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High Flow Oxygen Analyzer Design on High Flow Nasal Cannula (HFNC) for Monitoring Oxygen therapy in Adults

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ABSTRACT Side effects of using HFNC include gastric insufflation (air entry into the stomach) because HFNC increases positive airway. The next side effect of using HFNC is complications of pneumothorax and pneumomediastinum. This complication occurs in the case of children. In these cases, oxygen administration was reported to exceed the recommended protocol. Although the incidence of air leaks in the use of HFNC for adults has not been reported, similar events may also occur in adults, so close monitoring is needed, especially on oxygen flow. Making the design of the High Flow Oxygen Analyzer can be used for monitoring the flow and oxygen concentration in HFNC. This study aims to design a high flow oxigen analyser on high flow nasal canulla for monitoring oxygen therapy in adults based on Arduino microcontroller using Sensirion SFM-3000 flow sensor. Additionally, the flow value will be displayed on the TFT liquid crystal display. The independent variable in this study is the flow setting value, while the dependent variable is the SFM-3000 flow sensor. The largest error flow value is in the setting at 30 LPM with an error value of 2.70%. The flow value is set using a flowmeter, while the comparison tool used is a flow analyzer (Citrex H3). In the testing phase, the measurement value is 10 LPM to 60 LPM with a time of 5 minutes at each point. Based on the measurements that have been made, the largest error value is obtained at the value of 30 LPM, which is 2.70% and the smallest error value is at the value of 60 LPM, which is 0.74%. Data retrieval using a compressor and central oxygen is very influential on the results of the flow and oxygen concentration. The results obtained are more stable than without the use of a compressor and central oxygen. The conclusion from these results is that the calibrator module has a relative error (error value) that is still within the allowable tolerance limit, which is ±5%. And also the design of this device is portable and low cost and is made to be used in hospital agencies as a support for maintenance on HFNC equipment.

INDEX TERMS HFNC, Calibration, SFM-3000, Flow, Oxigen

I. INTRODUCTION

High Flow Nasal Canulla (HFNC)[1][2] is an oxygen delivery device with a mixing system of air and oxygen accompanied by heating and humidity control, delivered through a nasal cannula with a high current of up to 60 liters per minute (lpm) so that it can exceed the inspiratory effort of spontaneously breathing patients. Flow with optimal humidity and temperature is created by a humidifier which also functions as a heater and has its own water reservoir, the resulting temperature and humidity can reach 37°C and 44 mmH_2O/L [3]. Adding a humidifier to the circuit can reduce the oxygen concentration from 1% to 5%[4]. Patients with shortness of breath produce high inspiratory currents, thereby increasing the risk of mixing oxygen from low-flow oxygen delivery devices with room air, so that the concentration of oxygen (FiO2) that reaches the airways of these congested patients is getting lower and not optimal[3]. Side effects of using HFNC include gastric insufflation (air entry into the stomach) because HFNC increases positive airway. An increase in current of 10 lpm is known to cause an increase in nasopharyngeal airway pressure of 1.2 mmH_2O [5], as observed when healthy volunteers breathe with their mouths closed with the use of HFNC. Airway pressure will increase by about 3 cmH_2O at 30 LPM oxygen and by about 12 cmH_2O at 100 lpm [6]. The next side effect of using HFNC is complications of pneumothorax and pneumomediastinum. This complication occurs in the case of children. In these cases, oxygen administration was reported to exceed the recommended protocol. Although the incidence of air leaks in the use of HFNC for adults has not been reported, similar events may also occur in adults, so close monitoring is needed, especially on oxygen flow [7].

