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A Controlled Gas-based Dehydrator in Banana Drying Process for Home Industry

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Abstract

In order to increase the durability and quality of bananas, this research discusses the design of an economical gas-based dehydrator with the application of PID control for valves and gas, specifically for small and medium-scale home industries. The main objective was to develop a cost-effective and efficient solution for drying bananas without sacrificing nutritional quality and taste. The dehydrator system is designed using PID control to obtain accurate and precise temperatures during the drying process. The algorithm is that the PID control will regulate and adjust how much gas is released through the valve based on the difference between the desired and actual temperature in the drying room. The best constants of PID we get are P = 1, I = 2, and D = 3. By applying these constants, the time taken by the system to change a signal from 30ºC to 100ºC of temperature is about 5 minutes, with a maximum overshoot of about 10%. In addition, the system required 25 minutes to achieve a steady state with an error value of about 5% from the setpoint. From the results of this experiment, it would be declared that the performance of the dehydrator built has indicated good performance. The minimum temperature that could be generated by the dehydrator is 90ºC, while the maximum temperature is set 150ºC. The experiment shows that this dehydrator can reduce the water content of a 1-2 g banana fruit by up to 50% within 60 minutes and 26% for a 10 g banana fruit mass simultaneously. The results also show that the dehydrator maintained optimal banana fruit quality based on texture, colour, and taste. Thus, these results indicate the great potential of gas-based dehydrators with PID control as an innovative solution for the home fruit processing industry, offering a combination of efficiency and cost-effectiveness

Keywords: Banana; Dehydrator; Home industry; PID control

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1. Introduction

Food preservation has become an essential part of the food industry to extend the shelf life of food products and increase their stability [1]–[3]. One of the traditional methods of food preservation is drying. Food preservation through drying methods has long been recognized as one of the most effective ways to increase the shelf life of food products and maintain their nutritional quality. Also, drying food is a way to preserve seasonal foods for later use [4]. Food drying techniques reduce the water content in food, thereby inhibiting the growth of microorganisms that can cause damage [5], [6].

There are various methods for drying foods. But, the energy efficiency, consistency, and product cost are often challenging especially for producers in home industry [7]–[9]. Therefore, developing low-cost and simple instrumentation is still a challenge in the home industry. In addition, being easy to use and install with existing components has also become essential factors for producers.

On the other hand, an oven is a tool used to cook or bake food using heat. This tool operates by transferring heat directly to the food ingredients placed in the oven. It is commonly employed in home

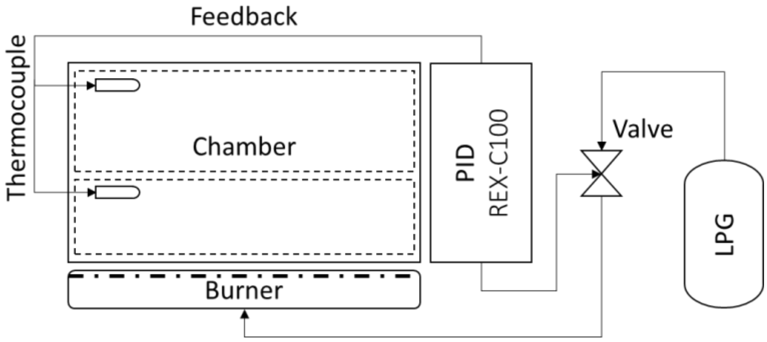

Fig. 1. Instrumentation system design of dehydrator

industries due to its adaptability for food drying applications. The oven uses LPG (Liquefied Petroleum Gas) as the primary fuel to generate heat in the drying chamber.

Meanwhile, banana, one of the fruits often found in Indonesia, has a unique taste and texture. Unfortunately, bananas are also known for their short shelf life. Therefore, dehydrating the banana can be a solution to extend the shelf life and utilize production surpluses [2], [10]. By considering the market potential, the need for affordable technology, and the economic and nutritional benefits of the banana dehydration, it is very relevant to conduct research on a low-cost dehydrator based on a PID controller. This article will examine further the design and effectiveness of this technology, as well as its potential application in Indonesia's small and medium scale food industry.

