Volume 4 Number 1 (2026)
January – June 2026
Page: 1-14

Journal of Creative Power and Ambition (JCPA)
https://edujavare.com/index.php/jcpa
E-ISSN: 3031-4054
DOI: 10.70610/jcpa.v4i01.1135

JOURNAL OF CREATIVE
POWER AND AMBITION
(JCPA)

Design of Gas Oven Temperature Control System Using PID Method

Wisnel[1], Eri Wirdianto[2], Prima Fithri[3]

[1,2,3]Departemen Teknik Industri Universitas Andalas; Indonesia
* Correspondence e-mail; wisnel@eng.unand.ac.id

Article history Submitted: 2024/02/01; Revised: 2024/02/11; Accepted: 2024/02/21

Abstract

This paper presents the design and implementation of an automatic oven for baking marble sponge cake using a PID-based temperature control system. The proposed system regulates oven temperature and air circulation to achieve stable and uniform baking conditions. Temperature control is implemented using a PID algorithm based on feedback from a K-type thermocouple sensor, while air circulation is controlled by a DC blower motor driven through PWM and a BTS7960 driver. The overall system is controlled by an Arduino Uno R3 microcontroller. PID parameters were determined using the Ziegler–Nichols reaction curve method, resulting in Kp = 16.4, Ti = 90 s, and Td = 22.5 s. Experimental results show that the oven was able to reach and maintain a setpoint temperature of 175 ∘C with acceptable stability during a 28-min baking process. Therefore, the developed system can be considered effective for automatic marble sponge cake baking requiring stable and controlled thermal conditions.

Keywords PID Controller, Conventional Gas Oven, Temperature Control

© 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution 4.0 International (CC BY SA) license, https://creativecommons.org/licenses/by-sa/4.0/.

INTRODUCTION

Sponge cake, owing to its mellow, fluffy texture, is among the most widely consumed bakery products, with general acceptance across various consumer segments. Of all the different types of sponge cake, marble cake is particularly popular. Sponge cake is most distinctive for its sponge-like texture made by whipping eggs and sugar at high speed until the batter widens (Das et.all, 2023). This process produces a form that is better able to retain air, yielding the volume and tender texture characteristic of its end product. Marble cake is distinguished by its marbled surface and cross-sectional pattern. It is adapted from the classic pound cake recipe by adding chocolate batter in the primary batter. The soft mixing of light and dark batters forming the marbled pattern is the icing of the cake. Marble cake generally contains wheat flour, butter, sugar, and eggs as main ingredients (W. Gisslen, 2017). Aside from visual qualities of the cake, the shape of the batter and the way in which it is baked will be one of the factors in ensuring its good quality.

In the construction of bakery products, the structural quality of the batter greatly affects the final product. The structure is established for that reason, with gluten interacting with the air that is trapped inside the batter matrix that consists of proteins, starches, and lipids. Well mixing will increase the structure of the batter to get better hold of gas or air and influence the elasticity and expansion of gluten. In cakes, structure is influenced by both gluten and the air distribution in the batter, both of which influence the growth of the volume, texture and evenness of the pore. Aside from the mixing, quality of the marble cake is greatly influenced by the baking method. Baking wrong may cause cakes that do not rise, bake uneven, collapse, harden and/or burn. Thus, proper control of temperature and baking time is necessary to make quality products. For instance, different types of cakes need different temperature and duration settings, and changes in temperature and duration parameters affect the physical and chemical properties of the cakes while baking (Ananda et al., 2023).

The oven is the baking infrastructure. Gas-fired ovens are frequently employed in micro, small and medium-sized businesses, and temperature and time settings are typically manually adjusted. Operators are never out of the heat and the doneness is usually tested visually (Awaludin & Waluyo, 2023). Operators experience these tasks to such an extent that they bring up inconsistency in results of the baking process. In practice, however, incorrect temperature and time management is one of the leading factors leading to poor product quality. Thermal cycling in the oven causes uneven heat distribution due to heat instability during baking. Low heat could potentially suppress the raising of the cake, thus leaving it denser than surface, while excessive heat can overcook the surface, causing it to end undercooked. Uneven heat also results in color, texture and doneness inconsistencies (Evalina et al., 2022; Finahari et al., 2025).

Therefore, ovens need temperature control methods that ensure a constant condition to meet the requirements of the process.

