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Development of an Arduino-Based Microcontroller System to Maintain Temperature Stability in the Plastic Waste Pyrolysis Process

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Abstract

This study aims to develop and evaluate a temperature monitoring and control system for a plastic pyrolysis model operating within the temperature range of 400–500 °C. The system is designed using a microcontroller to read signals from 4 thermocouples placed at various points within the pyrolysis chamber. The collected temperature data are processed, displayed on an LCD screen, and stored on an SD card. Temperature control is carried out using a potentiometer, while data logging is managed through push-button switches. An electric heater is used as the heat source, controlled by a relay, and temperature readings are calibrated using a commercial thermometer to ensure accuracy. The test results indicate that the system is capable of consistently monitoring and maintaining temperatures within the specified range. Although temperature variations were observed at different measurement points, the system generally demonstrated good performance in temperature control. The system effectively approached the target temperature, though temperature deviations were still influenced by heating rate and thermocouple characteristics. Additionally, the observed uneven temperature distribution highlights the need for improvements in the heating system design to enhance thermal uniformity within the pyrolysis chamber.

Keywords: *Arduino - based; microcontroller; plastic waste; pyrolysis; room temperature.*

1. Introduction

The rapid rise in living standards and the drastically increased use of plastics have a significant impact on the environment. Plastic items are produced in large quantities due to growing consumption in various sectors such as construction, packaging, textiles, consumer goods, transportation, and industrial machinery.

Sustainability, durability, cost-effectiveness, lightweight, as well as a wide array of other applications are increasing the demand to fulfill consumer and industrial needs (Gupta & Singhal, 2022). Plastic production continues to increase, but eventually all plastics become waste and end up in landfills. In addition, non-biodegradable plastics are a major problem as they take thousands of years to decompose, during which time they can harm human life, the environment, and marine life (Ekanayaka et al., 2022; (Shen et al., 2020). Although the production and combustion of plastics generated 850 million metric tons of different gases in the atmosphere in 2019, Carbon dioxide is a major contributor to greenhouse gases, accounting for about 76% of greenhouse gas emissions generated by human activities and potentially causing a range of serious illnesses such as headaches, anxiety, breathing difficulties, coma, shortness of breath, and seizures (Asokan et al., 2019; Min et al., 2022).

According to an annual study from the Center for International Environmental Law, CO_2 emissions from plastics and their combustion are expected to reach 2.8 gigatons per year by 2050 (Karlsson et al., 2024) Whereas, landfilling and burning 1 kg of plastic waste produces 253 grams and 673-4605 grams of CO_2, respectively (Eriksson & Finnveden, 2009; Maitlo et al., 2022). Therefore, to prevent higher gas emissions and encourage recycling of plastic waste, several technologies such as combustion, gasification, and pyrolysis have been developed. Among these

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technologies, pyrolysis plays an important role in converting waste plastics into energy products such as liquids, solids, and gases, which attracts the interest of researchers worldwide to ensure environmental and energy security (Su et al., 2021). The pyrolysis process involves the thermal decomposition of long-chain hydrocarbons into shorter hydrocarbon chains at high temperatures of 300-900°C in the absence of oxygen, producing valuable energy products, mainly liquids. This leads to favorable blending between conventional diesel and liquid hydrocarbons equivalent to gasoline (De La Flor Barriga & Rodríguez Zúñiga, 2022). Researchers investigated the pyrolysis process and reported that it can be used to convert waste plastics into biofuels through conventional and advanced pyrolysis. However, CaO (calcium oxide) showed higher bio-oil and hydrocarbon content results (Hoang et al., 2021; Su et al., 2022).

Plastic is a polymer consisting of carbon and hydrogen as its main components (Garcia-Garcia, 2024; Pradeep & Gowthaman, 2022). According to Pradeep et.al (Pradeep & Gowthaman, 2022) various types of plastics available in the market include *High Density Polyetlene* (HDPE), *Polyvinyl Cholride (*PVC), *Low Density Polyetlene* (LDPE), Polyethylene *Terephtalate (*PET), Polypropylene (PP), Polystyrene (PS), and others.

According to Thahir et al., 2019, this type of thermoplastic plastic will melt when heated to its melting point. Naphtha, the raw material for plastic manufacturing, can be converted into fuel through heating (Kandindi Muteba et al., 2023; Shi et al., 2024). Pyrolysis of waste plastic is the best heating method to reconvert waste plastic into fuel. It belongs to tertiary recycling as it produces a product that is either a chemical or a fuel (Mohod et al., 2014; Rashid, 2013).

