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Nine Channels Temperature Data Logger Design for Dry Sterilizer Calibration

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ABSTRACT In the process of sterilizing medical devices, a sterilizer that is able to produce an accurate and even temperature is needed. If the resulting temperature is not in accordance with the regulated temperature and is not evenly distributed, it will be fatal/damage to the material sterilized. Periodic calibration should be applied to the sterilizer to monitor its function. Based on the research that has been done, no one has done research on making a temperature data logger with 9 channels to calibrate the sterilizer. This study aims to design a temperature measuring device with 9 sensors that can measure simultaneously, so that the accuracy and the distribution of the temperature of a sterlisator can be obtained. This tool used a K thermocouple-type temperature sensor which will detect the temperature and further enters the analog signal conditioning circuit. This then enters the ATMegga 2560 which has been programmed and processed in such a way, leading to the display of the temperature on the 4x20 character LCD. Temperature measurement data will be further stored to SD Card every 10 seconds in the form of a txt file. Tests were carried out on sterilizers, continued by comparison with the Madgetech OctTemp2000 data logger. Based on the measurement and comparison data, the average error was obtained at a temperature of 50ºC with the smallest error value of 0.7% and the largest error value of 3.9%. At a temperature of 100ºC, the smallest error value is 1.6% and the largest error value is 10.5%. Furthermore, at a temperature of 120ºC, the smallest error value is 0.0% and the largest error value is 8.5%. The module resulting from this research is stable in response to temperature by looking at the very small uncertainty value. This research can be further used to help analyze the temperature distribution in a sterilizer. With these measurement results, this study is considered having a fairly high error value at several measurement points.

