DEVELOPMENT OF AUTOMATED DATA ACQUISITION SYSTEM FOR ISOPERIBOLIC BOMB CALORIMETER

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Abstract. The paper addresses the problem of automating the data acquisition process of an isoperibolic bomb calorimeter using modern technologies. Traditional temperature measurement methods in such devices rely on mercury thermometers and cathetometers to enhance accuracy, complicating the process of obtaining results. Modern automated calorimeters are expensive and not widely accessible. Therefore, the development of a cost-effective automated system for upgrading existing calorimeters is highly relevant. The aim of this study is to create an affordable and accurate temperature data acquisition system based on an Arduino microcontroller using the LabVIEW visual programming environment. The primary focus is on developing a user-friendly interface that visualizes real-time data. The research methods include analyzing the operational principles of existing calorimeters, studying data acquisition systems and their improvement methods, and applying visual programming to create an interactive user interface. The study develops an algorithm for converting analog signals from a temperature sensor into a digital format, ensuring high measurement accuracy. The study results include the development of software for Arduino, enabling temperature data transmission via a USB interface to a personal computer. Additionally, a LabVIEW-based block diagram for processing digital signals has been created. This diagram includes modules for data acquisition and conversion, a real-time data recording unit, and a functional module for storing the obtained results for further analysis. The conclusions confirm the effectiveness of the proposed approach: upgrading a calorimeter using Arduino and LabVIEW allows for the automation of temperature data acquisition, improves measurement accuracy, facilitates data processing, and significantly reduces equipment costs compared to fully automated commercial solutions.

Keywords: calorimeter; isoperibolic bomb calorimeter; Arduino; LabVIEW; visual programming.

Introduction

In modern laboratory research, measurement accuracy is critically important, especially when working with isoperibolic bomb calorimeters. Traditional temperature recording methods using mercury thermometers and cathetometers are outdated and inefficient, as they require significant time and do not provide automated data collection. At the same time, commercial automated systems, although offering high accuracy, are expensive and inaccessible to many laboratories [1].

Previously developed temperature measurement automation systems based on Arduino and LabVIEW have proven effective in real-time temperature monitoring [2]. In particular, proposed approaches included the use of an LM35 temperature sensor with LabVIEW and NI myDAQ, as well as the development of automated cryostat temperature control systems [3]. However, these studies did not take into account the specific requirements for isoperibolic calorimeters, such as the need for accurate temperature measurement under conditions of rapid changes typical of calorimetric experiments.

Significant contributions to the development of isoperibolic calorimeters were made by researchers who designed and calibrated high-precision systems for measuring the combustion energy of organic compounds [1]. Other works are devoted to the creation of cost-effective data acquisition systems based on open source software that allow for the automation of the process of taking readings and simplify their processing [2]. There are also studies that consider approaches to adapting and automating measurements using software solutions, in particular LabVIEW [3].

Thus, the aim of this study is to develop an affordable and accurate automated temperature reading system for an isoperibolic bomb calorimeter. The system is based on the Arduino microcontroller and the LabVIEW visual programming environment, which allows providing a convenient interface for visualization and processing the obtained data in real time.

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Materials and methods

This development was carried out for an isoperibolic bomb calorimeter, which is part of the equipment of the educational and scientific laboratory “DAK GPS” of the higher education institution “Podilsky State University”. The laboratory specializes in studying the parameters and improving the energy characteristics of solid fuels [6-8]. The development was implemented using the Arduino board [10] and LabVIEW software [11].

a) b)

