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DESIGN OF DIFFERENTIAL THERMAL ANALYSIS TOOL AIDS FOR MELTING POINT MATERIAL ANALYSIS

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ABSTRACT

This research aims to design differential thermal analysis tool aids to analyze the melting point of the material. Differential Thermal Analysis props have a furnace with a maximum temperature of 600 °C. The temperature sensor used is a K-type thermocouple with a measurement range of -200 °C to 1200 °C. A controller used to control the temperature of the furnace is Autonics with a digital temperature controller type TK4M. Measurement of the value of the temperature in the furnace using an Arduino Uno microcontroller connected to LabVIEW software via USB. Measurement of the melting point of the material used in these props is tested on material Indium (In), tin (Sn), and zinc (Zn) with melting points 152,5 °C, 231,5 °C, and 425 °C.

KEYWORDS: differential thermal analysis, the melting point of indium, tin melting point, the melting point of zinc.

1. INTRODUCTION

Natural sciences, including physics, are built upon facts, reasoning, and experimentation. Science and physics, as branches of natural sciences, rely on factual information, intellectual contributions, and experimental results provided by experts. James Conant's perspective on science, which regards it as a collection of interrelated concepts and conceptual schemes that grow as a result of a series of experiments and observations, aligns with this notion (Conant, 2023). Kuslan Stone also defines science as a collection of knowledge and methods for obtaining and utilizing that knowledge. Science is both a product and a process that cannot be separated (Paulus, K., & Irsyadiah, N., 2022). Therefore, learning science involves not only listening to lectures or reading textbooks but also conducting observations and experiments in a laboratory. The availability of teaching aids, including appropriate demonstration tools, is essential for enhancing the teaching and learning of physics (Wenno et. al., 2022).

Ramnarain et al. noted that many science teachers tend to focus on providing information and avoid using teaching aids or laboratory activities (Ramnarain et. al., 2022). Similarly, Kurnianto et al. observed that physics education in high schools still relies heavily on conventional methods, such as lectures, which may limit student engagement (Kurnianto, 2018). In the process of learning through lectures, students receive concepts presented by the teacher without verifying those concepts through practical experimentation.

Limitations in the availability of teaching aids in schools and universities are often due to the high cost of these aids and limited budgets for their purchase. One area where teaching aids are lacking is in the analysis of the thermal characteristics of materials. There are various options for analyzing the thermal characteristics of materials, one of which is Differential Thermal Analysis (DTA). DTA is a high-tech and complex analytical technique used to determine the characteristics of a sample accurately (Wei, 2018; Ebeid, E. Z., & Zakaria, M. B., 2021). These limitations have prompted researchers to develop DTA instruments by enhancing each component to create a simple, user-friendly, cost-effective, and accurate thermal analysis tool accessible to a wide range of users, especially students.

Rahim et al. defines teaching aids as tools used by teachers to clarify the subject matter presented to students and prevent verbalism. Effective learning should begin with direct or concrete experiences and progress to more abstract experiences. Learning is more effective when aided by teaching aids compared to learning without them (Rahim et. al., 2022).

It can be concluded that teaching aids are anything that can be used as a means or tool to stimulate students' minds, emotions, attention, and willingness through experiences, thereby promoting the natural learning process in students and engaging the senses in their use to support the effectiveness of learning. In the process of teaching and learning, teaching aids are utilized with the aim of assisting teachers in making the teaching and learning process more effective and efficient. Regarding the use of teaching aids in physics education, the intention is to make students interested, happy, and capable of comprehending the concepts contained within them, thereby challenging students' thinking abilities, and ultimately eliminating their fear of the subject of physics.

Differential Thermal Analysis (DTA)

Differential Thermal Analysis is a thermal analysis technique that uses a reference as a basis for comparing results, typically an inert material. Both the sample and reference materials are heated simultaneously in a single location, and the temperature difference between the sample and reference materials is recorded during the heating and cooling cycles. The DTA instrument, as shown in Fig. 1, involves heating or cooling sample and reference materials under identical conditions while recording the temperature difference between the sample and reference materials over time or temperature. The differential temperature can also increase between two inert samples when subjected to non-identical heat treatment. DTA is used to study thermal properties and phase changes that do not involve enthalpy changes. The DTA testing results in a curve that displays discontinuities at transition temperatures, and the slope of the curve at a specific point depends on the sample's microstructure at that temperature (Devi et al., 2021).

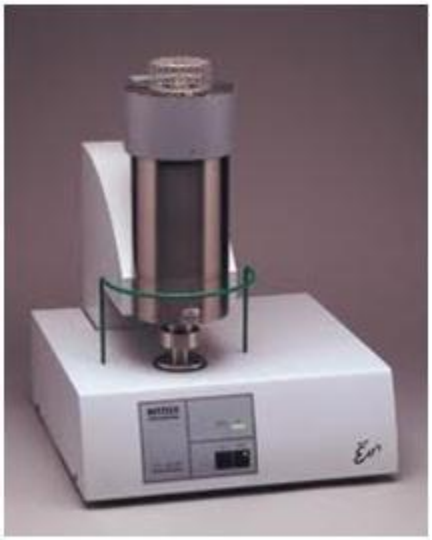

Fig. 1. Differential Thermal Analysis (DTA) Instrument

Factors affecting DTA testing results include sample weight, particle size, heating rate, atmospheric conditions, and the material's properties. In summary, DTA is a technique for recording the temperature difference between the sample and reference materials over time or temperature, where both specimens are subjected to identical temperatures in a controlled heating or cooling environment. The temperature of the sample and reference materials will be the same if no changes occur. However, when thermal events such as melting in the sample material occur, the sample temperature may be lower than that of the reference material.

Temperature Sensor – Thermocouple

Javaid et al. stated that a sensor is a device designed to detect phenomena or signals originating from changes in various forms of energy, such as electrical energy, physical energy, chemical energy, biological energy, mechanical energy, and so forth. Sensors are generally defined as instruments that can transform physical phenomena and convert them into electrical signals, either in the form of electrical current or voltage. Physical phenomena that can stimulate sensors to produce electrical signals include temperature, pressure, force, and the like. Meanwhile, sensors themselves consist of transducers, with or without signal amplifiers, organized into a sensing system. The key difference between a sensor and a transducer is that a transducer is a device that can convert energy from one form to another, where this transformation involves converting electrical energy into non-electrical forms of energy (Javaid et al., 2021).