INDEX TERMS Data Logger, Thermocouple, Sterilizer

I. INTRODUCTION

Sterilization is a process to kill all organisms contained in an object (tool or material). The purpose of sterilization in microbiology is to kill, inhibit growth, and remove all microorganisms contained in tools and materials to be used in a job in order to create an aseptic atmosphere. In general, sterilization can be done by 3 methods: mechanical, physical, and/or chemical. Mechanical sterilization can be done by using a microfilter, physical sterilization can be done by two methods of radiation and heating, while chemical sterilization can be done by using chemicals (disinfectants). The use of sterilizers through heating requires uniform and stable temperature conditions. Andrea Tabi stated that a constant warming environment will give a good response in the population (sterilized material) [1]. In this case, according to Arrahmi Amir, sterilization is the most effective process for decontaminating reusable equipment [2]. Therefore, Ibraham. M. Ismail mentioned that canned food companies require the implementation of operational procedures to ensure that a uniform processing temperature is achieved and maintained throughout the sterilization process [3]. On the other hand, Arif bin Ab Hadi added that non-uniform temperature distribution throughout the sterilizer for fresh fruit will lead to inefficient heat transfer [4]. Therefore, as recommended by the American National Standards Institute as quoted by B.M. Boca, the qualifications of the heat sterilization process must pay attention to the quality of the sterilizer [5]. In this case, J. Chen suggested that multi-temperatures calibration is very helpful to reduce error and improve measurement accuracy [6]. According to Alexander Giraldo, thermal sterilization of canned food is widely used in the food preservation industry. If such sterilization process is not applied, it will have an impact on losses. The process that provides information about recording temperature data in the sterilizer is a data logger. Data Logger is an electronic device that records data from time to time. This device is both integrated with sensors and instruments as well as external sensors and instruments. In short, data logger is a device for data logging. The data obtained from the temperature sensor is stored in a data logger, then the data is compared with the temperature on the display of the dry sterilizer [7]. O. Ojike has conducted research on a temperature data logger using six channels. The device was designed using LM35 as a sensor and Arduino Uno as a data processing element. In this case, the sensor response times were observed to be between three and four minutes. The use of Lm 35 as a sensor is not recommended in the calibration of the sterilizer [8]. R. Benyo further used a mathematical approach with the recommended interpolation function for temperature correction. The use of interpolation correction is greatly influenced by the initial data collection, so adjustments are needed when used on other devices [9]. Guanhua Xu also conducted a research project where he conducted a multi-parameter test, but it was used at low temperatures instead of at high temperatures [10]. Multichannel Temperature Monitor has also been carried out by Jaroonrut Prinyakupt but only uses 4 channels and used to measure the body temperature of workers [11]. Furthermore, Nisha Kashyap made a multi-channel data recording system for applications in meteorology field. The meteorological parameters used were varied, including ambient temperature, barometric pressure, altitude, light intensity, and relative humidity. This research does not focus on measuring temperature [12]. MH Abdullah, in addition, also developed in designing, prototyping, testing, and deploying a portable open source microcontroller-based temperature data logger to be used in rough industry field. The 5V powered data logger prototype was equipped with an open source Arduino microcontroller to integrate several thermocouple sensors, digital card storage, liquid crystal display (LCD), but still used 8 thermocouple sensors thermocouple [13]. Anuj Kumar further designed a data logger for measuring temperature, humidity and CO as well as CO_2 gas concentrations, using only 4 Channels [14]. Md. Rejvi Kaysir, in his previous research, made a multi-parameter data logger. However, in terms of temperature parameter, it has not been tested at high temperatures or sterilizer [15]. Zhiyuan He conducted a study showing the different temperature spectra, thus it requires multi-temperature testing that applies at different temperature levels [16]. Bhupesh Aneja also carried out a temperature measurement using 3 sensors, namely the LM 35 sensor, the PT100 sensor, and the 160-30 SMT sensor [17]. Zakia Rizkiyatussani and Syafiq Naufal Syayakti also conducted supporting research by creating a data logger consisting of 4, 5, and 8 channels. In this research, the sensor used is a thermocouple, where the number of measurement channels still does not meet the needs in the field [18][19][20]. Mohammad Rofi'I further added findings where he carried out previous research by making multi-channel data loggers used in water baths or water media [21]. In addition, Jose A conducted research on the uncertainty of temperature measurement results using multiple channels. There have been studies using thermocouples [22]. Devendra Singh K-further used thermocouple wire-type tool as obtained from low operating costs but having a high accuracy. This study observed the variation of the oil temperature value [23].H. On the other hand, another research project carried out by M. Hashemian employing thermocouples on temperature measurements on air media [24]. Hesham made a measuring instrument using a K Thermocouple-Type interfaced with Microcontrollers, where the tool was made by using 2 Thermocouple sensors [25]. Kambiz Farahmand also developed a tool to measure the response time of thermocouples. He carried out an experiment on the air velocities ranging from 0 to 4.11 m/s and small changes in temperature ranging from 24 to 38 C [26]. Yasin Karan also conducted measurement and designing of a calibration system Type-K thermocouple used in temperature measurement, whose results were further compared with a mercury thermometer [27]. H.E. Gad conducted research where he obtained the main advantage of this system method, in this case is the flexibility and ease of changing the type of sensor and the way of recording data. It is discovered that it is especially suitable for large and long distance installations where cost is a determining factor in choosing the measurement system. However, this study did not conduct test at high temperatures [28]. Based on various research projects that have been done, no one has done research on making a temperature data logger with 9 channels to calibrate the sterilizer. Based on the problems and conditions above, a research project was carried out to design a data logger with 9 channels used for sterilizer calibration. The purpose of this study is to obtain a data logger with 9 channels that can be used to determine the feasibility of the sterilizer. Data from the 9 channels measurement results can further be stored on a digital card

II. MATERIALS AND METHODS

A. EXPERIMENTAL SETUP

This research was carried out on temperature recorder that provides 9 channels for measurement using a k-type thermocouple temperature sensor. The length of each thermocouple sensor used is 1 meter to facilitate the placement of the sensor when calibrating the sterilizer. Data from the sensor were further processed using an analog signal processing circuit. In this analog signal processor, the main circuit is a series of buffers, filters, and boosters. The output of the thermocouple sensor is a small voltage of 0.004mV per 1ºC increase. Furthermore, it was converted from voltage to temperature using Arduino. Then, the temperature was displayed in 4x20 LCD (liquid crystal display). The measurement data were further stored to the SD Card every 10 seconds in the form of a txt file. In this case, the storage was done when the temperature on the sterilizer is reached. In order to test this, it is necessary to use a sterilizer and a comparison in the form of a commercial data logger, by placing sensors at the measuring points of the sterilization chamber according to the cage calibration standard. Furthermore, the temperature on the device was started and recorded.