2. Research Method

The goal of the project is to create a controlled gas-based dehydrator for banana drying process in the home industry. It should be able to produce a temperature suitable for the intended purpose. Therefore, the process consists of three stages: designing the system instrumentation, installing the PID controller, and designing the experiment.

2.1 Design of System Instrumentation

The dehydrator was designed for users engaged in home industry activities. Therefore, this dehydrator utilizes a commercial oven with a burner as the heat source for the drying process. In Addition, it should be developed by considering low-cost tools and materials.

According to Fig. 1, the dehydrator was designed with dimension 75×40×50 cm^3. It includes a chamber for placing fruits, a burner as a heat source for dry food, an LPG as gas fuel for a burner, a valve used to regulate the gas pressure in the LPG ensuring adequate fuel flow to the burner. Additionally, a PID Controller REX-C100 is integrated to maintain the temperature in the chamber through the valve. A pair of thermocouples are used to monitor the temperature in the chamber, providing feedback for the PID controller to regulate and maintain the desired temperature.

In this research, the dehydrator was developed by modifying the oven. However, the main challenge of using an oven in the drying process is the temperature fluctuations that can occur due to changes in gas flow. To overcome this, a PID (Proportional-Integral-Derivative) controller can be integrated into an oven to regulate the gas flow from LPG.

PID is one of the most common controllers used in various industrial applications due to its flexibility, reliability, and ability to provide precise control [11]–[13]. By implementing a PID controller, the system can compensate for disturbances and maintain the process temperature at the desired setpoint so that drying results are optimal and maintain food quality [14]. The use of PID in the design of food dryers allows a more stable drying process, reduces temperature fluctuations, and increases energy efficiency.

In developing a dehydrator, stable, accurate, and precise temperature control is essential points for consistent and optimal drying results. Therefore, the role of the PID controller becomes very relevant. PID controllers have been known as tools that can provide fast and accurate control responses in various industrial applications [12].

By integrating the PID controller into the dehydrator, the drying temperature can be kept constant following the specified setpoint, producing consistent and high-quality food products. Apart from that, the use of PID also has the potential to increase the energy efficiency of the drying process [15].

2.2 PID Control for Dehydrator

PID (Proportional-Integral-Derivative) control is used in various applications to control a parameter to match a desired setpoint [12]. Justification of the parameters and structure of PID control in regulating oven temperature through gas flow involves consideration of the dynamic aspects and characteristics involved in the drying process.

The use of PID control in oven temperature regulation via gas flow has several reasons that can be justified, such as dynamic response, overcoming uncertainties in the oven and compensating for external disturbances that can affect the temperature, a good balance between fast system response and stability, optimizing the use of gas flow for maintains temperature, and provides stability against temperature fluctuations. Thus, by considering these factors, the use of PID control to regulate oven temperature via gas flow can be optimized to achieve the desired performance by minimizing temperature deviations and maintaining operational stability.

The dehydrator system is designed using PID control to achieve accurate and precise temperatures during the drying process. The algorithm involves the PID control regulating and adjusting the amount of gas released through the valve based on the difference between the desired and actual temperature in the drying room. Here is a scheme used to manage the gas flow in the burner to obtain a constant temperature:

1. *Input and Sensor*
   - The input of this system is the temperature setpoint desired by the user.
   - The temperature sensor is placed in the dehydrator drying chamber which is produced by a heater (burner).
2. *Error (E)*
   The error is calculated by subtracting the actual temperature detected by the thermocouple from the desired setpoint.
   $$E_{(t)} = T_S - T_A \quad (1)$$
   Where $E_{(t)}$ is the error value, T_s is the temperature setpoint, and T_A is the actual temperature.
3. *Proportional (P) Control*
   Measures the difference between the setpoint temperature and the current actual temperature. The larger the difference, the greater the proportional influence on the control output. Increasing the P parameter can improve the system's response to rapid temperature changes.
   $$P_{output} = K_p \times E_{(t)} \quad (2)$$
   Where K_p is a proportional constant.
4. *Integral (I) Control*
   Responds to the difference between setpoint temperature and actual temperature over time. The I parameter helps overcome steady-state errors, preventing possible temperature offsets. For slow-changing ovens, increasing parameter I can improve system performance.
   $$I_{output} = K_i \times \int E\ dt \quad (3)$$
   Where K_i is a proportional constant.
5. *Derivative (D) Control*
   Measures the rate of change in temperature. Parameter D helps prevent overshoot or excessive temperature fluctuations. By adding this component, the PID control can respond more quickly to temperature changes.
   $$D_{output} = K_d \times \frac{d(Error)}{dt}, \quad (4)$$
   where K_d is a derivative constant.
6. *Total Output*
   The total output of the PID controller is a combination of the three components P, I, and D, so that
   $$Output = P_{output} + I_{ouput} + D_{output} \quad (5)$$
7. *Valve*
   - The output from the PID controller is used to regulate the gas flow valve which controls how much gas flow enters the burner.
   - When the temperature falls below the setpoint, the valve is widened to enhance gas flow and temperature. If the temperature is above the setpoint, the valve is decreased to reduce the flow of LPG gas and lower the drying chamber temperature.

2.3 Design of Experiment

This dehydrator is designed to retain nutrients by removing water content from the fruit, thus extending its shelf life. The purpose of this experiment was to determine how well a dehydrator works for drying bananas. The selection of the banana was based on their high water content and market attractiveness as a dry snack.

The experimental procedure begins by selecting bananas with uniform ripeness. They were sliced into different thicknesses, each ranging from 1 to 10 grams in mass. The banana slices are then placed in the dehydrator drying chamber with a specific temperature (setpoint) and a drying time of 60 minutes. After the drying process, the banana pieces are re-weighed to determine the difference in mass. Additionally, the percentage reduction in water content for each banana piece is calculated.

The results of this experiment will yield the optimal temperature and duration for drying bananas with a dehydrator. Understanding these parameters will enable the food industry to enhance the quality and efficiency of dried banana production. Simultaneously, consumers will enjoy the highest quality products that retain the nutrients and natural taste of the fruit.

3. Result and Discussion

In this research, a successful construction of a low-cost dehydrator was achieved. This energy-efficient device operates without the need for electrical power

Fig. 2. A dehydrator with integrated PID control

or solar heat, offering optimal heating efficiency. The primary energy source for this equipment is Liquefied Petroleum Gas (LPG), known for its efficiency compared to electricity.

The working principle is that the thermocouples measure the actual temperature and send this information to the controller. The controller then calculates the error, which is the difference between the desired and actual temperatures. Based on this error, the accumulation of previous errors and the rate of change of the error, the PID controller calculates the control signal to send to the valve. This control signal determines how wide the valve should open or close. A low-cost dehydrator is shown in Fig. 2.

The PID controller was installed in the instrumentation system of the dehydrator. In summary, when there is an error, the PID controller sends a signal to the gas valve to adjust the gas flow. The gas flow is then either increased or decreased to ensure that the temperature remains consistent with a predetermined setpoint. The block diagram of PID control is represented in Fig. 3.

According to Fig. 3, PID control is Used to regulate the process and reach the desired setpoint by adjusting the gas flow valve to maintain a stable temperature. When the temperature is input, it is declared as the setpoint. Proportional (P) control reacts to the current error. If the current temperature is lower than desired, the valve opens wider; conversely, it closes slightly if the current temperature is higher than desired. Integral (I) control responds to the accumulation of errors over time. If the temperature is consistently below the setpoint, the integral will increase, keep the valve wide open until the temperature reaches the setpoint. This will prevent systematic errors or biases that remain constant over a long period. On the other hand, the Derivative (D) control responds to the rate of change of the error, preventing excessive responses that could cause temperature oscillations around the setpoint temperature. If the temperature approaches the setpoint quickly, the derivative control closes the valve early to prevent overshooting.