Because detection of the side effects of oxygen therapy[8][9][10] is not easy, it is necessary to prevent the occurrence of side effects of oxygen therapy through the administration of oxygen which must be done with the right dose and method [5]. The most important thing in using machines that provide oxygen and ventilation is how to provide precise oxygen concentrations to patients during the treatment process[6] Some selection of flow, oxygen concentration (FIO2), and including the selection of some equipment can affect the actual flow value and oxygen concentration (FiO2).) is actually sent to the patient. Side effects of deviation cannot be ruled out and need to be considered[7]. Flow rate stability should be considered when selecting a device[11]. Clinical use of HFNC must be monitored because if this tool is unstable and inaccurate it can cause serious problems for patients[12]. From some of the case studies above, it can be concluded that problems that can arise when using HFNC include inappropriate administration of dose flow and oxygen concentration to the patient, which can be at risk of having an impact on the patient. And the presence of a humidifier on the HFNC device can reduce the oxygen concentration by 1-5% so that the dose given to the patient may not match the expected dose because there is a decrease in oxygen concentration before entering the patient's body. Although the incidence of air leaks in the use of HFNC for adults has not been reported, similar events may also occur in adults, so close monitoring is needed, especially on oxygen flow. The choice of flow, oxygen concentration (FIO2)[13][14], and including the selection of some equipment can affect the actual flow value and the actual oxygen concentration (FiO2) delivered to the patient. Side effects of deviation cannot be ruled out and need to be considered. Clinical use of HFNC must be monitored because if this tool is unstable and inaccurate it can cause serious problems for patients. So it is necessary to monitor the flow and oxygen concentration at the HFNC output where this monitoring plays an important role in knowing the flow dose and oxygen concentration delivered to the patient whether it is in accordance with the expected dose. In 2017 Hanif Zakki made a Measuring Instrument for Detecting the Volume of Medical Oxygen Gas Usage as the Basis for Determining Tariffs[15], this tool uses a flow sensor (hall effect) which can only measure a maximum flow of 20 lpm and there is a fairly large error of 13.5%. Muhammad Khosyi'in made a Volume Calculator and Oxygen Usage Timer[16], in this study the sensor used was the AWM5000[6] sensor where the sensor can only measure oxygen flow up to 20lpm and has an accuracy of only 44%-66.4% so that the manufacture of it's not good enough.

In 2018 Jalu. A. Prakosa made the Design and Simulation of Automatic Control Valves for Gas Flowmeter Calibrators from Bell Prover[17]. This study measures the gas flow rate at a measurement of 250 – 1200 LPM, but does not measure the gas flow rate which has a low range like that of an oxygen flowmeter for patients. Yunaifi Niswatul Firdaus made a Concentration and Oxygen Flow Measuring Device on a Ventilator[18]. This study measures oxygen levels and oxygen flow velocity with a character LCD interface to display the readings. The sensor used is the OCS 03F sensor. The accuracy value of this tool is good, but it can only measure gas flow rate at 0 – 10 LPM measurement and the response time according to sensor specifications is only 0.5 seconds. In 2019 Rustiana made a Design of a Gas Flowmeter Calibrator[19]. Aat has succeeded in measuring the flow of oxygen gas using the MCS100A120 gas flow sensor. However, this tool is only able to measure oxygen flow rate 0 – 10 LPM and has a fairly large average error of -8.326% so it is not suitable for HFNC tools. In 2020, Meving Oktheresia Yolanda conducted an Analysis of the Accuracy of Calibration Results in the Design of a Gas Flowmeter Calibrator Using a TFT LCD[20]. This tool uses the SFM4100[15] sensor. It has the advantage of already using a TFT LCD, the average error rate is 4.16% but can only take measurements from 0-15 Lpm so it is not suitable for HFNC devices with a high flow range. Based on existing research and case studies, the researcher will conduct a study entitled "Design of High Flow Oxygen Analyzer on High Flow Nasal Canulla (Flow Monitoring Analysis)" which is used to help facilitate medical personnel or equipment operators in monitoring incoming flow. into the patient's body so that oxygen therapy can be given according to the right dose. Here we will analyze the oxygen flow value that comes out of the HFNC device with the oxygen flow value set on the device. Clinical use of HFNC must be monitored because if this tool is unstable and inaccurate it can cause serious problems for patients. So it is necessary to monitor the flow and oxygen concentration at the HFNC output where this monitoring plays an important role in knowing the flow dose and oxygen concentration delivered to the patient whether it is in accordance with the expected dose.

This study aims to This study aims to design a high flow oxigen analyser on high flow nasal canulla on HFNC for monitoring oxygen therapy in adults based on Arduino microcontroller using Sensirion SFM-3000 flow sensor.

