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Monitoring the Stability of Oxygen Flow Analyzer on Oxygen Station in the Hospital

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ABSTRACT In addition to benefits, oxygen therapy also has certain dangers and side effects. Hence, oxygen therapy must be given at the proper dose by monitoring the patient regularly and adjusting the oxygen flowmeter. The accuracy of flowmeter under standard conditions is guaranteed by manufacturer. Through time and use, the precision may change and the flow accuracy given in a hospital setting may different from the original value. Related to this matter, current research was carried out aiming to conduct further research on oxygen flow analyzer which focused on discussing the accuracy and stability of the oxygen flow sensor against the gold standard. The contribution of this study is to increase the range of oxygen flowrate measurement to 15 liters per minute (LPM). Furthermore, this research used Arduino Mega, while the gas flow sensor used was legris flow sensor. The measurement results were further displayed on TFT LCD equipped with SD Card data storage. The gas flowrate was regulated using a flowmeter (GEA). Meanwhile the comparison tools used Oxygen Analyzer and 1 m3 oxygen gas cylinder. At the testing stage, the sensor reading value on the module that appeared on the TFT LCD was compared with the results of a comparison tool with a measurement range of 1 LPM to 15 LPM 6 times at each point. The conclusion from these results is that the calibrator module has a relative error that is still within the allowable tolerance limit of ±10%.

INDEX TERMS Calibration, Oxygen Flow Analyzer, Flowmeter, TFT Display

I. INTRODUCTION

Oxygen is useful for oxidative metabolism [1][2]. Oxygen therapy is a method of administering oxygen at a higher concentration than oxygen in the surrounding air [3]. Oxygen therapy is commonly used in the treatment of acute conditions such as hypercapnia, hypoxemia, and acute myocardial infarction [4][5][6][7][8][9]. However, oxygen therapy has certain dangers and side effects, where too much or too little oxygen is potentially damaging [10][11][2]. For this reason, the administration of oxygen therapy must be in accordance with the proper dose by monitoring the patient regularly by medical personnel [12][13]. Oxygen delivery assembly consisting of flowmeter, bubble humidifier, oxygen delivery tube and nasal insufflation catheter is assembled [14]. The gas flow rate is a static parameter [15]. The oxygen flow rate must be controlled by the doctor visually so that the oxygen entering the patient's body can be recorded and in accordance with the patient's needs [16] [17]. The integrated flowmeter consists of a venturi tube, a pressure sensor, a temperature sensor and an electronic unit [18]. Oxygen flowmeters usually measure oxygen gas flow in liters per minute (LPM). The flow rate generally delivered by this tool ranges from 0 to 15 LPM [19]. The accuracy of the flowmeter under standard conditions is guaranteed by the manufacturer. Through time and use, the precision may change and the flow accuracy given in a hospital setting may different from the original value. In addition, the output on a manual flow meter is sometimes not good because the small ball used as a reference for the flow of oxygen flow can choking due to dirtiness [20]. Several potential hazards have been identified in the configuration of the oxygen therapy system that result in decreased accuracy of flow rate measurement, including the use of an oxygen flow meter to flow the mixed gas, orientation of how the flow meter is installed, and pressure drops due to the use of medical gas connections and hoses. With reduced measurement accuracy at low flow rate settings, clinical users may not notice that flow rates may drop. In addition, inconsistencies in physical settings and labeling can lead to incorrect gas delivery to patients [21]. It is very difficult to measure precisely the flow rate of compressed gas oxygen [18]. In this case, it is necessary to conduct tool calibration in order to determine the correct value of the indication of the measuring instrument, so the tool is declared fit for use due to the difference in gas pressure flowing through the flowmeter [3] [14].

