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Analysis of Dialysate pH and Temperature Stability on Hemodialysis Machines Using Internet of Thing Technology

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ABSTRACT Therapy for kidney replacement with hemodialysis is a treatment that is carried out in patients with Chronic Kidney Failure to survive. Related to this matter, this study was done aiming to determine the stability of the dialysate fluid in the hemodialysis machine by measuring the temperature using the DS18B20 sensor and measuring the dialysate pH using the 4502C sensor on pre- and post-hemodialysis. Meanwhile, the research method and the manufacture of this module applied a pre-experimental research design with the independent variables involved are pH value and Dialysate Temperature, while the dependent variables are pH and Temperature Sensor. Furthermore, the control variable is the Traceable Tool. This research made a module using an Esp32 microcontroller system with an LCD that can be monitored using Android via the Internet of Things (IoT) system. In this case, the comparison of the results of the dialysate temperature values during pre and post-obtained the maximum measurement error of 0.2%. Based on the measurement and data analysis, it can be concluded that there was no effect of pH and temperature values during pre and post hemodialysis.

INDEX TERMS Chronic Kidney Disease, Hemodialysis, pH dialysate, Dialysate temperature, pH sensor, and Temperature sensor

I. INTRODUCTION

Chronic renal failure (CKD) is a progressive and irreversible renal function disorder in which the body is fail to maintain metabolism, fluid, and electrolyte balance causing uremia [1]. In this condition, kidney function has decreased so much causing the accumulation of toxins in the body, called uremia [2]. In a state of uremia, renal replacement therapy is needed to take over kidney function by eliminating body toxins so that severe symptoms do not occur [3]. The action of renal replacement therapy is called hemodialysis; a treatment action performed on CKD patients to survive [4]. Hemodialysis is a kidney replacement therapy where a person's kidney function has failed to perform its function [5]. Hemodialysis requires a dialysis machine and a special filter called a dialyzer (a semipermeable membrane) which is used to clean the blood, where the blood is further removed from the patient's body and circulated in a machine outside the body [6]. Hemodialysis works by washing blood through the ultrafiltration process so that fluid transfers in the form of dialysate, water, and blood through the semipermeable membrane in the dialyzer [7][8]. The World Health Organization (WHO) released data on an increase in the number of sufferers of Chronic Kidney Failure in the world in 2013 by 50% from the previous year (Bayhakki, 2017). The prevalence of chronic renal failure has reached epidemic proportions with 10-13% populations in Asia and America. This number is expected to continue to increase if the prevalence of diabetes mellitus and hypertension also continues to increase (Chin & Kim, 2009 in Susetyowati, et al., 2017). In Indonesia, Chronic Kidney Failure increased from 0.2% in 2013 to 0.38% in 2018 (RISKESDAS, 2018). This shows that patients with Chronic Kidney Failure increases every year. In this case, the prevalence of Chronic Kidney Disease in East Java was 0.2% in 2013 and increased in 2018. Based on the graph shown in the 2018 RISKESDAS Main Results, it can be seen that the prevalence rate of Chronic Kidney Failure in East Java is higher than the national average (RISKESDAS, 2018).

Based on the data from the Health Profile of East Java Province (2017), there were 1572 cases of kidney failure occurred in East Java. Furthermore, according to medical record data in 2016, the number of Chronic Kidney Failure outpatient visits undergoing routine hemodialysis was 49 people, while in 2017 there were 158 people. In January-June 2019, the number of patients undergoing hemodialysis with a diagnosis of chronic kidney failure was at an average of 140 people per month. The high prevalence of chronic kidney disease will affect the quality of life of patients. The effectiveness of hemodialysis can be seen from the decrease in urea and creatinine levels after hemodialysis [9]. Factors that affect the value of urea and creatinine in hemodialysis patients are blood flow velocity, duration of dialysis, and the dialyzer used. To achieve the effectiveness of hemodialysis, it is necessary to monitor and regulate the process [10]. One of the important settings is the regulation and monitoring of blood flow velocity during the hemodialysis process. The speed of blood flow is influenced by dialysate fluid to achieve the effectiveness of dialysate hemodialysis. It is influenced by flow rate factors, temperature, conductivity, dialysate pH, dialysate pressure, venous pressure, and arterial pressure [11][12]. The increase in dialysate temperature will cause vasodilation and hypotension in the body. In addition, if there is a decrease in dialysate temperature, it will cause vasoconstriction and hypertension in the body [13]. The recommended dialysate fluid temperature is between 35ºC to 37ºC or adjusted 0.5ºC – 1.0ºC below the patient's body temperature [14][15][16]. Low sodium concentration causes the risk of IDH (Intradialytic Hypotension) [17][18]. This is because the majority of sodium is excreted during hemodialysis by convection in ultrafiltration, therefore changing the concentration from low to high aims to maintain sodium balance [19][20]. The normal pH of dialysate fluids ranges from 6.9-7.6 [21]. If the pH is not normal, it will affect blood flow, causing impaired renal excretion, metabolic acidosis, and nutritional status [22]. To overcome this problem, temperature and pH become the effective indicators of hemodialysis quality, so the temperature and pH measurement values need to be stable [23].

