

Optimization of Milk Pasteurization Process Using PID Control System

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Abstrak

Produk susu merupakan komoditas peternakan yang produksinya terus meningkat, namun memiliki umur simpan yang singkat sehingga perlu dilakukan pasteurisasi. Penelitian ini mengoptimalkan proses pasteurisasi susu metode LTLT pada suhu 63 °C menggunakan kontrol PID dengan penyetelan Ziegler-Nichols orde 2. Sistem dirancang dengan Arduino Nano, sensor DS18B20, servo pengatur katup api, serta sensor MQ-02 untuk keamanan gas. Hasil pengujian menunjukkan sensor DS18B20 memiliki tingkat error rata-rata 0,85%, sedangkan kontrol PID dengan parameter $K_p=18$, $K_i=1,53$, $K_d=105,7$ mampu menjaga suhu dengan overshoot rata-rata 0,29% dan waktu mantap 0,36 menit. Uji ketahanan menunjukkan susu pasteurisasi bertahan hingga 23 jam pada suhu ruang, lebih lama dibanding susu murni yang hanya bertahan 8 jam.

Kata Kunci — DS18B20; LTLT; Pasteurisasi; PID; Ziegler Nichols

Abstract

Milk is a livestock commodity with increasing production each year, but it has a short shelf life and requires pasteurization. This study optimised the Low-Temperature Long-Time (LTLT) pasteurization process at 63 °C using a PID controller tuned by the Ziegler-Nichols second-order method. The system employed an Arduino Nano, a DS18B20 sensor, a servo motor for flame regulation, and an MQ-02 gas sensor for safety. Experimental results showed that the DS18B20 sensor achieved an average error of 0.85%. At the same time, the PID controller with parameters $K_p=18$, $K_i=1.53$, and $K_d=105.7$ maintained a stable temperature with an average overshoot of 0.29% and a settling time of 0.36 minutes. Shelf-life testing indicated that pasteurised milk lasted up to 23 hours at room temperature compared to only 8 hours for raw milk.

Keywords — DS18B20; LTLT; Pasteurization; PID; Ziegler Nichols

I. INTRODUCTION

Livestock in Indonesia proliferates thanks to fertile soil, which supports the growth of forage crops. This has increased

livestock products, including eggs, meat, and milk. Of all these products, milk shows a significant increase in production every year. In 2020, national milk production was recorded at 947,685.36 tons, according to the Central Statistics Agency. With nursing actions, thereby helping them cope with stress. The abundant milk product results every year are based on the increasing number of consumers for various needs because milk is one of the foodstuffs that are very much needed to meet the community's nutritional needs. Milk contains many benefits that are required to strengthen the immune system. Milk is a nutritious food that is widely consumed by the community [1]. The complete nutritional content of fresh cow's milk is very much needed for human health, so fresh cow's milk is widely consumed. Therefore, the standards of the quality of fresh cow's milk must be considered. The nutrition contained in fresh cow's milk is very high, which allows the development of pathogenic and non-pathogenic bacteria that can reduce milk quality. Public awareness of milk consumption makes milk an economic commodity with a strategic value. Therefore, milk quality must be maintained from production until it reaches the consumer [2].

One of the disadvantages of milk is its short shelf life or easy to spoil. To extend its shelf life, milk must be processed further. Pasteurization is a milk processing process that can be done. This is heating milk at a temperature below 100°C for a specific time, for example, at a temperature of 62°C–66°C for 30 minutes or 72°C–75°C for 15 seconds [3] - [5]. Thus, the pasteurization process followed by direct cooling can reduce protein damage and stop the development of microbes that are resistant to pasteurization temperatures and damage the enzymatic system they produce, which can reduce damage to nutrients and increase the shelf life of fresh milk. The obstacle for farmers in processing this milk is that the milk pasteurization used is less effective in maintaining the temperature during the pasteurization process. Often, milk pasteurization produces an inconsistent temperature that interferes with the milk pasteurization process, which impacts

the quality of the milk after the process is carried out [6] - [9]. Based on the description and problems, an innovation is needed to solve the problem by adding innovation in the form of creating a system that can control or stabilize the temperature in milk pasteurization so that farmers who process milk do not experience obstacles during the pasteurization process due to the unstable temperature used which can affect the results of the milk. Therefore, the author created an innovative tool that is useful for designing and implementing a temperature control system in milk pasteurization so that the tool can optimally stabilize the temperature during the pasteurization process and the processing results are no longer problematic.

