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Automatic Pre-Starting of Oil-Waste Fueled Stove Based on Microcontroller and HMI

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Abstract

The utilization of waste oil as an alternative cooking fuel is limited by its complex ignition process, which requires preheating to reduce viscosity and ensure stable combustion. Conventional methods, such as burning tissue paper, are unsafe, inefficient, and impractical, hindering broader adoption. This study presents the development of an automatic preheating system for waste oil stoves using an ESP32 microcontroller and HMI with TFT LCD display. The system integrates a thermocouple sensor for accurate real-time temperature monitoring and an automatic cut-off mechanism to halt fuel supply during ignition failure, and includes a buzzer for audible alarms during safety shutdowns to improving operational safety. The ignition sequence employs LPG as a preheater before automatically switching to waste oil at the optimal temperature, with programmed control of the blower, igniter, and valves. Experimental results showed thermocouple measurement accuracy with an average error of 4% and high reliability in fuel transition, except at low initial temperatures (31°C and 42°C) where insufficient heating time resulted in high viscosity and transition failure. The safety system effectively prevented hazards, while the HMI provided precise control and monitoring of actuators and combustion conditions. Overall, the proposed system enhances the safety, reliability, and practicality of waste oil stoves and demonstrates potential for industry innovation and renewable energy applications. Nevertheless, the system still requires LPG for the preheating stage and continuous electrical power, which can reduce effectiveness and make it harder to use in mobile or areas without electricity.

Keywords: Automation, Oil Stove, Microcontroller, ESP32, Human Machine Interface.

1. Introduction

The increasing amount of waste oil generated from vehicles such as motorcycles, cars, and industrial engines has become a major environmental problem. If not properly managed, waste oil can contaminate soil, rivers, and oceans, posing serious ecological and health risks [1], [2]. On the other hand, the dependence on fossil fuels like LPG for cooking remains high in Indonesia, with consumption reaching 8.7 million tons in 2023 [3]. This situation highlights the urgent need to find alternative energy sources, One of the potential solutions is the utilization of waste oil as cooking fuel [4].

Various studies have shown that waste oil can be used directly, or such as being used as an additive in new products, such as concrete mixes to increase their durability [5]. which is derived from petroleum refining and shares similar characteristics with conventional fuels, can be repurposed as stove fuel [6], [7]. This approach not only helps address the issue of fossil fuel dependence but also supports sustainable energy initiatives. However, despite its potential, adoption at the household and small industry level remains limited, primarily due to technical challenges in the initial ignition process.

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The main obstacle of conventional waste oil stoves is the high viscosity of the oil, which requires preheating before it can burn stably. In general, users must perform manual ignition, such as burning tissue or other additional materials in the combustion chamber [8]. This process is considered impractical, produces excessive smoke, and poses safety risks to users. As a result, public interest remains limited because of the complicated ignition process, inefficiency, and safety concerns [9], [10].

Recent advancements in microcontroller technology have enabled the automation of industrial and household appliances, improving efficiency and safety [11], [12]. Globally, automation in cooking appliances has evolved from simple timers to fully integrated systems capable of precise control, automated ingredient handling, and real-time monitoring [13]. For instance, smart stoves with temperature feedback systems, automatic flame regulation, and safety sensors have been developed to enhance convenience and user protection [14]. These smart cooking technologies demonstrate the potential of automation in reducing user intervention and ensuring safe operation. However, similar innovations for waste oil stoves remain very limited [15].

To address these challenges, this study proposes an automation system for waste oil stoves using an ESP32 microcontroller. The system incorporates a Human-Machine Interface (HMI) on a TFT LCD screen, enabling users to monitor and control the stove in real-time. It employs a staged operation, where LPG gas functions as a preheater to reduce the viscosity of waste oil. Once the target temperature is reached, the system automatically switches to waste oil fuel by closing the LPG valve and opening the oil valve. Additional features include precise temperature monitoring with thermocouple sensors and an automatic cut-off mechanism to ensure operational safety in the event of ignition failure [12], [16].

The main objective of this study is to develop an Arduino-based automation system that simplifies the ignition process of waste oil stoves, thereby improving practicality, efficiency, and safety. The expected outcomes are a reduction in LPG dependency, more effective utilization of waste oil, and a safer, cleaner, and more sustainable alternative cooking fuel solution for households and small industries.

2. Method

2.1 Method Design

This research was conducted using the technology engineering method which involves several stages including system design. This stage includes analyzing the needs of the waste oil-fueled stove control system. The system is designed using the ESP32 microcontroller as the main controller, TFT LCD as the HMI interface that connects humans with the controller [17], and several additional components such as blowers, electric valves, Thermocouple type K temperature sensors, and lighters. The system block diagram is used to visualize the relationship between these components as showsn in Figure 1.

