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Design and Develpoment of the Dry Method Autoclave Sterilization Heat from an Arduino Uno in Dential Equipment

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Abstract. *Sterilization occupies a fundamental position in the domain of dentistry, ensuring that the instruments utilized are entirely devoid of pathogenic microorganisms. An autoclave sterilization apparatus employing the dry heat technique, based on the Arduino Uno platform, is essential in providing a robust and effective methodology for the sterilization of dental instruments. The hardware configuration is comprised of a heating element, a temperature sensor, and a control system that is meticulously designed to uphold temperature with precision and reliability. The sterilization of dental instruments is imperative for upholding hygiene standards and averting cross-contamination. The primary aim of this research is to devise a sterilization device that is both efficient and effective through the implementation of the dry heat method, which is regarded as safer in comparison to traditional steam-based techniques. The architecture of this autoclave incorporates an Arduino Uno microcontroller as the central controller of the system, which autonomously regulates the temperature and duration of the sterilization cycle. The temperature sensor and heating element are systematically interconnected to maintain the temperature within the optimal range (100-150°C), which is critical for effective dry heat sterilization. Furthermore, a user-friendly interface has been integrated to facilitate the oversight of the sterilization process. This apparatus is adept at executing the sterilization procedure efficiently within a reduced timeframe, without compromising the integrity of the sterilization results. The system provides enhanced control and can be tailored to meet specific user requirements, thereby positioning it as an ideal solution for cost-sensitive dental clinics. This innovation is expected to significantly elevate hygiene standards within dental practices and may stimulate considerable advancements in the healthcare sector.*

Keywords: *Autoclave, Arduino Uno, Dental Equipment, Dry Heat, Sterilization*

1. INTRODUCTION

Technological advancements have led to the widespread adoption of automated control systems in various devices and equipment. As societal demands grow, numerous tools have been designed to streamline tasks, enhancing efficiency and convenience [1]. Sterilization refers to the process of eliminating microorganisms, including resilient spores, ensuring that objects (such as instruments, materials, or media) are free from both pathogenic and non-pathogenic contaminants.

Alternatively, it can be described as the eradication of all microbial life, whether in vegetative or spore form. In medical contexts, sterilization employs specific techniques to achieve a state where no viable microorganisms remain detectable [2]. While prior research has investigated dry heat sterilization, these studies have not thoroughly examined its application in dental tools or the necessary refinements to enhance its dependability.

An autoclave is a device that utilizes pressurized steam (121°C, 15 psi) for approximately 15 minutes to sterilize objects. This high-temperature environment effectively destroys microbes, including hardy bacterial endospores [3]. Essentially, autoclaves employ heated vapor (typically at 121°C and 15 psi) to sterilize laboratory and medical equipment,

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with a standard processing time of 15 minutes [4]. In contrast, dry heat sterilization relies on heated air to eliminate pathogens, offering greater efficiency and effectiveness compared to steam-based methods.

However, this approach demands more advanced instrumentation and precise temperature and timing controls [5].

Recent studies demonstrate the viability of Arduino Uno microcontrollers in automating sterilization procedures [6,7]. These systems often integrate temperature regulation or water heating mechanisms, aligning with findings that sterilization requires sustained temperatures of at least 80°C for a minimum of 10 minutes [8,7]. Arduino Uno, a widely utilized microcontroller, has proven adaptable in medical device innovation, enabling the creation of compact, cost-effective sterilization solutions [5].

This study distinguishes itself from earlier work by concentrating on dry heat sterilization tailored specifically for dental instruments, whereas prior research addressed broader applications. A critical limitation in existing systems is the absence of safety mechanisms, such as automatic locking, which could prevent accidental opening during sterilization and reduce contamination risks. Additionally, inefficient thermal distribution often leads to temperature fluctuations, compromising sterilization efficacy and equipment longevity. Thus, this research emphasizes enhancing dental instrument sterilization through optimized heat dispersion and the integration of automated locking mechanisms. Enhanced Safety and Process Stability in Sterilization Implementing robust safety measures minimizes disruptions and contamination risks during sterilization. Concurrently, an optimized thermal regulation system guarantees consistent temperature control, thereby improving operational effectiveness and preserving the sterility integrity of processed instruments.