Based on this description, the main problem addressed in this study is the unstable temperature during milk pasteurization, which leads to inconsistent product quality. Previous research has attempted to use fuzzy logic-based control and conventional PID systems. Still, these studies had limitations: fuzzy controllers often overlooked temperature accuracy and safety aspects (e.g., gas leak detection), while PID studies lacked direct application in farmer-scale pasteurization systems. The novelty of this research lies in applying a Ziegler–Nichols second-order tuned PID controller to maintain temperature stability in LTLT pasteurization at 63 °C, integrated with Arduino-based sensors (DS18B20) and a safety system (MQ-02 gas sensor). Thus, this study fills the gap by developing a temperature control system that is not only effective and precise but also safe and practical for local dairy farmers. The contributions are threefold: (1) designing a PID-based pasteurization system that maintains stable operation with overshoot of only 0.29% and settling time of 0.36 minutes; (2) integrating temperature control with gas leak detection for enhanced safety; and (3) empirically demonstrating that pasteurization with this system extends milk shelf life up to 23 hours at room temperature, compared to only 8 hours for raw milk.

II. LITERATURE REVIEW

A. Related Work

It would be helpful to use related studies as references for this research because they compare ongoing studies. For example, Mokh Sholihul Hadi in 2023 with the title Automatic Fire Furnace Control System for Milk Pasteurization Process Based on Fuzzy Logic. However, the results of this study have shortcomings, namely that the research only focuses on fuzzy logic without looking at the temperature parameters used for the milk pasteurization process. In addition, there is still no security in the study, such as gas leak detection, for the cook's safety, and the study looks at the results of milk produced by the system [10]. A unique hybrid Data Driven based PID controller improves temperature regulation in high-temperature-short-time milk pasteurization modules, surpassing the performance of traditional PID controllers [11]. This study presents a novel Extremum Seeking based PID controller designed to improve stability and reduce system

disturbances in milk pasteurization by achieving optimal temperature management [12].

This research article presents the development of a temperature control device for milk pasteurization utilising Arduino IoT. The gadget incorporates clever algorithms to achieve accurate temperature regulation, therefore improving both safety and quality [13]. A comparative analysis of PID control performance in milk pasteurization using PLC and MATLAB demonstrates the effectiveness of PID with Cohen Coon tuning in facilitating the design of a temperature stabiliser [14]. A fuzzy-PID hybrid controller is developed to improve temperature stability in milk pasteurization during ultra-high temperature milk processing. This controller combines the advantages of PID feedback and feedforward control methodologies [15].

B. Pasteurization

Pasteurization is a heating method at a temperature below 100°C for a certain period, which aims to reduce the number of microbes in milk without significantly disrupting its protein structure. The next step after pasteurization is rapid cooling, essential in inhibiting the growth of microbes that may remain after the heating process. This cooling also has the potential to damage enzymes such as phosphatase and lipase, which can positively affect the nutritional quality and shelf life of fresh milk [16], [17]. In the pasteurization process, there are two standard methods: Low-Temperature Long Time (LTLT), which heats milk at a temperature of 62°C–66°C for 30 minutes, and High-Temperature Short Time (HTST), which heats at a temperature of 72°C–75°C faster than LTLT, which only takes 15 seconds. Although HTST is more time efficient, the LTLT method is more effective in maintaining the nutritional content of milk. After pasteurization, the milk is cooled quickly using a refrigerator to a maximum temperature of 10°C to prevent the growth of microorganisms that can spoil the milk. The ideal storage temperature for pasteurized milk is between 3°C and 10 °C, where the development of spoilage microbes can be suppressed. The benefits of heating or pasteurization are extending the shelf life of milk, killing bacteria that cause disease, and stopping enzymes that spoil milk. The criteria for spoiled or non-spoiled milk are based on changes in colour, aroma, and texture.



Fig. 1. Pasteurization of Cow's Milk

C. PID (Proportional Integral Derivative) Control System

The proportional integral derivative control system (PID) is a controller system that creates an instrumentation system with feedback characteristics. PID control consists of three components: proportional, integral²⁴, and derivative. These components can work together or separately depending on the tool's response [18] - [20]. The block diagram of the PID control system can be seen in Figure 2.