II. METHODOLOGY

This research was conducted at Bangil Hospital, Pasuruan Regency using a high flow oxygen analyzer as a calibrator. The research design used in making the module is Pre-experimental with the type of After Only Design. In this design, the researcher only used one group of subjects and only saw the results without measuring and knowing the initial conditions, but there was already a comparison group.

This study uses the SFM-3000 flow sensor as the input of the flow, then the data flow will be processed using an Arduino microcontroller, and the flow results will be displayed on the Display LCD[21]. The variable in this study is the flow value setting, while the independent variable is the SFM-3000 flow sensor. The flow value is set using a flowmeter, while the comparison tool used is gas flow analysis (Citrex H3).

A. DATA ANALYSIS

Measurements of each parameter, oxygen concentration from 50-100% all were repeated 5 times. The average value of the measurement is obtained by using the mean or average by applying Eq (1). The average is the number obtained by dividing the number of values by the number of data in the set.:

$$\overline{x} = \frac{x1+x2\ldots+xn}{n} \quad (1)$$

where $\overline{x}$ indicates the mean (average) value for n-measurement, x1 indicates the first measurement, x2 shows the second measurement, and xn indicates the n measurement. The standard deviation is a value that indicates the level (degree) of variation in a group of data or a standard measure of deviation from its mean. The standard deviation (SD) formula can be shown in Eq (2):

$$\mathrm{SD} = \sqrt{\frac{\sum(xi-\overline{x})^2}{(n-1)}} \quad (2)$$

where xi indicates the amount of the desired values, x indicates the average of the measurement results, n shows the number of measurements. Uncertainty (UA) is doubt that appears in each measurement result. The uncertainty formula is shown in Eq (3):

$$UA = \frac{SD}{\sqrt{n}} \quad (3)$$

where UA indicates the uncertainty value from the total measurement, SD shows the resulted standard deviation, and n shows the amount of measurement. the % error shows the error of the system. The lower value Error is the difference between the mean of each data. The error can show the deviation between the standard and the design or model. The error formula is shown in Eq (4).

$$\%\mathrm{ERROR} = \frac{(x_n-\mathrm{x})}{x_n} \times 100\% \quad (4)$$

where xn is the value measured from the calibrator machine. The x is the value measured from the design.

III. RESULT

In this study, the module has been tested using a calibrator, namely a gas flow analyzer. The design shown in FIGURE 1. The digital part consists of the arduino[22] microcontroller which is the main board of the device and the SFM-3000 flow sensor. The overall circuit in this study can be seen in FIGURE 2.

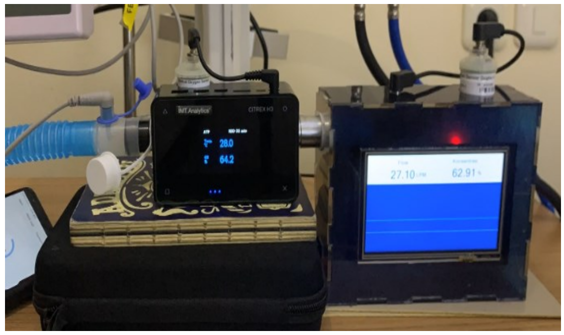

FIGURE 1 . Gas Flow analyzer Citrex H3 When Measuring the High Flow Oxygen Analyzer on the flow setting