Several studies have been previously carried out concerning the accuracy of the oxygen flowmeter [22] [23] [19] [24] [14] [21] [25] [26]. The results showed that the flow rate measurement had good precision and poor accuracy as the flowmeter ages. Muhammad Khosyi'in's research using the Mass Air Flow AWM 5104 Microbridge sensor could only measure flow rates at 0 – 10 LPM within one minute with a 16x2 Character LCD display [27]. Yunaifi's research could measure oxygen levels and oxygen flow rates. However, the ultrasonic ocs 3f sensor used could only measure flow rates in the 0-10 LPM range. In addition, the display used was only a 16 x 12 Character LCD [28]. Furthermore, Rustiana's research succeeded in measuring the flow of oxygen gas using the MCS100A120 gas flow sensor. However, this tool was only able to measure the flow rate of oxygen from 0 to 10 LPM, then it was displayed on a 16 x 2 character LCD. In addition, there was an error value of 7.67% at 1 LPM measurement [29]. Meving's research using a downmount oxygen flow sensor has succeeded in measuring the flow of oxygen gas with a range of 1-15 LPM. However, the display of the results were only in the form of numbers and was not equipped with storage. In addition, at the measurement point 12 LPM, 13 LPM and 15 LPM there were significant differences in values [3].

Based on the literature study that has been described, there are several things that need to be resolved through a study, including: 1) flow measurement range; 2) accuracy value; 3) portable display; and 4) data storage results. Therefore, in this study, an oxygen analyzer module was designed with a graphical display and data storage. The aim of this research was to develop previous research in analyzing the accuracy and stability of the sensor on the oxygen flow analyzer. This research is considered more effective because it has advantages in terms of 1) a larger measurement range, 2) more accurate reading of results, 3) appearing on a 5 inch TFT in the form of numbers and graphs, and 4) equipped with data storage in the form of an SD card.

This article has the following structure, where Section 1 (Introduction) contains the background of the research, Section II (Materials and Method) explains the materials used in the research, data collection, and procedures used and Section III (Result) contains the results and data analysis of the research that has been done. Furthermore, Section IV (Discussion) contains sections that need to be discussed regarding the findings in the research conducted and Section V (Conclusion) contains the conclusions of the research that has been done and suggestions for further research. The contribution of this study is as follows:

1. This research can be used as a reference by other researchers who want to develop an oxygen flow analyzer in the future and it is recommended to use another type of air flow sensor.
2. In this study, researchers have made a tool and analyzed the accuracy of the design of a dual pressure calibrator
3. This is influenced by the accuracy of the researchers, the flow rate of oxygen entering the module and the comparator is not stable, the quality of the flowmeter itself and the pressure in the tube which begins to decrease.

II. MATERIALS AND METHODS

This research was conducted as experimental research. The author proposed an Oxygen analyzer to measure the oxygen flow rate parameters in this study. Materials and methods are explained in the following sections.

A. DATA COLLECTION

In this study, researchers compared the oxygen analyzer module and the standard gas flow analyzer (IMTMedical) as the comparison device. The research design used SFM4100 legris gas flow sensor with measurement of oxygen flow rate up to 15 LPM with an increase of every 1 LPM and 6 times of data collection. In this case, flow measurement can be achieved using a variable bore device that produced a variable differential pressure from one side of the flow meter to the other [30] oxygen flows across the MEMS sensor and generates a voltage signal[31]. Flow control valve was controlled manually, rotating counterclockwise [32]. The results were further displayed on a 5 inch TFT (Thin Film Transistor) LCD in the form of numbers and graphs. In addition, it was also equipped with data storage on the SD Card so that the measurement results can be reviewed.

At the measurement stage, oxygen was flowed continuously from the oxygen cylinder to the regulator [33]. Then, the oxygen flow rate was regulated using a GEA brand flowmeter. The comparator module and comparator were connected in series where the output of the oxygen analyzer module entered the comparator input. FIGURE 1 and FIGURE 2 shows the measuring mechanical installation. The installation of data collection from the oxygen cylinder was carried out so that it can be read by the oxygen flow analyzer module, consisting of the oxygen cylinder, the oxygen analyzer module, and the standard gas flow analyzer (IMTMedical) as the comparison device. Furthermore, the flowmeter valve was opened. In this case, the measured points were 1 LPM to 15 LPM with an increase of 1 LPM for each measurement point. The oxygen module as shows by FIGURE 4, was began by pressing the START button to start the measurement. On the TFT LCD screen, the reading numbers and a graph of the stability of the oxygen flow rate were displayed. Then press SAVE U to save the measurement results. The measurement data results were further stored on the SD Card in txt form. Then, in order to stop the measurement while resetting the reading and image chart, pressed stop.

