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Research Article

Utilization of PID Controller to Optimize Energy Consumption in Hybrid Forced Convection Dryer

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Abstract: Drying is essential in food processing, particularly for grains or beans. This process can influence the characteristics and quality of the dried material. However, the drying process needs massive energy. This condition can increase the cost of production. Therefore, optimizing energy is needed during the drying process. This study proposed that a PID controller be utilized in the dryer to maximize energy efficiency. This method was implemented in forced convection and hybrid forced convection dryer. The proposed system was designed with an Arduino Mega as a controller, heater, and exhaust fan as actuators, AHT10 and PZEM-004T as sensors, and this system used household electricity as a power source. The AHT10 sensor was used as a device that measured the temperature and then it was used as parameter control of the PID controller to control the electric heater. In addition, PZEM-004T was used to measure power and energy consumption. This study aims to implement the PID controller to obtain the performance in optimizing energy consumption between two types of dryers, namely forced convection and hybrid forced convection, during drying. The performance will be assessed by comparing data on power and energy consumption for forced convection and hybrid forced convection. The results indicate that the hybrid dryer can significantly decrease power and energy consumption by 48.32% and 49.18%, respectively, compared to the forced convection dryer.

Keywords: energy, forced convection, hybrid dryer, optimization, PID controller

1 Introduction

The drying process is critical for removing liquid contents, which are then evaporated using heat energy, especially for beans. This process offers advantages in maintaining the condition of the dried material, making it suitable for long-term storage and convenient for delivery [1–3]. The drying process can also impact the composition of the dried material, affecting taste, acidity, quality, and chemical levels [4]. Furthermore, the drying process requires a significant amount of energy to generate heat and reduce the material's water content or moisture level. Consequently, the drying process can influence production costs [5]. Therefore, efficient energy in the drying process is needed to reduce production costs.

Various methods have been proposed to reduce energy consumption in the drying process. That method was applied to many dryer types, such as conventional dryers, adsorption dryers, condensation dryers, and heat pump dryers [6]. However, the proposed methods only modified the dryer system and controlled the dryer's temperature. Controlling the temperature is a popular method to obtain energy efficiency. Intermittent drying is one method that manipulates the temperature inside the dryer to get energy efficiency during the drying process by modulating airflow [7]. This method flows the heated air to the bed dryer within the specified time interval. The intermittent method was able to reduce energy consumption and preserve the quality of dried material. However, this method has a system sort of an on-off controller that will flow and stop the heated air within a specified time interval. The effect is that the system's response to achieving optimum temperature is low.

Another way to reduce energy consumption was conducted by adding insulation to the dryer [8]. The insulation was installed to maintain the temperature inside the dryer, so it was expected to obtain the desired temperature. The same method was also proposed by adding multiple heat producers to improve the heat transfer so that efficiency was obtained [9]. Nevertheless, the mentioned methods need additional material to ensure that energy consumption can be reduced. Furthermore, it may cost more, and this method cannot actively control the temperature.

Temperature is a measurable physical parameter that indicates the degree of warmth or coolness in a quantitative manner. Temperature is a parameter often used to be controlled in many applications. Many methods were utilized for controlling the temperature, such as an on-off controller [10] and Pulse Width Modulation (PWM) [11]. An on-off controller or two-position control is the simplest control method that does not need high computation. This method was successfully applied to control the temperature in the fermentation room [10]. However, the on-off controller has disadvantages since this method is very sensitive to input changes. These disadvantages also occur on the PWM controller. The rapid on-off cycling associated with PWM control can cause the actuator to break.

Proportional, Integral, and Derivative (PID) controllers were proposed as an alternative method to achieve energy efficiency [12]. PID controller is a combination controller comprising proportional, integral, and derivative. This method uses a setpoint as parameter control and automatically compensates for the changes in input value in the setpoint. PID controller works by tuning the proportional (P), integral (I), and derivative (D) parameters. Those parameters are tuned individually. The adjusting parameter is conducted to obtain the correction value and then applied to the input to achieve the desired result. P-controller is used to get steady operation but cannot omit the steady-state error. I-controller is used to adjust the error to zero by integrating the error. Last, the D-controller is used to anticipate and correct future actions of error. These features can be utilized to control a system that corresponds with user needs, for instance, the response speed or stability of the system. PID controller was implemented in many applications in previous studies, such as in controlling movement [13], household appliances [12], carbon controller [14], temperature [15], speed [16, 17], and industrial applications [18, 19].