Time controlling is also key to baking. Gas ovens use timers for operation time management and they shut off gas generation when the specified amount of time is reached (Harjianto et al, 2025). But many conventional ovens do not efficiently combine timers and temperature controls to meet the temperature and need to be manually monitored for them, hence required for desired baking results. This limitation is especially difficult for small and medium enterprises (SMEs) looking for the efficiency and quality consistency in product because of both the demand and quality. An important solution to overcoming these challenges is the application of proportional-integral-derivative (PID) control technology in the production of gas ovens. PID systems are capable of automatic temperature regulation and precise measurement. Baking temperatures can be appropriately set according to the product used (100°C, 160°C, 185°C, 200°C, and many more) with high stability. With a precision temperature of around ±2°C, the oven operates all the time during the specified baking period, so products achieve a desired quality (Yusuf & Saputra, 2020; Bahri et al., 2014). Automatic control is introduced to improve process accuracy, operational efficiencies and product quality.

Baking is a more general method of processing food that utilizes heat to cook and dry the food. The bakery is one of the largest suppliers of cookies and bread-bearing products. Important changes such as volume expansion, protein denaturation, starch gelatinization and caramelization occur during baking alongside the establishment of distinctive color, aroma and flavor in the bakery product. But baking can destroy some heat-sensitive nutrients like vitamin C and thiamine (Rusliman & Prayitno, 2024). Thus, the accurate control of process conditions is necessary for the bakery to be successful. Fig. 1 shows a schematic of an automatic control system for conventional oven.

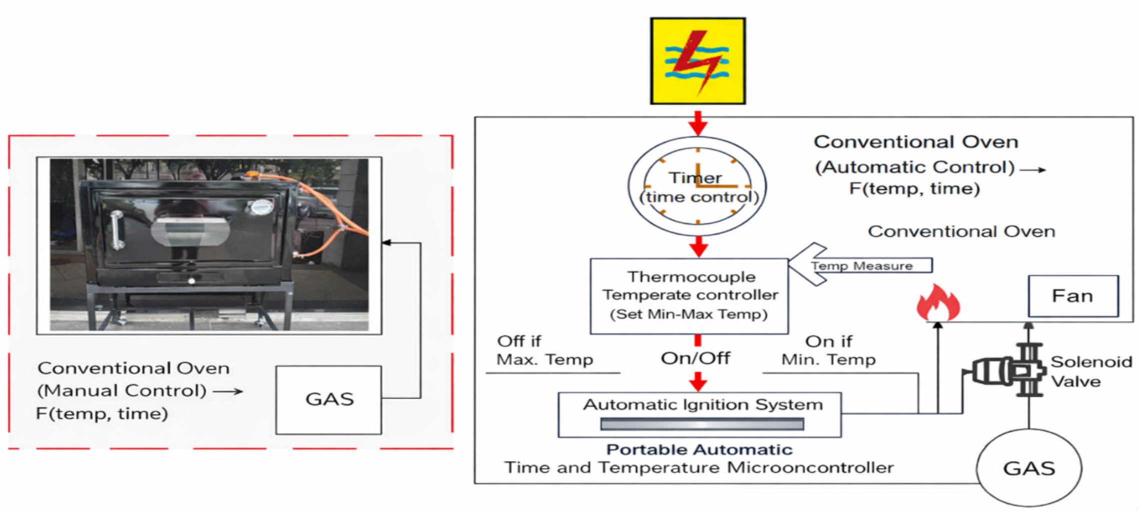


Figure 1. Automatic control scheme (timer, temperature, airflow) of conventional oven

METHODS

Design of the Automatic Oven Control System Blocks Diagram

The system design was carried out comprehensively for all circuits used in the automatic oven. This system is intended to regulate the oven chamber temperature automatically during the baking process. In this study, the Arduino Uno serves as the main control unit, coordinating sensor readings, receiving user inputs, and controlling the outputs of the heating element and fan. The interconnection between the components is illustrated in Figure 2 below.