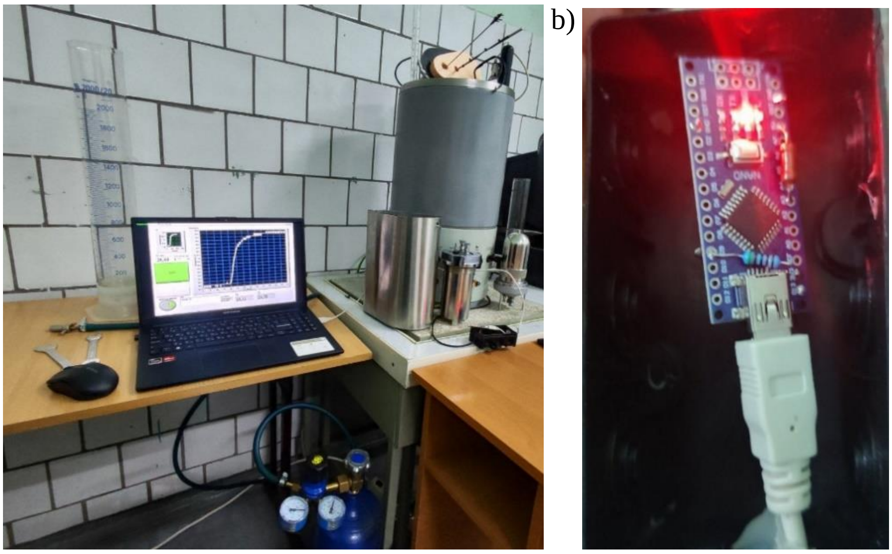

Fig. 1. **Isoperibolic bomb calorimeter with automatic reading system:**
a – general view; b – Arduino

The research methods included an analysis of the principles of operation of existing calorimeters, a study of temperature reading systems and ways to improve them. Visual programming was also used to create an interactive user interface. An algorithm was developed to convert the analog signal from the temperature sensor into a digital format, which allowed to increase the accuracy of measurements.

The developed system consists of hardware and software. The hardware includes an Arduino microcontroller, a temperature sensor connected to GND, A3, 3V3 ports, and a computer for data processing. The software includes code for the microcontroller that transmits temperature data via the USB interface, and a graphical interface in LabVIEW for processing, visualization, and saving the received data.

Results and discussion

The developed system allows to automate the process of taking temperature readings from an isoperibolic bomb calorimeter. Fig. 2 presents a general diagram of visual programming implemented in the LabVIEW environment. In this diagram, a number of interconnected functional blocks can be distinguished, which are responsible for individual stages of data acquisition, processing, transformation, and output. The diagram includes the following functional blocks.

1. Control unit: Responsible for starting and ending measurements, as well as recording the time of the study.
2. Data acquisition unit: Receives digital temperature values from the sensor and transmits them to the computer
3. Signal processing unit: Uses case structures to analyze and transform the frequency of readings in real time.
4. Visualization unit: Provides the construction of two graphs: the main one, which demonstrates temperature changes in real time, and the auxiliary one, which reflects the overall trend of changes.
5. Data storage unit: Allows to record the results obtained in the form of text files for further analysis.

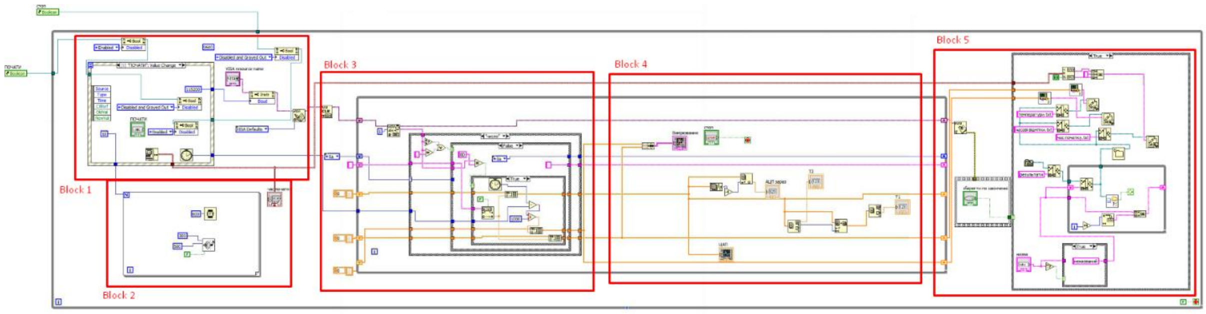

Fig. 2. **Block diagram of automation of the isoperibolic calorimeter (LabVIEW)**

This block diagram of visual programming provides automatic data acquisition and processing of temperature changes during calorimetric research. The operator controls the process through a convenient interface, the elements of which are shown in Fig. 2.