2. RESEARCH METHODS

This phase involves the development of an automated sterilization device employing dry heat technology.

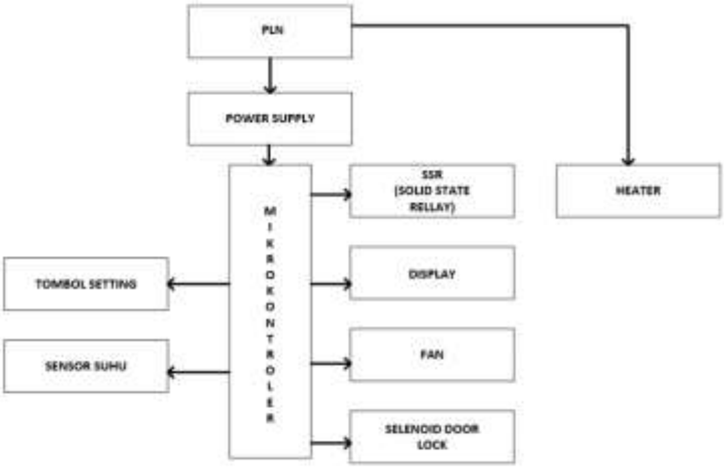

Figure 1. System Block Diagram

The system is energized by a conventional source electrical grid connection, energizing all circuit components. User-defined temperature and duration parameters are configured via the control interface and displayed on the integrated screen. Upon initialization, the heating element activates, elevating the chamber temperature to the preset value, which simultaneously triggers the countdown timer to commence the sterilization cycle. Upon timer expiration, the heater deactivates, and the cooling fan engages automatically. Chamber access is permitted only when internal temperatures fall below 37°C, signaled by an audible alert indicating process completion and instrument readiness.

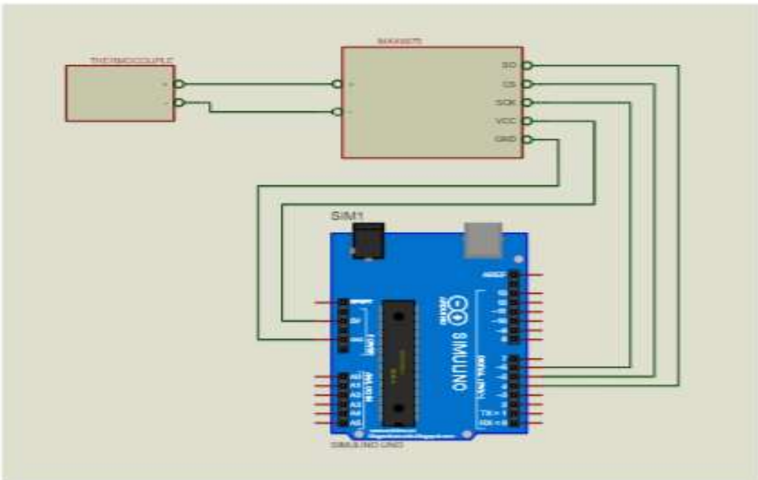

Figure 2. Sensor and Arduino Uno Circuitry

The measurement subsystem comprises two critical components: the MAX6675 thermocouple interface and its associated thermocouple probe. The thermocouple serves as the primary temperature transducer, generating a proportional electromotive force (EMF) that is subsequently converted to standardized temperature units.

The MAX6675 module precisely quantifies thermal differentials across junctions of dissimilar metals. While the hot junction accommodates measurements from 0°C to +1023.75°C, the cold junction operates within a -20°C to +85°C range. Notably, the MAX6675 maintains measurement accuracy despite cold junction fluctuations through integrated cold-junction compensation. Ambient temperature variations are transduced into voltage via an onboard diode sensor.