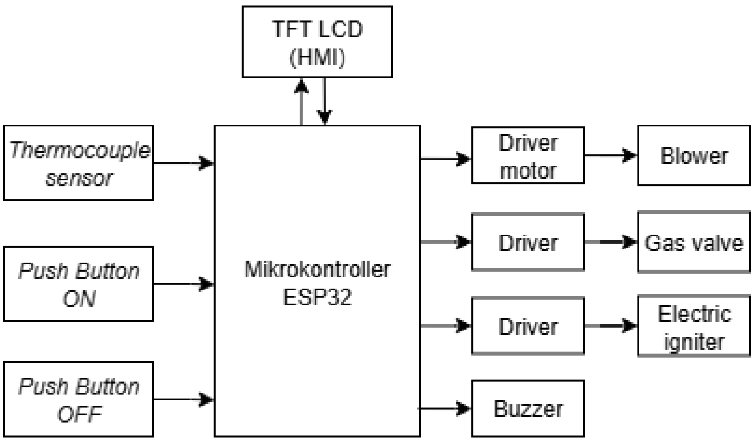

Figure 1. Block Diagram

Figure 1 shows the block diagram of the waste oil-fired stove control system. The ESP32 microcontroller serves as the central controller that processes all input signals and generates the required outputs. The ESP32 was chosen because it provides extensive GPIO pins, low power consumption, and integrated Wi-Fi support, which enables future development such as remote monitoring and cloud-based

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data storage [18]. The Human-Machine Interface (HMI) is implemented using a TFT LCD ILI9341. This display was selected because it is cost-effective, responsive, and capable of presenting graphical data clearly [19]. Temperature measurement is performed using a Type K thermocouple connected through the MAX6675 module. This combination was chosen due to its wide measurement range (0–1024 °C) and high resistance to elevated temperature environments [20]. To support manual operation, two push buttons are included in the system. The ON button allows users to start the stove, while the OFF button provides a direct shutdown option without relying on the HMI. Combustion air is supplied by a DC blower, which is controlled through an L298N motor driver. This driver was selected because it can convert the PWM signal from the ESP32 into an analog voltage, thereby regulating the blower's speed effectively [21].

The fuel supply system uses a gas valve that is controlled through a driver circuit consisting of transistors and relays. Since the ESP32 output voltage is not sufficient to directly activate the relay, a transistor is employed as an intermediate switch. This arrangement enables the ESP32 to send a HIGH signal to the transistor gate, which in turn energizes the relay coil with a 5V supply [22]. An electric igniter is also connected to the same driver system to ensure reliable ignition of LPG during the preheating phase. A buzzer is integrated into the system to provide an audible alarm in case of abnormal conditions or ignition failure. Power for the system is supplied from a 220V AC source. The AC voltage not only drives the gas valve and electric igniter through the driver circuit but also feeds a buck converter. This buck converter steps down the voltage to 12V DC, which is then used to power the blower and other low-voltage components. for the complete electrical circuit can be seen in Figure 2.