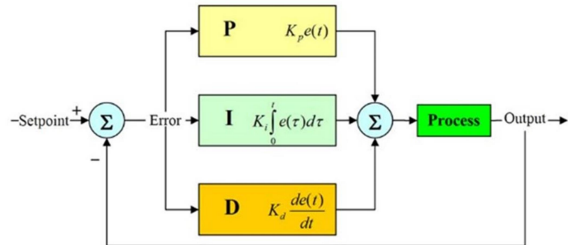


Fig. 2. Block Diagram of the PID system

D. Ziegler Nichols method of order 2

The type 2 method uses a closed loop system, but only Kp is used. The system is made to oscillate continuously by setting the value of the Kp parameter when the system response generates continuous oscillations with a constant value of Kcr. The Kcr value of the resulting response can be searched for other parameters, namely Pcr. Figure 3 shows the process of calculating the PCR value [21] - [24].

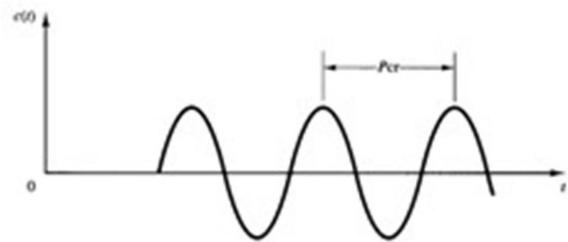


Fig. 3. Output Characteristics of System 2

III. METHODOLOGY

A. Design of Temperature Stabilizer System

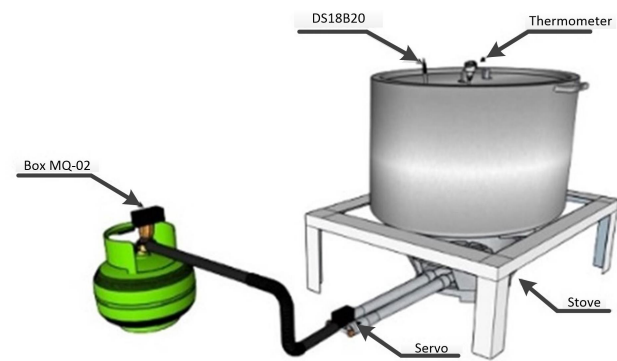


Fig. 4. Design of Temperature Stabilizer System

The temperature stabilizer system in the pasteurization process is designed for a milk capacity of 25 L.



Fig. 5. Design of Temperature Stabilizer System

B. Electrical Design of The Temperature Stabilizer System with PID

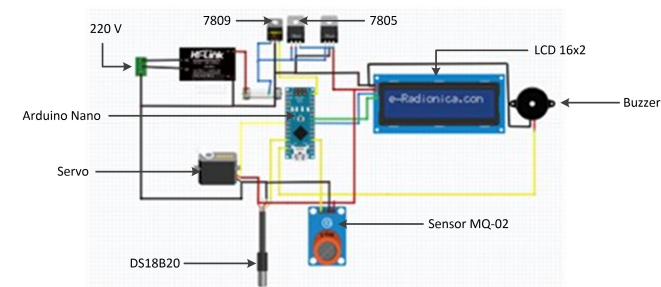


Fig. 6. Electrical Design

The system designer utilizes the DS18B20 sensor to monitor the temperature during pasteurization and the MQ-02 sensor for safety in case of LPG gas leaks. With LCD and buzzer indicators, the system designer regulates the intensity of the fire so that the temperature does not exceed the limit. A servo motor is used.

C. Electrical Design for Reading Milk Colour

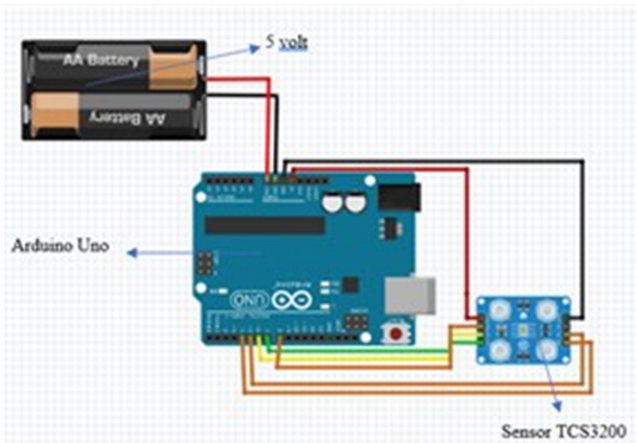


Fig. 7. Design of Temperature Stabilizer System

Figure 7 is the electrical system for reading R, G, and B values in milk colour. The system utilizes the TCS3200 sensor to measure milk colour.

