SVU-International Journal of Engineering Sciences and Applications (2025) 6(2): 155-159
Print ISSN 2785-9967 | Online ISSN 2735-4571
DOI 10.21608/SVUSRC.2025.376666.1279

Development of a Smart Ceramic Kiln Based on Effective Control of the Firing Process: An Applied Study

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Abstract— This research presents the development of a smart ceramic kiln equipped with an advanced control system designed to enhance firing precision, energy efficiency, and product quality. The electric kiln, capable of reaching temperatures up to 1000°C, utilizes an ESP32 microcontroller for real-time monitoring and control. Temperature regulation is achieved using K-type thermocouples placed in multiple zones, enabling precise adjustments across ten distinct firing stages. The system supports both manual and remote operation via Wi-Fi, allowing for real-time data logging and optimization of firing curves. Experimental results demonstrate significant improvements in temperature stability, reduced energy consumption, and enhanced ceramic integrity compared to traditional kilns. The smart kiln achieved an efficiency rate of 80%, minimizing defects and ensuring consistent product quality. Furthermore, the system is designed with scalability in mind, incorporating the potential for future cloud-based monitoring and automation upgrades. These advancements highlight the potential of intelligent kiln technology in modern ceramic manufacturing, offering a sustainable and efficient approach to high-quality production.

Keywords: Smart kiln; Ceramic processing; Temperature control; Energy efficiency; Remote monitoring.

1 Introduction

Ceramics are widely used in daily life for their hardness, corrosion resistance, brittleness, insulation, and heat resistance. They are utilized in pottery, bricks, glass, tiles, and various advanced applications like fiber optics, spark plugs, cooktops, energy storage application and artificial joints [1-3]. One critical aspect of ceramic production is the firing process, which involves heating ceramic materials to high temperatures to achieve the desired mechanical and aesthetic properties. The purpose of firing is to achieve the required quality and quantity by using the right flame quality, rate of heat change, heat dispersion, and firing temperature [4, 5]. Fire is a crucial step in the ceramic manufacturing process, therefore achieving certified products calls for regulated fire rates, appropriate internal temperature distribution, appropriate firing times, and regulated cooling [6, 7].Measurement and temperature control are essential components of ceramic furnaces. A variety of tools are employed in one furnace to accomplish varying levels of temperature control. Temperature management in the furnace should be done on a frequent basis for optimal product firing [8, 9]. The Studies show that intelligent control systems, such as those employing fuzzy-PID controllers, significantly improve the accuracy of temperature management in kilns, thereby reducing defects and improving product quality [10, 11]. Numerous research pertaining to ceramic furnace control may be found in the literature. That research used a variety of techniques to manage furnaces. Temperature control was accomplished in earlier research by using a variety of techniques, including PLC, NLX230, PID, and PI [4], [12, 13]. In addition to such research, PID controllers and fuzzy logic controllers have also been used in the literature to regulate high temperature furnaces [14-17]. Similar systems have studied a Ceramic Kiln effective in the precise control of firing schedules, as observed in ceramic kiln control systems based on PID technology [18]. These capabilities ensure consistent firing conditions, reducing the risk of defects and enhancing the reproducibility of ceramic properties. Recent advancements in control systems offer promising solutions to these issues, particularly through the use of smart technologies and the Internet of Things (IoT). As a result, there is an increasing shift toward modernizing ceramic kilns by integrating automated and intelligent control systems. These advanced kilns utilize sensors, microcontrollers, and specialized software to precisely regulate the firing process, ensuring greater consistency, lower energy consumption, and enhanced product quality.

Received: 07 May 2025/ Accepted: 07 November 2025
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Incorporating robust thermocouples and relay systems, the control panel is also designed for reliability and ease of maintenance. Research highlights that intelligent systems employing multi-sensor fusion and advanced hardware configurations can significantly enhance kiln efficiency and adaptability [19]. The integration of energy-efficient components, such as Kanthal-A1 resistors and high-temperature insulation materials, further supports sustainable operation, a critical consideration in modern ceramic production. This study presents an advanced control panel designed for an electric furnace used in firing ceramic products. Central to this system is its capability for remote control via mobile devices, enabled by the integration of the ESP32 Development Board with Wi-Fi connectivity. Such innovations align with trends in the ceramics industry toward automation and enhanced precision. Moreover, the proposed system facilitates real-time data recording and remote diagnostics, enabling precise adjustments and continuous monitoring. These advancements not only improve operational efficiency but also reduce energy consumption and environmental impact, as evidenced by systems utilizing waste heat recovery and predictive control. This study explores the development of a smart ceramic kiln equipped with an effective control system designed to manage the firing process. By integrating modern technologies such as PESP32 microcontroller, thermocouples, and wireless communication modules, the study aims to demonstrate how a smart kiln can enhance the efficiency of ceramic production while maintaining high-quality standards.