Pyrolysis of plastic waste is a process of material decomposition that occurs at high temperatures, either with or without a limited amount of available air (Qureshi et al., 2020). In this process, the molecular structure of the material is broken down into the gas phase, leaving a carbonaceous residue (Nguyen et al., 2020). The result of pyrolysis can be three phases: solid, gas, and liquid. The solid phase consists of carbon residue, the gas phase consists of components such as H_2O, CO, H_2 , and CH_4, while the liquid phase is pyrolytic oil which generally consists of tar and polyaromatic hydrocarbons (Ge et al., 2022; Sarker & Rashid, 2013).

In the process of energy extraction through pyrolysis, plastic waste is heated to the point of decomposition, causing the long plastic molecules to break down into shorter molecules, forming a gas or liquid after cooling (Passamonti et al., 2024). The gas or liquid resulting from the pyrolysis of these plastics can be utilized as fuel. It is important to note that each type of plastic has a different decomposition point, so the temperature of the pyrolysis chamber should be adjusted according to the type of plastic being treated. The heating rate and temperature of the pyrolysis chamber have a significant impact on the amount and properties of the fuel produced from the pyrolysis process (Yang et al., 2024). Therefore, to develop an efficient pyrolysis process and produce products with desired characteristics, a pyrolysis device capable of monitoring and regulating the heating rate and temperature of the heating chamber is required (Miandad et al., 2017; Rahman et al., 2020).

Several previous studies have developed devices to monitor and regulate the temperature in the pyrolysis chamber (Amiruddin & Sutopo, 2012; Hartulistiyoso et al., 2015). In the research of Mahmud and colleagues (Mahmud et al., 2023), a temperature and heating rate control device has been developed using fuzzy logic control and TRIAC as electronic contacts for electric heaters. Although this device is able to monitor the temperature at only one point, it is not equipped with data storage. On the other hand, research by Hartulistiyoso and team (Hartulistiyoso et al., 2015) involved monitoring the temperature at several points in the pyrolysis chamber using five thermocouples connected to a commercial data acquisition device (National Instrument), which were then read through a computer with LabView software. Temperature control in the pyrolysis chamber is done using a contactor separate from the data acquisition system. However, the use of commercial data acquisition devices and LabView software makes this monitoring device expensive and requires connection with a computer, making it less practical. (Pongoh et al., 2021).

In this paper, we present the development of an Arduino-based temperature monitoring and control system specifically designed for a plastic pyrolysis chamber. The system is capable of independently monitoring, recording, and regulating temperature from multiple points within the chamber using thermocouples, a relay-controlled electric heater, and input modules to set the desired temperature. Unlike many existing systems that rely on computer-based interfaces or proprietary components, the proposed system uses low-cost, widely available components and operates autonomously without requiring a constant computer connection. The novelty of this research lies in its integration of autonomous data logging and real-time control in a compact, affordable setup tailored for small-scale pyrolysis applications. Given the critical role of precise temperature control in optimizing pyrolysis processes and ensuring consistent product quality, the urgency of this development is underscored by the need for accessible, scalable solutions in waste-to-energy technologies. Therefore, this study aims to design,

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implement, and evaluate a reliable standalone temperature control system that enhances usability and thermal management in experimental or small industrial pyrolysis setups.

2. Methodology

The development of the temperature monitoring and control system for the plastic pyrolysis chamber was carried out in three primary stages: design, implementation, and operational testing.

In the design phase, system functionality was defined through block diagrams, component selection, and circuit mapping. The system was designed to monitor temperatures at multiple points within the pyrolysis chamber using calibrated K-type thermocouples and to regulate the heating process via a relay-controlled electric heater. A microcontroller board (NS.One/32), based on the ATMega32 chip, was utilized to read thermocouple signals, display real-time data on a 16×2 LCD, and store temperature records on an SD card. A multi-turn potentiometer was implemented for target temperature input, while push buttons (Mode, Record, Stop) were used to control the data logging process. The system supports both automatic (every 5 seconds) and manual logging modes, with time information retrieved from a DS1307 real-time clock (RTC) module.

The implementation phase involved step-by-step assembly of hardware modules, including the LCD, thermocouples, RTC, SD card, relay, and indicator LEDs. Each addition was followed by firmware integration using the Arduino IDE, and module-level testing was conducted to verify individual functionality—such as correct analog readings from the potentiometer, real-time accuracy from the RTC, and control logic of the relay. Calibration of temperature readings was performed against a commercial thermometer to ensure accuracy.