1) MATERIAL AND TOOL

This study used a k-type thermocouple as a temperature sensor as well as an Analog Signal Conditioner circuit consisting of a filter, buffer, and non-inverting amplifier circuit. In addition, ATMega2560 was also employed as a data processor, 4x20 LCD as a display, as well as SD Card and RTC (Real Time Clock) modules. Furthermore, the measuring instruments used in this research are avometer and data logger. The tools used in the experiment were the Fortune ztp78e sterilizer and the Elektro-Mag M6040P. Meanwhile, the standard tool used as a comparison is the Madgetech OctTemp2000 data logger.

2) EXPERIMENT

In this study, after the module is completed, an experiment was carried out to record the temperature of the sterilizer for one hour, with temperature settings of 50°C, 100°C, and 120°C using standard tools for comparison. From each tool, either the research module or the standard module, all sensors were placed at points according to the specified standard. In this study, the placement of measurement points used the AS2853 standard reference. Furthermore, the research data were obtained after the temperature in the sterilizer had been reached according to the setting. This data were collected by pressing the save button on the research module. Each result of the temperature data recorded were calculated manually in order to obtain the error value and a graph to compare and validate the results of this study.

B. THE DIAGRAM BLOCK

Based on FIGURE 1, after 9 sensors were placed at points according to the standard reference, the tool was turned on by pressing the on button. At this time, the entire circuit gets the voltage from the battery. The 9 thermocouple temperature sensors that have been installed on the tool further detected the temperature and processed into an analog signal processing circuit. The output of the Analog Signal Conditioner circuit was inputted to ATMega2560 for processing. Data processing from this sensor was done by making software on ATMega2560. For the adjustment to the comparison tool, parameter processing was carried out in the software. The results of data processing were then displayed on a 4x20 LCD and stored on the SD Card when the SAVE button was pressed. The data were stored in txt format which can be read with notepad or Microsoft excel, making it easier to process the data, both to calculate the errors and uncertainties.

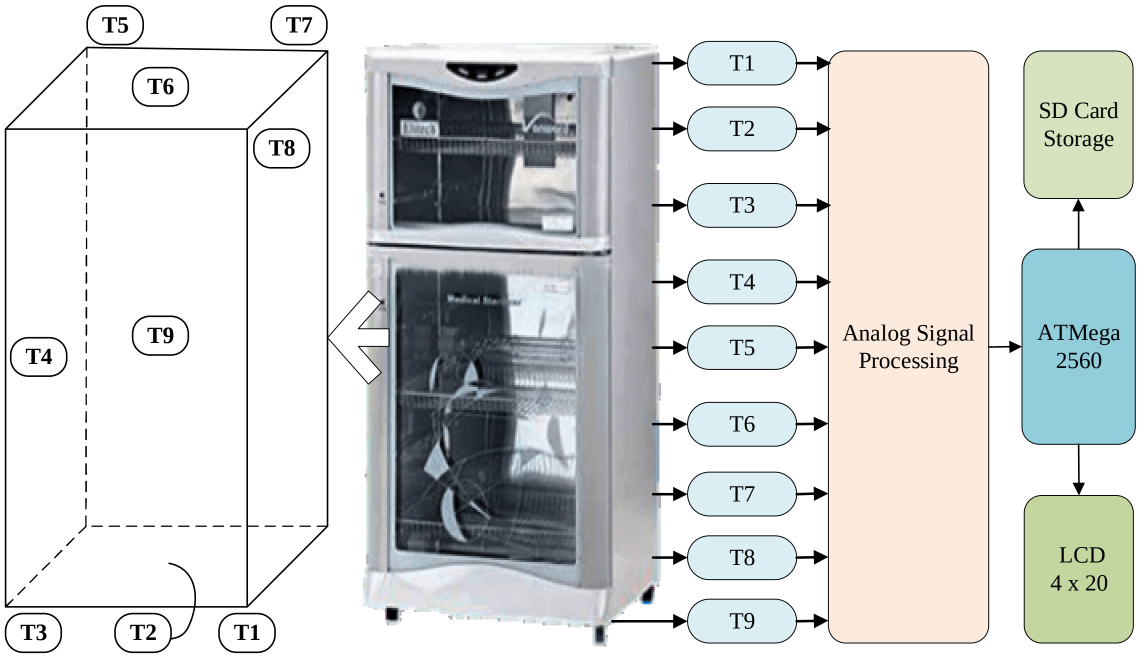

FIGURE 1. A total of 9 thermocouple sensors (T1-T9) were placed at the points according to the AS2853 standard. In the Sterilizer, the temperature setting was carried out at temperatures of 50, 100 and 120 C. This process was carried out until the temperature on the display of the sterilizer was stable or in accordance with the settings.