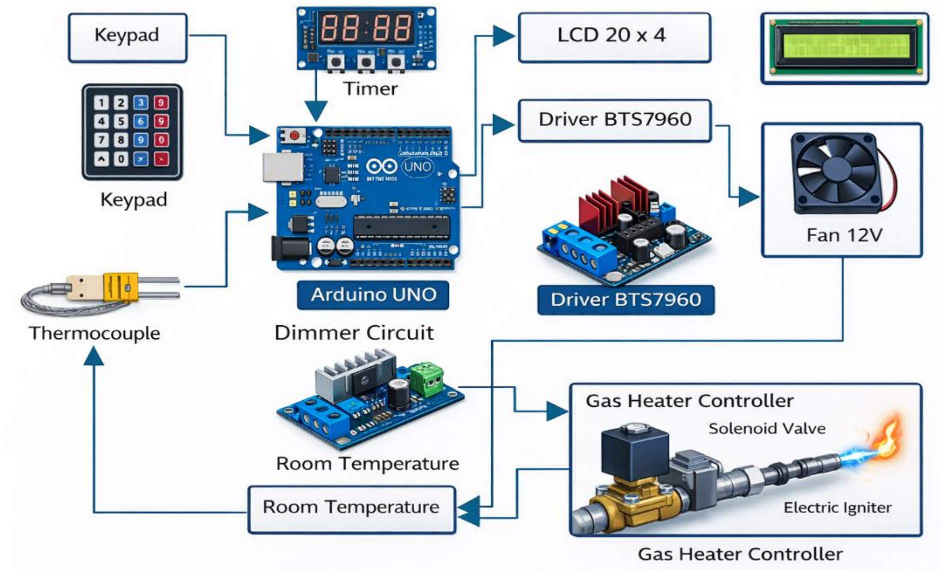


Figure 2. Diagram of the Automatic Oven Control System Blocks

The control system shown in Figure 2 below controls the oven temperature using an automated microcontroller-based approach. The Arduino UNO gets input from a keypad indicating the desired temperature and time, and the thermocouple measures the real-time oven temperature. The Arduino processes the sensor data and controls the dimmer circuit and the gas heater controller based on that feedback. The gas heater controller is equipped with a solenoid valve and an electric igniter that modulate the gas flow to maintain the set temperature. The driver BTS7960 controls the power to the 12V fan so that the airflow and heat of the oven are evenly distributed. There are also operational parameters displayed on an LCD 20 × 4 screen for current temperature and timer of the system. Through the continuous adjustment of gas flow and fan operation, based on thermocouple readings, the system keeps the oven temperature stable and accurate based on the programmed settings.

Mechanical Design of the Automatic Oven

Besides control system design, mechanical design of the oven, an essential component of the apparatus. The oven structure is designed to support the baking process in a safe, hygienic, and reliable manner under high-temperature conditions. Therefore, stainless steel was selected as the primary material for the oven construction. The selection of stainless steel is based on several technical considerations. This material has excellent corrosion resistance, preventing rust during prolonged use. Furthermore, stainless steel is easier to clean and is suitable for food processing equipment. The hygienic quality of the baked products is maintained through the use of this material, especially during cake baking. The mechanical design of the oven, functionally, ensures the structural stability and strength of the oven itself and supports the performance of the temperature control system. In addition, the mechanical design provides space for the heater, sensors, and fan to be installed. The oven chamber must be capable of retaining heat, facilitating even hot air distribution, and providing sufficient space for the heater, sensors, and fan. Properly designed mechanically, temperature regulation and air circulation in the oven are achieved more effectively. The mechanical configuration of the designed oven is illustrated in Figure 3.