A temperature sensor is a device used to detect phenomena or signals resulting from changes in various forms of energy, such as electrical, physical, chemical, biological, mechanical, and more. In general, a sensor is defined as a tool that can convert physical phenomena into electrical signals, either as current or voltage. Physical phenomena that can stimulate sensors to produce electrical signals include temperature, pressure, force, and more. In this context, a temperature sensor is a transducer that converts temperature changes into another physical quantity, such as voltage or current. The temperature sensor used in this instrument is a thermocouple.

Temperature is one of the fundamental physical quantities, defined as a relative measure of the thermal condition of an object. A temperature sensor is a transducer that converts temperature changes into another physical quantity, such as voltage or current. The temperature sensor used in this device is a thermocouple. Based on the Seebeck principle, proposed by the Estonian physicist Thomas Johan Seebeck, a thermocouple is a temperature detector composed of two different types of metals (Fig. 2). The two ends of these dissimilar metal materials generate a varying potential difference influenced by changes in the ambient temperature (Wu et al., 2020).

Fig. 2. The Seebeck Voltage Arising Due to Temperature Changes in a Thermocouple

Arduino Uno

Arduino Uno is a microcontroller board based on the ATmega328 microcontroller (Gadekar et al., 2021). The board features 14 digital input/output pins (with 6 pins usable as PWM outputs), 6 analog inputs, a

16 MHz crystal oscillator, a USB connection, a voltage source connector, an ICSP header, and a reset button. The top view of the Arduino Uno can be seen in Fig. 3.

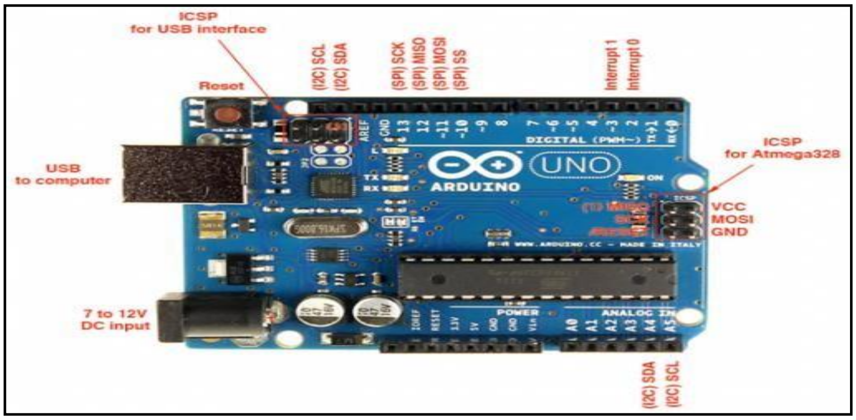

Fig. 3. Board of Arduino Uno

LabVIEW

LabVIEW is a programming software produced by National Instruments with a unique concept (Jennings et al., 2020). LabVIEW programs are known as Virtual Instruments (VIs) because their appearance and operation can emulate an instrument. In LabVIEW, users first create a user interface or front panel using controls and indicators. Controls include knobs, push buttons, dials, and other input devices, while indicators include graphs, LEDs, and other display devices. After creating the user interface, users build a block diagram containing VI code to control the front panel. The front panel is a gray background window section that contains controls and indicators. The front panel is used to create a VI (Virtual Instrument), run programs, and debug programs. The display of the front panel can be seen in Fig. 4. The block diagram is a white-backgrounded window section containing the source code created and serving as instructions for the front panel. The display of the block diagram can be seen in Fig. 5.