2 Materials and Methods

2.1 Control panel components

The smart ceramic kiln system utilizes advanced materials for its control panel and construction. The control panel includes an ESP32 microcontroller with Wi-Fi and Bluetooth for remote control, a 20×4 LCD for real-time monitoring, a 4×4 keypad for manual input, and a MAX31855 thermocouple for precise temperature measurement up to 1350°C. Additional components include a 30A relay for power control, an SCR dimmer for temperature regulation, and an ISKRA contactor for high-power switching. Durable thermocouples, signal lamps, and an electric selector switch enhance functionality and safety, **Fig. 1**.

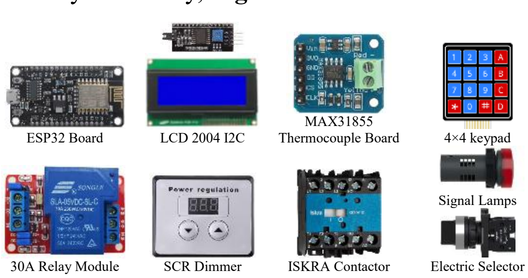

Fig. 1 Control Panel Components

2.2 Kiln Construction Materials

The kiln construction employs Ceramic Kiln Thermocouples Designed for high temperatures up to 1400°C, Kanthal-A1 wire resistors for heating, and high heat-resistant insulation bricks and fibers to maintain efficiency and withstand temperatures up to 1200°C, **Fig. 2.**

Fig. 2 Kiln Construction Materials**.**

2.3 Experimental methods

2.3.1 Block Diagram of the System

The block diagram of the designed system is shown in **Fig. 3**. ESP32 Board for remote control and data logging; LCD display to show real-time temperature and firing status; Keypad for manual programming of firing profiles and settings; temperature Sensor and K type thermocouple for Measuring kiln temperatures; Relay module controls the power to the kiln's heating elements, while the SCR dimmer regulates the power delivered to the heating elements, and precise temperature control; Contactor for switching high-power circuits in the kiln; Kanthal-A1 Wire Resistors for Heating elements to achieve temperatures up to 1000°C.

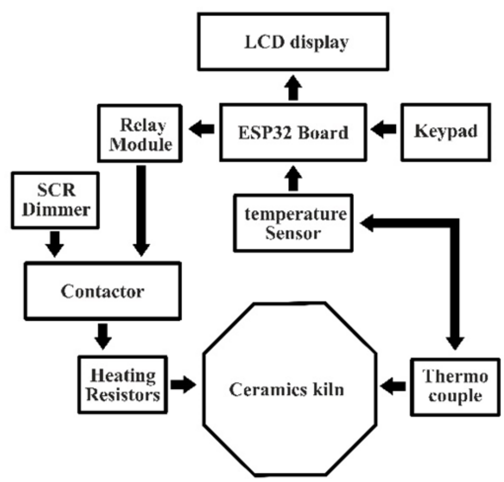

Fig. 3 Block Diagram of the System

2.3.2 System Design and Integration

The hardware components are developed and integrated into a cohesive control panel. As shown in **Fig. 4**, the system integration process involves assembling the control panel components—including the ESP32, keypad, LCD display, thermocouples, relay, and SCR dimmer—and connecting them to the kiln's heating system. This ensures seamless communication between the control panel and the kiln's resistors, enabling efficient monitoring, regulation, and execution of the firing process. Program the ESP32 microcontroller using Arduino IDE for managing firing curves, logging data, and enabling remote access via a mobile application. The control panel shown in **Fig. 5**. was assembled using the specified components. Connections were tested for reliability and proper operation.