FIGURE 1. The installation of data collection from the oxygen cylinder so that it can be read by the oxygen flow analyzer module, consisting of the oxygen cylinder, the oxygen analyzer module, and the standard gas flow analyzer (IMTMedical) as the comparison device

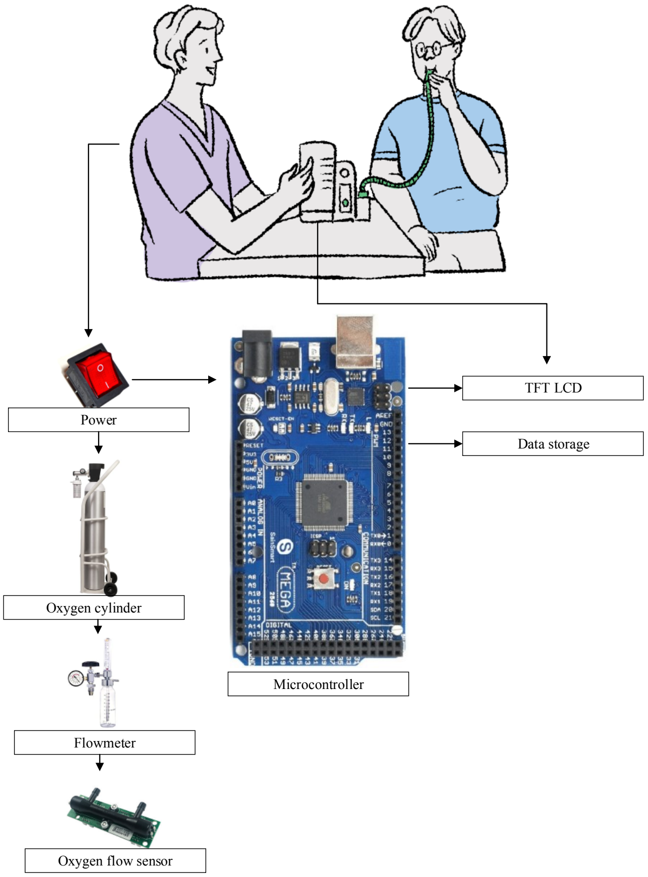

FIGURE 2. Oxygen flow analyzer module block Diagram using Arduino mega 2560 as the microcontroller and using SFM4100 legris as an oxygen flow reader sensor

FIGURE 2 shows that when the module gets voltage from the battery, it will activate all circuits and sensors. Arduino Mega microcontroller was the data processing center based on the program code entered into the microcontroller IC. The flowrate of the oxygen cylinder was then read by the SFM4100 sensor and then digital data was sent to Arduino Mega to be processed into a value in liters per minute (LPM). Furthermore, the data wwere displayed on the display in the form of numbers and graphs. In addition, the data were further stored on the SD Card.

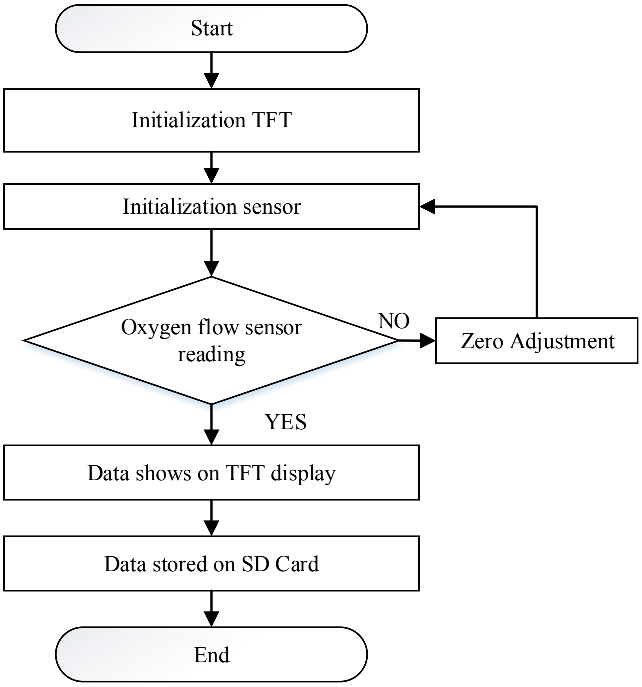

FIGURE 3 Start system when oxygen flow sensor detected data from sensor according to the gas flow setting on the flowmeter, and then the result measurement display it on the TFT LCD in the form of numbers and graphs.