D. System Flowchart

Based on Figure 8. The system starts by setting the time to 1800 s, and then the DS18B20 sensor reads the milk temperature in the process drum. The Ziegler Nichols 2nd order PID control system uses a set point of 63, so when the temperature is still below the set point, the sensor will continue to feed back the temperature reading. Still, when the temperature reaches the set point, the servo will adjust the fire intensity according to the PID input. When it reaches 1800 s, the servo will return to its initial position, and the buzzer indicator will be active.

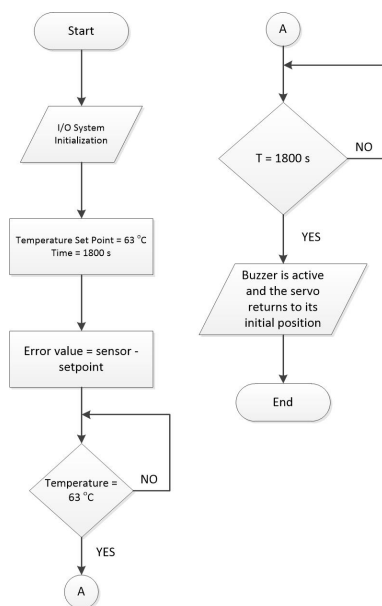


Fig. 8. Flowchart How the Pid System Works

E. Gas Leak Detection System Flowchart

The system starts with the MQ-02 sensor reading the gas content when pasteurization begins. Then, if gas is detected more than the ADC threshold value of 500 or a voltage of 2.4 volts, the buzzer indicator will be on, and the process is carried out until the pasteurization process is complete.

F. EXPERIMENTAL SETUP AND TESTING PROCEDURE

To evaluate the system performance, a series of controlled experiments were conducted:

1) Sample and Replication

- The pasteurization system was tested using fresh cow's milk with a volume of 25 L per batch.
- Each test was repeated three times to ensure data consistency and repeatability.

2) Sampling Frequency and Duration

- Temperature data were recorded at 1-second intervals using the DS18B20 sensor.
- Each pasteurization cycle lasted 30 minutes at 63 °C, followed by natural cooling to below 10 °C.

3) Environmental Conditions

- The tests were carried out in a laboratory room with an average ambient temperature of 28–30 °C and relative humidity of 65–70%.
- Ventilation was maintained to ensure safety during gas combustion.

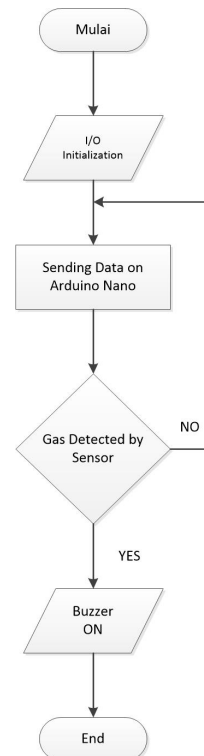


Fig. 9. Flowchart How the Pid System Works

4) Safety Procedures

- An MQ-02 gas sensor continuously monitored possible LPG leakage.
- A buzzer alarm was configured to activate if gas concentration exceeded 2.4 V (ADC $\geq$ 500).
- Fire extinguishers were placed near the setup during experiments as a precautionary measure.

5) Wiring Diagram and Bill of Materials (BOM)

- The system wiring diagram is shown in Figure X (update figure reference). It includes interconnections between Arduino Nano, DS18B20 temperature sensor, MQ-02 gas sensor, servo motor, TCS3200 color sensor, LCD display, and buzzer.

- The Bill of Materials (BOM) used in this study is summarized in Table I.

TABEL I

BILL OF MATERIALS (BOM) OF THE PASTEURIZATION SYSTEM

Component	Specification / Type	Function	Qty
Arduino Nano	ATmega328P	Main microcontroller	1
DS18B20 sensor	Digital, $\pm 0.5^{\circ}\text{C}$ accuracy	Milk temperature measurement	1
MQ-02 gas sensor	Range 200–10000 ppm	LPG leak detection	1
Servo motor	SG90, 180°	Valve actuator for flame control	1
TCS3200 color sensor	RGB detection	Milk color analysis	1
LCD 16x2 with I2C	5 V, I2C interface	Display temperature and sensor data	1
Buzzer	5 V piezoelectric	Alarm indicator	1
LPG stove + regulator	Household type	Heating source	1
Milk drum	Stainless steel, 25 L	Pasteurization container	1

IV. RESULT AND DISCUSSION

A. Tool Design Results

B. DS18B20 Sensor Testing

Calibration data were collected by comparing the DS18B20 sensor readings with a digital thermometer at 10 different temperature points. The results are shown in Table II.