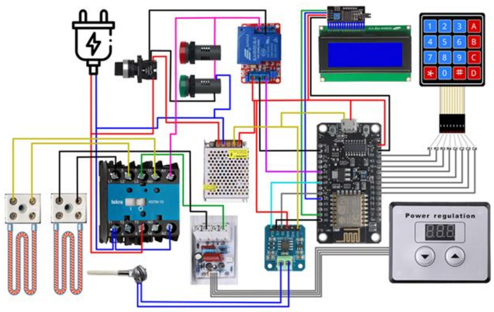

Fig. 4 System Circuit

Fig. 5 control panel

2.3.3 Firmware Programming

Custom firmware was developed for the ESP32 board, enabling Manual and remote control via Wi-Fi shown in **Fig. 6**., Configuration of firing curves with up to 10 points, Data logging every 10 minutes, and Delayed start functionality.

Fig. 6 Manual and remote control via Wi-Fi

Figure 7 shows the main display screen of the Kiln when it is off. On (No. 1) is the actual Kiln temperature, (No. 2) is the Wi-Fi connection status, and (No. 3) is the heating status.

Fig. 7 The main display screen of the Kiln when it is OFF

Figure 8 shows the display screen for setting operating points manually. On (No. 1) is the Set point temperature, (No. 2) is the set temperature holding time for the selected operating stage, (No. 3) is the heating stage "set point", and (No. 4) is the Wi-Fi connection status.

Fig. 8 The Display screen for setting operating points in manual setting

Figure 9 shows the Keyboard input parameters. the Numbers to enter temperature and time value. A Sterisk (*) to reset the temperature and time value and turn off the operation. A hashtag (#) to turn on the operation. F1: UP and F2: DOWN to navigate from the main display to/between set point lists. F3: UP and F4: DOWN to select the set point setting parameters.

Fig. 9 Keyboard input parameters

Figure 10 shows the main display screen of the Kiln when it is off. On (No. 1) is the actual Kiln temperature, (No. 2) is the Wi-Fi connection status, (No. 3) is the heating stage “set point”, and (No. 4) is the operating stage “set point” temperature.

Fig. 10 The main display screen of the Kiln when it is ON

Figure 11 shows the main display screen of Kiln remote control via Wi-Fi. On (No. 1) select the heating stage, (No. 2) set the temperature for the selected operating stage, (No. 3) set the temperature holding time for the selected operating stage, (No. 4) turn off/on the Kiln, (No. 5) data logger, and other command conversation such as setting the start time.