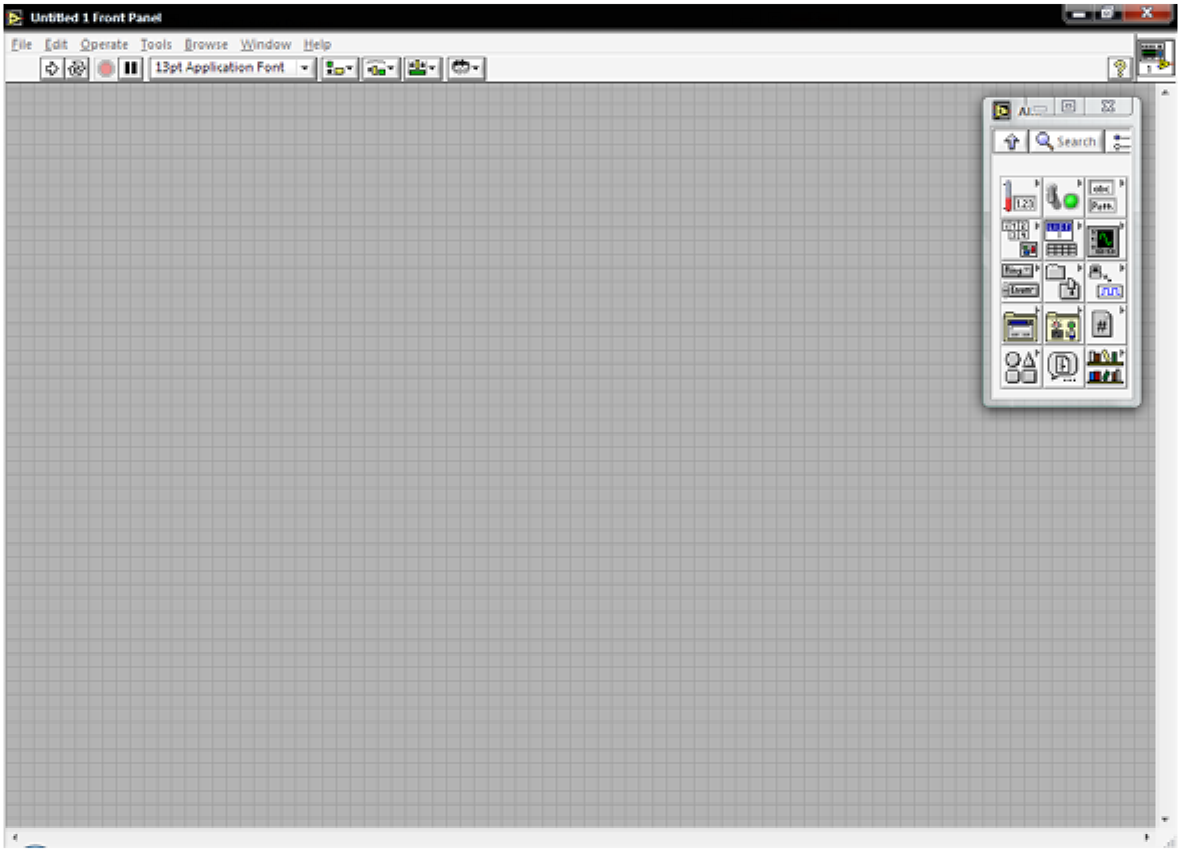

Fig. 4. Labview Front Panel

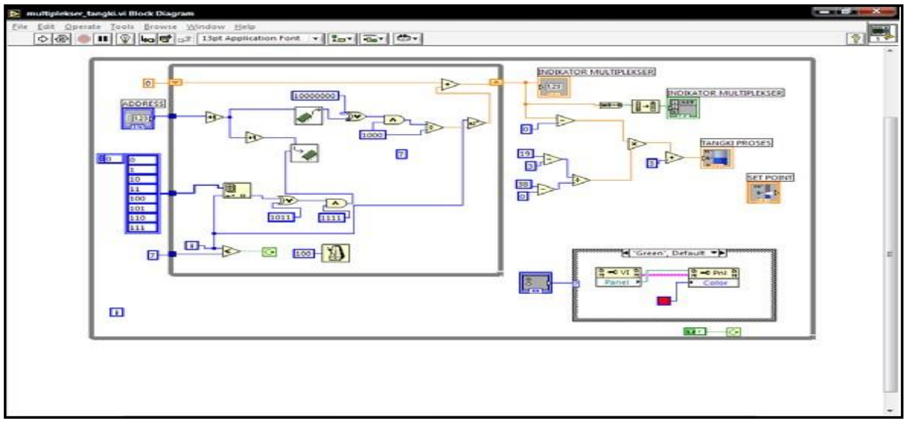

Fig. 5. Labview Block Diagram

2. METHODS

Hardware Design

The block diagram of the Differential Thermal Analysis Demonstrator System design is shown in Fig. 6.

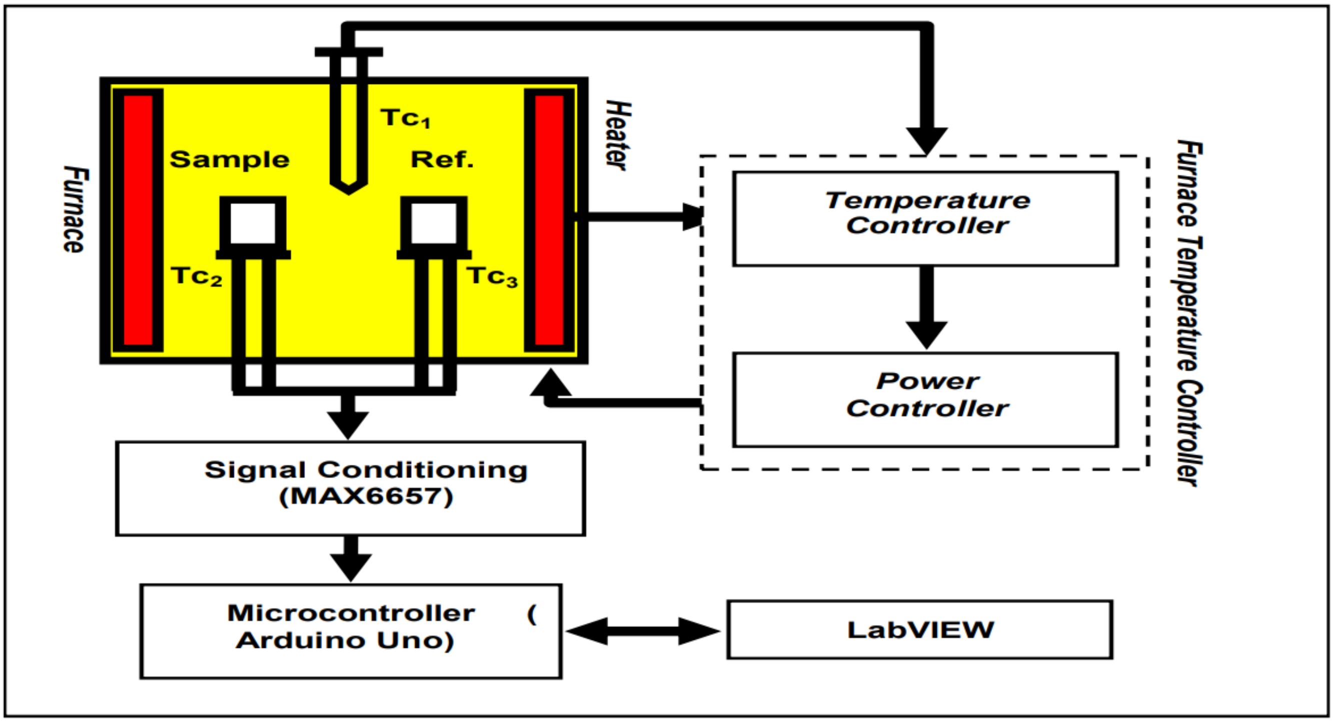

Fig. 6. Block Diagram of DTA Tool Aids

In Fig. 6, the designed system consists of a furnace design, a Furnace temperature controller design, a Temperature data acquisition system design using Arduino Uno microcontroller, and a Signal conditioning circuit design using the MAX6675 IC. The main components used in the hardware design include the Autonics TK4M Temperature Controller, Autonics SPC-1 35 Power Controller, Type K Thermocouple Sensor, Arduino Uno R3 Microcontroller, MAX6675 Signal Conditioning Module, Aluminum Pipe, Alumina Ceramic Tube, Kaowool, Ammeter, Voltmeter, Miniature Circuit Breaker (MCB), and Switch.