FIGURE 3 indicates when the module gets voltage from the battery, it will activate all circuits and sensors, and the microcontroller will further initialize. Then, the SFM4100 gas flow sensor will read the data according to the gas flow settings on the flowmeter and then display it on the TFT LCD in the form of numbers and graphs. In order to start saving the data, the START button is pressed. For re-measurement, the Zero Adjustment button is pressed. Meanwhile, in order to stop saving the data, the STOP button is pressed.

B. DATA ANALYSIS

In order to support data collection, several tools were needed, including an oxygen flowmeter or a calibrated oxygen therapy device or an oxygen analyzer. Measurements were carried out 6 (six) times at predetermined measurement points. The results of the measurements were further compared to a calibrated flowmeter setting or an oxygen analyzer. In this case, the calculation of data processing was described as follows:

Average is a number that represents a set of data obtained from the results of dividing the number of data values by the number of data in the set. The average can also be called as mean (in English). The average equation is shown in Eq. (1):

$$Average\ (\bar{X}) = \frac{\Sigma X}{n} \quad (1)$$

where $(\bar{X})$ is the average obtained from the division of the sum of the data values from 1 LPM to 15 LPM (ΣX) divided by the number of data samples(n). Standard deviation is a value that indicates the level (degree) of variation in a group of data or a standard measure of deviation from the mean. The standard deviation (SD) formula is shown in Eq. (2):

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{(n-1)}} \tag{2}$$

Where the value of X_i is the I data, while x is the average, and n is sample data. Error (average deviation) is an error referring to the difference between the setting value and the output value. The average deviation formula is shown in Eq. (3):

$$Error\% = \left(\frac{\text{Data Settings} - \text{average}}{\text{Data Settings}}\right) x100\% \tag{3}$$

Uncertainty is the magnitude of the error that may occur in the measurement. In this situation, the average value was obtained from several measurements. The uncertainty formula is shown in Eq. (4):

$$\text{UA} = \frac{Stdv}{\sqrt{n}} \tag{4}$$

where UA was obtained from the result of the standard deviation divided by the sample data (n).

I. RESULT

The results showed that the proposed design can be used to measure the oxygen flow rate in gas cylinders. This Oxygen Flow analyzer module consisted of one sensor used to measure the gas flow rate by utilizing the principle of convective heat transfer. In this case, oxygen flowed from the oxygen cylinder to the flowmeter. The flowmeter read the settings from 1 LPM, 2 LPM, 3 LPM, 4 LPM, 5 LPM, 6 LPM, 7 LPM, 8 LPM, 9 LPM, 10 LPM, 11 LPM, 12 LPM, 13 LPM, 14 LPM, and 15 LPM respectively. In this case, the flow sensor detected the flow rate, which then the data was processed on the arduino mega 2560. The output of the oxygen flow analyzer module was the oxygen flow value displayed on graphs and numbers and stored on the SD Card. On FIGURE 4, data retrieval was carried out by stringing a series between the oxygen cylinder, module and oxygen flow analyzer. The flowmeter measurement was carried out 6 times and the flow range setting was chosen from 1 LPM to 15 LPM because it adjusted the flowmeter for adults and followed the existing worksheet on the flowmeter calibration work method. For the error results from the oxygen flow analyzer module, the lowest error is 0.05%, while the largest is 0.84%. Therefore, the relative error value of the tool is 0.27%. Based on the author's experience during the research, the different types of flowmeters and hoses used at the time of measurement affect the reading of the instrument.