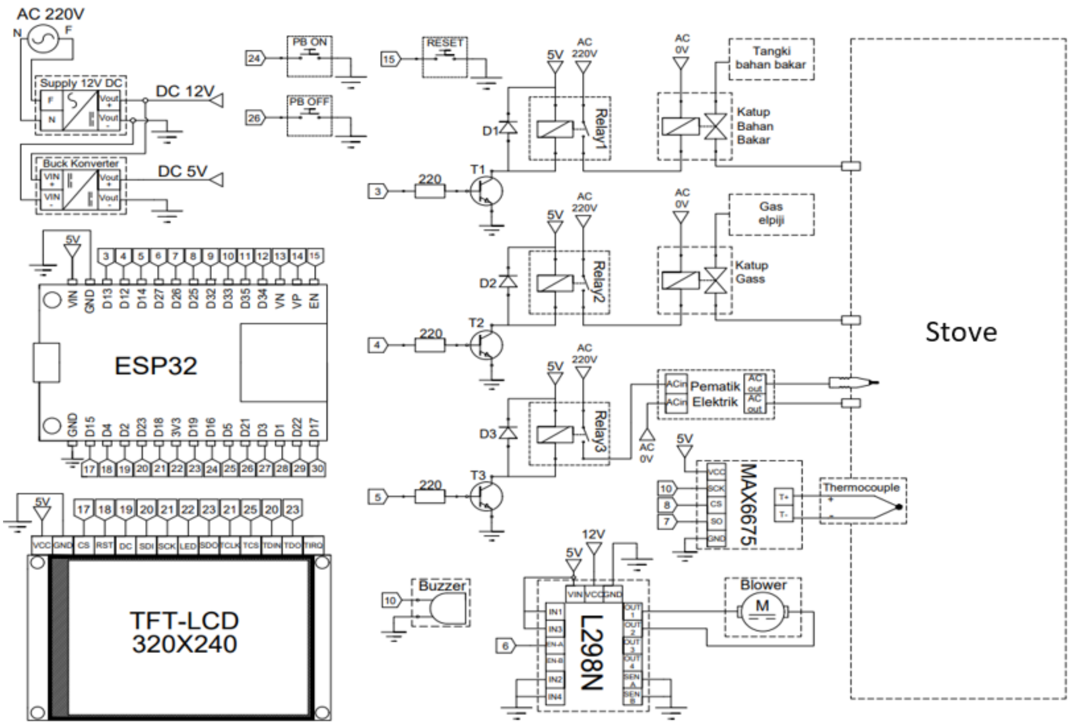

Figure 2. Overall Electrical Circuit

Figure 2 shows that all actuators such as fuel valves, electric lighters, and blowers point to the combustion furnace to ensure a controlled combustion process. To ensure that every component in the used oil stove control system functions optimally, it is necessary to configure the pin addressing on the ESP32 microcontroller. Each pin is connected to a specific device, ranging from relay drivers, TFT LCD modules, thermocouple sensors, to control buttons. Details of the pin addressing can be seen in Table 1.

Table 1. ESP32 Pin Addressing

No.	ESP32 Pin Address	Connected to	Device
1	Pin 3	Gate Transistor 1	Fuel relay
2	Pin 4	Gate Transistor 2	LPG gas relay

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3	Pin 5	Gate Transistor 3	Ignition relay
4	Pin 17	CS	TFT LCD
5	Pin 18	RST	TFT LCD
6	Pin 19	DC	TFT LCD
7	Pin 20	SDI & TDIN	TFT LCD
8	Pin 21	SCK & TCLK	TFT LCD
9	Pin 22	LED	TFT LCD
10	Pin 23	SDO & TDO	TFT LCD
11	Pin 25	TCS	TFT LCD
12	Pin 7	SO	MAX6675
13	Pin 8	CS	MAX6676
14	Pin 10	SCK	MAX6677
15	Pin 6	ENA	L298N
16	Pin 24	Push button ON	Push button
17	Pin 26	Push button OFF	Push button
18	Pin 15	Push button reset	Push button
19	Pin 30	Positive (+)	Buzzer

Based on Table 1, it can be seen that each pin on the ESP32 has a specific function that supports the overall system operation. These functions range from controlling actuators such as fuel valves, igniters, and blowers, to processing data from sensors and user interfaces on the TFT LCD screen. Proper pin configuration ensures good coordination between hardware and software, allowing the system to run according to the programmed logic. In addition, with the flowchart, it can describe the workflow in detail from the HMI, to the control of valves, lighters, and blowers by the ESP32 microcontroller based on the program created. The overall system flow diagram can be seen in Figure 3.

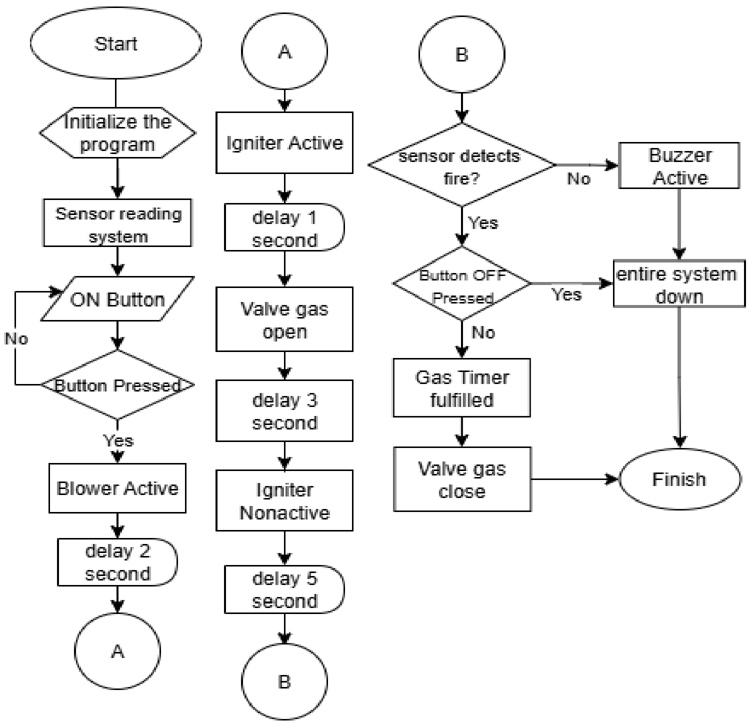

Figure 3. Flowchart System

Figure 3 illustrates how the HMI automatic mode control system works. The process begins with sensor initialization. If the ON button on the HMI is pressed, the blower will be activated, then the igniter will be activated until the igniter timer is fulfilled, and 1 second after that the gas valve will open. After that, the thermocouple sensor detects the flame by measuring the temperature difference before