In the furnace temperature controller section, there is a temperature controller that functions to regulate the temperature according to the desired Set Point (SP) value. Subsequently, this set point value will control the power controller to operate the heater to achieve the desired temperature inside the furnace. Temperature control within the furnace is managed using a PID (Proportional-Integral-Derivative) process. The temperature inside the furnace is measured by a Type K thermocouple sensor, which has a temperature range from -200°C to 1200°C. In accordance with the principles of a closed-loop control system, the output value from the thermocouple sensor (Tc1) serves as the Process Variable (PV), which is then fed back to the controller input. The input provided to the controller is the difference between the PV and SP values, commonly referred to as an error. The error signal is continuously processed until the difference between the PV and SP values becomes zero, meaning the error value equals zero. The controller's performance is determined by how quickly it responds to changes in the Manipulated Variable (MV) value. The MV value is responsible for regulating the power controller's output to control the heating of the heater.

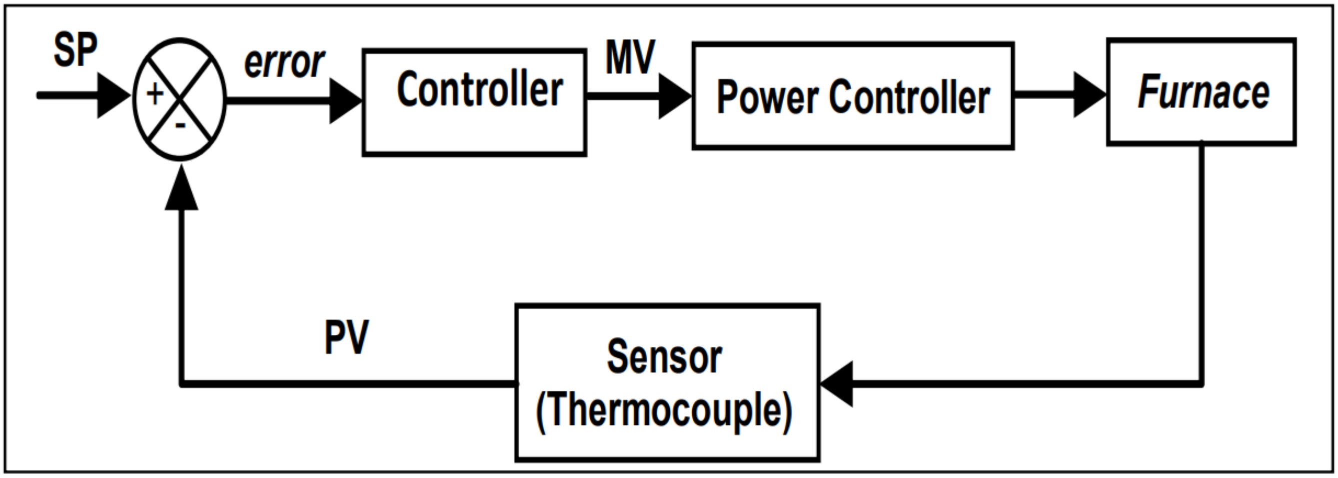

Fig. 7. Block Diagram of Temperature Control System

The heating process that occurs inside the furnace is controlled at a constant/controlled heating rate (Fig. 7). This condition is necessary for performing the subsequent Differential Thermal Analysis (DTA). Differential Thermal Analysis is a technique for recording the temperature difference between the sample material and reference material over time or temperature, where both materials are treated under identical temperatures in a controlled heating or cooling environment.

Inside the furnace, there are two thermocouple sensors (Tc2 and Tc3) designed to read the temperature values of the sample material and reference material inside the furnace. The temperature values inside the furnace will be converted into electrical quantities in the form of analog signals by the thermocouple sensors. The outputs of two thermocouples in the furnace will be connected to the IC MAX6675 as a signal conditioner. MAX6675 contains a signal amplifier, low-pass filter, buffer, and Analog to analog-to-digital converter (ADC). The signal conditioner functions to process the output signals from the thermocouples, which are initially in the form of small voltages, into larger voltages so that their output can be read by the ADC. The ADC is responsible for converting the analog signals from the thermocouple sensors into digital signals, allowing the data to be sent to a computer via serial communication by the Arduino microcontroller. Subsequently, the temperature measurement data received by the computer will be displayed in real-time every second through an interface system using LabVIEW software. LabVIEW will present temperature change data for the sample and reference materials in both numerical and graphical formats. Additionally, this interface serves as a data logger. The measurement data results will be further processed to determine the melting point values of the tested material.

Software Design

In the software design phase, two programs were employed. The first one involved programming for the Arduino Uno microcontroller using the Arduino Integrated Development Environment (IDE). This program's purpose was to read the temperature values of the sample and reference materials inside the furnace. The second program was the LabVIEW interface programming, used for monitoring and temperature data logging. The LabVIEW program performed the following tasks: (a) Initializing the serial communication port as an input for the thermocouple sensor; (b) Reading and displaying data values of the sample material's temperature, reference material's temperature, and the differential temperature between the sample and reference materials. Additionally, these three data points were presented in graphical form; (c) Setting the data sampling interval to 1 (one) second; (d) Storing the measurement data, with temperature values saved in text documents or Excel format, and the corresponding graphs in image format; and (e) Implementing the LabVIEW program for the front panel and block diagram, as shown in Fig. 8 and Fig. 9.