The duration of use of the hemodialysis machine affects the stability of the PH value, temperature, conductivity, and venous and arterial pressure. In the technical age of medical equipment, hemodialysis is used for 1040 hours or 5 years of use [24]. In this case, the average usage per day is 7 hours of use of the tool, while in the field, there are 3 shifts of the hemodialysis process, in this case, the use of the tool becomes 15 hours of use where each shift is approximately 5 hours. It is important to measure pH and the dialysate temperature to know the value because stable dialysis can affect the withdrawal of poison in the patient. In order to know the stability of the dialysate fluid in the hemodialysis machine, the temperature needs to be measured using the DS18B20 sensor [25], based on previous research [26]. The DS18B20 sensor has an error rate of not more than 2% [27], the use of the DS18B20 sensor is better to use ≤ 37 degrees Celsius which corresponds to the normal temperature of the blood. Furthermore, determining the stability of the dialysate liquid was by measuring the pH using a PH 4502C sensor. This device can measure the pH value in the range of 0.00 to 14 with a response time fewer than 5 seconds. Therefore, it is suitable to be used as a measuring instrument for measuring the pH of dialysate on hemodialysis machines.

In this study, the authors used previous research as a reference and benchmark for completing the research. Based on a literature search in 2015, Zhang P introduced a hemodialysis machine calibration detector with several parameters but no experimental protocol or device that can be used to test the accuracy and reliability of the hemodialysis machine detector.

The purpose of this study was to determine the stability of the dialysate fluid in the hemodialysis machine by measuring the temperature using the DS18B20 sensor and measuring the dialysate pH using the 4502C sensor on pre and post-hemodialysis. The contribution from this research is:

a. Using low-cost pH sensor (4502c Sensor) to minimize the cost of the research.
b. Monitoring the device using Android via the Internet of Things (IoT) system so the users can get the information of the patient every time.
c. The dialysate flow in a hemodialysis machine was set at 36.5 degrees Celsius to get the stability value so researcher can easily measure it.
d. pH sensor and temperature sensor can work during pre and post hemodialysis so researcher can get data.

I. MATERIALS AND METHODS

A. EXPERIMENTAL SETUP

Before conducting experiments, researchers must calibrate the hemodialysis analyzer so that the hemodialysis analyzer has a level of measurement with good accuracy in reading the experimental results. Techniques temperature and pH of the dialysate were measured on a hemodialysis machine that was connected to a calibrator module with a comparison tool for data collection. A hemodialysis analyzer (IBP HDC 75) was used to measure the temperature and pH of the dialysate on the hemodialysis machine, which was compared to standardized equipment. The measurement results were further recorded (six) 6 times at each measurement point.

1) MATERIALS AND TOOLS

The temperature sensor DS18B20 worked in the range of -55 to +125 degrees Celsius. The DS18B20 has the advantage of providing digital data with a precision of 0.5 Celsius throughout a temperature range of 10 to 85 degrees Celsius, making reading by the microcontroller easier. Meanwhile, PH 4502C sensor had a measurement range of 0.00 to 14.00 PH and a 98.5 percent percentage accuracy

2) EXPERIMENT

The goal of dialysis temperature measurement is to determine the value of the module's reading and then compare it to the value of the reading on a comparison tool. The dialysate flow in a hemodialysis machine is 36.5 degrees Celsius. In this case, the measurements were taken for six times.