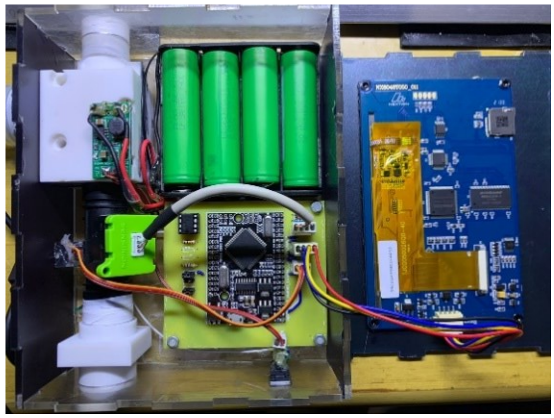

FIGURE 2. Overall circuit design in research on high flow oxygen analyzer

Data collection for the High Flow Oxygen Analyzer was carried out on the Gas Flow Analyzer at Bangil Hospital, Pasuruan Regency. In collecting this data, the settings for the parameters Flow 10, 20, 30, 40, 50, and 60 LPM are used and the oxygen concentration setting is 30%. Error or error is the difference from the actual value compared to the value that exceeds the module with the unit in this study, namely LPM (liters per minute). It can be seen in the table below that the largest error value from the measurement of the High Flow Oxygen Analyzer module is at the 30 LPM setting with an error value of 2.70%. While the largest error value is in the 60 LPM setting with an error value of 0.74%. This explanation can be referred to in TABLE 1. From the measurement results, the overall error value obtained from the High Flow Oxygen analyzer module can be said to be good with the highest error of 2.70% at the flow setting at 30 LPM. Although there is a fairly large error value, the error value obtained is still within the range of the calibration tolerance, which is ±5%. This explanation can be referred to in FIGURE 3**.**

TABLE 1
Error value for each setting in the comparison of the value of the High Flow Oxygen Analyzer module with the Citrex H3 comparison tool

Setting Flow	Error
10 LPM	1,62%
20 LPM	2,24%
30 LPM	2,70%
40 LPM	0,92%
50 LPM	1,43%
60 LPM	0,74%

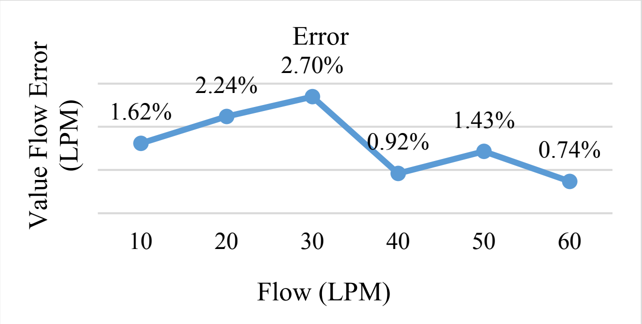

FIGURE 3. **Graph of the error value for each setting in the comparison of the value of the High Flow Oxygen Analyzer module with the Citrex H3 comparison tool**

If it is seen from the error value of each flow setting every minute, the longer the data and data collection time, the more stable the flow between the module and the calibrator will be. When viewed from the error value of each flow setting every minute, the longer the data collection time, the more stable the flow obtained between the module and the calibrator. TABLE 1 is the error value obtained by the actual value compared to the value that beats the High Flow Oxygen Analyzer module.

TABLE 2
Comparison Value of Standard Deviation of Each Flow Setting on the module and comparison tool

Setting flow	Standard Deviation	
	Calibrator	Modul
10 LPM	0,04	0,03
20 LPM	0,2	0,0
30 LPM	0,1	0,1
40 LPM	0,2	0,1
50 LPM	0,4	0,0
60 LPM	0,6	0,6

TABLE 2 is the standard deviation value obtained from measurements with the High Flow Oxygen analyzer module. It is said to be good, because the results of the standard deviation value do not exceed the average value of the High Flow Oxygen analyzer module measurement. TABLE 3 is the uncertainty value (UA) which is used to see how much deviation (accuracy) is from the High Flow Oxygen Analyzer module in reading the flow value. TABLE 4 is the correction value in this study proving that there is still an error or insecurity between setting the value and the average.

Refer to TABLE 2 it can be seen from the table above that the standard deviation obtained from measurements with the High Flow Oxygen analyzer module is said to be good, because the results of the standard deviation value do not exceed the average value of the measurement of the High Flow Oxygen analyzer module. This shows that the average value of the measurement of the High Flow Oxygen analyzer module can be used as a measurement representation of the overall data.