Fig. 8. Front Panel Programming Interface

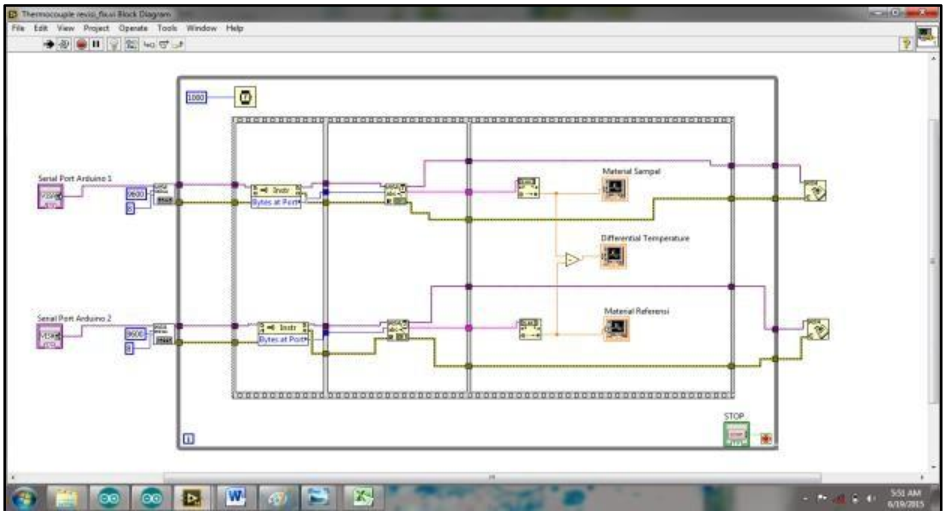

Fig. 9. Block Diagram Programming Interface

3. RESULTS AND DISCUSSION

After the system has been designed, it is necessary to conduct testing on the device that has been created and analyze the results of these tests. This is done with the aim of determining the overall performance of the device.

Material Melting Point Testing

The melting point is the temperature at which a compound begins to transition from a solid to a liquid state, up to complete melting. In another sense, the melting point can also be defined as the temperature at which a solid substance changes into a liquid in one atmosphere of pressure. In this research, the melting point testing involved three different sample materials: Indium (In), Tin (Sn), and Zinc (Zn). As for the reference material, Alumina (Al_2O_3) was used because the Alumina thermogram remains constant up to a temperature of 1200°C, indicating that Alumina undergoes no changes until that temperature. The material's melting point testing was conducted using the DTA demonstrator apparatus, as seen in Fig. 10.

Fig. 10. Differential Thermal Analysis Tool Aids

Melting Point Testing of Indium (In) Material

In this test, the sample material used is Indium (In), with a weight of 0.11 grams. As for the reference material, Alumina ($Al2O3$) was used, with its weight matched to that of the sample material. The results of the melting point testing of Indium (In) material are as follows. In this test, the melting point testing results for Indium (In) material are shown in Fig. 11 to Fig. 14. During the heating process in the furnace, as observed in Fig. 11, a thermal reaction occurs in the sample material, while in the reference material, it remains stable with no thermal reaction (Fig. 12). If we only consider the sample material, it's challenging to determine its melting point value. Therefore, by using the technique of differential thermal analysis, the melting point value can be determined by comparing the temperature difference (differential temperature) between the sample and reference materials, as shown in Fig. 13. To determine the melting point value, the differential temperature is compared to the temperature value of the reference material (Fig. 14). The differential temperature values are plotted on the Y-axis, and the temperature values of the reference material are on the X-axis, allowing the melting point value to be determined. In Fig. 14, it is evident from the graph that an endothermic reaction occurred in the sample material, taking place within the temperature range of 152.5°C to 164.5°C. In an endothermic reaction, the system's temperature (sample material) generally decreases, indicating that heat is absorbed from the surroundings. This reaction signifies the process of melting of Indium (In) material, with the initial melting occurring at 152.5°C and complete melting at 164.5°C. The theoretical melting point of Indium (In) is 156.6°C.