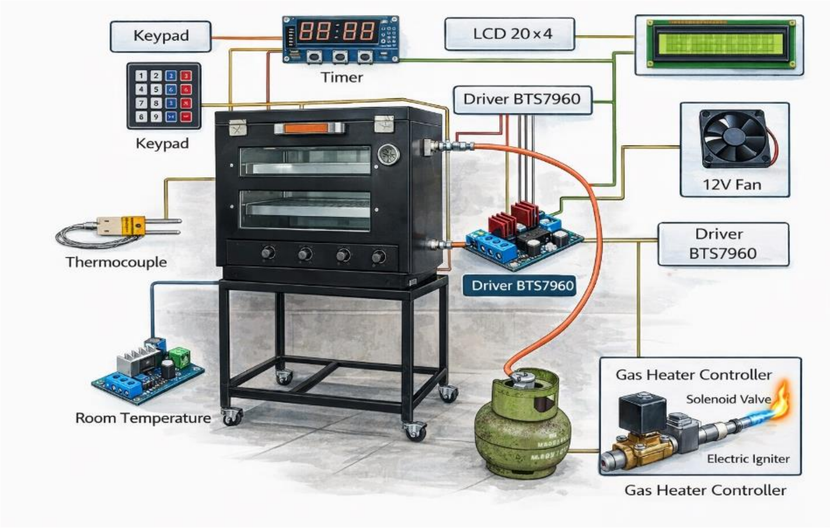


Figure 3. Mechanical design of oven and control system blocks

Overall System Circuit Design

It describes the complete circuit of all the circuits employed in an automatic oven control system. For the Arduino Uno in this system, it acts as the controller (the “brain” of the circuit), with which the circuit makes all the input, processing and output of the circuit coordinated. The system is running on a power source with a voltage in the range of 5 to 12 volts. As a general rule, the type-K thermocouple sensor is used to read the temperature of the oven chamber, the keypad is employed for inputting operational parameters, the LCD displays system information, the dimmer circuit controls the heater and BTS7960 driver regulates the motor or fan operation. All these pieces work together such that the baking process can take place automatically, stably, according to the user’s requirements. The full control circuit of the automatic oven system can be illustrated in Figure 4.

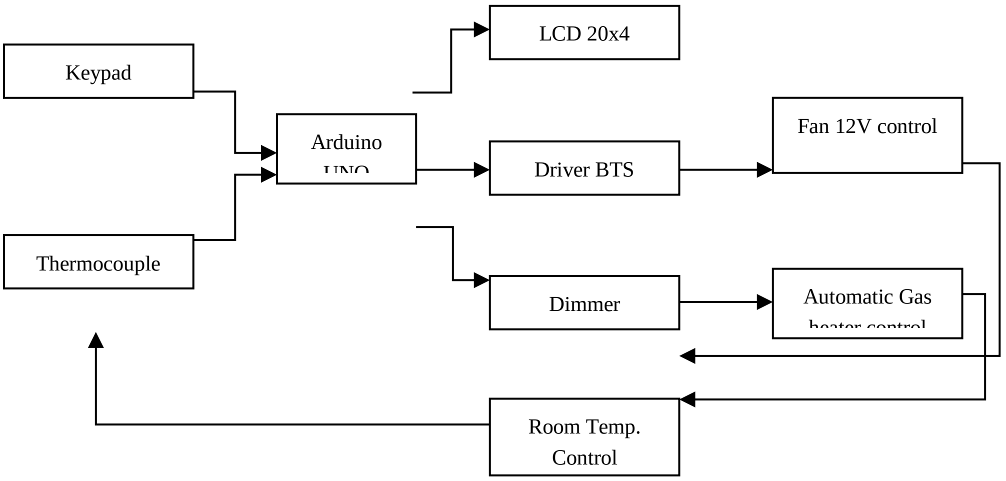


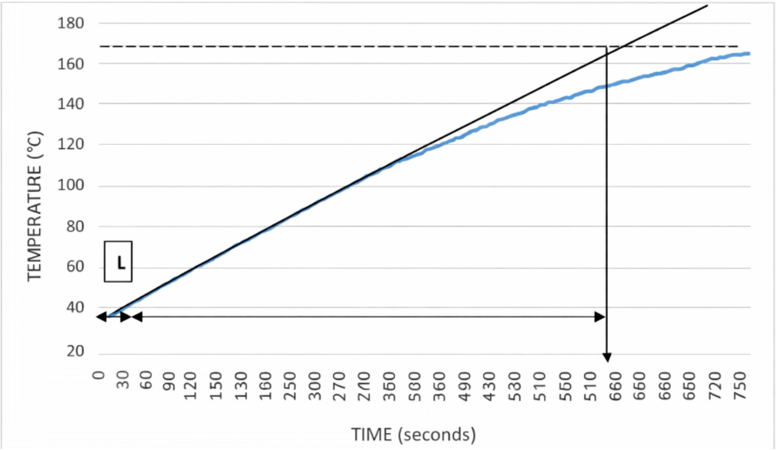
Figure 4. Block Diagram of the Automatic Oven Temperature Control System

RESULTS AND DISCUSSION

Results

PID Tuning Based on the Ziegler–Nichols Reaction Curve Method

The PID controller parameters were determined using the first Ziegler–Nichols tuning method, namely the reaction curve method. In this procedure, the oven was operated under open-loop conditions by supplying 220 VAC to the heating element without feedback control, and the temperature response of the baking chamber was recorded over time. This test was conducted to identify the process characteristics



required for controller tuning, namely the apparent dead time (L) and te time constant (T).