For optimal performance, the MAX6675 and thermocouple cold junction must maintain thermal equilibrium, necessitating isolation from heat-producing components.

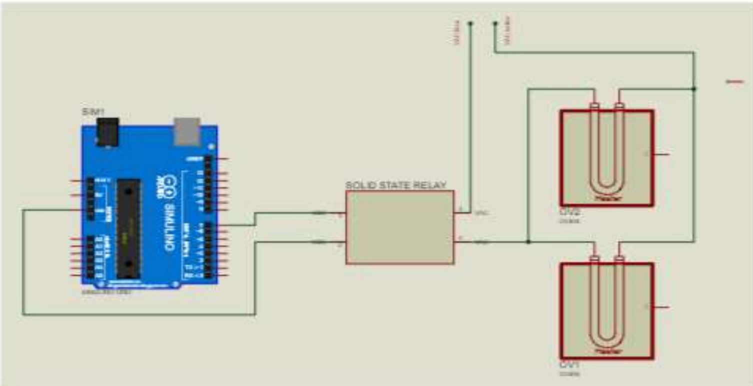

Figure 3. Heating Element Circuit

A solid-state relay modulates power delivery to three 300W heating elements, ensuring precise temperature regulation as required by the dry heat sterilization protocol.

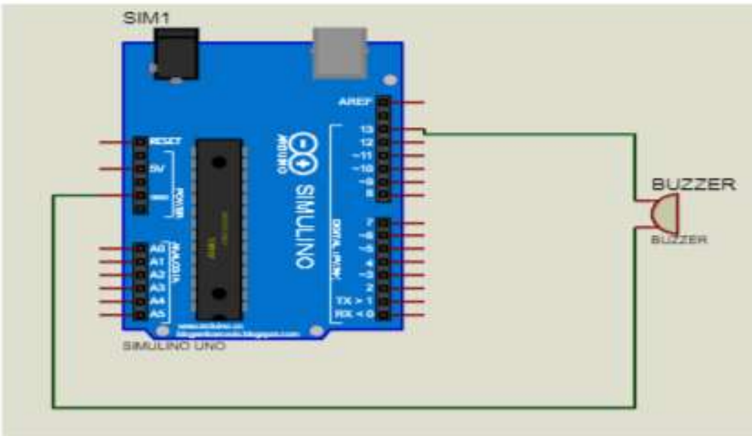

Figure 4. Auditory Alert System

This subsystem generates acoustic notifications upon cycle completion to prevent user oversight.

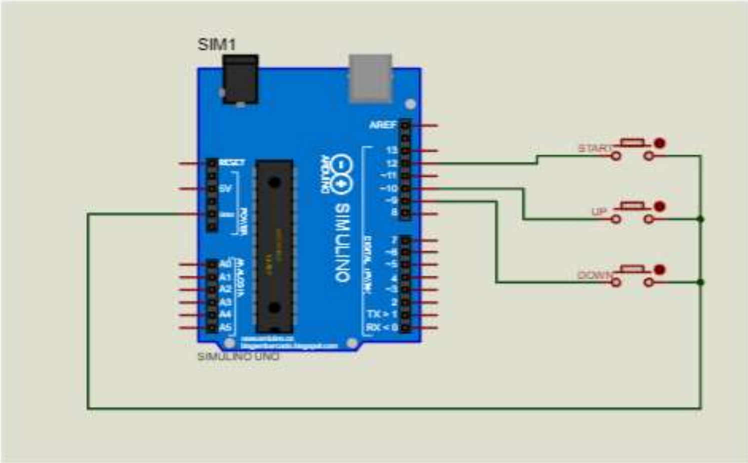

Figure 5. Control Interface Circuit

The tactile interface provides multifunctional control through three dedicated actuators:

Increment Button: Facilitates parameter adjustment and menu navigation

Decrement Button: Enables value reduction and option selection

Initiation Button: Executes commands and confirms menu selections

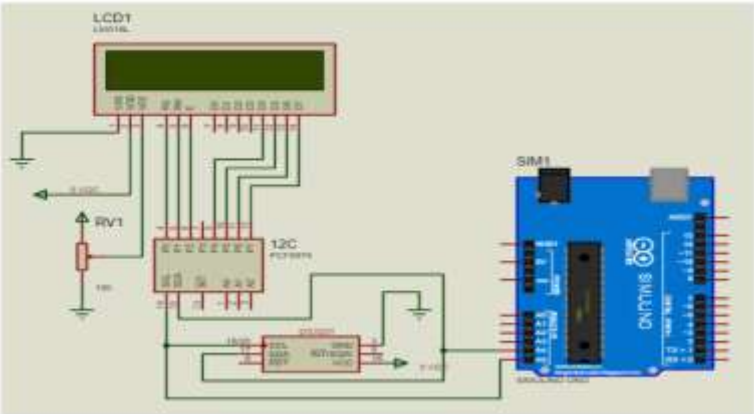

Figure 6. Temporal Management and Display Circuit

The Real-Time Clock (RTC) module serves as the system's chronometric reference, enabling programmable cycle durations. Temporal data is presented via an I²C-interfaced LCD display, with RTC synchronization maintained through dedicated SDA and SCL connections.

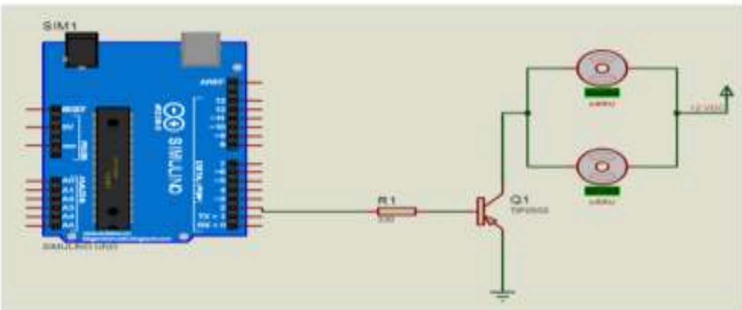

Figure 7. Thermal Management Circuit

This subsystem regulates post-sterilization cooling, employing microcontroller-controlled relays to activate ventilation fans until ambient chamber temperature is achieved.

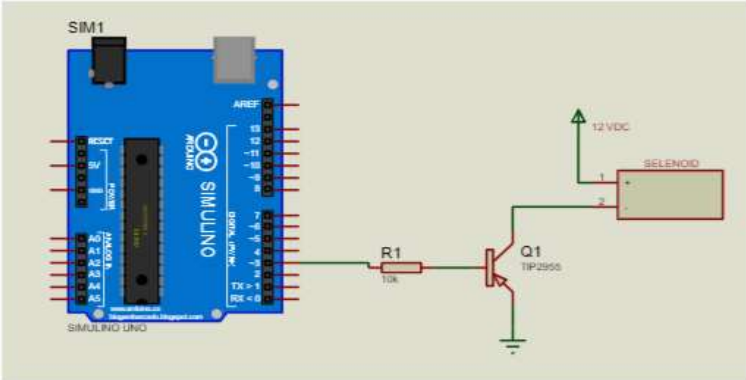

Figure 8. Access Control Mechanism

An electromechanical locking system, comprising a solenoid actuator under microcontroller governance, ensures secure containment during operation and automated egress upon safe conditions.