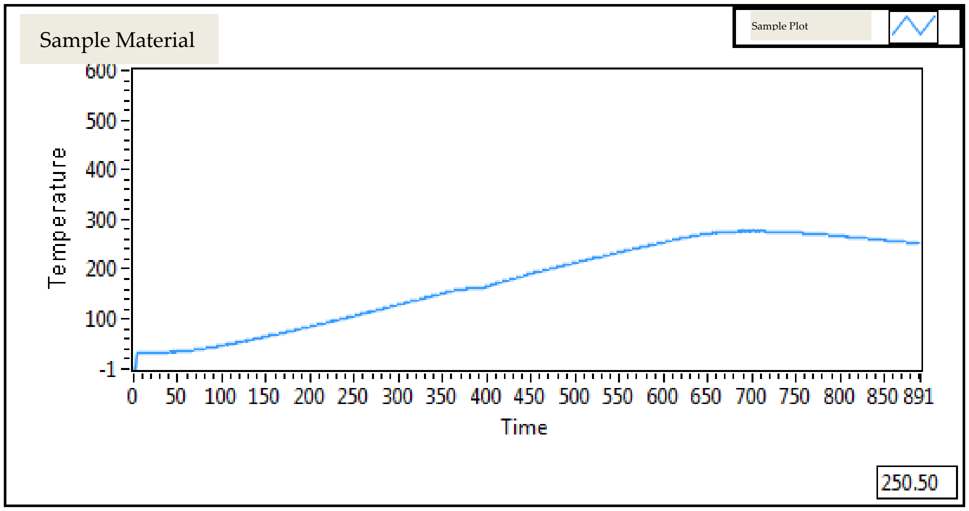

Fig. 11. Testing for Indium Sample Material

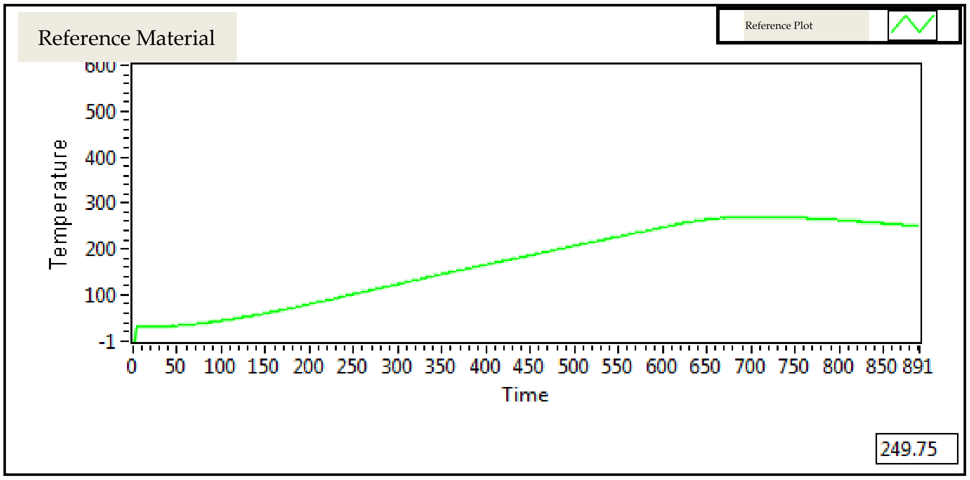

Fig. 12. Testing for Indium Reference Material

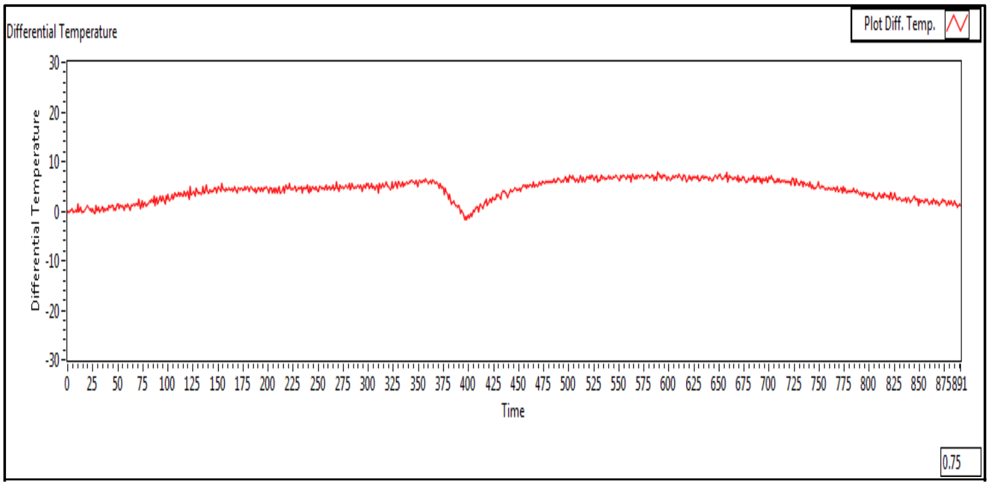

Fig. 13. Indium Differential Temperature Testing

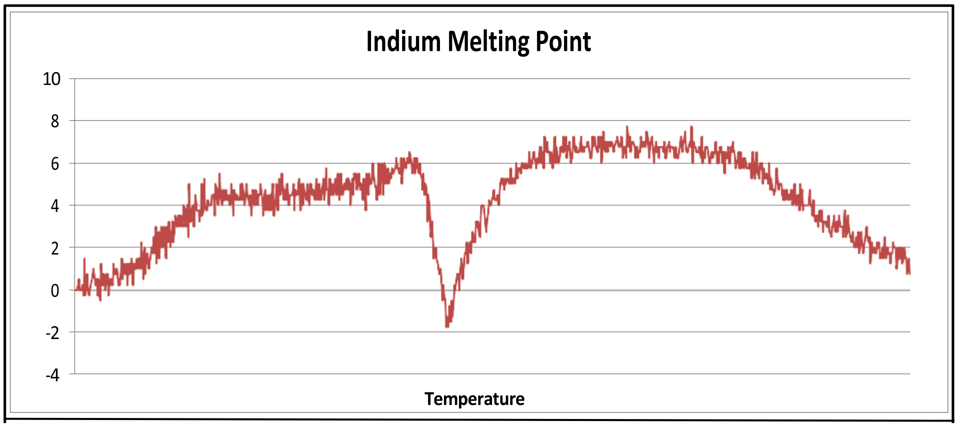

Fig. 14. Determination of Indium Melting Point

Melting Point Testing of Tin (Sn) Material

Similarly, to the testing conducted on Indium (In), the testing results for the melting point of Tin (Sn) material are shown in Fig. 15 to Fig. 18. During the heating process in the furnace, as observed in Fig. 15, a thermal reaction occurs in the sample material, while in the reference material, it remains stable with no thermal reaction (Fig. 16). In Fig. 17, it is evident from the graph that an endothermic reaction occurred in the sample material, taking place within the temperature range of 231.5 °C to 245.75 °C. This reaction signifies the melting process of Tin (Sn) material, with the initial melting occurring at 231.5 °C and complete melting at 245.75 °C. The theoretical melting point of Tin (Sn) is 231.9 °C.