Figure 5. Uncontrolled Response Graph

As shown in Fig. 18, the open-loop response produced $T = 612$ s and $L = 45$ s. These values were then substituted into the Ziegler–Nichols reaction-curve equations to determine the controller parameters listed in Table 1, yielding $K_p = 16.4$, $T_i = 90$ s, and $T_d = 22.5$ s. Based on these results, the PID configuration was selected because it provided a balanced performance in terms of rise time, steady-state accuracy, and dynamic stability.

Table 1. PID parameters with the reaction curve method on the Zigler-Nichols method

Pengendali	Kp	Ti	Td
P	18,6	~	0
PI	16,8	100	0
PID	**16,4**	**90**	**22,5**

Open-Loop Thermal Response of the Oven

The uncontrolled heating response is summarized in Table 2. The chamber temperature increased from 30.0 °C at the initial condition to 180.0 °C after 940 s. This result confirms that the heating element was capable of raising the oven temperature to the required baking range. However, without feedback control, the temperature rise could not be precisely regulated, which may lead to overshoot and unstable thermal conditions during baking.

Table 2. Open-Loop Temperature Rise Before Controller Implementation

No.	Time (s)	T Res. (°C)	No.	Time (s)	T Res. (°C)
1	0	30.00	18	500	136.00
2	30	33.50	19	525	139.75
3	60	39.50	20	560	144.25

4	90	48.75	21	590	147.50
5	120	54.50	22	625	151.50
6	150	61.50	23	650	154.25
7	180	68.25	24	680	157.00
8	210	76.00	25	710	161.50
9	240	83.25	26	755	164.75
10	270	90.75	27	800	165.75
11	300	97.75	28	850	167.25
12	330	104.75	29	870	170.00
13	360	111.00	30	890	172.25
14	390	117.00	31	900	175.00
15	420	122.00	32	920	178.25
16	450	127.50	33	940	180.00
17	480	132.75			

The open-loop response also indicates that the oven behaves as a slow thermal process with a noticeable delay. This characteristic justifies the application of PID control to improve the transient response and maintain the chamber temperature near the desired operating point.

Closed-Loop Temperature Response Under PID Control

After the tuning parameters had been obtained, the controller was implemented using $K_p = 16.4$, $T_i = 90$ s, and $T_d = 22.5$ s. The closed-loop response is presented in Table 3. The measured temperature increased from approximately 28.50 °C and approached the setpoint of 175 °C within approximately 14 min. At 14 min, the measured temperature reached 174.75 °C, indicating that the controller drove the system very close to the desired value with a negligible steady-state error.

Table 3. Temperature changes in the grill until it reaches the setpoint with the value setting Kp= 16.4 Ki= 90 Kd=22.5

No	Time T Res.	Err.	No	Time T Res.	Err.	No	Time	T Res.	Err.

	(s)	(°C)			(s)	(°C)			(s)	(°C)	
1	0,5	28.50	146.50	19	11	155.50	19.50	37	20	174.75	0.25
2	1	29.50	146.50	20	11.5	159.75	15.25	38	20.5	175.50	0.50
3	1,5	31.25	143.75	21	12	163.00	12.00	39	21	172.75	2.25
4	2	40.00	135.00	22	12.5	167.00	8.00	40	2.5	173.50	1.50
5	2.5	47.75	127.25	23	13	170.00	5.00	41	22	172.50	2.50
6	3	52.50	122.5	24	13.5	173.00	2.00	42	22.5	172.25	2.75
7	3.5	60.00	115.00	25	14	174.75	0.25	43	23	175.00	0
8	4	68.25	106.75	26	14.5	177.00	2.00	44	23.5	174.50	0.50
9	4.5	75.00	100.00	27	15	177.75	2.75	45	24	177.50	2.50
10	5	84.00	91.00	28	15.5	178.50	3.50	46	24.5	172.25	2.75
11	5.5	92.00	83.00	29	16	175.25	0.25	47	25	173.00	2.00
12	6	100.25	74.75	30	16.5	175.25	0.25	48	25.5	172.50	2.50
13	6.5	107.25	67.75	31	17	174.75	0.25	49	26	175.50	0.50
14	7	114.25	60.75	32	17.5	173.50	2.50	50	26.5	175.00	0
15	7.5	120.50	54.50	33	18	172.25	2.25	51	27	177.50	2.50
16	8	126.75	48.25	34	18.5	172.00	3.00	52	27.5	176.70	0
17	8.5	132.50	42.50	35	19	172.00	3.00	53	28	175.50	0.50
18	9	137.35	37.65	36	19.5	173.25	1.25				