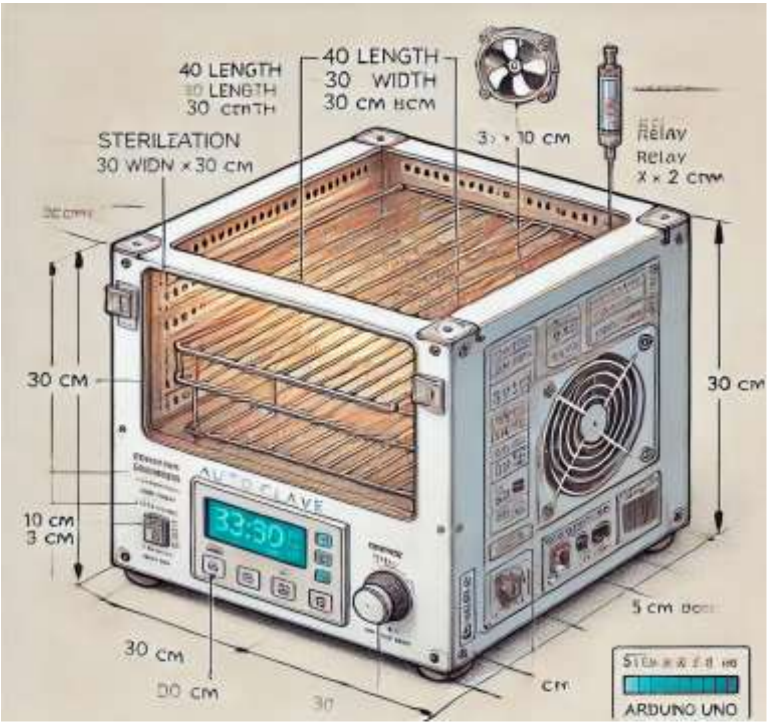

Figure 9. Enclosure Schematic

Presents the physical design architecture of the sterilization chamber assembly.

3. RESULTS AND DISCUSSION

This section elaborates the sequence of operations within the system, which can be visually represented in the system flowchart in Figure 3.10 below.