Furthermore, to generate accurate temperature control, the PID constants need to be tuned. Those, were obtained by trial-and-error method (manual tuning). According to Fig. 4, the best constants of PID we get are P = 1, I = 2, and D = 3. By applying these constants, the time taken by the system to change a signal from 30ºC to 100ºC of temperature is about 5 minutes, with a maximum overshoot of about 10%. In addition, the system required 25 minutes to achieve a steady state with an error value of about 5% from the setpoint.

The next stage is characterizing the dehydrator by applying various setpoints of temperature. The purpose is to determine the minimum temperature in the chamber that the instrument can produce during drying. The test was done by varying temperatures. The result shows that system could not achieve a temperature under 90ºC. It indicates that this temperature is the minimum degree the dehydrator could be generated. Meanwhile, the maximum temperature is set at 150ºC to prevent the bananas from burning during the drying process.

With the dehydrator characteristic, the experiment could be executed. The banana drying process involved various mass samples ranging from 1 to 10 grams at a temperature of 100°C. The experiment result is displayed in Table 1, showing different responses for each sample. Samples with a mass of 1-2 g showed the fastest decrease in water content, reducing up to 50% within 60 minutes.

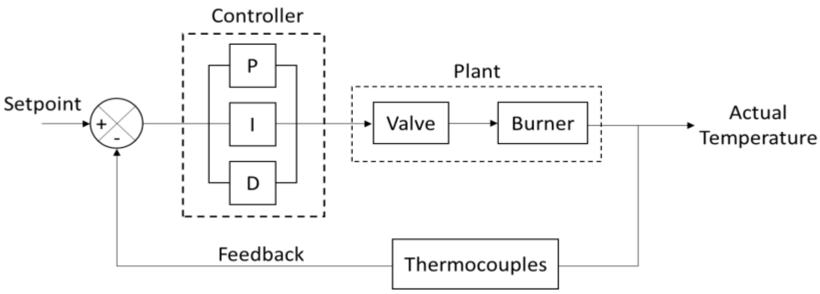

Fig. 3. Block diagram PID control of dehydrator

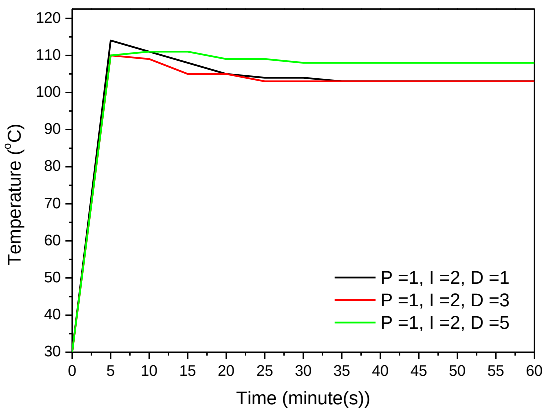

Fig. 4. Temperature responses of dehydrator while tuning PID constants

Table 1. The differences in each mass of banana pieces form 1-10 g.

Initial Mass (m_i)	Final Mass (m_f)	Water Reduction ($\Delta m = (m_i - m_f$)	Percentage (%)
1 g	0,5 g	0.5 g	50%
2 g	1 g	1 g	50%
3 g	1.7 g	1.3 g	45%
4 g	2.4 g	1.6 g	40%
5 g	3.1 g	1.9 g	38%
6 g	4 g	2 g	33%
7 g	4.9 g	2.1 g	30%
8 g	5.7 g	2.3 g	29%
9 g	6.4 g	2.6 g	28%
10 g	7.4 g	2.6 g	26%