A. THE DIAGRAM BLOCK

FIGURE 1 shows the battery as a voltage source for all circuits. The pH sensor and temperature sensor read the next value from the pH and temperature sensor on the ESP 32 ADC pin. Data that enters the Arduino in the form of analog is then converted to digital on the ADC pin of the microcontroller. The received ADC data is converted into pH and temperature values which are then transmitted on the Blynk platform. On the Blynk platform, it displays the value of the sensor reading on Android.

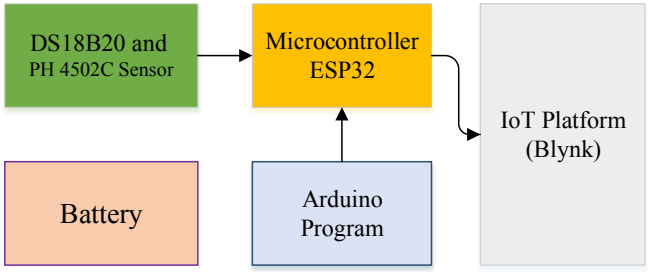

FIGURE 1. The Diagram Block of Development of Hemodialyzation Machine.

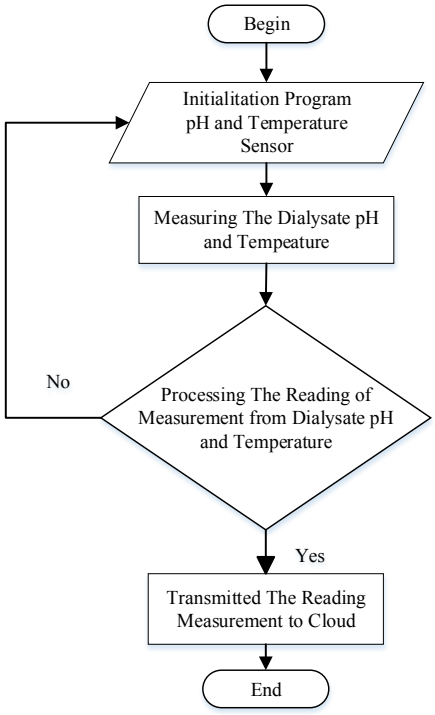

FIGURE 2. The flowchart of Arduino process

B. THE FLOWCHART

FIGURE 2 shows that after the tool is turned on, it will initialize. After that, it will get ADC data from the flow sensor, pH, and temperature which reads the value that will be processed on thel microcontroller and ESP 32 and then transmitted on the internet of things platform. FIGURE 3 further present the Android performance of data initialization and then receives data that have been processed by ESP 32 via the Blink platform, pH and Temperature data are displayed on Android.