To test the DS18B20 sensor, the author tested its ability to perform measurements displayed on the LCD. Ten temperature measurement experiments with the DS18B20 sensor and a digital thermometer were carried out for sensor calibration. The results of the experiments can be seen in Figure 11.



Fig. 10. Design Results

TABEL II

DS18B20 CALIBRATION DATA

Trial	Thermometer ($^{\circ}\text{C}$)	DS18B20 ($^{\circ}\text{C}$)	Error ($^{\circ}\text{C}$)	Error (%)
1	30.0	30.2	+0.2	0.67
2	35.0	34.8	-0.2	0.57
3	40.0	39.7	-0.3	0.75
4	45.0	44.6	-0.4	0.89
5	50.0	50.5	+0.5	1.00
6	55.0	55.3	+0.3	0.55
7	60.0	59.6	-0.4	0.67
8	65.0	64.7	-0.3	0.46
9	70.0	70.6	+0.6	0.85
10	75.0	74.4	-0.6	0.80
Average error			0.45	0.75



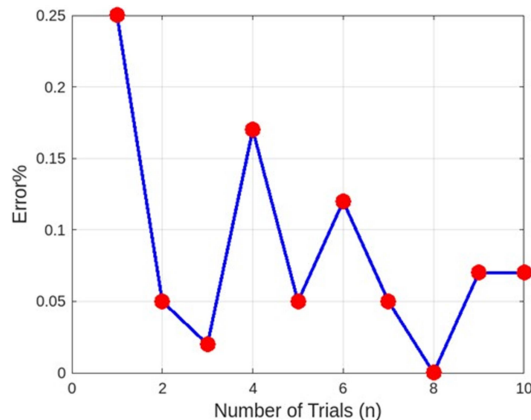


Fig. 11. Results of Obtaining Error% for Each Experiment

The test results indicate that the DS18B20 Sensor is very good for use in the milk pasteurization process. The test results with a thermometer showed an error of 0.85%.

C. Proportional Integral and Derivative (PID) Method Testing

In this study, the author used Ziegler Nichols Order 2 tuning to determine the value of the PID using a cylindrical gain until the response oscillates constantly. In the test using only proportional control parameters, while the integral and derivative control parameters are set to 0, the KP control value is increased from 0 until the system reaches a constant oscillating response. The response results of the closed-loop system can be seen in Figure 12.

The Ziegler-Nichols tuning method test order 2, where the proportional control parameter 30 produces a system that oscillates constantly. Thus, the KP value of 30 is the KCR (critical gain). After obtaining a constant oscillating system response, the PCR value (critical period) can be determined. The PCR value can be determined by measuring the oscillation period, the time between one peak (hill) and one valley on the system response graph. Based on Figure 12, the system oscillates constantly at $X_0 = 2052$ seconds and $X_1 = 2099$ seconds.

In the tuning stage, the second-order Ziegler-Nichols method was used to determine the PID parameters. The initial step was to turn off the integral and derivative components ($K_i = 0$, $K_d = 0$), so that only the proportional parameter (K_p) was tested. The K_p value was then increased gradually (5, 10, 15, and so on) until the system exhibited constant oscillation. In this study, stable oscillation was achieved when $K_p = 30$, which was defined as the critical gain (Kcr).

Next, the oscillation period (critical period / Pcr) was determined by measuring the time interval between two consecutive peaks on the system response graph. The measurements yielded $X_0 = 2052$ s and $X_1 = 2099$ s, resulting in $Pcr = 47$ s. These Kcr and Pcr values served as the basis for calculating the PID parameters using the second-order Ziegler-Nichols rule.