This rapid reduction can be attributed to the relatively larger surface area in small samples, allowing for more efficient and quick water evaporation. In contrast, samples with a larger mass, specifically 10 g, experienced only a 26% decrease in water content during the same experimental period. Furthermore, the rate of water reduction for each of banana piece is of interested for analysis. According to Fig. 5 the reduction in water content follows a linear trend. Heavier banana pieces take longer to reduce water content due to uneven heat distribution and increasing density during the drying process. These factors significantly contribute to lower drying efficiency. This indicates that the thickness and size of the sample play an essential role in determining the drying speed.

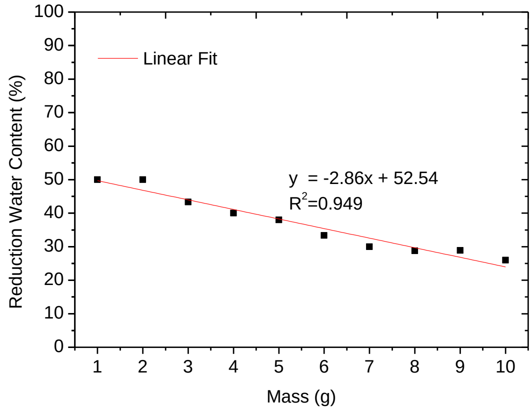

Fig. 5. Pieces of post-dried bananas from 1-10 g

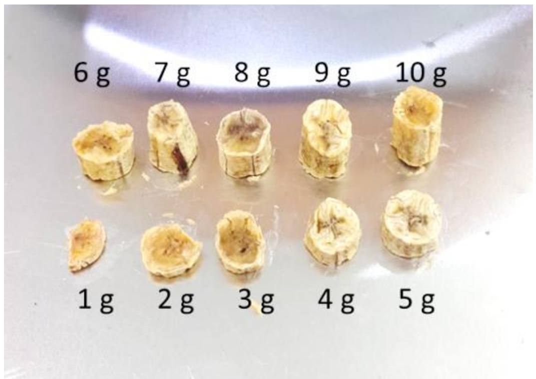

Fig. 6. Pieces of post-dried bananas from 1-10 g

The bananas dried in a dehydrator machine for 60 minutes were observed to assess the physical changes in color and texture. The post-dried bananas are shown in Fig. 6. Following the drying process, the banana pieces exhibit a slight brownish color change due to heating and a more rigid texture resulting from water loss. Despite these changes, the sweet taste of the banana slices remained. Further elaboration is needed to thoroughly assess the performance of the dehydrator.

From the results of this experiment, it can be concluded that the built dehydrator has demonstrated good performance, showing great potential in drying bananas. However, several aspects must be examined and optimized for optimum outcomes. Although dehydrators are effective in drying small masses of samples, they appear to have limits in handling larger pieces with the same efficiency. This might be due to the dehydrator's heating and air circulation capabilities, which may not be ideal for samples with higher volumes. It suggests that dehydrator technology has to be improved or adjusted in order to boost drying efficiency for big components.

Furthermore, the performance of the dehydrator can also be influenced by the design of the rack or tray where the fruit is placed, as well as the distribution of hot air flow. Drying quality and effectiveness may be increased with better designs that allow for uniform air circulation across the drying space, particularly for larger samples.

4. Conclusions

A controlled gas-based dehydrator for drying bananas in the home industry was successfully constructed. After conducting a series of experiments with a PID-based dehydrator controlling the gas valve on banana fruit objects, it was revealed that precision control through the PID system provided more consistent and optimal drying results. Integrating the PID controller with the gas valve enables more stable temperature regulation, preventing sudden fluctuations that could compromise the quality of the fruit. Bananas dried using this method show a better texture, maintained nutritional content, and a more intensive flavour than conventional drying methods. Therefore, using a dehydrator with PID control on the gas valve is highly recommended to improve the quality of dried banana production.

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Additional Information