A small overshoot was observed after the setpoint had been reached. The temperature increased to 177.00 ∘C, and a maximum of 178.50 °C, corresponding to an overshoot of approximately 3.5 °C. After this transient phase, the temperature returned to the vicinity of the setpoint and fluctuated within a relatively narrow range around 175 °C. At the end of the 28-min baking period, the oven temperature was recorded at 175.50 °C, indicating that the control system was able to maintain acceptable thermal stability throughout the baking process. The corresponding controlled temperature trend is shown in Fig. 6.

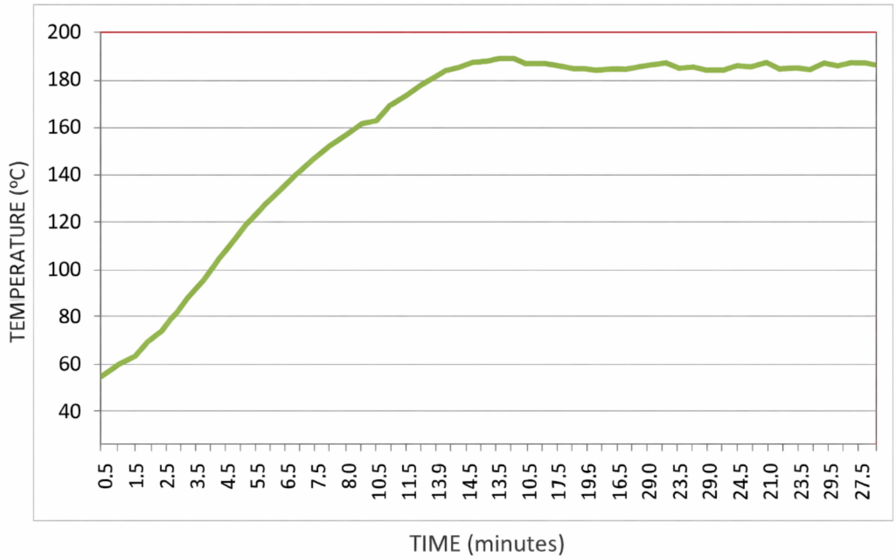


Figure 6. Controlled Response Graph

Discussion of Control Performance

The experimental results indicate that the implementation of the PID controller significantly improved the temperature regulation performance of the gas oven compared to the uncontrolled condition. In the open-loop test, the oven temperature increased gradually from 30 °C to 180 °C within 940 seconds, showing that the heating system had sufficient capacity to reach the required baking temperature. However, without a feedback control mechanism, the temperature rise could not be stabilized near a specific setpoint, which could potentially result in overheating or inconsistent baking conditions. This finding confirms that conventional gas ovens without automatic control are highly dependent on operator supervision and are prone to temperature fluctuations.

The application of the PID controller demonstrated a clear improvement in system response characteristics. Using the Ziegler–Nichols reaction curve tuning method, the obtained parameters (Kp = 16.4, Ti = 90 s, and Td = 22.5 s) produced a stable closed-loop response. The system was able to reach the desired setpoint temperature of 175 °C within approximately 14 minutes, which indicates a relatively fast rise time for a thermal system of this scale. This result shows that the proportional component contributed to accelerating the response, while the integral component helped reduce steady-state error and the derivative component improved system damping to reduce oscillation.

A small overshoot of approximately 3.5 °C was observed when the temperature reached its peak value of about 178.5 °C. This behavior is common in PID-controlled thermal systems due to the thermal inertia of the heating chamber and the delayed response of temperature sensors. Nevertheless, the overshoot remained within an acceptable tolerance range for baking applications and the temperature quickly returned to the setpoint region. This indicates that the selected PID parameters achieved a good balance between responsiveness and stability, which is an important requirement in thermal process control.