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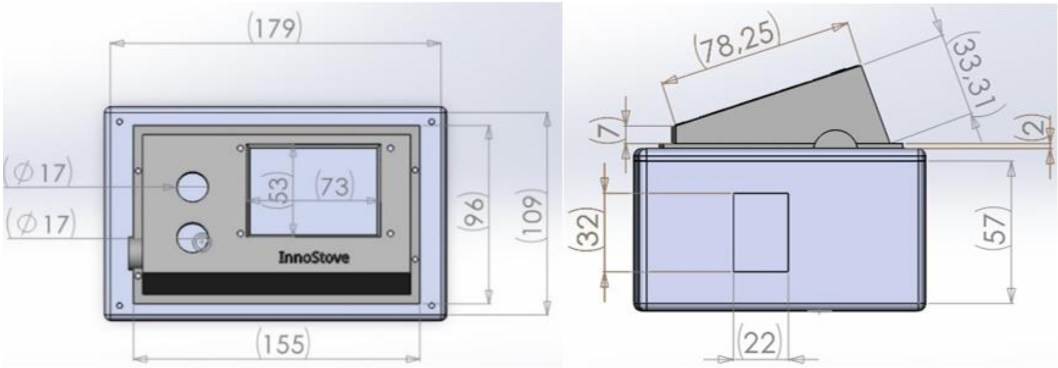
and after the gas valve opens. If there is no temperature increase within 5 seconds after the gas valve opens, the system indicates a flame ignition failure, the alarm sounds, and the system shuts down completely. If the sensor detects a flame, the gas remains active until the gas timer completes.

In order for the control system to be operated ergonomically and protected from environmental factors, a mechanical box must be designed as the main enclosure. This design takes into account the installation position of components such as controllers, TFT LCD screens, control buttons, and supporting components. The mechanical box design can be seen in Figure 4.



(a) (b)

Figure 4. Mechanical Box Design: a) Front View, b) Side View

Figure 4 shows the mechanical design of the device, which consists of two main parts with separate designs but designed to be combined. The first part is a block with dimensions of 179 x 109 x 57 mm, while the second part is a special design for a 73 x 53 mm TFT LCD module and a circular push button with a diameter of 17 mm. The overall mechanical design showing the layout of the controller box and the shape of the used oil stove used is shown in Figure 5.

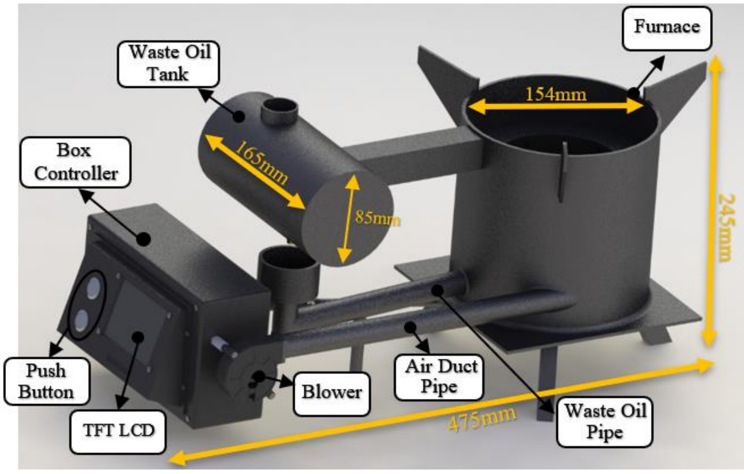


Figure 5. Overall Mechanical Design

Figure 5 illustrates the overall mechanical design of the waste oil-fueled stove system. The stove has a total length of 475 mm and a height of 245 mm, with the combustion chamber diameter measuring 154 mm. The waste oil storage tank has a diameter of 85 mm and a length of 165 mm, providing adequate capacity while maintaining compactness. The controller unit which will be used for the placement of components and TFT LCD screens as control and monitoring devices is deliberately positioned on the side opposite to the combustion chamber to minimize exposure to high temperatures. To further reduce heat conduction, the controller casing is constructed from plastic material, which exhibits low thermal conductivity compared to metals. Additionally, the blower is strategically installed adjacent to the controller box. Beyond supplying airflow to the furnace to ensure stable combustion, the blower also contributes to passive cooling of the controller compartment.

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2.2 Experimental Procedure

The experimental procedure was systematically designed to evaluate the performance and reliability of the automatic preheating system under controlled laboratory conditions at the Department of Electrical Engineering, Universitas Negeri Padang. All experiments were conducted in a well-ventilated environment to ensure safe operation during combustion testing.