In this study, the PID controller is utilized to optimize the energy consumption in a forced convection dryer by controlling the electric heater. A temperature sensor was used as parameter control to measure the temperature inside the dryer. PID controller was used to control the electric heater and exhaust fan to maintain the temperature. Furthermore, the PZEM-004T sensor was used to measure the energy consumption when the dryer ran. The goal of this study is to implement and tune the PID controller. Thus, the performance difference between two types of dryers, forced convection and hybrid forced convection, can be known.

2 Research Method

2.1 The Control Design

During the drying process, it is imperative to consider the electrical energy consumption utilized for the product's drying. Energy (W) represents a property intrinsic to a given system, facilitating its operation. Whenever work is performed, energy is transferred from one system to another. The rate at which this energy is expended in performing the work can be described as power (P), quantified in Watts (W). Power can be calculated by multiplying voltage (V) and current (I). In terms of commercial energy consumption, the unit of measurement is kilowatt-hours (kWh), which is determined by multiplying the power (in kW) by the time interval (in hours). This unit is the standard measurement in customer's electricity invoices.

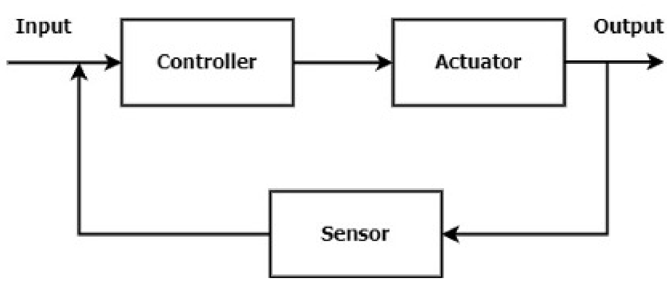


Figure 1: The proposed control system diagrams.

Figure 1 illustrates the proposed control system that comprises a controller, actuator, and sensor. Arduino Mega was used as a controller in this system. The controller controls the electric heater as an actuator to maintain the temperature and is controlled by the Proportional, Integral, and Derivative (PID) methods. The PID method was used to control the temperature to conform to the temperature set point or ideal drying temperature. Therefore, the sensor has an important role since it supervises the output of the electric heater so the controller can adjust the temperature. Moreover, an exhaust device was also used in this study as an actuator to maintain the temperature inside the drying chamber.

2.2 The Energy and Power Measurement

The purpose of controlling the electric heater is to reduce electrical energy and power consumption. kWh meter sensor, the PZEM-004T, is employed to calculate the energy usage of the electric dryer in this study, as shown in Figure 2. The PZEM-004T sensor is equipped to measure voltage (V), current (A), power (Watt), and energy consumption (kWh). Its wiring involves two main sections: voltage and current input terminals and serial communication. This module has a serial data communication interface through a TTL serial port. The PZEM-004T sensor can measure currents up to 100A. It has a voltage measurement range of 80-260VAC with a frequency range of 45-65Hz. In terms of power measurement, this device can measure up to 22,000W and boasts an accuracy of ±1%.

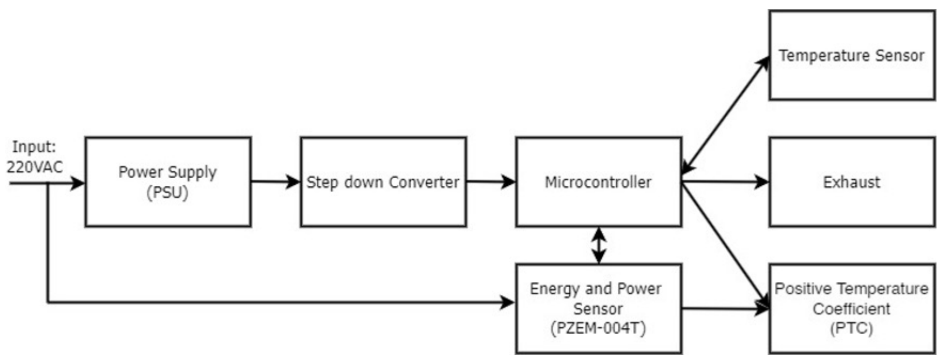


Figure 2: The design of energy and power measurement.