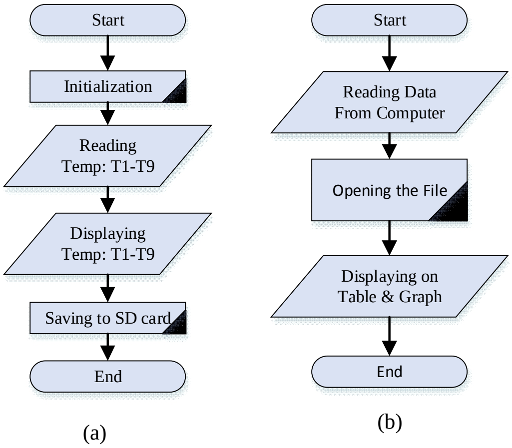

FIGURE 2. (a) Nine thermocouple sensors detected the temperature in the sterilizer. The results were processed and displayed on the LCD and stored on the SD card. (b). The measurement result data that have been stored in the form of a txt file will be read through the computer.

C. THE FLOWCHART

In FIGURE 2, when the device was turned on, the initialization process was carried out on the LCD and sensors. Then, the thermocouple sensor took temperature readings. The temperature reading results were further displayed on the device display and stored on the SD Card. After the temperature reading data were stored, the user can insert the SD Card into the computer to open the txt file. When the txt file is opened, a table of measurement results are displayed displayed. In FIGURE 3, the test was carried out by comparing the research module with the comparison module. Tests were carried out at temperatures of 50, 100 and 120 ºC. From the results of this test, it will be seen how many errors exist.

FIGURE 3. In order to test the research module, a comparison test was carried out using a comparison tool. As many as 9 Sensors from the research module and the comparison module were placed close to each other in the sterilizer

III. RESULT

In this study, the data logger has been tested using a fortune ztp78e sterilizer and Elektro-Mag M6040P. The standard tool used for comparison is the Madgetech OctTemp2000 data logger.

1) DESIGN MODULE

This module used a k-type thermocouple as the temperature sensor as well as an analog signal conditioning circuit consisting of a filter, buffer, and non-inverting amplifier circuit. In addition, ATMega2560 was also used as the data processor, 4x20 LCD as display, as well as SD Card and RTC module. The measuring instruments used in this research are avometer and data logger. Results of Temperature Measurements are in the forms of Modules with Comparison Tools.

TABLE 1

Measurement results at 50ºC. The average calculation of the data that has been stored was carried out. Furthermore, the errors were calculated. In each channel, the measurement uncertainty (U_{95}) was also calculated.

Sensor	U_{95}Design	U_{95}Standard	Error (%)
T1	1.3	0.6	0.7
T2	0.7	0.3	3.9
T3	0.6	0.3	0.7
T4	0.7	0.6	3.3
T5	0.3	0.7	2.0
T6	0.9	0.3	3.3
T7	0.3	0.0	0.7
T8	0.7	0.3	1.3
T9	0.7	0.7	1.4

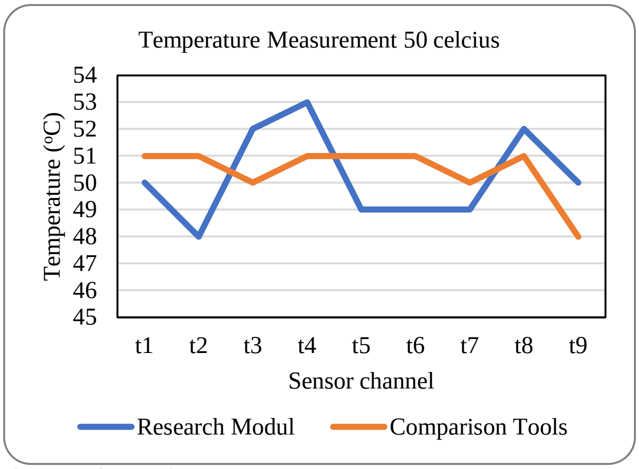

FIGURE 4. Graph of Temperature Measurement Results in the research module and comparison tool. The sterilizer was set at 50ºC. The measurement process was carried out until the temperature was stable or reached the setting temperature.