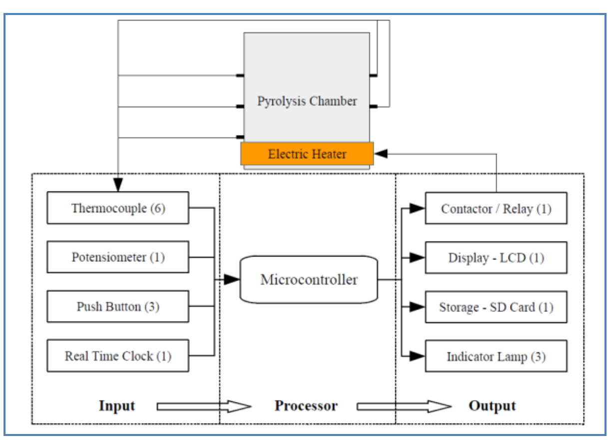

Figure 1. Input/output diagram of the temperature monitoring and control system.

In the operational testing phase, the system was installed on a plastic pyrolysis device designed to operate between 400–500 °C. Performance evaluation focused on the system's ability to read, display, log, and regulate temperatures in real time. Additional validation included tests for consistency among thermocouples, calibration reliability, and transient response—measuring how quickly sensors responded to changes in temperature. These tests ensured data quality and system stability under working conditions.

3. Results and Discussion

The pyrolysis chamber monitoring and control system that has been installed on the pyrolysis device model is shown in Figure 2. The functions of each input/output device as well as the overall system performance have been tested, and the results are described in detail in the next section.

3.1 Component Function Testing

As explained earlier, input/output devices were integrated into the system in phases, and each new component was verified according to the predefined criteria. The system successfully reads temperature data from six sensors and time data from the RTC module, displays information on an LCD, and saves logs to an SD card, which can then be transferred to a computer for further analysis—demonstrating effective modular functionality consistent with modern sensor-based systems (Hermann et al., 2022)

Temperature control also performed reliably: the target temperature set via potentiometer accurately triggered heater activation through a relay, maintaining chamber conditions as designed. This implementation aligns with recent studies showing similar Arduino-based temperature control frameworks using potentiometers and relay-driven heaters for precise thermal management in experimental setups (Yang et

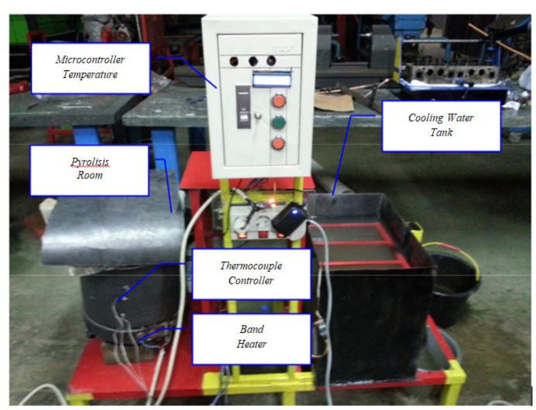

Figure 2. Temperature monitoring and control system installed on the plastic pyrolysis model

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al., 2024) .

3.2 Temperature Value Consistency

The results of the consistency test of temperature values from several thermocouples placed at the same measurement location are shown in Figure 3.

Ideally, all thermocouples should produce the same temperature value. However, significant discrepancies can occur due to factors such as surface condition and contact quality with the measured object. During testing, thermocouples 2–5—with clean surfaces—produced consistent readings, while thermocouple 1 with a corroded surface showed much lower values. This rust layer hinders heat transfer to the sensing junction, causing underestimation of the true temperature. As temperature increases, discrepancies among clean sensors remain under 10 °C, but differences reach up to 50 °C for corroded ones—highlighting the importance of maintaining clean sensor surfaces to ensure measurement confidence.

These observations align with prior studies showing that corrosion and sheath damage alter thermocouple electromotive output and reduce accuracy (Aydinli & Caglar, 2010)

Moreover, thermocouple mounting quality and contact resistance critically influence heat conduction to the junction, a key factor in measurement error (Daffallah et al., 2017)

3.3 Temperature Sensor Calibration Process

Calibration of the temperature sensor is done by comparing the reading value on the analog pin connected to the thermocouple with the reading value of a commercial temperature measuring instrument, as shown in Figure 4. The temperature value read from the thermocouple in Figure 4 is the average value of thermocouples 2-5 shown in Figure 3. From the calibration results, it can be seen that the temperature value read from the thermocouple tends to be lower than the value read from the commercial temperature measuring instrument. This is due to the long length of the sensor cable, which results in a signal voltage drop from the thermocouple. It can be concluded that the longer the thermocouple cable, the lower the temperature value read from the thermocouple.