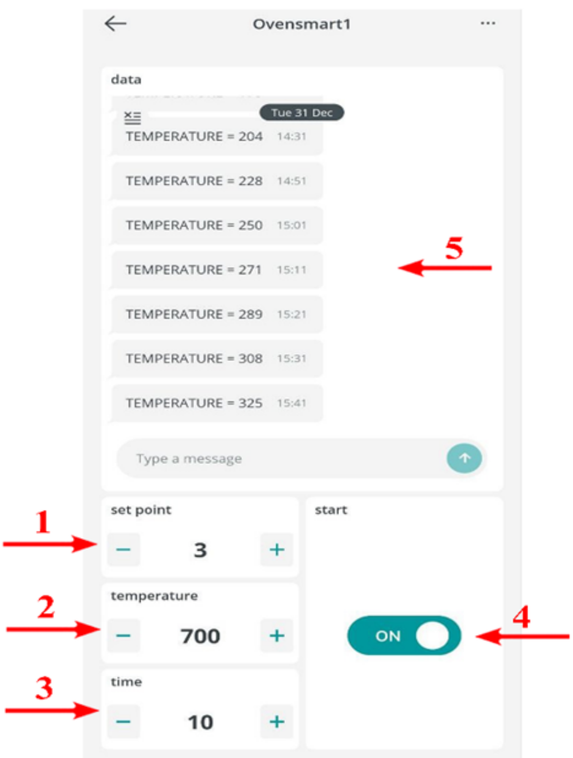

Fig. 11 The main display screen of Kiln remote control via Wi-Fi

2.3.4 Calibration of temperature

Calibration of temperature sensors ensures the accuracy and reliability of measurements critical for controlled firing processes in ceramic kilns. The procedures involve exposing sensors to a controlled environment and comparing their outputs against known standards. In this study, three independent calibrations were conducted to validate the performance of the temperature control system. The results are evaluated for consistency, drift, and stabilization behavior to ensure optimal kiln operation. The calibration results, shown in **Fig. 12** and **Table 1**, reveal that Calibration 1 exhibits stable temperature readings with minimal deviations after the initial heating phase. In contrast, Calibration 2 shows a slight overshoot between 20 and 30 minutes, but aligns closely with Calibration 1 after the 10-minute mark, indicating consistent control. In contrast, Calibration 3 displays higher variability, with noticeable fluctuations between 30 and 40 minutes, and consistently lower temperature readings, suggesting potential calibration drift or sensor variance. Despite these differences, all calibrations achieve a relatively stable temperature of approximately 100°C after 20 minutes, demonstrating satisfactory stabilization across the procedures.

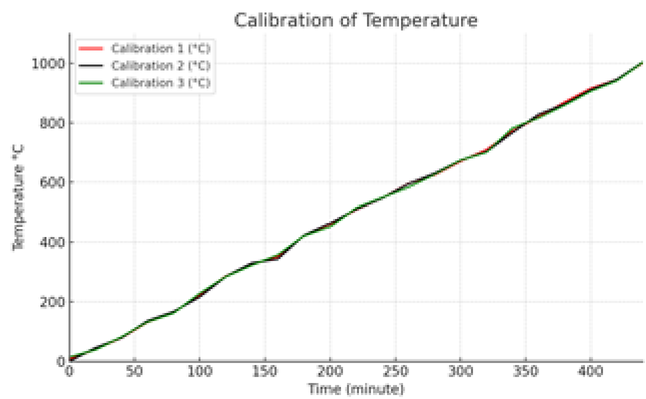

Fig. 12 Calibration of temperature

Table 1 Statistical analysis of calibration data

Calibration	Std. Deviation	One-Sample Test			Correlations	
		t	df	Sig.		
No. 1 (°C)	1.092	14.135	47	0.000	.999**	0.000
No. 2 (°C)		14.129	47	0.000	.999**	0.000
No. 3 (°C)		14.129	47	0.000	.999**	0.000

Statistical results showed that the standard deviation of all calibration readings was low, at 1.092°C, demonstrating high repeatability and stability in the device's performance. The one-sample t-test also showed statistically significant differences at a significance level of 0.000 for all readings, while the correlation coefficients between the three readings reached 0.999, indicating a very strong correlation that enhances confidence in the calibration results and supports the adoption of the arithmetic mean of the readings as a reliable standard value in analysis. Kiln energy efficiency is calculated by comparing the useful energy output (e.g., heat for firing materials) to the total energy input [20]. The Efficiency (%) = (Useful Energy Output / Total Energy Input) * 100. This is typically expressed as a percentage. Several factors influence kiln efficiency, including kiln design, operating temperature, material properties, and heat loss. Efficiency of furnace can be calculated as:

Ƞ = Qout/Qin=807.2/1008=80%.
Qin = 0.24×Power×time=0.24×2500×28×60=1008 kcal.

The operating conditions indicate that the furnace is supplied with a voltage of 220 V and a current of 9 A. Heat in furnace is calculated as:

Qout = 0.24×V×I×t=0.24×220×9.1×28×60=807.2 kcal.

3 Conclusion

The development of a smart ceramic kiln with an advanced control system has demonstrated significant improvements in temperature regulation, energy efficiency, and product quality. Utilizing an ESP32 microcontroller and K-type thermocouples, the kiln can achieve precise temperature control up to 1000°C across ten distinct zones, ensuring uniform heat distribution. The integration of both manual and remote control via Wi-Fi allows real-time monitoring, data logging, and optimized firing curves, reducing energy consumption and enhancing reproducibility. Experimental results confirm an efficiency of 80%, with improved ceramic integrity and minimal defects compared to traditional kilns. The smart kiln outperforms conventional systems in firing precision and ease of operation, with features such as scheduled firings and remote diagnostics. Additionally, the system is designed for scalability and future upgrades, including cloud-based data integration and enhanced automation. This study underscores the potential of smart kiln technology in modern ceramic manufacturing, offering a more sustainable and efficient approach to high-quality production.