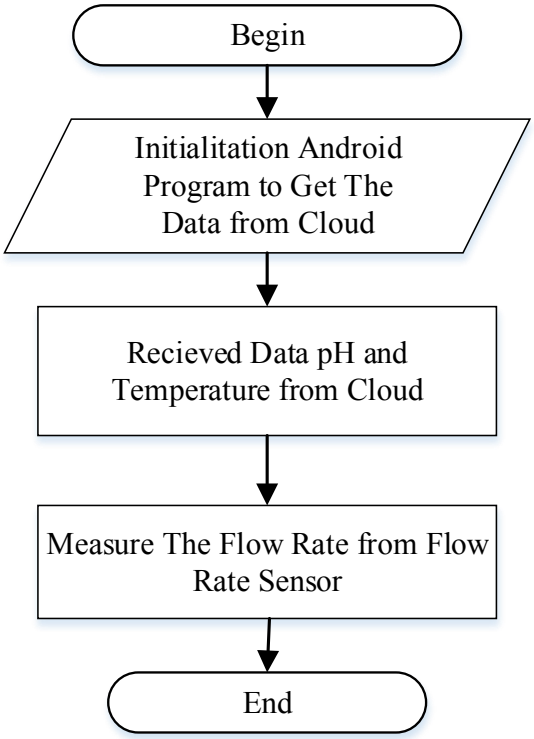

FIGURE 3. The Flowchart of Personal Computer

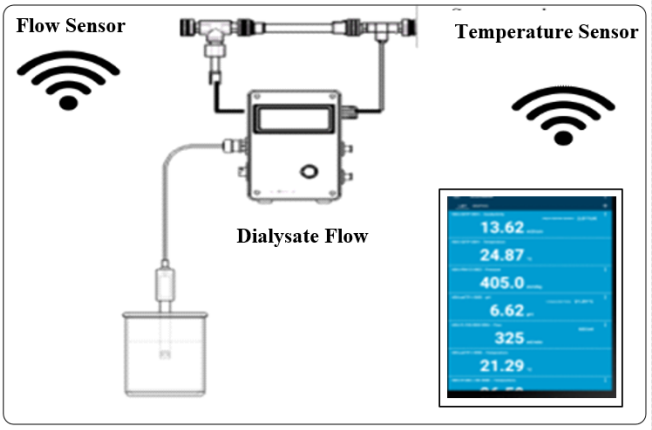

FIGURE 4. Module Design of Dialysate Flow with Sensor Flow and Temperature Sensor Displayed with Smartphone

II. RESULT

This section shows the result from the measurement of this research. Design module that author built in this research was adding the IoT and displayed using smartphone in the system. The result further shows the measurement of Dialysate pH.

A. METHOD OF EXPERIMENT

FIGURE 4 shows a picture of the method that researcher used in this research. Inside the box consists of a control circuit and batteries. Then, there is ESP32 for data retrieval that researcher get from the sensor, which will be displayed on Android smartphone. In the picture, there is also an ON/OFF switch and a charger module to complete the tool so that it can be used in a mobile. Module, comparison with hemodialysis machine. The comparison was made by comparing the output pH and temperature of the measured dialysate and comparing it with standard and traceable tools

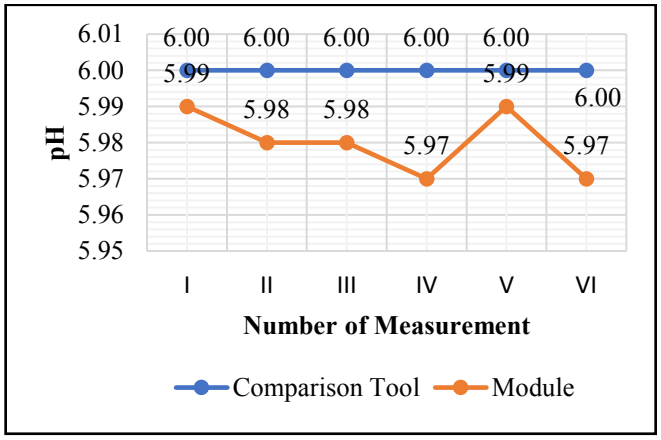

FIGURE 5. Comparison of Output pH and Temperature from 1st Measurement of Dialysate pH between Module and Comparison Tool

FIGURE 5 shows the graph of the first reading on the module has a value of 5.99 and the comparison tool has a value of 6.00; the graph of the second reading on the module has a value of 5.98 and the comparison tool has a value of 6.00; the graph of the third reading on the module has a value of 5.98 and the comparison tool has a value of 6.00; the graph of the fourth reading on the module has a value of 5.98 and the comparison tool has a value of 6.00; the module's fourth reading yielded a value of 5.97, while the comparison tool yielded a value of 6.00. The module's V reading yielded a value of 5.99, while the comparison tool yielded a value of 6.00. The module's VI reading yielded a value of 5.97, while the comparison tool yielded a value of 6.00.

The 2nd Measurement from this research shows the reading on the module that obtained a value of 7.04 and the comparison tool obtained a value of 7.00. The second reading on the module obtained a value of 7.03 and the comparison tool obtained a value of 7.00. The third reading on the module obtained a value of 7.05 and the comparison tool obtained a value of 7.00. Furthermore, the fourth reading on the module obtained a value of 7.05 and the comparison tool obtained a value of 7.00. Meanwhile, the fifth reading of the module obtained a value of 7.02, and the comparison tool was 7.00. The sixth reading of the module obtained a value of 7.03, and the comparison tool was 7.009.