Thermocouple sensor accuracy was assessed through comparative measurements against a calibrated non-contact infrared thermogun (measurement range: -50° - 380°C, accuracy: ±2%). The thermocouple was positioned directly inside the combustion chamber at the center point to capture core furnace temperature, while the thermogun measured surface temperature at a standardized distance of 1 meter from the furnace bottom. Five temperature levels (44°C, 100°C, 130°C, 154°C, and 185°C) were tested with three repetitions at each level to ensure data consistency. Temperature readings from both devices were recorded simultaneously. The thermocouple output was acquired by the ESP32 microcontroller via the MAX6675 module and displayed in real-time through both the Serial Monitor in Arduino IDE and the HMI screen. Ambient temperature was maintained at 25±2°C throughout testing, and the furnace was allowed to cool completely between successive measurements to prevent thermal carryover effects.

The Human-Machine Interface functionality was evaluated through systematic activation sequence testing. The test protocol involved pressing the ON button on the HMI and monitoring the sequential activation of system components according to the programmed logic. Complete operational cycles were performed to verify repeatability and consistency. Each cycle recorded the precise timing of blower activation (initial speed 60% at t=0s), igniter activation (t=1s), gas valve opening (t=3s with blower speed increase to 80%), and maximum blower speed attainment (100% at t=4s). The system response to the OFF button was tested five times to confirm immediate and complete shutdown of all actuators. Visual indicators on the HMI display were cross-verified with actual component states using a multimeter to measure voltage signals at actuator terminals.

The automatic safety cut-off mechanism was rigorously tested under six different initial temperature conditions (30°C, 42°C, 48°C, 75°C, 100°C, and 143°C) with one repetitions per condition. For each test, the system was initialized at the specified temperature, and the thermocouple recorded baseline temperature immediately before LPG valve opening. Temperature was continuously monitored at 1-second intervals for 5 seconds post-valve opening. The cut-off algorithm was programmed to trigger if temperature increase remained below 5°C within this timeframe, indicating ignition failure. Successful cut-off activation was verified by monitoring gas valve closure, buzzer alarm activation, and system shutdown through both visual HMI indicators and physical valve state inspection. Tests simulating successful ignition (temperature rise >5°C) were conducted to confirm that the cut-off system appropriately remained inactive, allowing normal operation to proceed.

The fuel transition capability from LPG to waste oil was evaluated through ten independent trials with varying initial oil temperatures ranging from 31°C to 296°C. Waste oil (SAE 20W-50 viscosity grade) was pre-loaded into the combustion chamber before each test. The experimental protocol initiated with HMI activation, followed by the programmed sequence of blower operation at 100% speed (to accelerate thermal transition), igniter activation, and LPG valve opening. Transition time was defined as the duration from LPG ignition until stable waste oil combustion was achieved, indicated by sustained flame without LPG support. Temperature and transition time was recorded at the precise moment when the system automatically switched from LPG to waste oil fuel. Each trial monitored flame stability for an additional 60 seconds post-transition to confirm sustained combustion. Initial oil temperature was measured using the thermocouple sensor. Failed transitions were characterized by flame extinction after LPG valve closure or inability to achieve self-sustained waste oil combustion.

2.3 Data Analysis Technique

Data analysis was conducted using both descriptive and inferential statistical methods to evaluate system performance across all experimental procedures. For thermocouple accuracy assessment, percentage error was calculated using the formula: Error (%) = $(T_{thermocouple} - T_{thermogun}) / T_{thermogun} \times 100\%$. The mean error and standard deviation were computed across all temperature measurements to determine sensor reliability and precision.

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HMI control system performance was analyzed through descriptive statistics, documenting the timing sequence, response consistency, and actuator activation patterns across multiple operational cycles. The analysis focused on verifying that all components responded according to the programmed logic and identifying any timing deviations from the designed flowchart specifications.

For the cut-off safety system, effectiveness was quantified by calculating the success rate, defined as the ratio of correct system responses to total test attempts under various temperature conditions. Temperature gradient analysis ($\Delta T/\Delta t$) was performed to distinguish between successful ignition and failure scenarios, validating the 5°C threshold criterion for safety activation.

Fuel transition performance was evaluated through correlation and regression analysis to establish relationships between initial oil temperature, transition temperature, and transition time. Success rate calculations identified the percentage of successful transitions relative to total attempts, while failure case analysis determined critical temperature thresholds for reliable operation.

3. Result and Discussion

3.1 Result

The thermocouple sensor was tested to evaluate its accuracy in monitoring furnace temperature by comparing the sensor readings with those obtained from a non-contact infrared thermogun. The thermocouple sensor was placed directly inside the combustion chamber to measure the core temperature of the furnace, while the infrared thermogun measured the furnace temperature at a distance of 1 meter from the bottom of the furnace. The thermocouple output was read by the ESP32 microcontroller and then displayed in real-time via the Serial Monitor in the Arduino IDE. The temperature comparison test between the two devices is shown in Figure 6.