If the temperature measurement data in Figure 4 is approximated with a linear function, a straight line is obtained with a very high correlation level of 0.9995. Thus, the temperature value read from the thermocouple can be calibrated by converting the value to the actual temperature using the linear function y = 1.1721x - 2.01. Keep in mind that the sensor type and cable length can affect the temperature value read from the thermocouple. Therefore, for different sensor types and cable lengths, it is necessary to perform a separate calibration (Elektronika, 2017).

3.4 Temperature Sensor Transient Response

The transient response of the temperature sensor is shown in Figure 5. From the figure, it can be seen that the temperature sensor equipped with a protective coating has a relatively slow response. When a thermocouple with an initial temperature of 30°C is attached to a surface with a temperature of 200°C, it takes about 5 minutes for the thermocouple to reach steady state, which is a temperature of 200°C. The slow response of the thermocouple is related to the presence of a heat shield layer that has a large heat capacity, so it

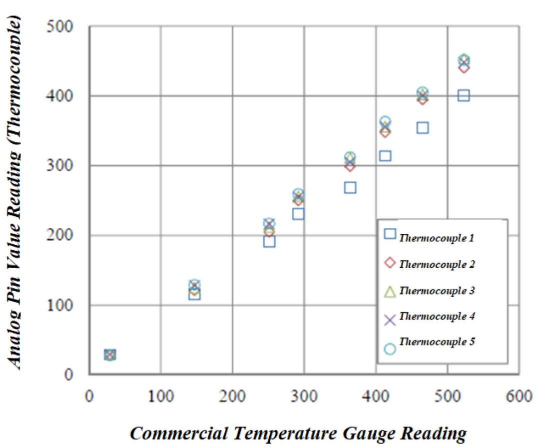

Figure 3. Consistency of temperature values obtained from multiple thermocouples.

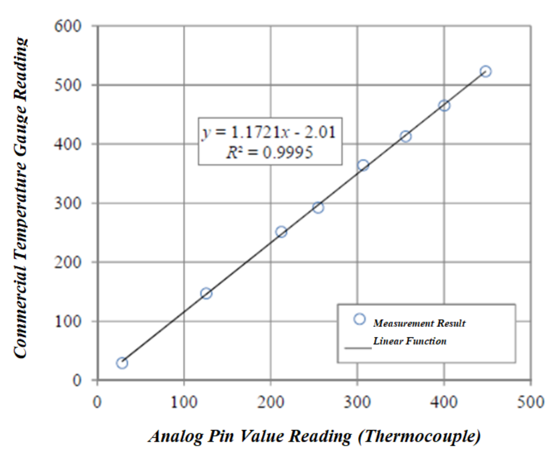

Figure 4. Determination of calibration function by linear regression.

takes a long time to raise the temperature of the thermocouple shield. For unshielded thermocouples, steady state can be achieved within a few seconds. However, these sensors cannot be used to measure high temperatures for long periods of time, such as in the pyrolysis process of plastics (Ramos et al., 2017).

3.5 Temperature Monitoring and Control Testing

To ensure the overall performance of the system, monitoring and controlling the temperature of the pyrolysis chamber was tested. In this operational test, the pyrolysis chamber was heated and the temperature was maintained at 450° C for 60 minutes. The test results show that the device can monitor the temperature at several locations of the pyrolysis chamber and control the temperature of the pyrolysis chamber to approach the set target temperature.

Monitoring the temperature at various locations in the pyrolysis chamber revealed temperature variations. Thermocouple 1, which is close to the band heater, shows the highest temperature, while thermocouples 2 and 4, which are 10 cm away from thermocouple 1, show slightly lower temperatures. Thermocouples 3 and 5, which are 20 cm away from thermocouple 1, show even lower temperatures. Figure 6 shows that the further away from the heater, the temperature tends to be lower. This temperature variation in the pyrolysis chamber has been observed in previous studies by Hartulistiyoso et al. (Hartulistiyoso et al., 2015). To ensure an even temperature throughout the pyrolysis chamber, it is necessary to pay attention to the layout of the heater (Foysal, 2021).

Figure 6 also shows that the temperature controller has functioned well, with the pyrolysis chamber temperature close to the target temperature of 450° C.