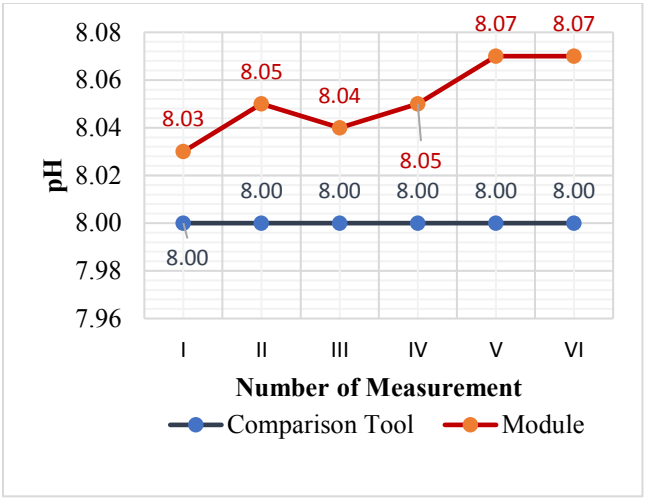

FIGURE 6. Comparison of Output pH and Temperature from 3rd Measurement of Dialysate pH between Module and Comparison Tool

FIGURE 6 shows the graph of the first reading on the module obtained a value of 8.03 and the comparison tool obtained a value of 8.00, the second reading on the module obtained a value of 8.05 and the comparison tool obtained a value of 8.00, the third reading on the module obtained a value of 8.04 and the comparison tool obtained a value of 8.00, the fourth reading on the module yielded a value of 8.05, and the comparison tool yielded a value of 8.00, the V reading yielded a value of 8.07, and the comparison tool yielded a value of 8.00, the VI reading yielded a value of 8.07, and the comparison tool yielded a value of 8.00, and the VI reading yielded a value of 8.07, and the comparison tool yielded a value of 8.00.

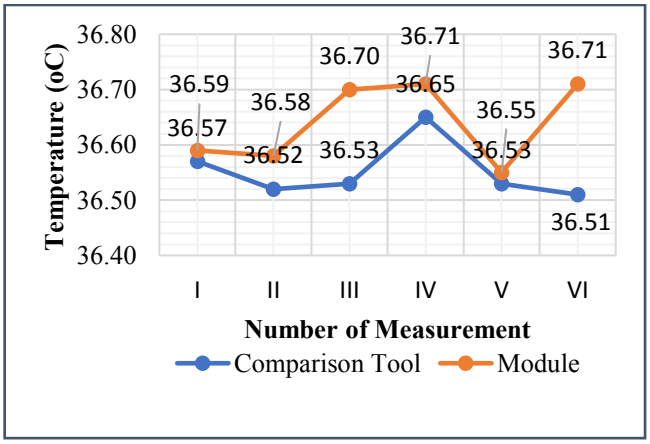

FIGURE 7. Comparison of Output pH and Temperature from 5th Measurement of Dialysate pH between Module and Comparison Tool

FIGURE 7 shows the graph of the first reading on the module obtained a value of 36.59 °C and the comparison tool obtained a value of 36.57 °C. The second reading of the module obtained a value of 36.58 °C and the comparison tool obtained a value of 36.52 °C. The third reading of the module obtained a value of 36.70 °C and the comparison device obtained a value of 36.53 °C. Furthermore, the value of the fourth reading on the module is 36.71 °C, and the value of the comparison tool is 36.65 °C. The value of the V reading on the module is 36.55 °C, and the value of the comparison tool is 36.53 °C. In addition, the reading to the VI on the module obtained a value of 36.710 C, and the comparison tool obtained a value of 36.510 C.

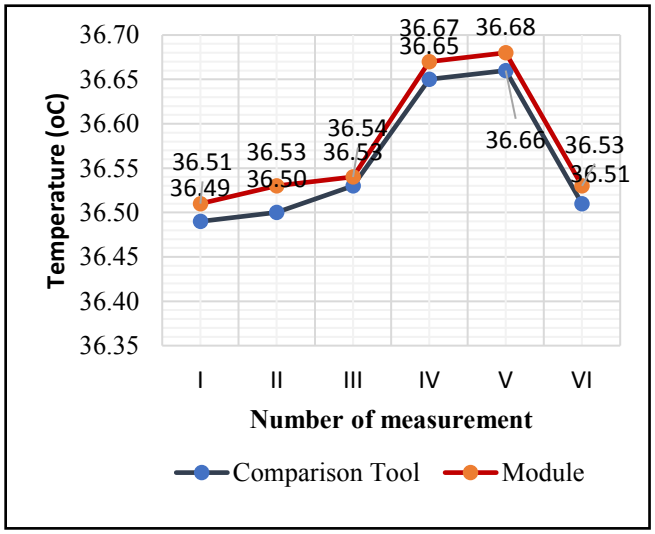

FIGURE 8. Comparison of Output pH and Temperature from 4th Measurement of Dialysate pH between Module and Comparison Tool