TABLE 3
Uncertainty Comparison Value (UA) for each flow setting on the module and comparison tools

Setting flow	Uncertainty	
	Calibrator	Modul
10 LPM	0,02	0,01
20 LPM	0,09	0,00
30 LPM	0,04	0,04
40 LPM	0,09	0,04
50 LPM	0,18	0,00
60 LPM	0,27	0,27

Refer to TABLE 3 it can be seen from the table above if the uncertainty value (UA) is used to see how much deviation (accuracy) is from the High Flow Oxygen Analyzer module in reading the flow value. Relative uncertainty is closely related to measurement accuracy, which can be stated if the smaller the uncertainty, the higher the accuracy. In this study, the largest deviation value was found at the flow setting of 60 LPM which had the same value of 0.27, while the smallest deviation value was at the flow setting at 20 LPM and 50 LPM with a small value of 0.

TABLE 4
Correction Comparison Value for each flow setting on the module tool and its comparison tool

Setting flow	Correction Value	
	Calibrator	Modul
10 LPM	0,12	-0,04
20 LPM	0,42	0,86
30 LPM	-0,26	0,56
40 LPM	-1,44	-1,06
50 LPM	-4,64	-3,87
60 LPM	-6,50	-6,01

The correction value is an additional value given to compensate for the addition of errors systematically. The correction value in this study proves that there is still an error or inequality between the setting value and the average. From the TABLE 4, it can be seen that the improvement value indicates an error in the system. So, increase the correction close to 0, the better the tool works. Based on the data above, the largest correction value in this study was found in the 60 LPM flow setting, namely 6.50 on the calibrator and 6.01 on the module. For the smallest value on the flow setting of 10 LPM, namely 0.12 on the calibrator and 0.04 on the module. If on average, the correction value of the calibrator for each flow setting is 2.05, while the average correction value for the module is 1.60. So it can be said that when comparing the correction values of the two calibrators and the module, the correction value of the high flow oxygen analyzer module is smaller than that of the gas flow analyzer calibrator. A measuring instrument can be said to be good if it has high accuracy and precision. Not all measuring instruments that have good precision also have good accuracy. In addition, measuring also requires good sensitivity or good response to small input signal changes.

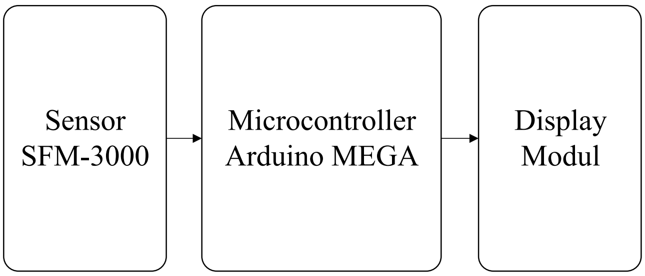

FIGURE 4. The diagram block of the system in research design of high flow oxygen analyzer using SFM-3000 sensor

This paragraph can explain FIGURE 4 the block diagram above has 3 main parts, namely process input and output, the input consists of the Sensirion SFM - 3000 flow sensor which is the source of input data on the microcontroller, the process section consists of a microcontroller which functions to receive data from the sensor and process it so that the sensor value can be adjusted. show on the display, in the output process there is a display that serves to display data that has been processed by the microcontroller. In collecting oxygen concentration data, the increase and decrease in oxygen concentration in the calibrator and module increases or decreases slowly which takes a long time so that the oxygen concentration value is stable and close to the setting value on the HFNC tool, unlike the flow parameter which has increase or decrease the flow so quickly to approach the HFNC setting value. From the research that has been done, it takes more than 5 minutes for the oxygen concentration value to be stable. A measuring instrument can be said to be good if it has high accuracy and precision. Not all measuring instruments that have good precision also have good accuracy. In addition, the measurement also requires good sensitivity or good response to small changes in the input signal. Refer to FIGURE 5 turn on the ON button after the module is turned on then the process will initialize after the initialization process is complete it will continue in the next section, namely the selection of starting conditions, when the condition starts to value false then the process will return to initialization and if the condition starts to be true then the process will continue on sensor readings flow and continues on the display of the value read by the sensor.