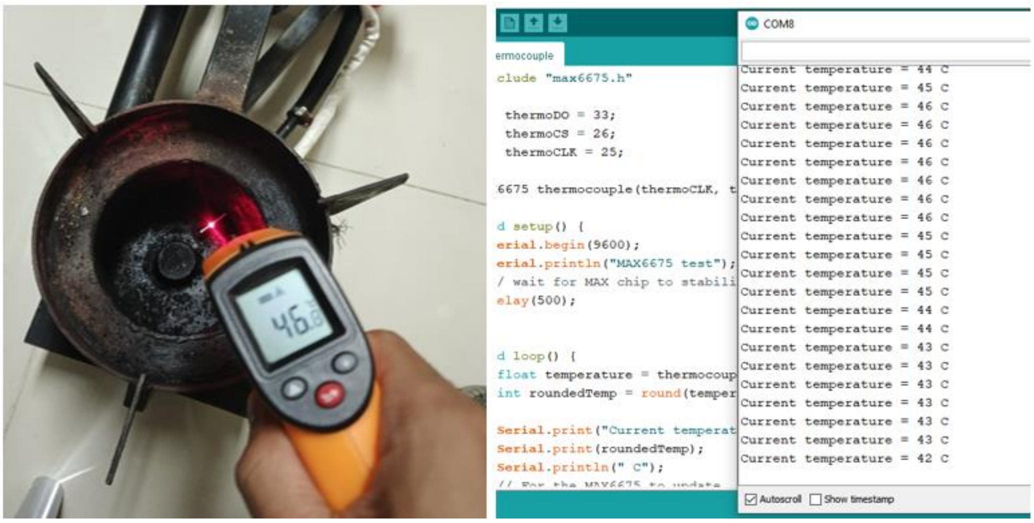

Figure 6. Measuring Temperature Between Thermocouple And Thermogun

Figure 6 shows During testing, both devices recorded temperature values simultaneously at several different heating levels. Thermocouple data was read by the ESP32 microcontroller via the MAX6675 interface module and displayed in real-time on the serial monitor and TFT LCD screen. Meanwhile, thermogun readings were manually recorded at the same time intervals. All data was then analyzed by calculating the percentage error between thermocouple and thermogun measurements as shown in Table 2.

Table 2. Thermocouple Sensor Accuracy Test Result

Test	Thermocouple Temperature (°C)	Thermogun Temperature (°C)	Error (%)
1	44	46	4
2	100	103	3
3	130	135	4
4	154	162	5

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5	185	192	4

The test results in Table 2 show a high level of accuracy, with an average error of 4% across all measured temperature ranges. This small error is due to the difference in the operating principles of the two devices, where the thermocouple measures the temperature at the direct contact point inside the furnace, while the thermogun measures the surface temperature non-contact, which is influenced by the emissivity of the material and environmental conditions. Additionally, the different thermal response of the sensors can also cause reading deviations even when measurements are taken simultaneously. These relatively small errors do not significantly impact system performance, as the measurement tolerance remains within acceptable limits. This indicates that thermocouple sensors are reliable for real-time temperature monitoring in automatic stove systems. The next test is to verify the performance of the Human Machine Interface (HMI) in controlling and monitoring the operation of the waste oil-fueled stove. The testing process included evaluating the response of the ON/OFF button, to the initial ignition process of the waste oil stove, as shown in Figure 7.

Figure 7. Oil Stove HMI Display

Figure 7 shows the results of the HMI design with 6 indicators, 4 of which are for the status of the actuator whether it is active or not, and 2 of them are for the speed value of the blower and the temperature value in the furnace. for test results can be seen in Table 3.

Table 3. Test Result of the Control System Via HMI

Time (s)	Button ON	Button OFF	Blower Speed (%)	Flame Igniter	Valve Gas
0	Pressed	-	Active (60%)	Non-active	Non-active
1	-	-	Active (60%)	Active	Non-active
3	-	-	Active (80%)	Active	Active
4	-	-	Active (100%)	Non-active	Active
240	-	-	Active (100%)	Non-active	Non-active
-	-	Pressed	Non-active	Non-active	Non-active

Table 3 shows the sequence of system operations after the ON button is pressed. At 0 seconds, the fan is activated at 60% speed, followed by the ignition being activated at 1 second. The gas valve begins to open at second 3, the fan speed increases to 80%, and the gas fuel remains active for a predetermined duration to achieve sufficient temperature for the waste oil to burn. As shown in the table, this process lasts for 240 seconds, though the duration may vary depending on the viscosity and initial temperature of the waste oil. This process continues until the OFF button is pressed, which stops all system operations. The test results show that the HMI successfully controls each component precisely according to the designed flow. Subsequently, the cut-off system is tested to evaluate its effectiveness in mitigating hazardous conditions that may arise if the LPG gas valve opens without ignition. This is

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achieved by comparing the temperature values recorded by the thermocouple sensor before and after the LPG valve is opened. The test results for the cut-off system are presented in Table 4.