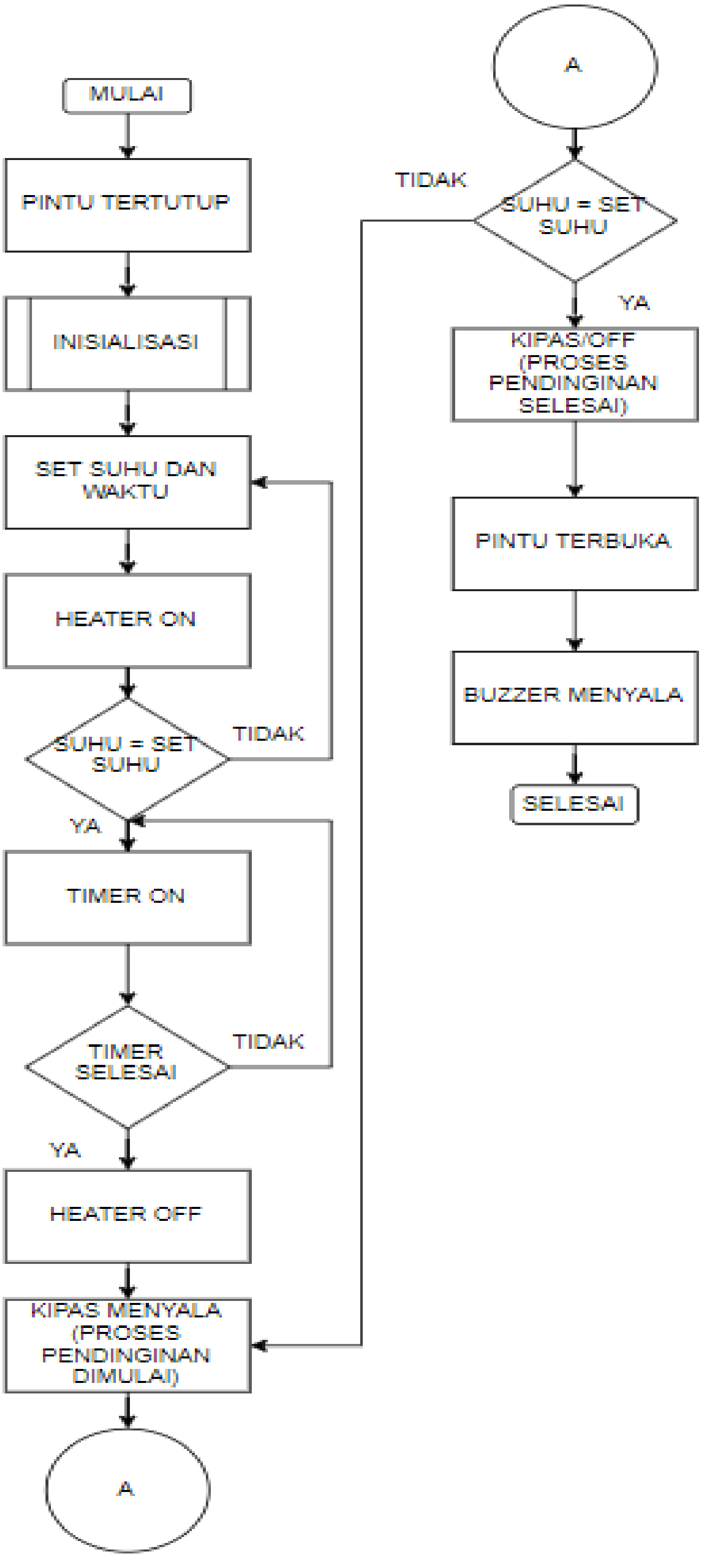

Figure 10. System Flowchart

Explanation:

- The system starts by initializing all components. After the initialization phase, the user can manually set the desired temperature and the duration timer based on the sterilization requirements.
- Once activated, the heating element powers on and begins to elevate the chamber's temperature. When the preset temperature is reached, the timer begins its countdown automatically. The heating process continues until the timer ends, at which point the heater also shuts off.
- Following the heating cycle, the system transitions to the cooling phase. The fan is activated and side ventilation is opened, allowing hot air to be expelled and replaced with cooler ambient air.
- When the temperature sensor detects that the chamber temperature has decreased to 37°C, the cooling mechanism is deactivated, and the door lock is released automatically.
- The timer will emit an alert sound, signaling to the user that the sterilization cycle is complete and the surgical instruments can be safely retrieved in a time-efficient manner.
- Measurement of Target Temperature Achievement

Table 1. Measurement of Target Temperature Achievement

Target Temp	Device	Initial Temp	2 Min	4 Min	6 Min	8 Min	10 Min	12 Min
110°C	MAX6675 Sensor	25°C	65°C	90°C	105°C	108°C	110°C	110°C
	Digital Thermometer	25°C	60°C	85°C	100°C	107°C	120°C	110°C
120°C	MAX6675 Sensor	25°C	70°C	100°C	115°C	118°C	120°C	120°C
	Digital Thermometer	25°C	68°C	95°C	110°C	117°C	120°C	120°C
130°C	MAX6675 Sensor	25°C	80°C	110°C	125°C	128°C	130°C	130°C

Stability Measurement over One Hour

Table 2. Stability Measurement over One Hour

Target Temp	Device	Initial	5 Min	10 Min	15 Min	20 Min	25 Min	30 Min
110°C	MAX6675	25°C	65°C	90°C	105°C	108°C	110°C	110°C
	Thermometer	25°C	60°C	85°C	100°C	107°C	110°C	110°C
120°C	MAX6675	25°C	70°C	100°C	115°C	118°C	120°C	120°C

	Thermometer	25°C	68°C	95°C	110°C	117°C	120°C	120°C
130°C	MAX6675	25°C	80°C	110°C	125°C	128°C	130°C	130°C

Target Temp	**Device**	**35 Min**	**40 Min**	**45 Min**	**50 Min**	**55 Min**	**60 Min**
110°C	MAX6675	110°C	110°C	110°C	110°C	110°C	110°C
	Thermometer	110°C	110°C	110°C	110°C	110°C	110°C
120°C	MAX6675	120°C	120°C	120°C	120°C	120°C	120°C
	Thermometer	120°C	120°C	120°C	120°C	120°C	120°C
130°C	MAX6675	130°C	130°C	130°C	130°C	130°C	130°C