FIGURE 4. Data retrieval by stringing a series between the oxygen cylinder, module, and oxygen flow analyzer

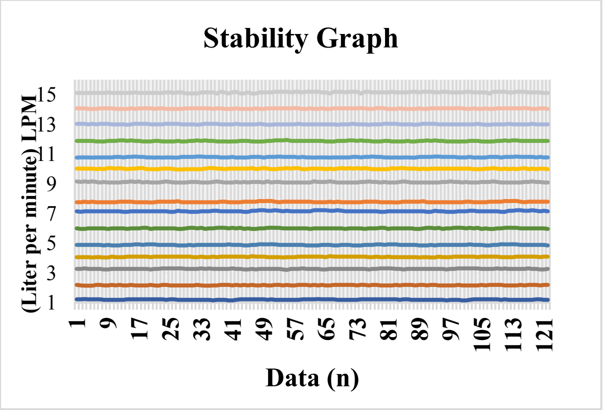

FIGURE 5. Stability graph from point 1 LPM to 15 LPM as much as 120 data taken. The X-axis is the amount of data and the Y-axis is the pressure value in liter per menit (LPM)

Based on FIGURE 5, data collection was carried out when the pressure was above 1000 psi. Based on the graph above, it can be concluded that the module readings have been stable but less linear. This can be affected by oxygen pressure, unstable oxygen flow rate and the quality of the flowmeter itself.

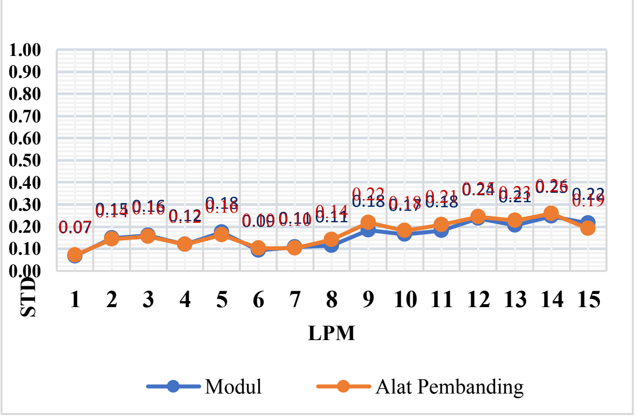

FIGURE 6. Standard deviation graph obtained from processing raw data from 1 LPM to 15 LPM. The X-axis is the pressure value in liter per menit (LPM) and the Y-axis is the standard deviation value

Based on FIGURE 6, the calculation of the standard deviation was intended to determine the closeness of the measurement results to one another in repeatitive measurements. The value of the standard deviation reflected the level of precision of the tool. The graph shows a comparison of the standard deviation values between the comparison tool and the calibrator module. In the measurement using a comparison tool, the highest standard deviation value is 0.26 at the measuring point 14 LPM, while the lowest value is 0.07 at the measuring point 1 LPM. Meanwhile, the results of data processing from the calibrator module obtained the highest standard deviation value of 0.25 LPM at 14 LPM measuring points and the lowest value of 0.07 LPM at 1 LPM measuring point. Furthermore, based on the comparison chart, the standard deviation started from the measuring point of 10 LPM, the standard deviation value or high standard deviation up to the measuring point of 15 LPM. This is because the calibrator module for measuring 10 LPM to 15 LPM is less precise. In addition, more precision at measuring points 1 LPM to 5 LPM.

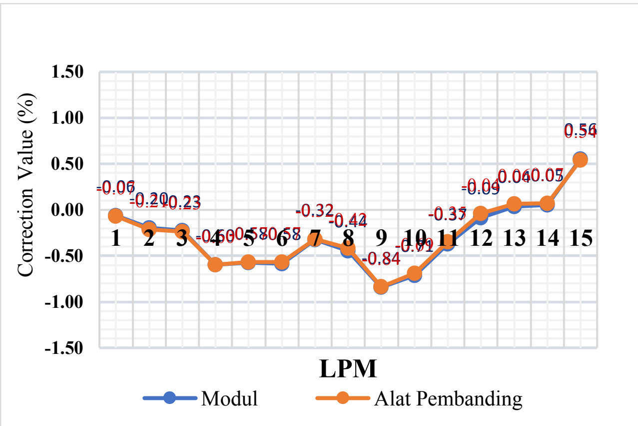

FIGURE 7. Correction Value graph obtained from processing raw data from 1 LPM to 15 LPM. The X-axis is the pressure value in liter per menit (LPM) and the Y-axis is the correction value in procent (%)

