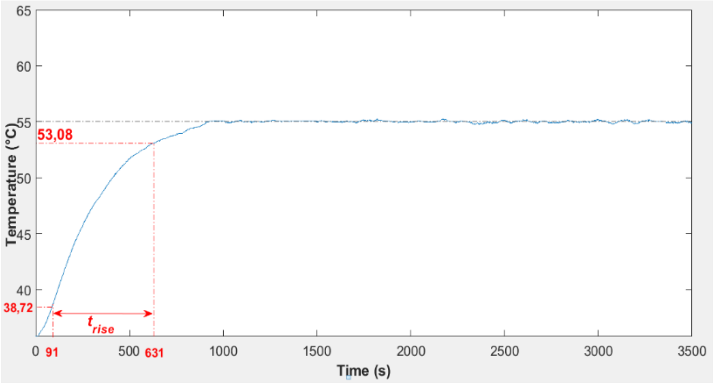

Fig. 11. The result of dryer room temperature with PID controller

The output of the PID controller on the temperature test in the Hohenheim tunnel dryer in the form of Pulse Width Modulation (PWM) to control the fan outlet can be seen in Fig. 12. Clearly, the graph shows that when the temperature is below the set point of 55.0, the PWM value is 0, then when the time reaches 929 seconds (15 minutes 29 seconds) or the temperature reaches 55.05, the PWM value begins to increase, which is 4.29.

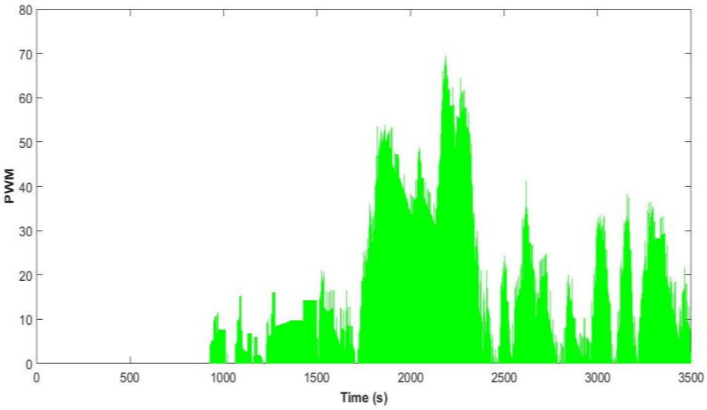

Fig. 12. PID controller PWM output

The PID controller adjusts the PWM value according to the error generated by the system so that the rotational speed of the fan outlet will adjust to the PWM value given by the PID controller so that the temperature in the drying chamber is stable at the setpoint value. The maximum value of PWM generated by PID output is 69.77.

3.5 System testing with disturbance.

We conducted this test to determine the system's overall performance with the PID controller and to pay attention to the system's recovery time when it was disturbed. Recovery time is required for the system to return to the steady-state value after being disturbed. The shorter the recovery time, the better the response to the system.

Fig. 13 shows the results of the system response with a given disturbance (disturbance). The disturbance model that we provide is by opening the dryer cover for 1 minute so that the temperature in the drying room decreases by 5 to 6 °C. After being disturbed until the temperature drops to 48.9 °C, then the temperature in the drying chamber could rise and stabilize at 55 °C with a recovery time of 423 seconds (7 minutes and 3 seconds). Thus, it can be said that the system can return to the steady-state value after being given a disturbance lower than 10 minutes.

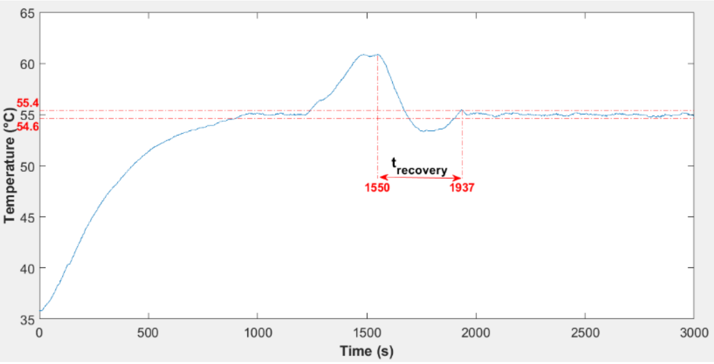

Fig. 13. System testing with lowered temperature interference

Under the same scheme, we get the system response results by being given a second disturbance by overheating the system at about 5-6°C higher than the setpoint, as shown in Fig. 14. It was obtained that the temperature in the drying chamber could drop and stabilize at 55 °C with a recovery time of 387 seconds (6 minutes and 27 seconds). It can be seen that the temperature oscillates above 2 %. This indicates that the system is experiencing problems in lowering the excessive temperature. In order not to interfere with the function of the PID controller, this condition must be avoided, thus checking the outlet fans must be carried out regularly to ensure that the outlet fans are functioning correctly.

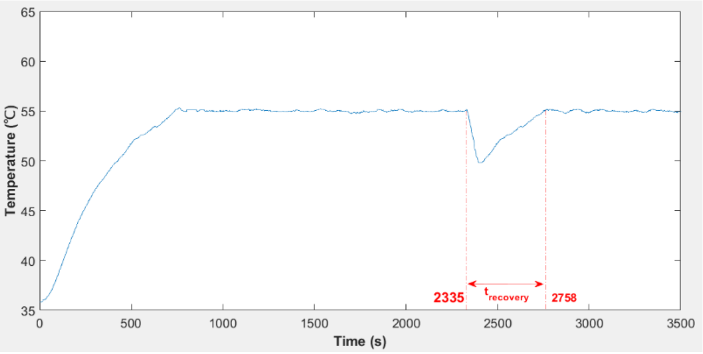

Fig. 14. System test results given an increased temperature Interference

4. Conclusions.

This research has successfully applied the PID controller to the Hohenheim tunnel dryer with the first Ziegler-Nichols tuning method with the obtained control parameters KP = 81.504, KI = 8.1504, and KD = 203.76. Based on the results of the response of the drying system after the PID controller was applied with a set point of 55 °C, to meet the drying criteria of agricultural products. When the system is given a decrease in temperature disturbance, the system can stabilize the temperature at its setting point with a recovery time of 7 minutes 3 seconds. However, when the system is shown an increase in temperature disturbance, the temperature response oscillates above 2 %, with a recovery time of 6 minutes 27 seconds.

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