Temperature Drop Analysis Without Cooling Mechanism

Table 3. Temperature Drop Analysis Without Cooling Mechanism

Target Temp	**Device**	**Initial**	**2 Min**	**4 Min**	**6 Min**	**8 Min**	**10 Min**	**12 Min**
110°C	MAX6675	110°C	95°C	82°C	71°C	62°C	55°C	49°C
	Thermometer	110°C	97°C	85°C	74°C	65°C	58°C	52°C
120°C	MAX6675	120°C	105°C	92°C	80°C	70°C	62°C	56°C
	Thermometer	120°C	108°C	95°C	83°C	73°C	65°C	59°C
130°C	MAX6675	130°C	115°C	102°C	90°C	79°C	70°C	63°C

Extended Cooling Time Temperature Drop (Without Active Cooling)

Table 4. Extended Cooling Time Temperature Drop

Target Temp	**Device**	**Initial**	**14 Min**	**16 Min**	**18 Min**	**20 Min**	**22 Min**	**24 Min**	**26 Min**	**28 Min**	**30 Min**
110°C	MAX6675	120°C	42°C	39°C	36°C	34°C	32°C	30°C	29°C	28°C	27°C
	Thermometer	120°C	45°C	42°C	39°C	37°C	35°C	33°C	32°C	31°C	30°C
120°C	MAX6675	120°C	50°C	47°C	44°C	41°C	39°C	37°C	35°C	34°C	33°C
	Thermometer	120°C	53°C	50°C	47°C	44°C	42°C	40°C	38°C	37°C	36°C

Sub-chapter

Upon completing the experiment, data analysis was conducted to determine the system's precision and the percentage of deviation. The calculations were carried out using the following formulas:

Mean (Average) Calculation:

The average is computed by summing all observed values and dividing by the number of data points:

$\bar{X} = (X_1 + X_2 + ... + Xn) / n$

Where:

- $\bar{X}$ = Mean value
- $X_1 + X_2 + ... + X_n$ = Total of all measurements
- n = Total number of measurements

Deviation Calculation:

- Deviation = $\bar{X}$ - Setpoint (UUT)
- Difference = Set Temperature - Sensor Reading
- Percentage Deviation = (Difference / Set Temperature) × 100%

Average Deviation:

Average Deviation = Total Deviation / Number of Data Points

Where:

- UUT = Preset value
- $\bar{X}$ = Average of observed values

Accuracy Percentage:

This value reflects how close the observed data is to the actual setpoint:

Accuracy (%) = 100% - Deviation (%)

Average Accuracy:

Average Accuracy = Total Accuracy Values / Number of Accuracy Data Points

Functionality Testing of Device Components

A system functionality check was performed to ensure that all components operate as intended.

Table 5. Functionality Testing of Device Components

No.	Component	Test Result
1	Power Cable	Functional
2	Control Buttons	Functional
3	Display Panel	Operational
4	MAX6675 Sensor	Working
5	Heating Element	Operational
6	Fan and Vent Mechanism	Functional
7	Solenoid Valve	Operational

Table Presentation

The Calisto MT caption or title is 10 pt in size, bold and placed above the table in the format as shown in the example. Each table must use a number (such as: "Table 1"). Table 1 is typed with spaces, numbered according to the appearance in the text in open table format. The table only shows horizontal lines. The maximum number is 3 tables. The table title indicates "what", "where", "when". The table comes from a quote, and the source below the table must be written in 7pt font size. The table must not be truncated. They should be made into one page. They should not exceed the margin. Long tables (outside the 2 column margins) are placed at the beginning or end of the page (as shown in Table 2). The tables must be explained/described in a paragraph or sentences.