FIGURE 7 shows a graph of the comparison of the oxygen flow rate correction value between the comparator and the calibrator module, where data collection was done 6 times. The purpose of calculating the correction value is to show the accuracy value of a measuring instrument. The tolerance limit of the permissible correction value is 10% of the measurement point value. Based on the graph of the comparison of the correction values above, the highest correction value for the module is -0.84 LPM at the measurement point of 9 LPM and the lowest correction value for the module is -0.04 LPM at the measurement point of 13 LPM. Meanwhile, the highest correction value for the comparison tool is -0.84 LPM at the measurement point of 9 LPM and the lowest correction value for the comparison tool is -0.04 at the measurement point 12 LPM. This is because the sensor readings were unstable at the beginning of the oxygen gas flow rate reading, so there was a spike as an initial starting and the researcher's reading power and sensor characteristics affect the gas flow rate readings. However, the correction value at each measuring point was still within the allowable tolerance limit, which is ±10% of the setting value of the measuring point.

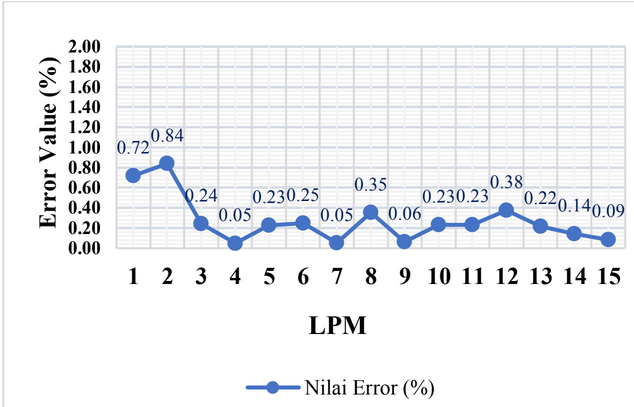

FIGURE 8. Error Value graph obtained from processing raw data from 1 LPM to 15 LPM. The X-axis is the pressure value in liter per menit (LPM) and the Y-axis is the error value in procent (%)

Based on FIGURE 8, the highest relative error value was at the measurement point of 2 LPM of 0.84%, followed by 0.72% at the measurement point of 1 LPM. Meanwhile, the lowest relative error value is at the measurement point of 4 LPM and 7 LPM of 0.05%. For the relative value of the average error of the tool is 0.27%.

This is because the sensor readings were unstable when they first start reading the oxygen gas flow rate, so there was a spike as an initial starting and the researcher's reading power and sensor characteristics affect the gas flow rate readings. However, the error value at each measuring point was still within the allowed tolerance limit, which is ±10% of the setting value of the measuring point.

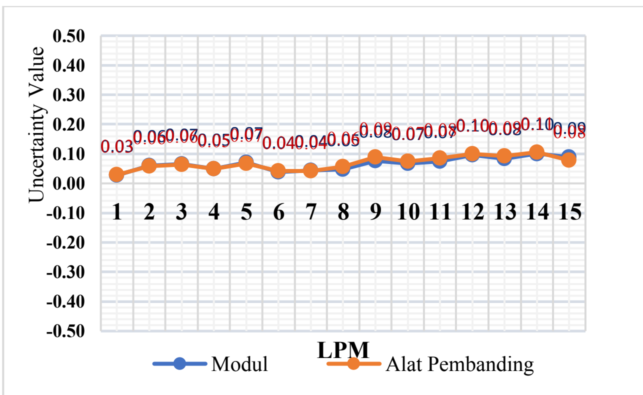

FIGURE 9. Measurement Uncertainty Value graph obtained from processing raw data from 1 LPM to 15 LPM. The X-axis is the pressure value in liter per menit (LPM) and the Y-axis is the uncertainty value

Based on FIGURE 9, the purpose of calculating measurement uncertainty is to provide an idea of the quality of the measurement. Measurement uncertainty describes doubts about the results of a measurement. The measurement uncertainty value indicates the quality of the measurement, where the smaller the measurement uncertainty, the more precise the tool is. The measurement uncertainty value on the comparison tool s the highest value at the measuring point of 14 LPM with a value of ±0.11, while the lowest value is at the measuring point 1 LPM with a value of ±0.03. Furthermore, in terms of the calibrator module, the highest value of measurement uncertainty is at the measuring point of 14 LPM with a value of ±0.10, while the lowest value is at point 1 LPM with a value of ±0.03.