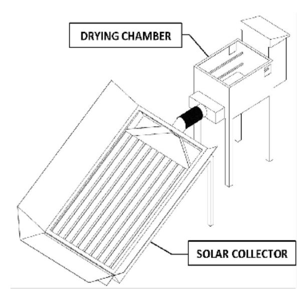


Figure 3: Design of the proposed dryer.

In this study, the electricity used by this system is sourced from a household electricity supply of 220VAC. This 220VAC power is then converted to 12VDC by the Power Supply Unit (PSU). The drying device itself only requires a voltage of 5VDC to supply power to its microcontroller, sensors, and actuators. For this purpose, a Step-Down Converter XL4015 is used to reduce the 12VDC voltage from the PSU to 5VDC as shown in Figure 2.

2.3 The Dryer Design

The drying device in this research consists of two main components: the solar collector and the drying chamber, as shown in **??**. In the solar collector, solar heat energy is collected and then transferred to the drying chamber for the drying process. Inside the drying chamber is a Positive Temperature Coefficient (PTC) heater that operates using electric energy. The PTC heater functions as an additional heating device if the solar energy supplied by the solar collector is insufficient. In the convection drying method, the heat inside the drying chamber is solely provided by the PTC heater. However, in the hybrid convection method, the heat is sourced from solar energy with assistance from the PTC heater if the temperature obtained from solar energy is insufficient for the drying process. The PID control system controls the heat within the drying chamber according to the predefined setpoint to produce high-quality products.

2.4 Experimental Procedures

In this study, the proposed system was examined by comparing it with convection drying to determine the power consumption of each drying method. The testing procedures used two methods using the same drying device to obtain a comparison of power usage during the drying process. The setpoint for the test was 40°C, which is considered the ideal temperature for drying agricultural products and grains [1, 20]. Test data for each drying method were collected every 5 minutes. The testing scenarios for each drying method under investigation were as follows:

1. Forced Convection Drying The drying device entirely carries out the drying process in this method. Testing was conducted at night without the assistance of sunlight and solar heat. The testing was done to determine the amount of power the drying device requires when the heat source is solely electric heaters. Testing for this method was carried out for 4 hours to match the testing duration of the hybrid drying method.
2. Hybrid Drying The testing process for this method was conducted for 4 hours during the Peak Sun Hour (PSH) at the testing location. PSH represents the total hours when solar irradiance reaches its maximum peak. The standard maximum solar irradiance intensity used is 1 kW/m^2 [21]. PSH is the total time (in hours) when solar irradiance intensity reaches 1 kW/m^2 within one day. The testing location for PSH was in Bandung city, where it occurred over 4 hours between 10 a.m. and 2 p.m. This method activated the solar collector to aid the drying process. Thus, for 4 hours, the grains were dried by solar heat with assistance from the drying device. This testing was done to determine the power required by the drying device when the heating process is carried out using electric heaters with the assistance of external solar heat.

2.5 Performance Evaluation

The proposed system used many sensors to measure the parameters, control, and use power and energy. However, usage measurement of power and energy is the main goal in this study. Hence, the PZEM-004T sensor was calibrated to obtain a high performance. It was calibrated by comparing it with the existing device, KWE-PM01. The relationship between the sensor and the compared device was modeled by linear regression. Linear regression, written in Equation 1, was used as the calibration method of the PZEM-004T sensor as observed data (y) to KWE-PM01 as the true data (x) [22].

$$Y = a + bX \tag{1}$$

a and b are determined by the following formulas:

$$a = \frac{\sum y \sum x^2 - \sum x \sum xy}{n(\sum x^2) - (\sum x)^2} \tag{2}$$

$$b = \frac{n \sum xy - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \tag{3}$$

Where Y is the dependent variable or response variable, X is the independent variable or predictor variable, and a and b are the intercept line or constant variable and the slope line, respectively. Then, the linear regression in Equation 1 was applied in the system and the measured result was evaluated by calculating the coefficient of determination (R^2) as written in Equation 4. Thus, the sensor performance can be confirmed that the result has a direct relation or has no different with KWE-PM01 result and indicates the fitting of linear regression model [23–25].

$$R^2 = r^2 = \left(\frac{n \sum xy - \sum x \sum y}{\sqrt{(n \sum x^2 - (\sum x)^2) - (n \sum y^2 - (\sum y)^2)}} \right)^2 \tag{4}$$