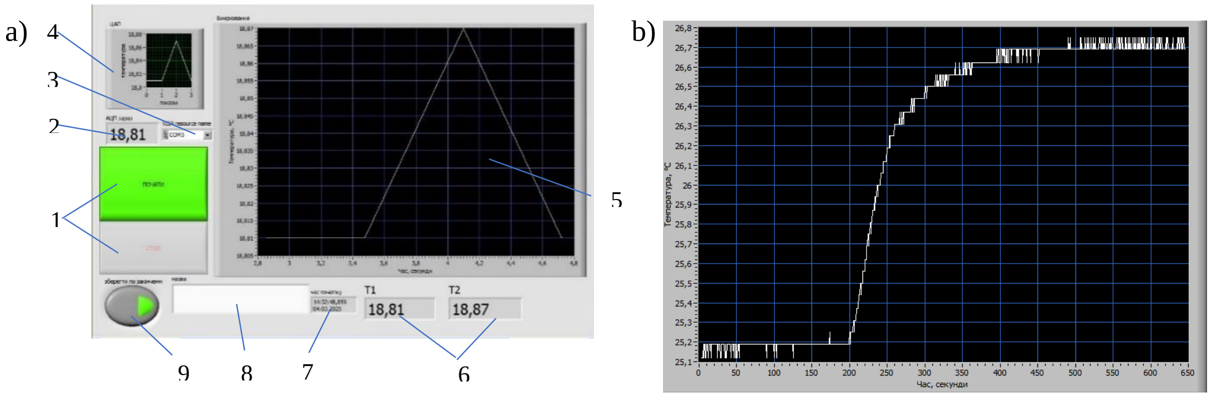

Fig. 2. **Interface of the calorimeter program (a) and real-time temperature monitoring interface with live graph updates (b):** 1 – start and end measurement button; 2 – current value of the analog-digital signal; 3 – COM port selection menu; 4 – auxiliary graph of visualization of digital signal changes; 5 – graph of indicator changes depending on time; 6 – temperature limit values – maximum and minimum; 7 – indicative windows for time and date of measurements; 8 – window for entering the measurement name; 9 – button for saving data upon completion

One of the key features of the developed system is real-time data visualization. As shown in Figure 2b, the main temperature graph updates continuously as new readings are received from the Arduino-based sensor. Each point on the graph corresponds to a temperature value sampled and processed in real time, with the data acquisition frequency configured at one-second intervals. This real-time display allows the operator to immediately observe temperature changes during the combustion process and to track system behavior without delays. The dynamic updating of the graph is achieved through LabVIEW graphical programming interface, which processes and renders incoming data continuously.

Block 1 contains components responsible for starting and ending the measurement process, as well as for fixing the start time of the experiment according to the general chronological system of the computer (Fig. 3). Visually, the operation of this block is represented by a group of buttons that allow to control the start and end of the process. Block 1 is connected to block 2, which is responsible for the sound notification of the start of the recording. To do this, an audio signal is generated with a given frequency (for example, 10 signals in 500 ms).

Block 3 is a block for capturing and processing digital data that we receive from Arduino (Fig. 4). Built on the principle of case structures with operational selector switches. The essence of the work of case structures is that, depending on the conditions used, certain operations are performed. In the case structure, there are operators (states) that are responsible for the status of the received unit of information of the corresponding type (Od, Oa-byte, etc.), and its use depending on what functionality should be performed. A separate case selector ("?") allows the system to display which case to execute. One of the important case structures in the middle of block 4 is the operational block, which is responsible for converting the signal sampling frequency to real time in seconds.