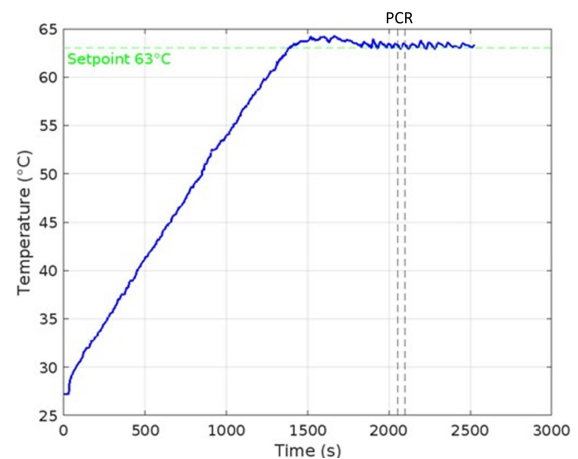


Fig. 12. Ziegler Nichols 2 PID Tuning Results

If the KCR and PCR values are obtained, the next step is to find the TI and Td values by entering them into the Ziegler Nichols Order 2 PID formulas. If the TI and TD values have been obtained, the next step is to find the KI and KD parameter values using the following formula.

D. Overall Testing

In testing a long-term pasteurization system called the Low Temperature Long Time (LTLT) method, the temperature needs to be maintained between 62°C and 65°C for 30 minutes. This study uses a temperature of 63°C to observe the response of the servo actuator in achieving temperature stabilization, with PID parameters adjusted using the Ziegler-Nichols tuning method. The primary purpose of this test is to evaluate the performance of all components in the pasteurization system as a whole. The author applied PID control parameters in this test with $K_p = 18$, $K_i = 1.53$, and $K_d = 105.7$. The complete results of the test can be seen in the graph Figure 13.

The final parameters used in the test were $K_p = 18$, $K_i = 1.53$, and $K_d = 105.7$. The test results showed that the system could maintain the pasteurization temperature at 63°C for 30 minutes with stable performance. The average undershoot value was 0.28%, average overshoot 0.29%, and maximum overshoot 1.28%. This proves that the second-order Ziegler-Nichols adjustment method is effective in optimising temperature control in the milk pasteurization process.

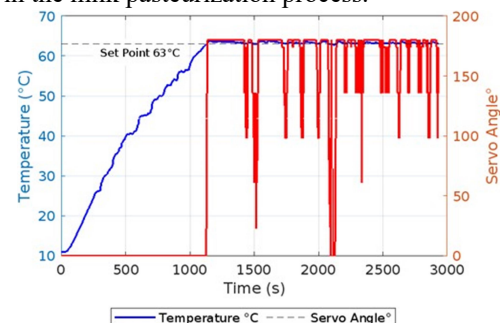


Fig. 13. PID Test Results Using Ziegler Nichols Order 2

The figure above shows the results of the pasteurization system test according to the long-term test method at low temperatures for 30 minutes. From the 30-minute system test, the average undershoot was 0.28%, while the average overshoot was 0.29% with a maximum overshoot of 1.28%. The settling time was 0.36 minutes and the rise time was 17 minutes. In the gas sensor test, the gas sensor reading was stable at 0.5 volts or 100 in the analogue, digital converter value (ADC 10 bit), and the buzzer remained off because there was no gas leak, while when the temperature reached 63 °C for 30 minutes, the buzzer was on because the pasteurization process was complete. The following are the results of the graph of the overall temperature value using the Ziegler Nichols PID Order 2, which can be seen in Figure 13.

During the 30-minute LTLT pasteurization test, temperature readings were logged every minute. The servo motor adjusted the gas valve based on PID output. Table III shows the temperature log and servo position (0° = closed, 90° = half open, 180° = full open).

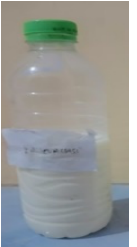
TABEL III
DS18B20 CALIBRATION DATA

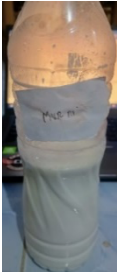
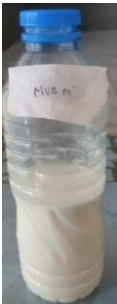
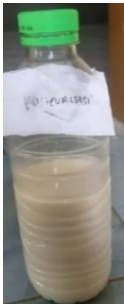
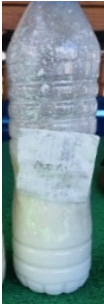
Time (min)	Temperature (°C)	Servo Position (°)	Remark
0	28.5	180	Heating start
5	45.2	160	
10	55.8	140	
15	62.3	110	Near setpoint
20	63.1	95	Stabilized
25	63.0	90	Stable
30	62.9	90	Process end

E. Testing the Resistance of Milk in a Normal Room

In this trial, the author tested the resistance of fresh or pure milk with milk from the trial results using a system for pasteurization with the PID method at normal room temperature. The test results can be seen in Table IV.