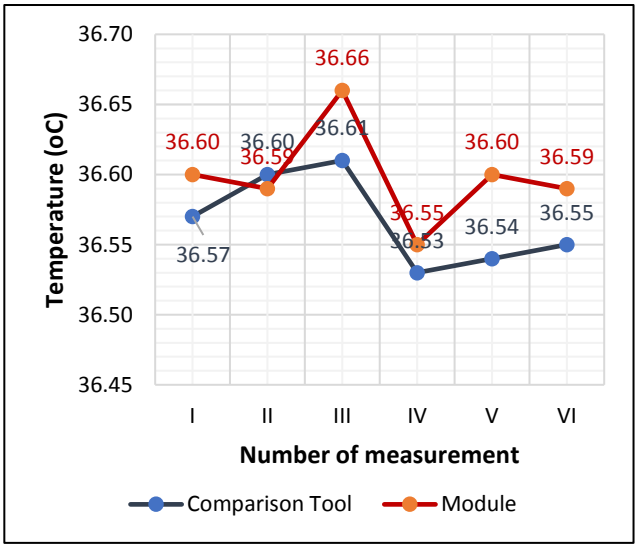

FIGURE 9. Comparison of Output pH and Temperature from 6th Measurement of Dialysate pH between Module and Comparison Tool

FIGURE 8 shows the graph of the first reading on the module obtained a value of 36.51 ºC and the comparison tool obtained a value of 36,49 ºC. The second reading on the module obtained a value of 36.53 ºC and the comparison tool obtained a value of 36.50 ºC. The third reading on the module obtained a value of 36.54 ºC and the comparison tool obtained a value of 36,55 ºC. The fourth reading of the module obtained a value of 36.67 ºC, and on the comparison tool, a value of 36.65 ºC was obtained. On the V reading of the module, the value is 36.68 ºC, and on the comparison tool, a value of 36.66 ºC was obtained. On the sixth reading on the module, the value is 36.53 ºC, and the comparison tool, a value of 36.51 ºC was obtained. FIGURE 9 shows the graph of the first reading on the module obtained a value of 36.60 °C and the comparison tool obtained a value of 36.57 °C. The second reading on the module obtained a value of 36.59 °C and the comparison tool obtained a value of 36.60 °C. The third reading on the module obtained a value of 36.66 °C and the comparison tool obtained a value of 36.61 °C. The fourth reading of the module yielded a value of 36.55 °C, while the comparison tool yielded a value of 36.53 °C. The fifth reading yielded a value of 36.60 °C, while the comparison tool yielded a value of 36.54 °C, and the value was attained on the fifth reading. The sixth reading obtained a value of the comparison tool of 36.55 °C, while the module obtained a value of 36.59 °C.

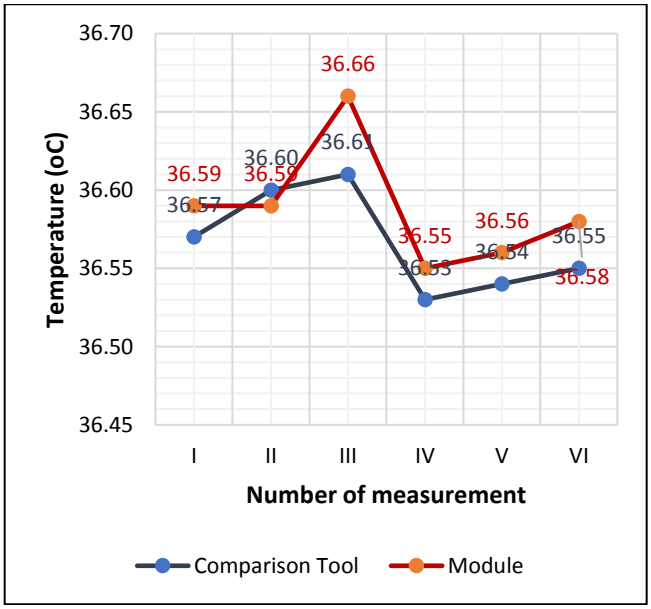

FIGURE 10. Comparison of Output pH and Temperature from 7th Measurement of Dialysate pH between Module and Comparison Tool