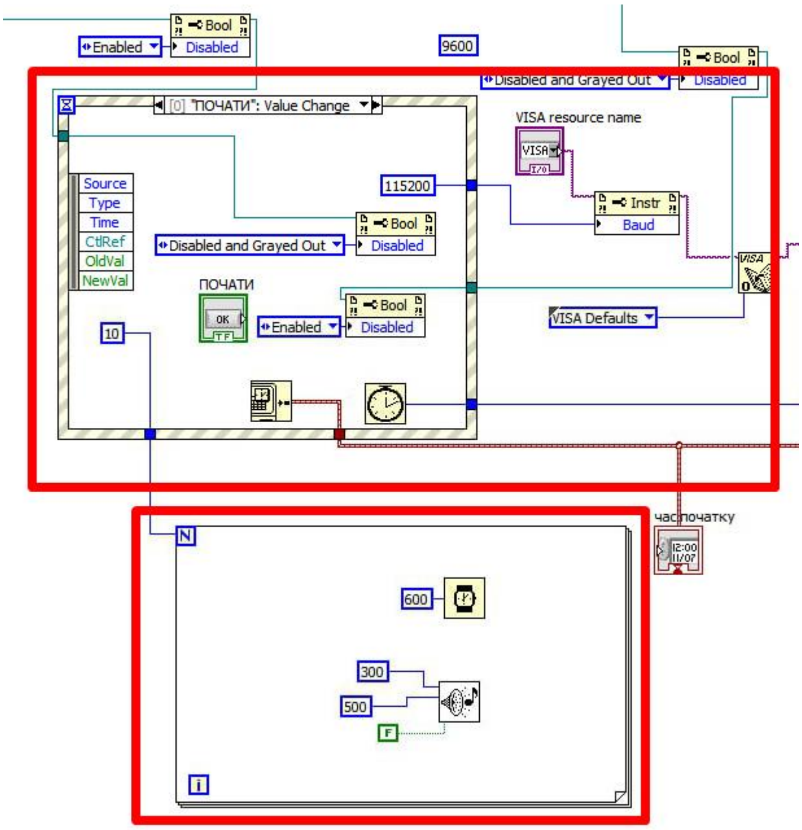

Fig. 3. **Control and sound notification unit**

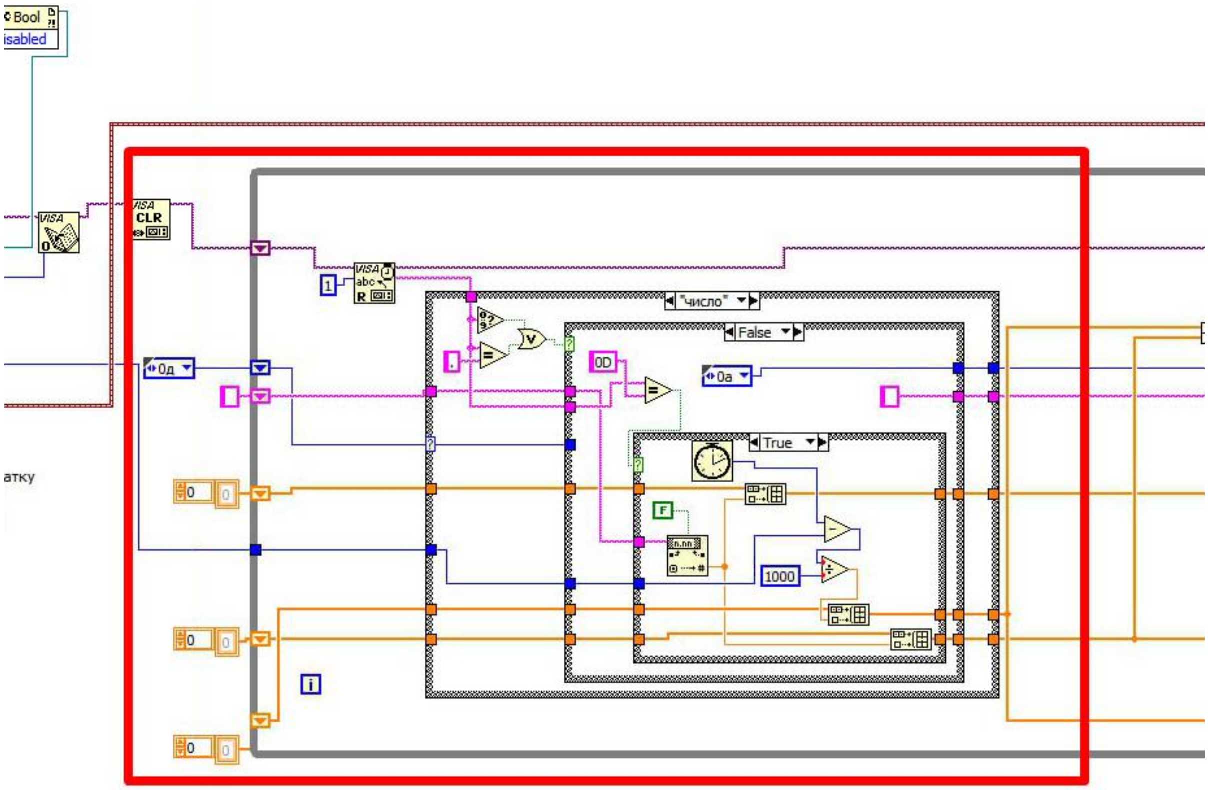

Fig. 4. **Block for capturing and processing digital data**

Block 4 is an indicative block. It is responsible for demonstrating the performance of the calorimeter, namely, building graphs of direct readings (Fig. 5). As a result, two graphs are displayed on the program interface - the main and duplicate. The main graph shows changes in parameters in real time (in seconds), the duplicate (DAC) graph displays a general view of the graph in the order of signal arrival without reference to the passage of time on the clock. There are also indicators of the value received from the Arduino at the current time and two temperature indicators - minimum and maximum – for the measurement period.

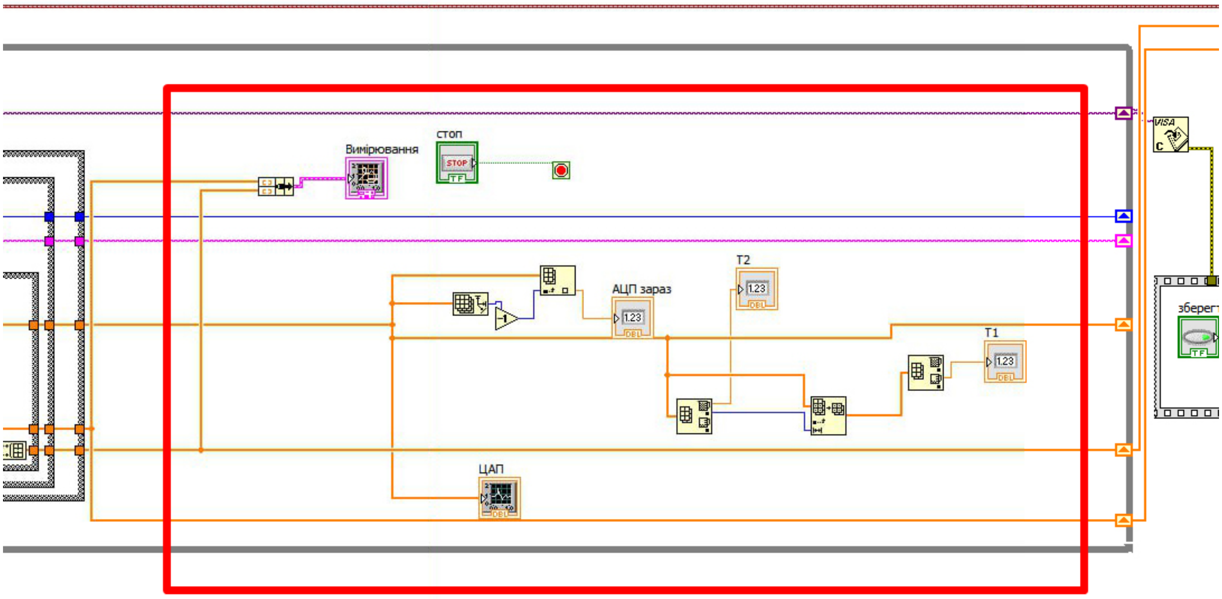

Fig. 5. **Indicative block**

To assess the reliability of the developed system, experimental measurements were carried out using biomass samples such as miscanthus and poplar. The temperature curves obtained during combustion exhibited the expected shape for isoperibolic calorimetric processes, including a distinct temperature rise and stabilization phase. These results were qualitatively consistent with those obtained using traditional mercury thermometers.

Furthermore, the final calculated calorific values based on the automated system differed only slightly from those determined by classical methods. In the tested cases, the variation in results remained within an acceptable range (not exceeding 2%), which indicates a good level of agreement for practical applications. These findings suggest that the developed system is capable of providing reliable data without the complexity and cost associated with commercial calorimeters.

Block 5 (Fig. 6) is responsible for saving data on the computer. Contains a button and functionality that allow to save data after completion, if necessary. This block contains case structures that are associated with the folder to which the data will be saved.

Text files are stored there:

- temperature, according to the schedule,
- timestamps,
- time and date of measurement.