TABEL IV
RESULTS OF TESTING THE RESISTANCE OF MILK IN A NORMAL

Time	Pure Milk	Pasteurization	Characteristics
0 hours			Pure milk - Aroma remains - Color remains Pasteurized milk - Aroma remains - Color remains
	Not Stale	Not Stale	

8 hours	 Stale	 Not Stale	Pure milk - sour milk aroma - Color changes Pasteurized milk - Aroma remains - Color remains
15 hours	 Stale	 Not Stale	Pure milk - Sour aroma - Color changes Pasteurized milk - Aroma remains - Color remains
24 hours	 Stale	 Stale	Pure milk - Sour aroma - Color changes Pasteurized milk - Aroma remains - Color changes slightly
28 hours	 Stale	 Stale	Pure milk - Sour aroma - Color changes Pasteurized milk - Sour aroma - Color changes

Based on Table IV, the results of the milk resistance test in a standard room between pasteurized milk and pure milk show that pure milk can last up to more than 7 hours, while milk with

a pasteurization process using a system lasts up to 23 hours. However, when 24 hours of pasteurized milk begins to go stale due to a slight colour change, and also the aroma of the milk is slightly sour, the results of stale or unstable milk can be seen based on the colour of the milk, based on the tests that have been carried out it can be seen that stale milk will fade or the value of R, G, B will increase if the milk is stale. In addition to being seen from the colour, it can also be seen from the aroma and texture of the milk. Stale milk has a slightly sour smell, a yellowish colour, and a fairly thick texture. The durability of pure milk is faster, namely 8 hours; this is due to the presence of microbes in the milk that produce acid for a long time, for the factor of stale pasteurized milk, namely the temperature factor in the normal room, which is too hot. So, for pasteurized milk to last longer, it is stored at a temperature of 4-10 °C.

F. Testing the Resistance of Milk Under Cold Storage

In addition to room temperature testing, a validation test was carried out by storing both raw and pasteurized milk samples in a refrigerator at a temperature of 3–10 °C. This aimed to evaluate the shelf-life improvement under recommended storage conditions after LTLT pasteurization.

The results indicate that raw milk spoiled within 1 day at cold storage, while pasteurized milk maintained freshness up to 3–4 days, and began to show noticeable spoilage on day 5. This finding supports the effectiveness of LTLT pasteurization in combination with proper cold storage (3–10 °C), which is consistent with international standards.

TABEL IV

SHELF-LIFE TEST OF MILK UNDER COLD STORAGE (3–10 °C)

Time (days)	Raw Milk	Pasteurization Milk
0	Fresh (no change)	Fresh, no change
1	Sour aroma, color change	Fresh, no change
2	Spoiled	Fresh, no change
3	–	Still fresh, no change
4	–	Slight changes in aroma
5	–	Noticeable sour aroma

V. CONCLUSION

Based on all the tests that have been carried out, the design of the system with PID control using the DS18B20 and MQ-2 sensors, as well as servo output, buzzer, and LCD, shows good effectiveness. The DS18B20 sensor has an average error of 0.85%, making it the correct feedback for a control system such as the PID control used in this system. This system uses PID Tuning with the Ziegler-Nichols method order 2 using a Kcr value of 30, producing constant oscillations to obtain a Pcr value of 47. The MQ-02 sensor effectively monitors gas leaks, with the buzzer active when gas is detected at a voltage of 2.4

volts or an ADC value of 500. Then, testing the milk pasteurization temperature control with parameters KP = 18, KI = 1.53, and KD = 105.6, found an average undershoot error of 0.28% and an average overshoot of 0.29%, with a maximum overshoot of 1.28%. The servo system works well, moving the servo according to the PID input at a temperature close to 63°C. Milk durability tests show that pasteurized milk is more durable than whole milk, as seen from the colour change after 8 hours (whole milk R = 21, G = 23, B = 21; pasteurized milk R = 18, G = 21, B = 21 after 24 hours). Furthermore, validation under cold storage (3–10 °C) demonstrated that pasteurized milk retained good quality for up to 3–4 days compared to only 1 day for raw milk, confirming that LTLT combined with proper refrigeration significantly extends shelf life. However, this study found several obstacles, such as the selection of servo motors not being able to regulate the gas valve optimally, so the right setting must be used for the LPG gas regulator.

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