The results of the research module were compared with a comparison tool (standard), in this case is by using Madgetech OktTemp2000. After the display, a stable temperature was shown according to the setting temperature and further stored in the SD Card. Based on the existing data, the standard deviation was then calculated and the final result determined the uncertainty value.

Furthermore, TABLE 1 shows the uncertainty value of each sensor, both from the research module and the standard module. In addition, the error value was also calculated based on the difference between the research module and the standard module. The smallest average error value for 50ºC temperature data is 0.7% on sensor 1, while the largest is 3.9% on sensor 2. However, the uncertainty values both in the research module and in the comparison tool are almost all below 1, which means the research module is stable in measuring or the level of precision of the results of this research module is quite high. In addition, FIGURE 4 shows a trend graph comparison of the measurement values of each sensor between the research module and the standard module at the 50ºC sterilizer temperature setting.

TABLE 2

Measurement results at 100ºC. The calculation of the average of the data that have been stored was carried out. In addition, the errors were also determined. Furthermore, the uncertainty (U_{95}) of each channel was also calculated

Sensor	U_{95}Design	U_{95}Standard	Error (%)
T1	0.3	0.3	4.7
T2	0.7	1.0	3.6
T3	0.3	0.3	5.1
T4	0.3	0.3	7.4
T5	0.3	0.3	5.8
T6	0.0	0.3	5.8
T7	0.3	0.3	10.5
T8	0.0	0.3	4.1
T9	0.3	0.3	1.6

Based on TABLE 2, it shows the uncertainty value of each sensor at a temperature setting of 100ºC. The uncertainty value displayed is from the research module and the standard module. In addition, the error value was also calculated based on the difference between the research module and the standard module. The smallest average error value for 100ºC temperature data is 1.6% on sensor 9 and the largest is 10.5% on sensor 2. On sensor 1 and sensor 2, the error that occurs was smaller than the 50ºC measurement. However, the uncertainty values in both the research module and the comparison tool are almost all below 1, which means the research module is stable in measuring or the level of precision of the module resulting from this research is quite high. Furthermore, based on the following FIGURE 5, it shows a trend graph comparison of the measurement values of each sensor between the research module and the standard module at the 100ºC sterilizer temperature setting.

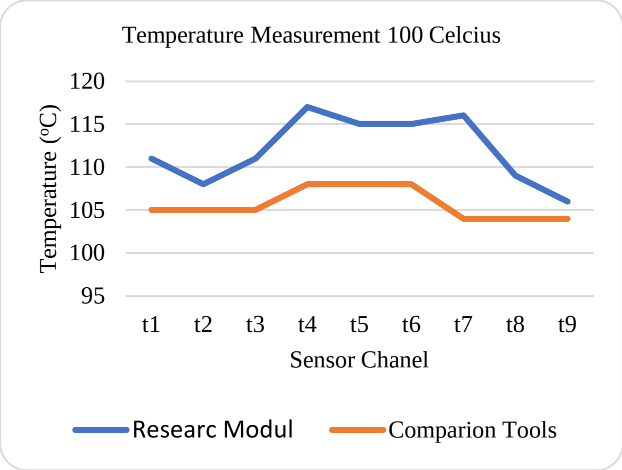

FIGURE 5. Graph of Temperature Measurement Results in the research module and comparison tool. The sterilizer was set at 100ºC. The measurement process was carried out until the temperature was stable or reached the setting temperature

TABLE 3 shows the uncertainty value of each sensor at a temperature setting of 120ºC, where the smallest average error value for temperature data of 120ºC is 0.0% on sensor 9, while the largest is 8.5% on sensor 7. On the comparison tool, almost all of them are below 1 which means the research module is stable in measuring or the level of precision of this research module is quite high. Furthermore, FIGURE 6 shows a trend graph comparison of the measurement values of each sensor between the research module and the standard module at the 120ºC sterilizer temperature setting.