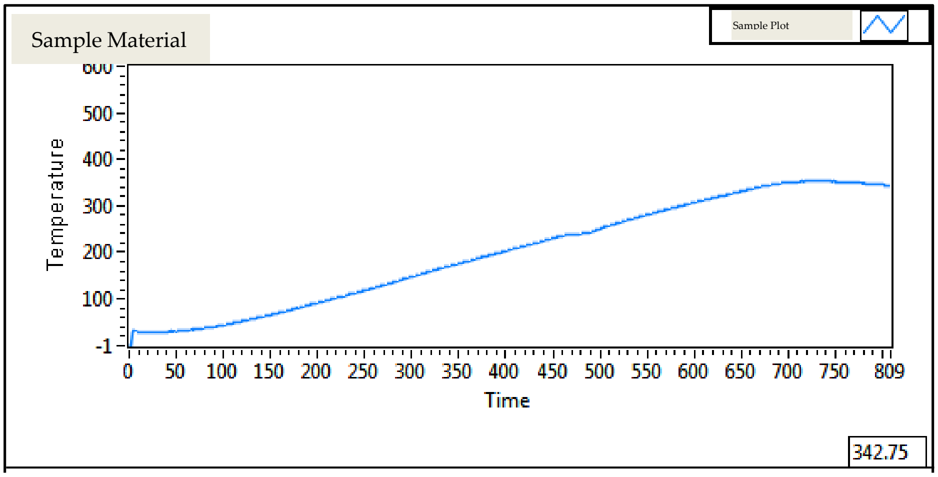

Fig. 15. Testing for Tin Sample Material

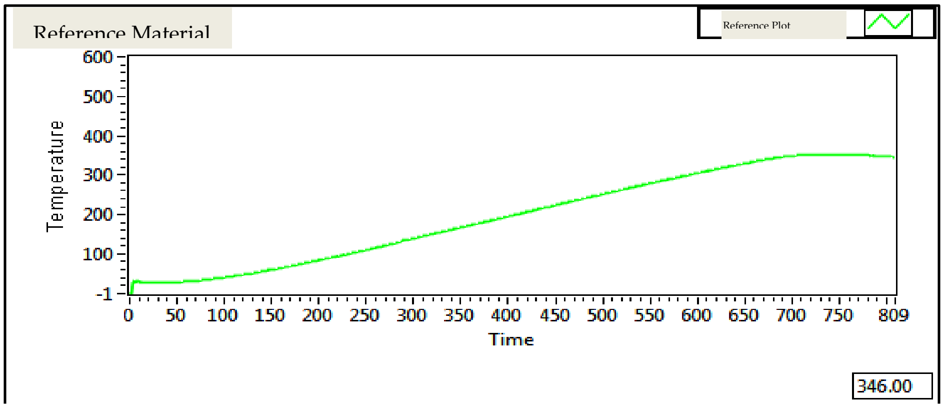

Fig. 16. Testing for Tin Reference Material

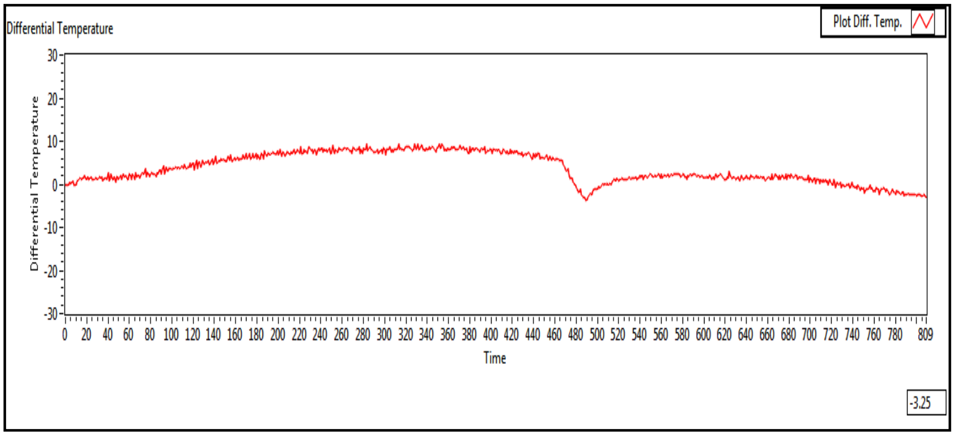

Fig. 17. Tin Differential Temperature Testing

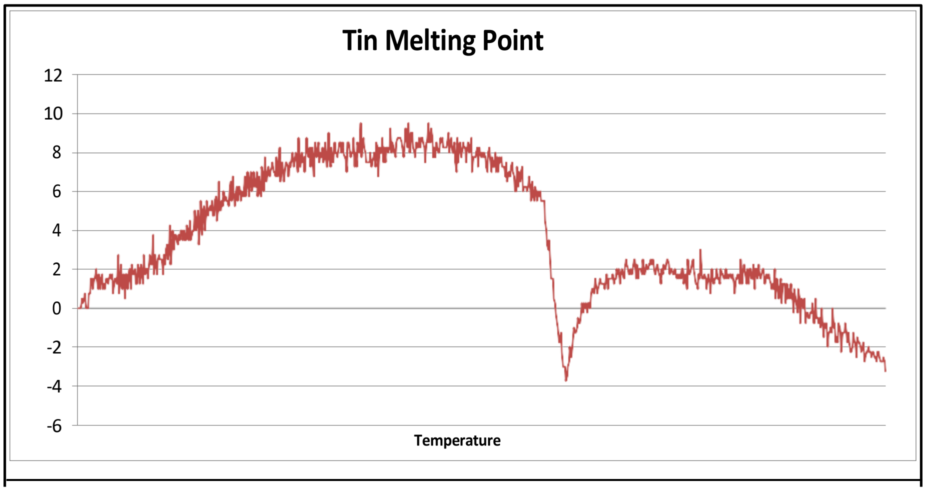

Fig. 18. Determination of Tin Melting Point

Melting Point Testing of Zinc (Zn) Material

In this test, the sample material used is Zinc (Zn), with a weight of 0.13 grams. As for the reference material, Alumina (Al_2O_3) was used, with its weight matched to that of the sample material. The results of the melting point testing of Zinc (Zn).