Tabel 6. Table Formatting

Column 1	Column 2	Column 3	Column 3
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Image Presentation

Temperature Rise Evaluation

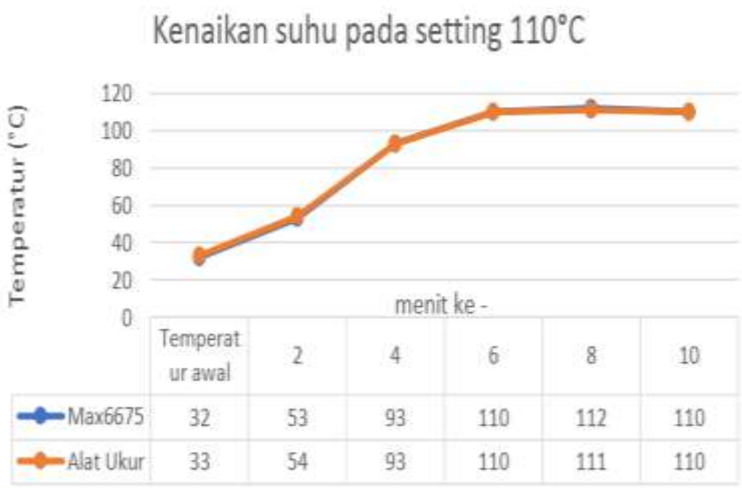

Figure 11. Temperature Rise Evaluation

Temperature Rise at 110°C

The graph indicates a gradual increase in temperature correlating with the two-minute measurement intervals. The system took approximately 10 minutes and 6 seconds to reach 110°C.

Figure 12. Temperature Rise at 110°C

Temperature Rise at 120°C

Similarly, the data show a consistent rise in temperature, with a total time of approximately 10 minutes and 24 seconds required to reach 120°C.

Figure 13. Temperature Rise at 120°C

Temperature Rise at 130°C

The temperature increased steadily over time, reaching 130°C in roughly 10 minutes and 48 seconds.

Figures 4.5, 4.6, and 4.7 represent temperature stability graphs at setpoints of 110°C, 120°C, and 130°C respectively, each demonstrating the ability of the device to maintain a consistent thermal environment over time.

Figure 14. illustrates the cooling behavior at a setpoint of 110°C.

- With the cooling system active, the chamber cooled down to approximately 29°C in about 12 minutes.
- Without active cooling, it took nearly 30 minutes to reduce the temperature to 34°C.

Figure 15. shows the same comparison for 120°C:

- The cooling system brought the temperature down to 29°C in around 12 minutes.
- In passive mode, the temperature dropped to 35°C after 30 minutes.

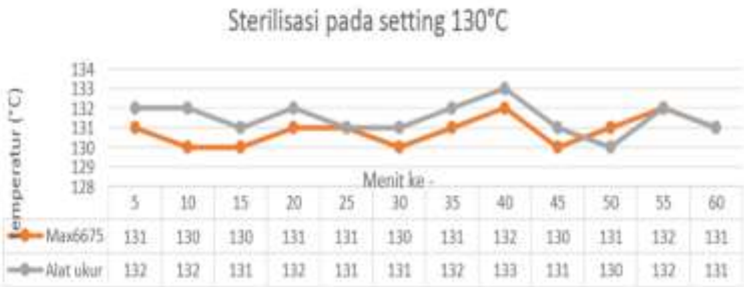

Figure 16. presents the result for 130°C:

- Using active cooling, the chamber reached 30°C in 12 minutes.
- Without it, a similar temperature of 36°C was achieved only after 30 minutes.

4. CONCLUSION

The conclusion encompasses a comprehensive synthesis of the findings derived from the discourse, as well as a broader generalization of the outcomes of the conducted research. In light of these conclusions, the author is also positioned to proffer recommendations for pragmatic implementations, theoretical advancement, and avenues for subsequent inquiry.

ACKNOWLEDGEMENTS

If necessary, this section contains a thank you note from the author by mentioning the source of funding or the party providing research funding, or the name of the institution/person who helped with our research.

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