II. DISCUSSION

In this study, researchers have made a tool and analyzed the accuracy of the design of a dual pressure calibrator (+ and -) that can be used for two devices at once, namely the sphygmomanometer and suction pump using one sensor, namely the PSS-C01V-R18 autonics sensor. The PSS series analog pressure sensor features a compact rectangular design (L 11.8 mm x T 29.3 x P 24.8 mm, including pressure port). The results of the tool testing can be seen in the TFT LCD on the tool and can also be seen on the PC/Laptop. On the positive pressure measurement on the sensor reading module, the pressure works according to its characteristics, resulting in the largest Ua on the measurement of 250 mmhg and the lowest Ua on the measurement of 50 mmHg. Meanwhile, on the negative pressure measurement, the module produces the largest Ua on the first 10 kpa suction pump on the first Suction Pump Under Test (UUT) and the lowest Ua on the measurement of 80 kpa on the second UUT suction pump. On standard positive pressure measurements, it is known that Ua is greatest on measurements of 250 mmHg and Ua is lowest on 50 mmHg measurements. On standard negative pressure measurements, it is known that Ua is greatest on the measurement of 600 mmHg on the third suction pump and the lowest Ua on the measurement of 10 kPa on the first suction.

The results of monitoring and recording sensor readings at positive pressure for 4 minutes at the measurement point of 50 mmHg on three different brands of tensimeters are seen on the graph of the highest and lowest range produced sensor readings that are 7 mmHg where if converted to kpa units then the result is approximately only 0.9 kPa with the output voltage of the sensor stable at 2,841 V DC. At the point of measurement of 100 mmHg the highest and lowest range produced sensor reading is 14 mmhg where if converted to kpa units then the result is approximately 1.8 kPa with the output voltage of the sensor stable at 2,968 V DC. At the point of measurement of 150 mmHg the highest and lowest range produced sensor readings are 9 mmhg where if converted to kpa units then the result is approximately 1.18 kPa with an output voltage of stable at 3,083 V DC. At the point of measurement of 200 mmHg the highest and lowest range produced sensor reading is 20 mmHg where if converted to kPa units then the result is approximately 2.6 kPa with the output voltage of the sensor stable at 3.213 V DC. At the strengthening point of 250 mmHg, the highest and lowest range produced sensor reading is 70 mmHg where if converted to kPa units then the result is approximately 9.2 kPa with the output voltage of the sensor stable at 3.326 V DC. At the point of measurement -10 kPa the graph range is 2 Kpa with the output voltage of the sensor stable at 2.528 V DC. At the point of measurement -20 kPa the graph range is -20 kPa with the output voltage of the sensor stable at 2.352 V DC. At the point of measurement -30 kPa the graph range is -30 kPa with the output voltage of the sensor stable at 2.165 V DC. At the point of measurement -40 kPa the chart range is 0.7 kPa with the output voltage of the sensor stable at 2.008 V DC. At the point of measurement -50 kPa the graph range is -50 kPa on the first suction and 1.4 kPa for the second suction with the output voltage of the sensor stable at 1.814 V DC. At the point of measurement -60 kPa the chart range is 1.2 kPa on the first suction and 0.7 kPa for the second suction with the output voltage of the sensor stable at 1.644 V DC. At the point of measurement -70 kPa the chart range is 1 kPa on the first suction and 1.1 kPa for the second suction with the output voltage of the sensor stable at 1.470 V DC. At the point of measurement -80 kPa the graph range is 0.8 kPa with the output voltage of the sensor stable at 1.286 V DC. At the point of measurement -85 kPa the chart range is 0.7 kPa with the output voltage of the sensor stable at 1.203 V DC. At the point of measurement 500 mmHg the chart range is 13 kPa with the output voltage of the sensor stable at 1,528 V DC. Previous research carried out by Yosef Kurniawan made dpm with two modes but with a vacum limit of up to -400 mmhg with two different sensors [20]. In 2019, a study done by Abdul Cholid Ridwan made dpm with two modes equipped with temperature and humidity but with two different sensors as well [22]. This study successfully measured the sphygmomanometer and suction pump using the PSS-C01V-R18 autonics sensor as a medium of positive and negative pressure readings using one sensor. Furthermore, this module produced a reading output that is close to the standard tool so it is said to be accurate as a calibrator to calibrate the sphygmomanometer and suction pump according to the calibration working method.