There is also a case that offers to save the results with and without a name. If there is no name, then automatically that is an unnamed file.

Compared to commercial isoperibolic calorimeters and previously reported Arduino-based measurement systems [14; 15], the proposed solution provides a unique balance of affordability, adaptability, and functionality. While commercial devices offer high precision and full integration, they are often prohibitively expensive and closed to user-level modifications. In contrast, earlier open-source systems, though cost-effective, typically lack features tailored to the specific demands of calorimetric experiments, such as synchronized signal sampling, real-time visualization, or user-friendly interfaces.

The developed system addresses these limitations by combining reliable sensor performance, real-time data processing, and a LabVIEW-based interface optimized for calorimetric tasks. This makes it suitable not only for academic and research laboratories but also for broader use in experimental setups where flexibility and cost are critical factors.

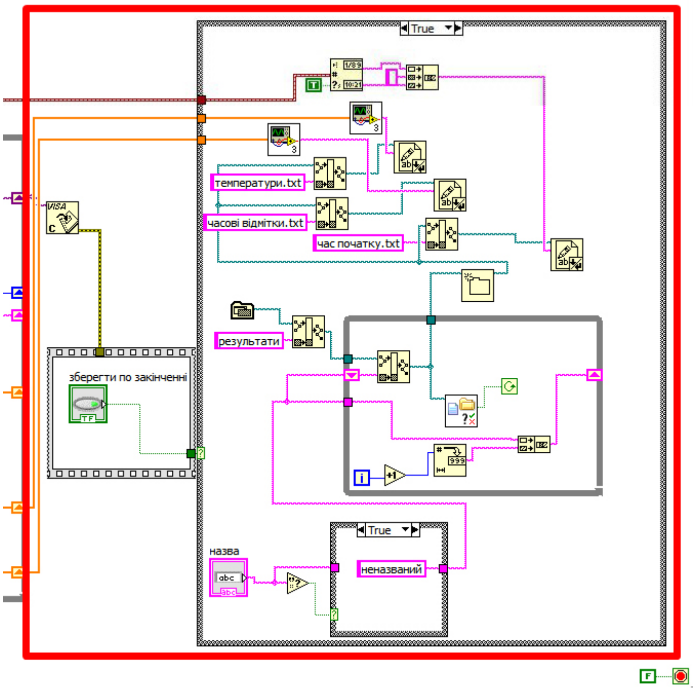

Fig. 6. **Data storage block**

Testing of the system showed its high accuracy and ease of use. The temperature graphs obtained during the experiments correlate with traditional measurement methods, but their acquisition is significantly simplified and accelerated.

The scientific novelty of the work lies in the development of an automated system for an isoperibolic bomb calorimeter based on the Arduino microcontroller and the LabVIEW software environment. The proposed approach provides accurate and fast temperature measurement in real time. For the first time, case structures are used for digital conversion of an analog signal, which increases the stability and reliability of the obtained results. In addition, the integration of open hardware and software solutions allows for a cost-effective alternative to expensive commercial automated systems without losing measurement accuracy.

The practical significance of the development lies in the possibility of automating the process of taking temperature readings, which minimizes the influence of the human factor and increases the accuracy of experimental studies. The proposed system is significantly cheaper than commercial analogues, which makes it available for use in educational and scientific laboratories. In contrast to commercial isoperibolic calorimeters such as IKA C6000, which may cost tens of thousands of dollars, the developed system relies on widely available and affordable components. This significant reduction in cost makes the solution accessible for use not only in university laboratories but also in resource-limited environments and small research facilities. Despite the minimal financial investment, the system maintains sufficient accuracy and functionality for a wide range of calorimetric experiments. Thanks to the convenient graphical interface in LabVIEW, processing and analysis of the obtained data is simplified.

Conclusions

During the research, an automated system for taking readings from an isoperibolic bomb calorimeter was developed based on the Arduino microcontroller and the LabVIEW programming environment. The proposed system allows:

1. Automate the temperature measurement process, reducing the influence of the human factor and increasing the accuracy of measurements.
2. Provide real-time data recording, which significantly improves the analysis of the results obtained.