References

[1] Abd-Elrahim, R.F.A., H.M. Abdelmotalib, and M.A. Hassan, *Possibility of obtaining Transparent Glaze from the Local clays of Qena Governorate.* 2023. 7(2): p. 536-554.

[2] Cheng, L.-Q., et al., *Electrocaloric materials and applications based on multilayer ceramic capacitors.* Journal of Materiomics, 2025. 11(5): p. 101056.

[3] Samantaray, S., et al., *Ceramic-ceramic nanocomposite materials for energy storage applications: A review.* Journal of Energy Storage, 2024. 99: p. 113330.

[4] Bayindir, R., *Design and construction of an electrical furnace to fire ceramic product.* 2007.

[5] Guo, J., et al., *Glass and glass-ceramics from red mud tailings: Understanding the evolution mechanism.* Ceramics International, 2023. 49(16): p. 27430-27438.

[6] Yu, L., et al., *Enhancing the sustainable production of cost-effective ceramics with high strength using kaolin, sewage sludge and blast-furnace slag.* Chemical Engineering Journal, 2024. 480: p. 148184.

[7] Fu, F., et al., *Production of high-value-added lightweight glass ceramics based on phosphorus tailings and coal gangue.* Ceramics International, 2024. 50(10): p. 16725-16735.

[8] TITE, M.S., *CERAMIC PRODUCTION, PROVENANCE AND USE—A REVIEW.* 2008. 50(2): p. 216-231.

[9] Arvanitidis, A.L., M. Kostoglou, and M.C. Georgiadis, *Modeling, optimization and control of a ceramic tunnel kiln for consistent product quality under changing production demands.* Computers & Chemical Engineering, 2024. 189: p. 108812.

[10] He, W. *Fuzzy-PID Control Technology in Glaze Firing Process Control System of Roller Kiln for Bone China*. in *Big Data Analytics for Cyber-Physical System in Smart City*. 2020. Singapore: Springer Singapore.

[11] Tseligorov, N.A., et al., *Modeling of the tunnel kiln control system taking into account the features of the pid controller and fuzzy logic.* Journal of Physics: Conference Series, 2021. 2131(2): p. 022022.

[12] Wang, Y., Y. Zhang, and B. Wang. *The control research of PID in heating-furnace system*. in *2011 International Conference on Business Management and Electronic Information*. 2011.

[13] Jing, C., et al. *Logic Control Algorithm Based on Panboolean Algebra and Its Application for Temperature Control of Ceramic Roller Kiln*. in *2008 IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application*. 2008.

[14] Radakovic, Z.R., V.M. Milosevic, and S.B. Radakovic, *Application of temperature fuzzy controller in an indirect resistance furnace.* Applied Energy, 2002. 73(2): p. 167-182.

[15] Paranchuk, Y., D. Jancarczyk, and P. Falat, *Study and Analysis of Dynamics and Energy Efficiency of Arc Steelmaking Furnace Electrical Mode with a Fuzzy Control Algorithm.* 2023. 16(8): p. 3451.

[16] Murthy, B.V., Y.V.P. Kumar, and U.V.R. Kumari. *Fuzzy logic intelligent controlling concepts in industrial furnace temperature process control*. in *2012 IEEE International Conference on Advanced Communication Control and Computing Technologies (ICACCCT)*. 2012.

[17] Phan, V.D., et al. *Development of an Adaptive Fuzzy-Neural Controller for Temperature Control in a Brick Tunnel Kiln*. Electronics, 2024. 13, DOI: 10.3390/electronics13020342.

[18] Zhang, J., *Research on the Design of Ceramic Kiln Control System Based on PID.* Chemical Engineering Transactions, 2017. 59: p. 709-714.

[19] YH Zhu, J.W., *Intelligent Temperature Control of Ceramic Kiln Based on Data Fusion Technology.* Applied Mechanics Materials, 2012. 128: p. 177-180.

[20] Milani, M., et al., *Numerical analysis of an entire ceramic kiln under actual operating conditions for the energy efficiency improvement.* Journal of Environmental Management, 2017. 203: p. 1026-1037.