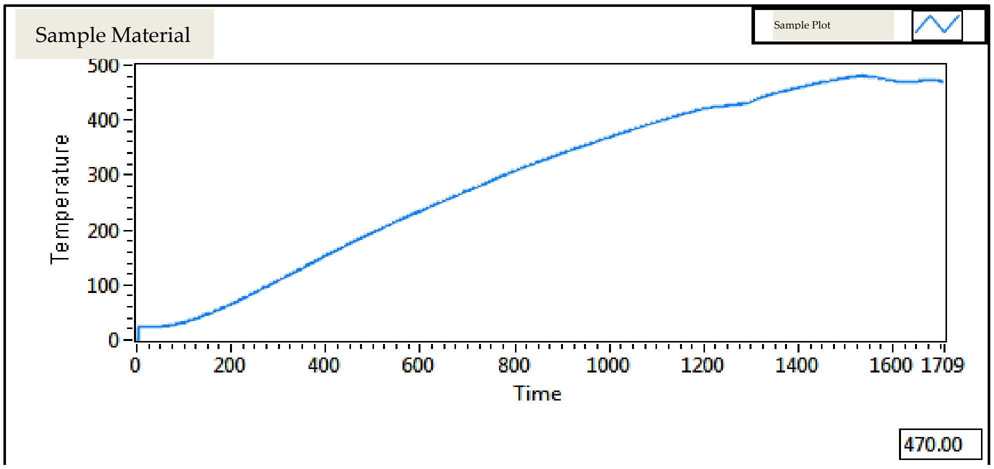

Fig. 19. Testing for Zinc Sample Material

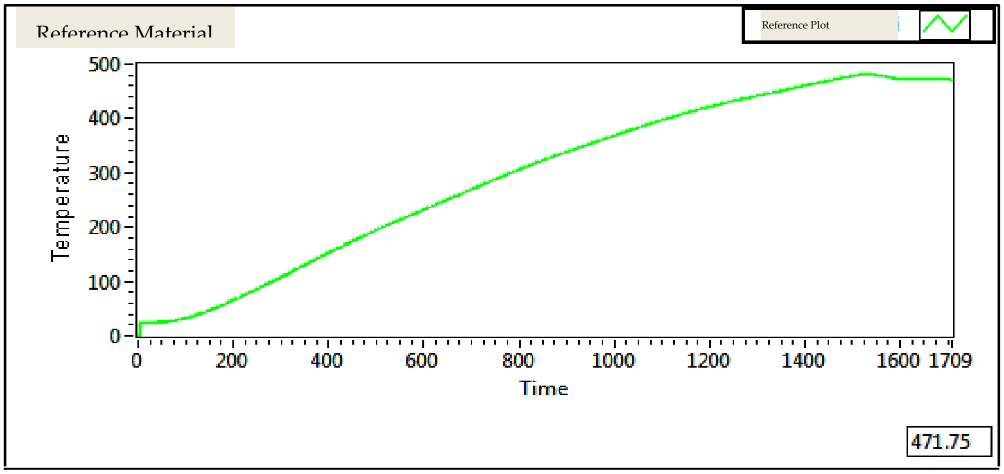

Fig. 20. Testing for Zinc Reference Material

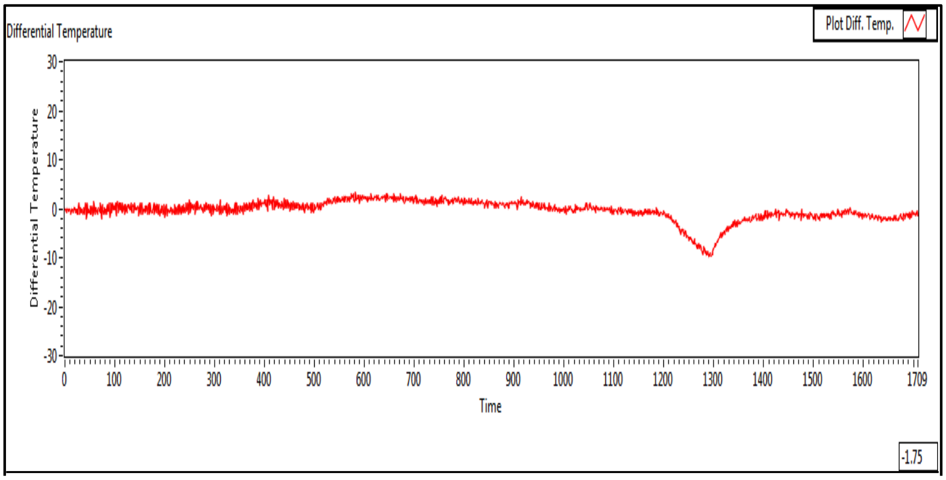

Fig. 21. Zinc Differential Temperature Testing

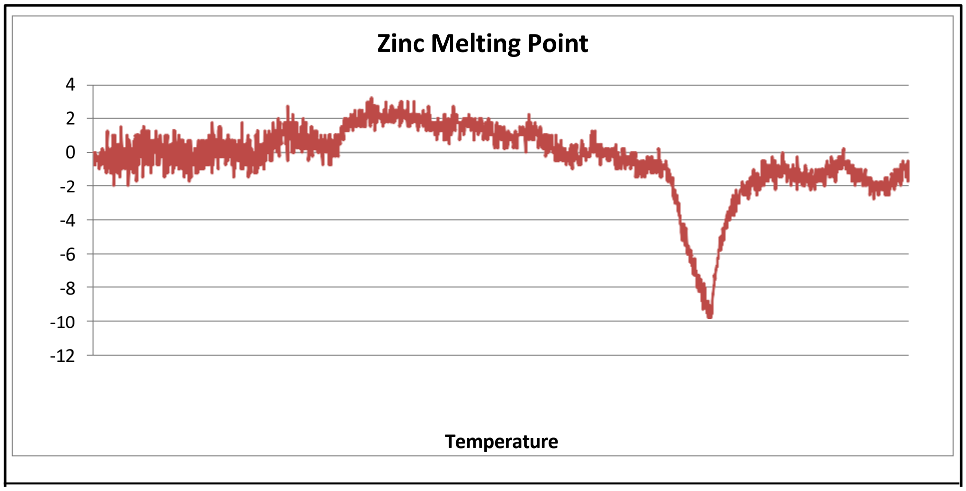

Fig. 22. Determination of Zinc Melting Point

Similar to the testing conducted on Indium (In) and Tin (Sn), the graphs depicting the results of the melting point testing of Zinc (Zn) material are presented in Fig. 19 to Fig. 22. Throughout the heating process within the furnace, Figure 19 illustrates a thermal reaction occurring in the sample material, while the reference material in Figure 20 remains thermally stable with no observed reaction. Fig. 21 displays clear evidence of an endothermic reaction within the sample material, occurring within the temperature range of 425 °C to 444.25 °C. This reaction signifies the melting process of Zinc (Zn) material, commencing at 425 °C and reaching complete melting at 444.25 °C. The theoretical melting point of Zinc (Zn) is 419.5 °C. Table 1 presents the results obtained from the testing of the three materials.

Table 1. Testing of Material Melting Point

Material	Temperature		Theoretical Value (°C)
	Start to melt (°C)	Perfect Melting (°C)	
Indium (In)	152.50	164.50	156.60
Tin (Sn)	231.50	245.75	231.90
Zinc (Zn)	425	444.25	419.50

4. CONCLUSIONS

This research has successfully designed a Differential Thermal Analysis (DTA) tool aids to measure the melting points of three materials: Indium, Tin, and Zinc. The melting points of these three materials were determined using Alumina (Al_2O_3) as a reference, resulting in the following melting temperatures: Indium (In) melting point is 152.5 °C, Tin (Sn) melting point is 231.5 °C, and Zinc (Zn) melting point is 425 °C. The melting points obtained using this teaching aid closely approximate the theoretical values, with a small margin of error ranging from 0.17% to 2.6

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