The results showed that the proposed design can be used to measure the oxygen flow rate in gas cylinders. This Oxygen Flow analyzer module consisted of one sensor which was used to measure the gas flow rate by utilizing the principle of convective heat transfer. The oxygen will flow from the oxygen cylinder to the flowmeter. The flowmeter reads settings from 1 LPM, 2 LPM, 3 LPM, 4 LPM, 5 LPM6 LPM, 7 LPM, 8 LPM, 9 LPM, 10 LPM, 11 LPM, 12 LPM, 13 LPM, 14 LPM and 15 LPM respectively. The flow sensor will detect the flow rate which then the data will be processed on the arduino mega 2560. The output of the oxygen flow analyzer module is the oxygen flow value displayed on graphs and numbers and stored on the SD Card.

The flowmeter measurement was carried out 6 times and the flow range setting was chosen from 1 LPM to 15 LPM because it adjusted the flowmeter for adults and followed the existing worksheet on the flowmeter calibration work method. For the error results from the oxygen flow analyzer module, the lowest error is 0.05% and the largest is 0.84%. so that the relative error value of the tool is 0.27%. Based on the author's experience during the research, the different types of flowmeters and hoses used at the time of measurement affected the reading of the instrument. This research provided more development than previous research because the Oxygen analyzer module that the author has made has been supported by the results of the treatment on the sensor and flowmeter. In addition, the oxygen flow manager module was accompanied by a graphical display and storage. The oxygen flow analyzer module error was smaller than before [27][28][29][3]

The limitation of this research is that the storage was only limited to SD Card and IoT has not been implemented so it cannot monitor the results remotely. In addition, the module only focused on one parameter. Based on this, it is necessary to make further considerations regarding the circuit and program for the sensor.

III. CONCLUSION

The purpose of this research is to conduct further research on Oxygen flow analyzer which focuses on discussing the accuracy and stability of the oxygen flow sensor against the gold standard. Based on the results that have been obtained at the time of measurement or data collection from the module and comparison tool which is then carried out data analysis, it can be concluded that the highest relative error value is at the 2 LPM measurement point of 0.84%. Meanwhile, the lowest relative error value is at the measurement point of 4 LPM and 7 LPM of 0.05%. For the relative value of the average error of the tool is 0.27%. There is a difference in reading values between the module and the comparison tool. This is influenced by the accuracy of the researchers, the flow rate of oxygen entering the module and the comparator is not stable, the quality of the flowmeter itself and the pressure in the tube which begins to decrease.

This research can be used as a reference by other researchers who want to develop an oxygen flow analyzer in the future and it is recommended to use another type of air flow sensor that has a higher sensitivity and accuracy than the SFM4100 Legris. This research was to determine the sensor response and analyze the accuracy of the design of a dual pressure calibrator (+ and -) that can be used for two devices at once (sphygmomanometer and suction pump) using one sensor (pss-C01V-R18 autonics). This study successfully measured the tensimeter and suction pump using the PSS-C01V-R18 autonics sensor as a medium of positive and negative pressure readings using one sensor. This module produces a reading output that is close to the standard tool so that it is said to be accurate as a calibrator to calibrate the sphygmomanometer and suction pump in accordance with the calibration working method. Thoroughly, the research in the design of this calibrator can be concluded that the sesnsor response used is very responsive to positive and negative pressure readings. For future research can use a battery system so it does not always rely on adapter cables that are used continuously and look for other sensor references that can be used to read positive and negative pressures with just one sensor and that have thoroughness in mmhg units more thoroughly.

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