Table 4. System Cut-off Test Result

Test	Initial Temperature (°C)	Temperature after 5 Seconds Gas Valve Open (°C)	Status Cut-off	Status
1	30	32	Succeed	Gas valve closed, alarm active
2	42	43	Succeed	Gas valve closed, alarm active
3	143	142	Succeed	Gas valve closed, alarm active
4	100	99	Succeed	Gas valve closed, alarm active
5	48	55	Fail	Gas valve stays open
6	75	84	Fail	Gas valve stays open

Table 4 shows the system's ability to respond to potential hazards when the LPG gas valve is open without combustion occurring. In tests 1-4, the system successfully activated the closure mechanism, closing the gas valve when no significant temperature increase was detected within 5 seconds and activating the alarm, indicating that no combustion occurred. Meanwhile, tests 5 and 6 showed the system in a different condition, namely when a temperature increase of more than 5°C was detected within 5 seconds after the gas valve was opened. In this condition, the system ignored or did not execute the system cut-off algorithm and kept the gas valve open, as the system indicated that ignition was successful. These results highlight the system's reliability in ensuring consistent performance under all conditions, while also providing a basis for testing the fuel transition time from LPG gas to waste oil, as shown in Figure 8.

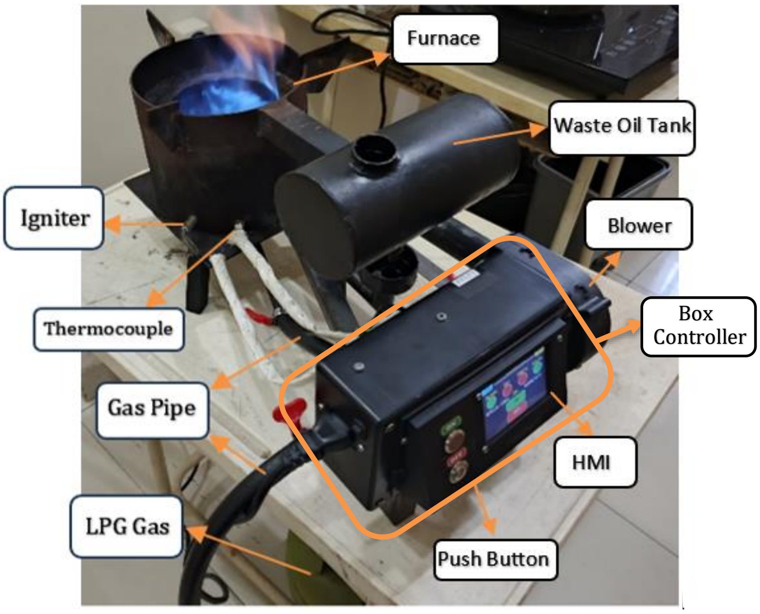

Figure 8. Fuel Transition Testing

In Figure 8, testing of fuel transfer from LPG gas to waste oil was conducted 10 times with waste oil already in the combustion chamber from the start. Through the HMI by pressing the ON button, then executing the logic according to the flowchart and testing in Table 2, namely activating the blower (set to 100% speed to accelerate the transition process), igniter, and LPG valve gradually, the LPG gas ignites until the required time and temperature are reached so that the viscosity of the waste oil can decrease and become thinner, thereby enabling it to be used as fuel. The results can be seen in Table 5.

Table 5. Fuel Transition Test Result

Test	Initial Temperature (°C)	Transition Temperature (°C)	Transition Time (s)	Status
1	54	497	480	Succeed

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2	125	492	300	Succeed
3	210	464	200	Succeed
4	240	453	120	Succeed
5	296	430	60	Succeed
6	32	512	360	Succeed
7	35	510	300	Succeed
8	35	520	240	Succeed
9	31	431	180	Failed
10	42	414	150	Failed

Table 5 shows the results of the transition time test from LPG fuel to waste oil. The test results prove that the higher the initial temperature of the waste oil in the furnace, the faster the transition process takes place. However, at initial temperatures that are too low (31°C and 42°C) with insufficient heating time, the transition process fails because the oil does not reach the required transition temperature. To further evaluate the effectiveness of the developed system, a comparative analysis was carried out between the automatic ignition design and conventional waste-oil stoves. This comparison highlights not only the improvements in safety, and ease of operation, but also the practical limitations that still exist in both approaches. The comparison is presented in Figure 9.