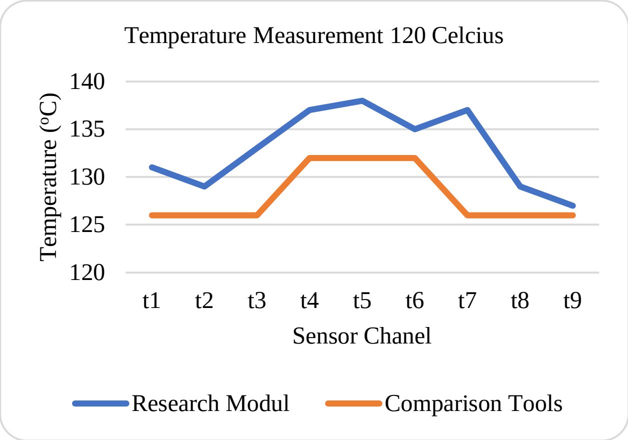

FIGURE 6. Graph of Temperature Measurement Results in the research module and comparison tool. The sterilizer was set at 120ºC. The measurement process was carried out until the temperature was stable or reached the setting temperature

TABLE 3

Measurement results at 120ºC. The average calculation of the data that have been stored was carried out. Furthermore, the errors were calculated. In addition, the uncertainty (U_{95}) of each channel was also calculated.

Sensor	U_{95}Design	U_{95}Standard	Error (%)
T1	0.3	0.3	4.0
T2	0.3	0.3	3.2
T3	0.3	0.0	5.3
T4	0.3	0.6	4.1
T5	0.7	0.6	4.3
T6	0.3	0.3	2.3
T7	0.3	0.3	8.5
T8	0.3	0.0	2.1
T9	0.3	0.3	0.0

FIGURE 7, 8, and 9 show in-depth analysis of the temperature distribution in a dry sterilizer for temperatures of 50°C, 100°C, and 120°C, respectively. The radar graph shows that the sterilization temperature is close to the setpoint at point T9 at temperature settings of 50°C, 100°C, and 120°C with error values of 1.4%, 1.6% and 0%. The temperature measurement point at T8 occupies a measurement point that is close to the setpoint temperature after T9 with error values of 1.3%, 4.1%, 2.1%. In addition, the measurement points of T1, T2, T3, T4, T5, T6, and T7 produced temperature measurements that have a larger difference with the setpoint temperature.

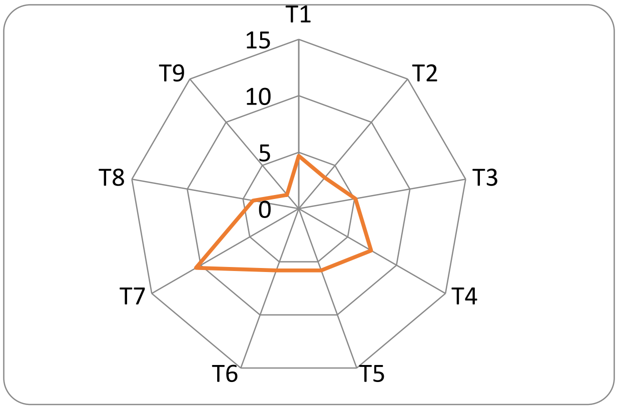

FIGURE 7 The radar graph shows the temperature distribution in the dry sterilizer room between T1 – T9 for the temperature at a setpoint of 50 °C.

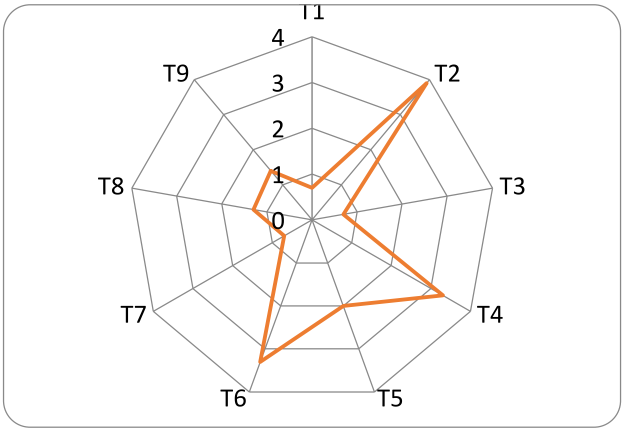

FIGURE 8 The radar graph shows the temperature distribution in the dry sterilizer room between T1 – T9 for the temperature at a setpoint of 100 °C