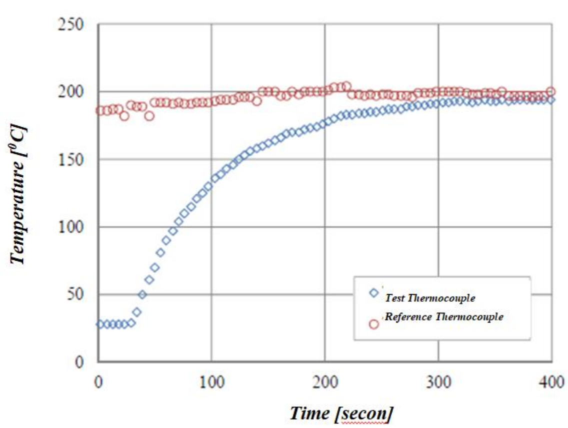

Figure 5. Transient response of the temperature sensor.

Although there are temperature fluctuations with a period of about 100 seconds, as seen in Figure 7, the deviation of the temperature value is relatively small, which is below 10° C. These temperature fluctuations are related to the relatively slow transient response of the thermocouple. When the temperature rises and the thermocouple indicates 450° C, the actual temperature of the pyrolysis chamber has already exceeded 450° C. Therefore, although the heater has been turned off, the temperature indicated by the thermocouple continues to rise above 450° C. On the contrary, when the temperature drops and the thermocouple indicates 450° C, the actual temperature of the pyrolysis chamber is already lower than 450° C. As a result, even though the heater has been turned on, the temperature indicated by the thermocouple still drops. To reduce the temperature fluctuation, a sensor with a faster response is required. Another alternative is to develop a control algorithm that can compensate for the slow transient response.

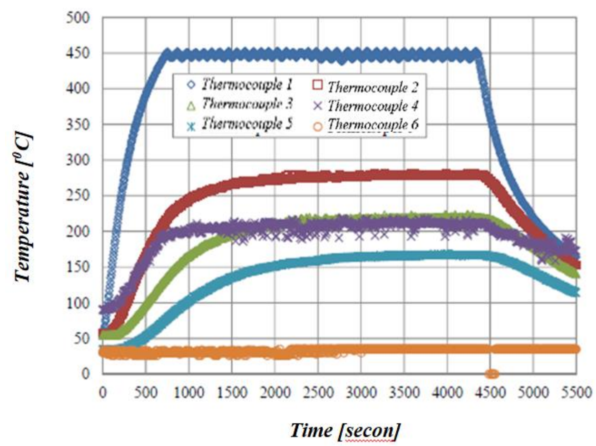

Figure 6. Temperature changes at different parts of the pyrolysis chamber.

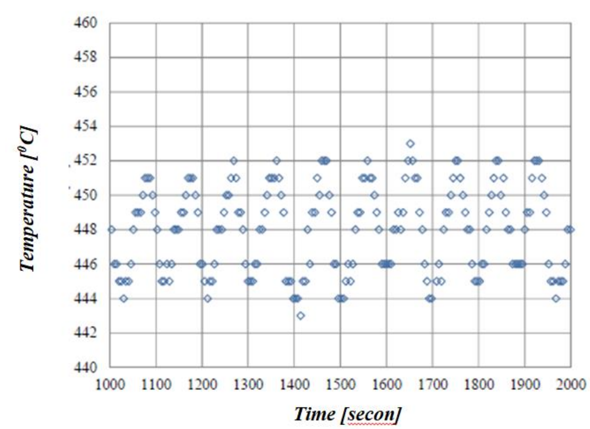

Figure 7. Temperature fluctuations in the pyrolysis chamber when the temperature control system is working with a target temperature of 450^0 C.

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4. Conclusion

This study successfully developed a temperature monitoring and control system for a pyrolysis chamber using an Arduino-based microcontroller. The system acquires temperature data from multiple sensors placed within the chamber, displays the readings on an LCD, and stores them periodically on an SD card. Temperature control is achieved by comparing the measured temperature with a user-defined target, set via a potentiometer, and adjusting the electric heater accordingly.

To ensure measurement reliability, sensor performance was evaluated through consistency, calibration, and transient response tests. Results showed that with clean sensor surfaces, temperature readings across different sensors were consistent, with deviations under 10 °C. Calibration against a commercial thermometer revealed a linear correlation, while transient tests indicated that sensors with protective coatings responded more slowly due to higher thermal inertia.

Overall, the system performed well in both monitoring and regulation functions. It successfully detected temperature variations across different chamber zones—typically lower in areas farther from the heat source—and maintained the chamber temperature close to the target. Although minor fluctuations occurred, the deviation remained within acceptable limits (<10 °C). These fluctuations were attributed to sensor lag and can be mitigated by using faster sensors or implementing an improved control algorithm.

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