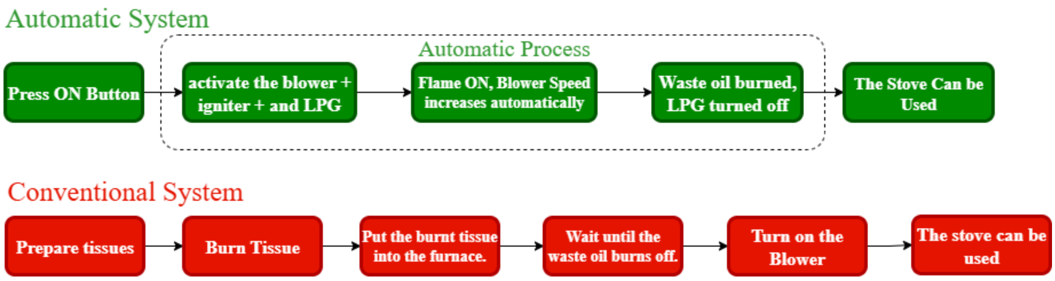

Figure 9. Comparison Diagram of Automatic and Conventional System

Figure 9 compares the proposed automatic ignition system with conventional manual methods. Traditional waste-oil stoves require repeated manual preheating using tissue or similar materials, often resulting in unstable combustion, excessive smoke, and safety risks. In contrast, the automatic system employs a microcontroller-based sequence that requires only a single input by pressing a button on the HMI, which then controls the activation of the blower, LPG, igniter, and oil valve, ensuring reliable fuel transition and stable combustion. Furthermore, the automatic stove is particularly advantageous for long-duration cooking, such as rendang preparation, since the flame remains stable as long as oil is available, eliminating the need for repeated re-ignition. However, compared to conventional systems, the automatic design still has some drawbacks: it requires LPG as an auxiliary fuel for the preheating phase to reduce waste oil viscosity, and it relies on continuous electrical power to operate the control system and actuators, whereas conventional systems operate independently without these dependencies

3.2 Discussion

This study presents significant methodological advances compared to previous studies in waste oil stove technology. Unlike previous studies that focused on fuel processing or mechanical burner design optimization [9], [10], this study proposes a holistic approach at the system level that integrates ignition automation, real-time safety monitoring, and user interface design simultaneously. The thermocouple accuracy, with an average error of 4.0%, is in line with similar temperature monitoring systems that report an error range of 3-6%, confirming the reliability of the sensor for combustion applications [20]. However, this study surpasses conventional used oil stoves, by eliminating manual heating using paper materials and the risk of fire that has historically limited adoption in households [8].

The automatic shut-off mechanism represents a critical safety advancement absent in previous designs addressing the risk of uncontrolled fuel release through real-time temperature feedback [6], [8]. Compared to recent automation efforts in cooking appliances that primarily target LPG or natural gas systems, this research specifically addresses the unique challenges of waste oil combustion, including viscosity management and combustion reliability [14]. The 80% transition success rate significantly surpasses conventional manual methods that require multiple combustion attempts with unpredictable flame stability [9].

However, this system has limitations compared to purely mechanical designs that do not require electrical power and LPG consumption for initial ignition, resulting in additional fuel costs and limiting off-grid and mobile applications. The ESP32 microcontroller platform provides advanced computing capabilities that enable future IoT integration for remote monitoring and data logging, in line with the trend of smart kitchen appliances, although these automation features increase system complexity and dependence on electrical power [18]. A trade-off analysis shows that although automated systems require higher initial investment and a continuous power supply, they offer significant advantages in operational safety through automatic shutdown mechanisms and user convenience through one-button operation, effectively addressing the main adoption barriers identified in previous studies although this introduces new dependencies on LPG availability and continuous electricity supply that may limit their application in resource-constrained environments [8], [9]. This performance-resource compromise results in complementary deployment scenarios: the automated system is best suited for residential and small-industry settings with stable infrastructure, while conventional designs are more practical for mobile or off-grid applications where operational autonomy is prioritized over enhanced safety features.

4. Conclusion

From the results of this study, an automatic ignition system for waste-oil stoves based on the ESP32 microcontroller with an HMI interface was successfully developed. The system integrates a thermocouple sensor for real-time temperature monitoring, which also serves as the main parameter in the automatic fuel shut-off mechanism, while the HMI functions as the central platform for monitoring and control. Experimental results demonstrated reliable performance in transitioning from the initial heating phase using LPG to the main combustion phase with waste oil under the specified conditions. This solution provides a reliable, safe, and practical technical approach for utilizing waste oil as an alternative energy source. However, its reliance on LPG as an auxiliary fuel during the preheating process and on a continuous electrical power supply remains a limitation compared to conventional stoves, particularly in mobile applications or areas without access to electricity. Future work should therefore focus on reducing LPG consumption, improving overall energy efficiency, and enhancing performance at low initial oil temperatures. Furthermore, integrating IoT capabilities for remote monitoring and data logging, supported by the ESP32 microcontroller's built-in Wi-Fi, could further extend its applicability in both residential and industrial settings.

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