Furthermore, the overall performance evaluation to understand the difference in energy usage between the proposed (V_2) and compared method (V_1) was calculated by using percentage change (C) as written in Equation 5 [26].

$$\%C = \frac{(V_2 - V_1)}{|V_1|} \tag{5}$$

3 Results

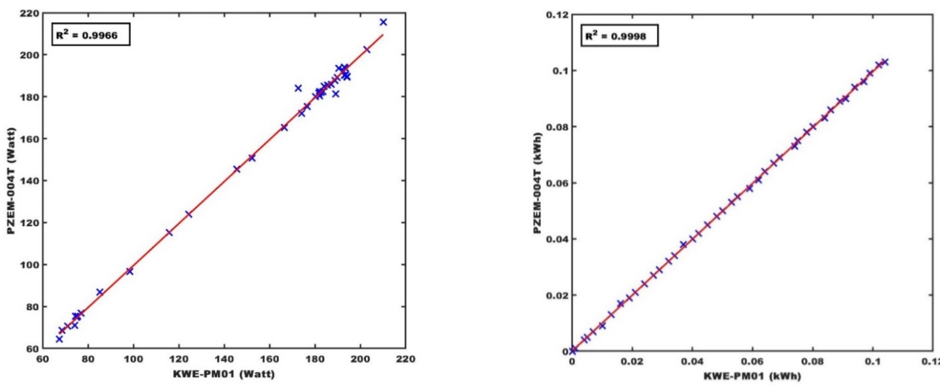
The sensor in this study was designed to have high accuracy to support the measurement of power and energy consumption. The PZEM-004T sensor was calibrated with an electrical energy meter, KWE-PM01, as a comparator or reference instrument device. Linear regression was applied as a method to calibrate the sensor. Figure 4 depicts the measurement relationship between the sensor and comparator in the power and energy consumption measurement after calibration.

The results show that the sensor has a good relationship with the calibrator to measure the power and energy. Since the obtained result indicates the coefficient of determination of regression approaching 1, that is 0.9966 and 0.9998. Thus, the sensor performance is excellent and fits the linear regression model.

Table 1 shows the average accuracy of sensor measurement after calibration. The result indicates that the sensor can measure power and energy, and it is close to the reference instrument device measurement value with a high accuracy exceeding 98%. Thus, the high accuracy obtained also proves that the sensor correlates well with the reference instrument device and gives confidence that the sensor can work excellently when measuring power and energy.

Table 1: The average accuracy of the sensor after calibration

No.	Measurement	Average Accuracy
1	Power	98.84%
2	Energy	99.30%



(a) (b)

Figure 4: Calibration results between sensor PZEM-004T and reference device, KWE-PM01: (a) power and (b) energy measurement.

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In this study, the PID controller was tuned with different parameters, as shown in Table 2. Table 2 and Figure 5 describe the results of the control response from several PID tunings. Those were obtained by experimental test and then applied in the PID algorithm. Parameter control number 5 was chosen in this study, with Kp= 3700, Ki=7.2, and Kd= 1.35. The parameter control was chosen since it had a better response than other parameters with the smallest value of rise time (Tr), peak time (Tp), settling time (Ts), and offset. However, the primary consideration in choosing parameter control is based on the rise time and the settling time. Those parameters were chosen to respond to temperature change and achieve stability quickly. Thus, the system can maintain the desired temperature during drying and be expected to optimize energy and power consumption.

The result is shown in Figure 6 that forced convection drying has the highest power consumption, with an average of 139.73 Watts, then the proposed method or hybrid drying, with an average of 72.21 Watts. Furthermore, a similar result was also shown in the energy consumption test. The energy consumption of the hybrid method has the lowest distribution than the forced convection method. Hybrid drying can offer better results than forced convection drying. Those results indicate that hybrid drying performs better and can significantly reduce power usage by 48.32%, as shown in Table 3. Moreover, the