FIGURE 10 shows the graph of the first reading on the module had a value of 36.59 °C and the comparison tool had a value of 36.57 °C. The second reading on the module had a value of 36.59 °C and the comparison tool had a value of 36.60 °C. The third reading on the module had a value of 36.66 °C and the comparison device had a value of 36.61 °C. The fourth

reading of the module yielded a value of 36.55 °C, while the comparison tool yielded a value of 36.53 °C. The fifth reading yielded a value of 36.56 °C, while the comparison tool yielded a value of 36.54 °C, and the value was attained on the fifth reading. On the sixth reading, the comparison tool obtained a result of 36.55 °C, while the module obtained a value of 36.58 °C (TABLE 1).

TABLE 1
Data Collection of pH Dialysate Pre-reading and Post Reading from Machine 1, Machine 2, and Machine 3

Data Collection pH Dialysate						
Measurement Result of	Machine 1		Machine 2		Machine 3	
	Reading					
	Pre	Post	Pre	Post	Pre	Post
I	7.37	7.39	7.38	7.34	7.35	7.34
II	7.34	7.41	7.36	7.37	7.34	7.35
III	7.35	7.35	7.34	7.35	7.32	7.34
IV	7.36	7.36	7.36	7.33	7.31	7.33
V	7.36	7.38	7.36	7.38	7.32	7.37
VI	7.37	7.37	7.37	7.40	7.33	7.38

III. DISCUSSION

In the first measurement, researcher obtained difference of measurement between module and comparison tool by 0.01 to 0.03. From the 2nd measurement, researcher obtained difference of measurement between module and comparison tool by 0.01 to 0.05. From the 3rd measurement, researcher obtained the difference of measurement between module and comparison tool by 0.03 to 0.07. From the 4th measurement, researcher obtained the difference of measurement between module and comparison tool by 0.01 to 0.02. From the 5th measurement, researcher obtained the difference of measurement between module and comparison tool by 0.03 to 0.04. From the 6th measurement, researcher obtained the difference of measurement between module and comparison tool by 0.01 to 0.05.

When the findings of the dialysate pH value at the time of pre and post are compared, the variance of 0.03 is still within the dialysate pH range of 6.9 - 7.6. The findings of the dialysate temperature values at the time of pre and post were compared in the study of temperature measurements, and the greatest difference in measurement error is 0.2 percent.

This study's findings are superior to the earlier research. The results of the research can be used to calculate the value of the dialysate pH and temperature on an IOT-based hemodialysis machine utilizing Esp32 [27][29][30]. This study also discovered flaws, such as the need to replace the ESP32 for the communication data. In addition, the IoT system must be faster to transmit the data to cloud. For program improvements, accuracy should be improved by improving the parameters on the measuring instrumen. Furthermore, the measurement results on the tool should be stored and equipped with an SD card, and the calibration sheet results can be directly displayed on the web.

This research's data from sensor readings can be used to determine how the value of the dialysate pH and temperature can be determined according to a standard to support the dialysis process' effectiveness, which should be more practical and user-friendly. So that the patient-handling process can be completed properly.

IV. CONCLUSION

The purpose of this study is to determine the stability of the dialysate fluid in the hemodialysis machine by measuring the temperature using the DS18B20 sensor and measuring the dialysate pH using the 4502C sensor on pre and post-hemodialysis. This research made a module using an Esp32 microcontroller system with an LCD that can be monitored with Android via the Internet of Things (IoT) system. In addition, the comparison of the results of the dialysate temperature values at the time of pre and post-obtained the maximum measurement error of 0.2%. From the measurement and analysis data, it can be concluded that there is no effect of pH and temperature values during pre and post-hemodialysis. For further research, it is hoped that the measurement data on the instrument can be stored and included with the SD card, and the findings of the calibration sheet are also directly displayed on the web to support better research in the future.

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