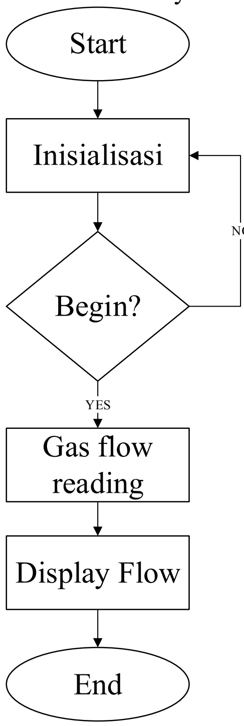

FIGURE 5. The flowchart system in research design of high flow oxygen analyzer using SFM-3000 sensor

IV. DISCUSSION

After testing the High Flow Oxygen analyzer module, data collection and analysis were carried out to determine the accuracy of the value of the SFM-3000[23] sensirion sensor output as a flow sensor used to monitor the flow value on the HFNC (High Flow Nasal Canulla) device. After conducting experiments on research to obtain flow values, the results obtained on the High Flow Oxygen analyzer module are as follows. On the calibrator and the High Flow Oxygen analyzer module at flow settings 10, 20, 30, 40, 50, and 60 LPM the flow values are stable. The setting flow value which has the lowest error value is 0.74%, it is found in the flow setting of 60 LPM and the highest error value is when setting the flow at 30 LPM at 2.70%. The best data distribution is at flow settings 20, and 50 LPM with a standard deviation value of 0 which also produces an uncertainty of 0. An uncertainty value of 0 can be interpreted if the stability of the results is good because there is no change in each measurement. While the correction value is still said to be good with the highest value being 6.50 on the HFNC calibrator and 6.01 on the High Flow Oxygen analyzer module which is at the flow setting of 60 LPM which means the measurement accuracy is still fairly good. The implications of this study are used to help facilitate medical personnel or equipment operators in monitoring the flow that enters the patient's body so that oxygen therapy can be given according to the right dose. The researcher will analyze the oxygen flow value that comes out of the HFNC device with the oxygen flow value set on the device.

Due to various factors, the module made by the author is still far from perfect, both in terms of planning, manufacturing, and the workings of the module. So there are several shortcomings that have been analyzed from the tool that the author made. The output on the flow sensor still has to be adjusted and converted again to LPM so that the results can be the same as the gas flow analyzer calibrator tool manufacturer. Henceforth, the author suggests comparing the use of a differential flow sensor with this sensor[24][25]. Then have to readjust the value of the flow sensor conversion to better fit the scale requested. and then the flow results obtained have a fairly large error value when added to the use of a humidifier, due to the presence of water vapor produced by the humidifier[26].

IV. CONCLUSION

The purpose of this study is to test and prove the value of the flow parameter setting on the High Flow Oxygen analyzer by comparing it with the HFNC calibrator, namely the gas flow analyzer. Measurement of flow parameter monitoring on the High Flow Oxygen analyzer module can be known through the Sensirion SFM-3000 sensor using an HFNC gas flow analyzer calibrator. In the measurement of the flow parameter setting which has the lowest error value of 0.74%, it is found in the flow setting of 60 LPM and the highest error value is when setting the flow at 30 LPM of 2.70%. The standard deviation and uncertainty (UA) has a value of 0 at the flow setting of 20, and 50 LPM. And the biggest correction value is ±6.50 on the HFNC calibrator and ±6.01 on the High Flow Oxygen analyzer module which is at the flow setting of 60 LPM.

Based on the data obtained, the flow reading value is close to the flow setting parameter, namely the flow setting of 10 LPM with the difference between the module and the comparison tool being 0.16. For the standard deviation and uncertainty (UA) values, the values that are closest to the standard are when setting flow 20, and 50 LPM, which is 0. As for the smallest correction value from the measurements that have been made, it is found in the flow setting at 10 LPM, which is 0.12 for HFNC calibrator and 0.04 for High Flow Oxygen Analyzer module correction. After 5 minutes of reading the flow that has been done, it can be seen that the longer the data collection is carried out, the more stable the flow value from the module and calibrator tool. Based on the testing of the High Flow Oxygen Analyzer module that has been carried out by comparing the measurement results to the CITREX H3 HFNC gas flow analyzer calibrator which has been calibrated and the results obtained are said to be good and can perform their work functions. For developments that can be done in the future is to use another flow sensor, which has a smaller error, then use a central compressor in module data collection, and finally take data with a longer time so that the results obtained are more stable.

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