Temperature stability is a critical factor in determining the quality of marble sponge cake because uneven heating can affect the expansion of the batter, moisture distribution, and texture formation. With the integration of the thermocouple sensor, Arduino-based controller, and blower-assisted air circulation system, the developed oven was able to maintain temperature fluctuations within a narrow band around the setpoint. The addition of forced air circulation also contributed to more uniform heat distribution inside the chamber, which is essential for ensuring consistent baking results. This finding supports previous studies stating that controlled thermal conditions can improve the consistency and quality of bakery products.

From an engineering perspective, the developed system also demonstrates the practical advantages of applying low-cost microcontroller technology for small and medium-scale bakery industries. The use of Arduino Uno, PWM-based fan control, and automated gas flow regulation provides a relatively simple yet effective solution for improving process efficiency and reducing operator dependency. This approach can help small businesses improve product consistency while minimizing manual monitoring during the baking process.

Overall, the results confirm that the PID-based control system is suitable for thermal regulation in conventional gas ovens. The controller was able to maintain the oven temperature close to the desired setpoint with acceptable overshoot and steady-state performance. Future improvements could focus on implementing adaptive PID tuning, improving insulation design to reduce heat loss, or integrating IoT-based monitoring systems to allow remote supervision of the baking process. These improvements could further enhance system performance and industrial applicability.

CONCLUSION

According to the design and experimental evaluation of the proposed system, it could be confirmed that the produced automatic oven operation worked according to the desired setpoint in terms of maintaining stable thermal conditions for marble sponge cake baking. By specifying PID control parameters for Kp=16.4, Ti=90 s, and Td=22.5 s, the oven reached and maintained a temperature of around 175 ∘C during a 28-min baking period. Further control over the air circulation could also be employed to help distribute heat from the oven chamber evenly, and remove excess heat, in a timely manner if required. As a result, the produced oven, which has temperature control and blower system, can facilitate the baking process and enhance the stability of oven temperature while in operation.

Aknowledgement

This research was funded by Industrial Engineering Department of Engineering Faculty of Andalas University under the Research Contract No: No. B/76/UN16.09/SPK/PT.01.03/RKAT-UNAND/2025

REFERENCES

Ananda, S. H., Nendissa, D. M., Nendissa, S. J., Rosmawati, A., Hati, R. P., Ghaffar, M., Nahriana, L. Y. N., Tuarita, M. Z., Meiyasa, F., Sinaga, Y. M. R., Khurniyati, M. I., Falasifah, N., Maerani, & Aprianti, G. E. (2023). Teknologi pengolahan pangan (A. Masruroh, Ed.). Widina Bhakti Persada.

Awaludin, M. I., & Waluyo, B. D. (2023). Design of electric oven temperature control system using PID method. Telekontran, 11(2), 129–139.

Bahri, S., Muchtar, H., & Dermawan, E. (2014). Prototipe sistem kendali PID dan monitoring temperatur berbasis LabVIEW. In Seminar Nasional Sains dan Teknologi 2014.

Das, R. S., Tiwari, B. K., & Garcia-Vaquero, M. (2023). The fundamentals of bread making: The science of bread. In Traditional European breads (pp. 1–40). Springer. doi: 10.1007/978-3-031-23352-4

Evalina, N., Pasaribu, F. I., Azis, A. H., & Sary, A. (2022). Penggunaan Arduino Uno untuk mengatur temperatur pada oven. Rekayasa Elektrikal dan Energi, 4(2), 122–128.

Evalina, N., Pasaribu, F. I., Azis, A. H., & Sary, A. (2022). Penggunaan Arduino Uno untuk mengatur temperatur pada oven. Rekayasa Elektrikal dan Energi, 4(2), 122–128.

Finahari, N., Rubiono, G., & Soebiyakto, G. (2025). Applied technology application: LPG-fueled ovens for small businesses. Jurnal Aplikasi Teknik dan Pengabdian Masyarakat, 9(3), 361–366.

Gisslen, W. (2017). Professional baking (7th ed.). John Wiley & Sons.

Harjianto, Lestari, S. D., Anam, M. K., As’ari, H., & Qiram, I. (2025). Penerapan teknologi gas oven rotary untuk mendukung optimasi produksi pada UMKM D’Lor Bakery. TEKIBA: Jurnal Teknologi dan Pengabdian Masyarakat, 5(1), 243–255.

Yusuf, C., & Saputra, D. I. (2020). Optimasi kendali suhu pada sistem nirkabel penetasan telur berbasis PI dan PI anti-windup. Journal Otomasi, Kontrol & Instrumentasi, 12(2), 79–101.