3. Optimize the process of data collection and processing, thanks to a convenient graphical interface that allows to visualize measurement results and save them in text format for further analysis.
4. Increase measurement accuracy through digital conversion of an analog signal and the use of case structures for data processing.
5. Reduce the cost of automation of measurements, as the proposed system is a much cheaper alternative to commercial automated calorimeters.

References

[1] Campos J.B., Martínez-Gómez A.J., Orozco-Guareño E. Design and building of an isoperibolic calorimeter: measurements of enthalpy of formation for derivatives of glycidol. Measurement Science and Technology, vol. 30, 2019, 035902. DOI: 10.1088/1361-6501/aafeb4

[2] Vallejo W., Diaz-Uribe C., Fajardo C. Do-it-yourself methodology for calorimeter construction based in Arduino data acquisition device for introductory chemical laboratories. Heliyon, vol. 6, 2020, e03591. DOI: 10.1016/j.heliyon.2020.e03591

[3] Flandorfer H., Gehringer F., Hayer E. Individual solutions for control and data acquisition with the PC. Thermochimica Acta, vol. 382, 2002, pp. 77-87. DOI: 10.1016/S0040-6031(01)00739-0

[4] Kucher O., Mykhailova L., Pustova Z. Management of the solar power development in households of Ukraine. Vide. Tehnologija. Resursi - Environment. Technology, Resources, vol. 1, 2024, pp. 222-226. DOI: 10.17770/etr2024vol1.7964

[5] Unyay H., Piersa P., Zabochnicka M., Romanowska-Duda Z., Kuryło P., Kuligowski K., Kazimierski P., Hutsol T., Dyjakon A. Torrefaction of willow in batch reactor and co-firing of torrefied willow with coal. Energies, vol. 16, 2023, 8083. DOI: 10.3390/en16248083

[6] Ivanyshyn V., Bialkovska O., Yermakov S., Sikora O., Oleksiyko S. Influence of miscanthus biomass torrefaction parameters on the quality characteristics of the torrefied product. Proceedings of International conference “Engineering for Rural Development”, Jelgava, Latvia, 2024, pp. 79-84. DOI: 10.22616/ERDev.2024.23.TF016

[7] Yermakov S., Rud A., Vusatyi M. The distribution of cash expenses for the creation of bioenergy willow plantations in Ukraine. Vide. Tehnologija. Resursi - Environment. Technologies. Resources, vol. 1, Rezekne, Latvia, 2023, pp. 74-80. DOI: 10.17770/etr2023vol1.7191

[8] Yermakov S., Hutsol T., Rozkosz A., Glowacki S., Slobodian S. Evaluation of effective parameters of biomass heat treatment in processing for solid fuel. Proceedings of International conference “Engineering for Rural Development”, 2021. DOI: 10.22616/ERDev.2021.20.TF241

[9] Mentado J., Mendoza E. Calibration and testing of an isoperibolic micro-combustion calorimeter developed to measure the enthalpy of combustion of organic compounds containing C, H, O and N. Journal of Chemical Thermodynamics, vol. 59, 2013, pp. 209-213.

[10] Arduino Home Page. Arduino - analogRead. [online] [25.02.2025]. Available at: https://www.arduino.cc/reference/en/language/functions/analog-io/analogread/

[11] LabVIEW Features and Applications. [online] [25.02.2025]. Available at: https://www.ni.com/en/shop/labview.html

[12] Golub G., Tsyvenkova N., Kukharets S., Holubenko A., Omarov I., Klymenko O. European Green Deal: An experimental study of the biomass filtration combustion in a downdraft gasifier. Energies, vol. 16, 2023, 7490. DOI: 10.3390/en16227490

[13] Mudryk K., Hutsol T., Wrobel M., Jewiarz M., Dziedzic B. Determination of friction coefficients of fast-growing tree biomass. Proceedings of International conference “Engineering for Rural Development”, vol. 18, Jelgava, Latvia, 2019, pp. 1568-1573. DOI: 10.22616/ERDev2019.18.N506

[14] Puji A. Real Time Temperature Monitoring Using LABVIEW and Arduino. [online] [25.02.2025]. Available at: https://www.scribd.com/document/329751669/122-Real

[15] Shin C., Criss C.M. Precision isoperibol calorimeter with automatic data acquisition and processing. Review of Scientific Instruments, vol. 46, 1975, pp. 1043-1046. DOI: 10.1063/1.1134390