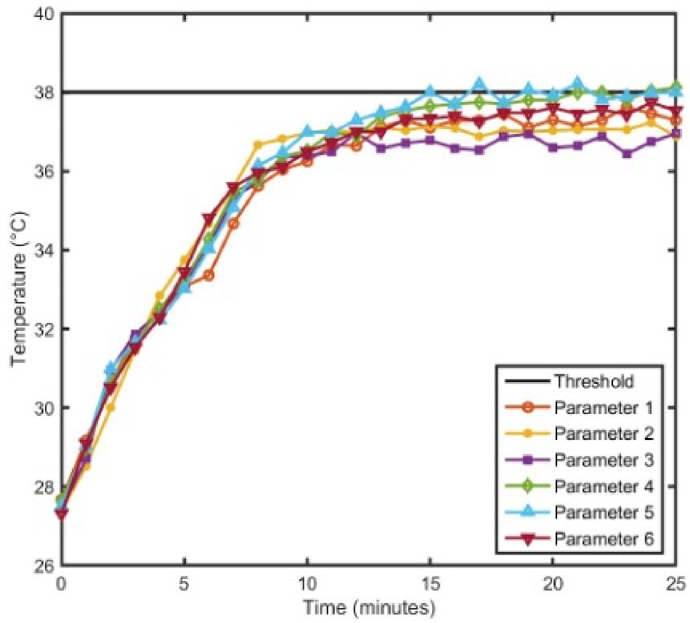


Figure 5: Comparison of temperature response for each PID parameter control.

Table 2: The control responses from several PID tuning parameters

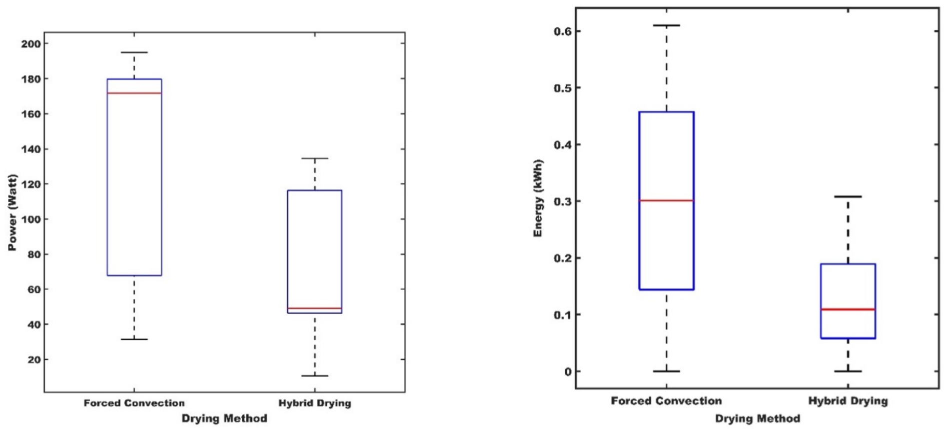
Parameters	Time (Minutes)			
	Tr	Tp	Ts	Offset (%)
1	-	-	22	2.00
2	-	-	-	2.53
3	-	-	-	3.35
4	21	25	13	0.78
5	15	17	12	0.57
6	-	-	14	1.58

decreased power usage indicates that energy usage can be influenced. Thus, hybrid drying can obtain better results with 49.51% energy consumption.

Table 3: The measurement result of energy consumption between forced convection and hybrid drying

Method	**Average Power Usage (Watt)**	**Average Energy Usage (kWh)**
Forced Convection Drying	139.73	0.61
Hybrid Drying	72.21	0.31
Percentage Change	**48.32%**	**49.18%**

This study's difference in energy usage indicates that PID control can affect system performance. When the system used forced convection drying, the system entirely used an electric heater. Hence, the controller tried to maintain the temperature in ideal condition



(a) (b)

Figure 6: The comparison results of the forced convection and hybrid drying: (a) power and (b) energy consumption.

by keeping the electric heater working. However, in the hybrid system, the temperature could rapidly rise since there is assistance from solar thermal. Thus, the electric heater only worked once the temperature exceeded the reference or desired values. This condition causes the hybrid system to have the lowest energy usage or consumption.

4 Conclusion

The PID controller has been applied to the drying system. The effect of the PID controller can influence the dryer's performance. The results indicate that the hybrid dryer can significantly decrease power and energy consumption by 48.32% and 49.18%, respectively, compared to the forced convection dryer. Those results are caused by the hybrid system that can utilize solar thermal to obtain the desired temperature. The electric heater only worked once the temperature was below the desired value. This condition causes the hybrid system to have the lowest energy usage or consumption. However, the temperature inside the dryer still depends significantly on the external temperature conditions. Therefore, further optimization methods, especially in tuning the PID controller, are necessary to enhance the dryer's performance in the future.

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