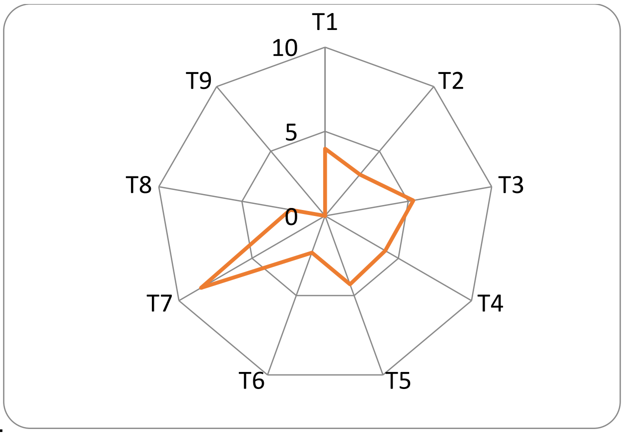

FIGURE 9 The radar graph shows the temperature distribution in the dry sterilizer room between T1 – T9 for the temperature at a setpoint of 120 °C

IV. DISCUSSION

The research design of the Temperature Data Logger has conducted experiments to record the temperature of the sterilizer with temperature settings of 50ºC, 100ºC, and 120ºC, while the previous studies are still at temperatures below 100ºC. Meanwhile, the standard tool used for the comparison is the Madgetech OctTemp2000 data logger. All 9 sensors were further placed at points according to the specified standard, in this case, is using the AS2853 reference standard.

Based on the measurement and comparison data, the average error was obtained at a temperature of 50ºC with the smallest error value of 0.7% and the largest value of 3.9%. At a temperature of 100ºC the smallest error value is 1.6% and the largest is 10.5%. Then, at a temperature of 120ºC, the smallest error value is 0.0% and the largest is 8.5%. The smallest error approaching the setpoint or temperature setting can be found on the T9 and T8 sensors. The average uncertainty value is below 1 whether at 50ºC, 100ºC, and 120ºC temperature measurements. Furthermore, the uncertainty above 1 is in T1 at 50ºC measurement of 1.3.

Apart from T1 at a temperature setting of 50ºC everything is below 0. This proves that the research module was stable in response to temperature.

With the results of the calculation of the error, the drawback in this study is that it still has a fairly high error value. The magnitude of the error value occurred can be influenced by the location of the sensor module as a result of the research with a comparison tool whose position is slightly different. In this research trial, it was difficult to place the sensor because of the rigid sensor cable. It is necessary to conduct re-test for some medical support devices that use high temperatures. For placing the sensor, it can be conducted by the assistance of a cube-shaped framework so that the sensor position is more stable. Therefore, it is expected that the accuracy of this research module will be better. In addition, this research can be improved on analog signal processing whether in the buffer circuit, filter, and amplifier so that the error value becomes smaller. This research used 9 thermocouple sensors. In addition, this module can also be used to help analyze the temperature distribution of the sterilizer or the temperature of the enclosure simultaneously with 9 sensors. The module from the results of this study is also expected to help the process of calibrating the temperature of the enclosure so that the quality of materials or medical devices that require the sterilization process will be improved and guaranteed.

V. CONCLUSION

The purpose of this study was to record and monitor whether the temperature distributed in the sterilization chamber corresponds to the temperature setting. Based on the measurement and comparison data, the average error was obtained at a temperature of 50ºC with the smallest error value of 0.7% and the largest value is 3.9%. At a temperature of 100ºC, the smallest error value is 1.6% and the largest is 10.5%. Then, at a temperature of 120ºC, the smallest error value is 0.0% and the largest is 8.5%. The smallest error approaching the setpoint or temperature setting can be found on the T9 and T8 sensors. The average uncertainty value is below 1 whether at 50ºC, 100ºC, and 120ºC temperature measurements. The research module is stable in response to temperature by looking at the uncertainty value. The development of this research can be done by using a circuit or developing other analog signal conditioning circuits. Therefore, the error value is not high and the module used in any device is not only a dry sterilizer measuring instrument, instead it can be used for other enclosed temperature measurement such as a bacterial incubator.

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